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Research for Medical Imaging and Radiation Sciences

 Springer

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This book is dedicated with love and affection to my brilliant and charming wife Trish, the most caring person I know.
Euclid Seeram, PhD, FCAMRT

I dedicate this book to my wife Debbie, my best friend and partner. Without her support my research career would not exist
Professor Rob Davidson, PhD, MAppSc (MI), BBus, FASMIRT

Thank you to my wife and two daughters for their love and unconditional support.
Dr Andrew England, BSc(Hons), MSc, PhD

To my mum Maureen and father Pat McEntee, thank you for your unquestioning support.
Professor Mark F. McEntee, BSc (Hons) Radiog., PhD, F(IIRRT), SF(HEA)

Preface

Research in medical imaging technologies (radiography, nuclear medicine, magnetic resonance imaging) and radiation sciences (radiation therapy) is an evolving area of study in diagnostic radiography, magnetic resonance imaging, nuclear medicine and radiation therapy. For example, radiography education and training evolved from hospital-based “one on one” training and hospital-based schools, which involved classroom-based instruction coupled with clinical practice, to college-based and university-based educational programs. University-based programs offer degrees ranging from undergraduate degrees (bachelor’s) to graduate degrees such as masters’ degrees [Master of Arts (MA) or Master of Science (MSc)] and Doctor of Philosophy (PhD) degrees. The latter two degrees specifically require that students engage in research as part of the fulfilment of meeting the requirements for graduation. This evolution of the education in medical imaging and radiation sciences now requires that research be a part of curricula in medical imaging and radiation sciences as is evident in professional radiography (radiological technology) and therapy organizations, such as the American Society of Radiologic Technologists (ASRT), the Canadian Association of Medical Radiation Technologists (CAMRT) and the Society and College of Radiographers (SCoR).

The SCoR’s research vision, for example, is “to improve patient care and outcomes by continuing to develop, grow and implement a high-quality evidence-base that addresses key patient-focussed research priorities”. To accomplish this strategy, the SCoR offers the following three aims: “Embed research at all levels of radiography practice and education; raise the impact and profile of radiography through high quality research focussed on improving patient care and/or service delivery; and expand UK radiography research capacity through development of skilled and motivated research-active members of the profession”. In a similar vein, the American Society of Radiologic Technologists (ASRT) and the CAMRT have also embedded research in the curricula for radiography and radiation therapy. Furthermore, the CAMRT has also embedded research in the magnetic resonance, nuclear medicine and radiation therapy. An interesting study by Vikestad et al. investigated the opinion of radiographers on the need for radiography research and found that “the majority of radiographers agreed that there was a need for radiography research and

that radiographers/ radiation therapists should take a leading role in such work. The results indicate that radiographers/radiation therapists would benefit from training in informal and formal research skills. Finally, in an article entitled “*Inclusion of evidence and research in European radiography curricula*”, England and McNulty point out that “the inclusion of evidence and research topics within undergraduate radiography curricula is paramount.....A set of core evidence and research objectives are essential for the newly qualified practitioner”.

Professional medical imaging and radiation sciences organizations offer journals in which scholarly research studies are published in an effort to provide their members and other readership with an exposure to the nature of research in the profession. Examples of these journals include:

1. *The Journal of Medical Imaging and Radiation Sciences*, journal of the CAMRT
2. *Radiologic Technology*, journal of the ASRT
3. *Radiation Therapy*, journal of the ASRT
4. *Radiography: An International Journal of Diagnostic Imaging and Radiation Therapy*, journal of the SCoR and the European Federation of Radiographer Societies
5. *Journal of Medical Radiation Sciences*, an international and multidisciplinary peer-reviewed journal that accepts manuscripts related to medical imaging/diagnostic radiography, radiation therapy, nuclear medicine, medical ultrasound/sonography, and the complementary disciplines of medical physics, radiology, radiation oncology, nursing, psychology and sociology; *Journal of the Australian Society of Medical Imaging and Radiation Therapy*; and New Zealand Institute of Medical Radiation Technology

With the above ideas in mind, radiation protection is now an integral part of the curriculum in radiologic technology

The overall goal of this book is:

1. To meet the educational requirements on research principles and concepts (for entry to practice) of the following professional radiologic technology associations: the American Society of Radiologic Technologists (ASRT), the Canadian Association of Medical Radiation Technologists (CAMRT), the College of Radiographers in the United Kingdom, and radiography societies and associations in Asia, Australia, Europe and Africa
2. To meet academic requirements in the teaching of research principles and methodologies in medical radiation science in programs/courses taught at the bachelor's degree level

The scope of this book covers topics ranging from the nature of scientific research, quantitative and qualitative approaches essentials, research planning, and literature review fundamentals to research methods, data collection, analysis, and interpretation; communicating research findings; and examples of published research in medical imaging journals.

With the above objectives in mind, this book can be used as an introduction to research in medical imaging, for both students and professional technologists, and

as a supplement for applied fields such as biomedical engineering technology programs.

The book is organized into 8 chapters as follows:

Chapter 1 presents an overview of the nature and scope of research according to the scientific method, including key characteristics of the scientific method, the importance of research, evidence-based practice, the steps in research process cycle, and, finally, the nature of ethics in research. Chapter 2 provides an essential outline of the differences between quantitative and qualitative research approaches. Chapter 3 deals with the elements of planning your research and reviews major formulating a research question, research planning, the nature of hypotheses, a detailed description of research ethics and elements of the research proposal. While Chap.4 addresses the steps in the literature searches, reviews and writing literature reviews, Chapter 5 examines a detailed description of types of quantitative and qualitative research methods and designs.

Chapter 6 presents the approaches to data collection, analysis and interpretation through an explanation of various aspects of descriptive statistics, correlation and the rudiments of inferential statistics. Furthermore, this chapter covers image quality and comparison, and specifically includes a description of physical measures, psychophysical measures and observer performance tests. Chapter 7 outlines the essential requirements for communicating research findings. In particular, the method of communicating your research findings, knowing your audience, research output types, journal selection and criteria for evaluating a journal, as well as elements of a conference presentation.

Finally, Chap. 8 reviews selected published examples of research in medical imaging in various medical imaging journals.

Best wishes in your pursuit of the study of the essential principles of research using the scientific method.

Burnaby, BC, Canada
Canberra, ACT, Australia
Cork, Ireland
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Euclid Seeram
Robert Davidson
Andrew England
Mark F. McEntee

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The single most important and satisfying task in writing a book of this nature is to acknowledge those individuals who have provided the motivation for preparing and writing a textbook of research fundamentals for medical imaging and radiation professionals, as well as those who perceive the value of its contribution to the medical imaging sciences literature. It is indeed a pleasure to express sincere thanks to these individuals. First, I would like to thank my professors in my graduate science studies (MSc) who have taught me the elements of scientific research, and statistics. Furthermore, I am grateful to Dr. Rob Davidson, PhD, and two medical physicists, Dr. Hans Swan, PhD, and Dr. Stewart Bushong, DSc, who evaluated my PhD research proposal and approved the research processes applied to the conduct of the investigation. In addition, my continued and improved understanding of scientific research are centred around the works and expertise of several notable individuals whose textbooks on research have provided me with the tools needed to do original research and to be a part of the team of editors who wrote this book. In particular, I acknowledge the published works of Jennifer R Gray, PhD, Susan K Grove, PhD, and Susanne Sutherland, PhD, specifically their textbook *Burns and Grove's: The Practice of Nursing Research: Appraisal, Synthesis, and Generation of Evidence*. Additionally, I have learned more about scientific research from another free and open access textbook entitled *Social Science Research: Principles, Methods, and Practices* by Anol Bhattacharjee, PhD, of the University of South Florida, Tampa Library Open Access Collections at Scholar Commons textbook. Throughout the chapters that I have written, I have purposefully used several quotes so as not to detract from the authors' original meaning. I personally believe that these quotes and illustrations have added significantly to the clarity of the explanations. Best wishes; keep on learning and enjoy the pages that follow.

Euclid Seeram, PhD, Canada

In the health professions, research often starts with a need to improve clinical practice or outcomes. Mine started in the 1980s when as a CT radiographer I was concerned about the radiation dose to the foetus during CT pelvimetry examinations. I was encouraged by my boss, Graham Tidswell, and mentored by radiologists at Flinders Medical Centre in South Australia and especially by Emeritus Professor Michael Sage, the professor of radiology at that time. My research career began when becoming an academic at Charles Sturt University, New South Wales, Australia, and starting my PhD. I was fortunate to have great supervisors being Professor Bruce Hartley, PhD, a physicist; Dr. Hans Swan, PhD, a physicist; Professor Steve Meikle, PhD, a physicist; and Professor Sarah Lewis, PhD, a radiographer (one of the very few Australian radiographers with a PhD at that time). While getting a good start in research through good supervision and support is important, to me a passion is needed to sustain the research journey. My PhD was undertaken on a part-time basis over 7 years. My passion for that project and research that followed has been maintained over many years. I am fortunate that I am and have mentored and supervised many research students and colleagues. My focus to these people is not just the technical aspects of undertaking research, I hope that I am also instilling the passion that is needed to sustain the research journey. I know this book will help with your understanding of the technical aspects research and I hope this book will also instil some of that passion that is needed. The professions within medical radiation sciences, as do all professions, need passionate people in research to grow the profession's body of knowledge. Enjoy the book, and importantly, enjoy undertaking research.

Rob Davidson, PhD, Australia

I have been deeply passionate about research since my undergraduate days at Liverpool University. Having the opportunity to undertake clinical research as a radiography undergraduate fuelled my desire to pursue a career in research. Twenty-two years later, I am now a senior lecturer in radiography, have completed master's and doctoral level qualifications, and have published and presented at leading conferences and in key peer-reviewed journals. For me, research has given me the opportunity to contribute to enhancing patient care, and this is the essence of being a radiographer. Numerous people have helped influence my research and career trajectories, too many to list and thank personally. In contributing to this textbook, I am reminded and would like to thank my current and past colleagues, lecturers, students, friends and family, both from the UK and internationally. Research has given me a career that I love dearly and hopefully this textbook will engage others in the radiographic community to engage in research. Establishing a career in research is not easy but is exceptionally rewarding. In writing this dedication. I am reminded of the unwavering support of my wife and children, without whom this would all be much more difficult. Good luck to those who will read this textbook, and I look forward to seeing the fruits published and presented within our radiographic community.

Andrew England, PhD, UK

As an educator for the past 20 years, I am acutely aware of the challenges students face in understanding the broad range of concepts necessary to become a healthcare professional in the medical radiation sciences, not the least of which is statistics. My contribution is provided for those students. I would like to sincerely thank Dr. Euclid Seeram for his invitation to contribute to this textbook. Euclid is a prolific writer, but more than that, he is a gentleman and a scholar, and it is an honour to be associated with his work. Although my lecturers at university would barely have believed it, my interest in research began at the University of Ulster under the guidance of Nuala Thompson and Billy Rae. Their supervision allowed me to develop my own research questions and to carry out my experiments virtually independently, a new experience as a student. My PhD supervisors professor Patrick Brennan and Geraldine O'Connor likewise understood the value of independent research. Professor Brennan went on to be my mentor for many years and continues to be an inspiration to researchers globally. I would also like to acknowledge other important academic mentors, Kate Matthews for taking a chance on me in University College Dublin, Professor Peter Hogg for his generosity and inclusiveness at the University of Salford. More recently, Professor Michael Maher, professor of radiology at University College Cork, has demonstrated great vision and support of a fledging Department of Medical Imaging and Radiation Therapy.

Professors Helen Whelton, Jeanne Jackson, Nicole Muller and Paula O'Leary have helped us on our way supporting our development so we can support others through scholarly works such as this.

Mark F. McEntee, PhD, F(IIRRT), SF(HEA)

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Chapter 1

The Nature and Scope of Research



Euclid Seeram

1.1 Research in Medical Imaging and Radiation Sciences: Inclusion in the Curriculum

Research in medical imaging technologies (radiography, nuclear medicine, and magnetic resonance imaging) and radiation sciences (radiation therapy) is an evolving area of study in diagnostic radiography, magnetic resonance imaging, nuclear medicine, and radiation therapy.

As mentioned in the Preface of this book, professional medical imaging and radiation sciences organizations offer journals in which scholarly research studies are published in an effort to provide their members and other readership with an exposure to the nature of research in the profession. Examples of these journals include the following:

1. *The Journal of Medical Imaging and Radiation Sciences: journal of the CAMRT*
2. *Radiologic Technology: journal of the ASRT*
3. *Radiation Therapy: journal of the ASRT*
4. *Radiography*: an international journal of diagnostic imaging and radiation therapy, *journal of the SCoR* and the European Federation of Radiographer Societies
5. *Journal of Medical Radiation Sciences*: an international and multidisciplinary peer-reviewed journal that accepts manuscripts related to medical imaging/diagnostic radiography, radiation therapy, nuclear medicine, medical ultrasound/sonography, and the complementary disciplines of medical physics, radiology, radiation oncology, nursing, psychology and sociology, *journal of the Australian*

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These journals are all *peer-reviewed* journals, which simply mean that they have editorial boards of subject matter experts whose main function is to review and evaluate all articles prior to accepting them for publication. These journals may also publish scholarly and academic papers relating to literature reviews, review papers, and other short interesting and related articles on recent developments in the medical imaging and radiation therapy. Examples of three articles based on research according to the *scientific method* (“a method of research in which a problem is identified, relevant data are gathered, a hypothesis is formulated from these data, and the hypothesis is empirically tested” (Dictionary.com, 2020)) are as follows:

1. Seeram, E., Davidson, R., Bushong, S., & Swan, H. (2016). Optimizing the exposure indicator as a dose management strategy in computed radiography. *Radiologic Technology*, 87(4);380–391.
2. Raed, M. K. M. A., England, A., Tootell, A. K., & Hogg, P. (2020). Radiation dose from digital breast tomosynthesis screening - a comparison with full field digital mammography. *Journal of Medical Imaging and Radiation Sciences*, September 14. <https://doi.org/10.1016/j.jmir.2020.08.018>
3. Davidson, R., Alsleem, H., Floor, M., & van der Burght, R. (2016). A new image quality measure in CT: Feasibility of a contrast-detail measurement method, *Radiography*. <https://doi.org/10.1016/j.radi.2016.04.003>
4. Abdullah, K. A., Mark, F., McEntee, M. F., Warren Reed, W., & Kench, P. (2020). Evaluation of an integrated 3D-printed phantom for coronary CT angiography using iterative reconstruction algorithm. *Journal of Medical Radiation Sciences*, 1–7. <http://doi:10.1002/jmrs.387>

1.2 What Is Research?

The four examples of medical imaging research papers published in the journals listed above all follow the same format in reporting the elements used in conducting research. The first point that is noteworthy is that the research is focused on *science* (a systematic and organized body of knowledge in any area of inquiry) and is conducted using the *scientific method*.

1.2.1 The Scientific Method: Key Characteristics

The scientific method “refers to a standardized set of techniques for building scientific knowledge, such as how to make valid observations, how to interpret results, and how to generalize those results. The scientific method allows researchers to independently and impartially test preexisting theories and prior findings and to

subject them to open debate, modifications, or enhancements. The scientific method must satisfy the following four key characteristics:

- *Logical*: Scientific inferences must be based on logical principles of reasoning.
- *Confirmable*: Inferences derived must match with observed evidence.
- *Repeatable*: Other scientists should be able to independently replicate or repeat a scientific study and obtain similar, if not identical, results.
- *Scrutinizable*: The procedures used and the inferences derived must withstand critical scrutiny (peer review) by other scientists” (Bhattacharjee, 2012).

An important consideration to pay attention to is that “the scientific method operates primarily at the empirical level of research, i.e., how to make observations and analyze these observations” (Bhattacharjee, 2012).

In general, research involves at least four major tasks: find a problem that needs to be explored and which can be expressed as a question, collect enough data used to provide answer(s) to the question using relevant data analysis tools (statistical analysis), provide an answer to the question, and finally report and evaluate the research. These four tasks require a thorough and defined set of steps that ensure a valid answer to the question and satisfy the key characteristics of the scientific method. These steps will be described later in this chapter.

1.3 The Importance of Research: Evidence-Based Practice

Conducting research requires a good deal of time, effort, and cost in order to provide results that are meaningful and can be applied in practice. In general, research adds to knowledge, improves practice, and provides a basis for policy debates (Creswell & Guetterman, 2019).

1.3.1 Evidence-Based Practice

Evidence-based practice (EBP) has its roots in *evidence-based medicine* (EBM), the latter defined as “the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients.” (Sackett et al., 1996) The basic tenet of EBM is to apply the results of research to the care and management of the patient. EBP on the other hand is a term used when the methods of EBM are applied to other professions that are not included in internal medicine (Lavelle et al., 2015). In medical imaging and radiation sciences, the term is used to enable “understanding, interpretation, and application of the best current evidence into radiology practice, which optimizes patient care.” (Lavelle et al., 2015) In summary, EBP seeks out research findings and after appraisal, uses these findings as an objective rationale for use in clinical practice and in policy making.

The use of research findings in practice has evolved into what has been termed “translating research into practice” and is now referred to as “implementation science” as briefly outlined in an editorial by McEntee and Hogg (2020). Furthermore, implementation science is defined as the scientific study of methods to promote the systemic uptake of research findings and other evidence-based practices into routine practice and, hence, to improve the quality and effectiveness of health services (Bauer et al., 2015). It is not within the scope of this book to describe the details of EBP and implementation science; however, the interested reader should refer to the works listed in References (Sackett et al., 1996; Lavelle et al., 2015; McEntee & Hogg, 2020; Bauer et al., 2015) and the special issue of Radiography, entitled *Translating Research into Practice* (2020).

1.4 Types of Scientific Research

Based on the purpose of the research, scientific research can be placed into three major categories, namely, exploratory, descriptive, and explanatory. A brief description is provided by Bhattacharjee (Bhattacharjee, 2012), as follows:

- *Exploratory research* is often conducted in new areas of inquiry, where the goals of the research are (1) to scope out the magnitude or extent of a particular phenomenon, problem, or behavior, (2) to generate some initial ideas (or “hunches”) about that phenomenon, or (3) to test the feasibility of undertaking a more extensive study regarding that phenomenon (Bhattacharjee, 2012).
- *Descriptive research* is directed at making careful observations and detailed documentation of a phenomenon of interest. These observations must be based on the scientific method (i.e., must be replicable and precise) and, therefore, are more reliable than casual observations by untrained people (Bhattacharjee, 2012).
- *Explanatory research* seeks explanations of observed phenomena, problems, or behaviors. While descriptive research examines the what, where, and when of a phenomenon, explanatory research seeks answers to why and how types of questions. It attempts to “connect the dots” in research, by identifying causal factors and outcomes of the target phenomenon (Bhattacharjee, 2012).

1.5 The Research Process Cycle: Steps in Conducting Research

Most research textbooks and research studies published in the literature provide a general process for conducting scientific research. The research process is cyclical and consists eight steps illustrated in Fig. 1.1:

1. Problem identification
2. Literature review

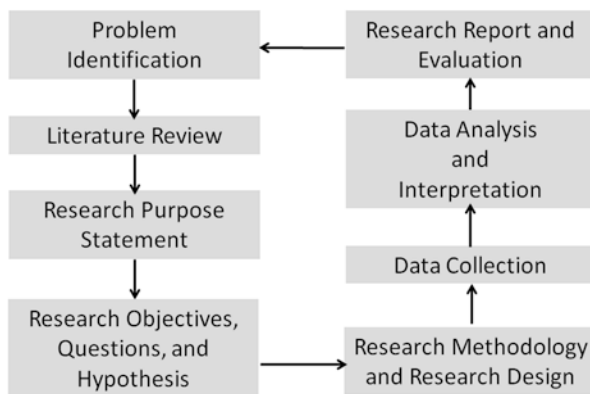


Fig. 1.1 The fundamental steps in the research process

3. Research purpose statement
4. Research objectives, questions, and hypothesis
5. Research methodology and research design
6. Data collection
7. Data analysis and interpretation
8. Research report and evaluation

The *cyclical* nature of the research steps plays a major role in improving the quality and integrity of the research. Each of these will be described in detail in later chapters; however, a brief overview of key characteristics will be outlined next.

The following research study according to the scientific method will be used to illustrate the steps of the research process:

Seeram, E., Davidson, R., Bushong, S., & Swan, H. (2016). Optimizing the exposure indicator as a dose management strategy in computed radiography. *Radiologic Technology*, 87(4):380–391

1.5.1 Problem Identification

One of the first steps to conducting research is identifying a problem that needs investigation. This requires not only a statement of the topic but also more importantly identification of the major issue (the problem) concerning the topic, the justification for the problem, and the significance of researching it for the specific profession. The problem identification involves a statement of what is already known about the topic and what is not known. This means that there is a gap in the knowledge and that the research study intends to fill this gap.

An illustration of the problem identification from the research paper by Seeram et al. (Seeram et al., 2016) is as follows:

The exposure indicator (EI) is a numerical parameter used in computed radiography (CR) to inform operators about the amount of exposure to the imaging plate. The EI indicates whether appropriate radiographic techniques were used for an examination, and can help radiologic technologists control and manage radiation dose. In fact, EI can be “used as a surrogate for dose management.” Furthermore, the EI is the “key to controlling exposure levels” in CR, and optimizing the EI is closely linked with optimizing kilovoltage (kV) and milliampere seconds (mAs). Two significant and fundamental problems in CR imaging are “exposure creep” (ie, using exposures greater than required to produce diagnostic-quality images) and the wide exposure latitude, or dynamic range, of the digital detector. The potential harm associated with exposure creep is unnecessarily high radiation doses to patients, whereas wide exposure latitude can result in images with high noise levels caused by low exposure or increased radiation doses to patients caused by high exposure.

1.5.2 *The Literature Review*

In order to avoid replication of prior research, it is necessary to conduct a literature review of the already existing knowledge based on the research topic. The literature review requires a thorough search of research published on the topic. The literature review should focus on identifying a gap in the knowledge, since the outcomes will guide the development of the statement of the research problem. There are at least three stages in the literature review: input, processing, and output. While *input* refers to having a documented plan for the review and requires physical and online use of bibliographical databases, *processing* is a demanding stage, since it requires careful and critical appraisal, analysis, and synthesis of the literature found. *Output* on the other hand addresses a well-written review that “presents a logical argument for why the research question should be studied and for the specific way of studying it that is being proposed” (Gray et al., 2017).

A brief illustration of the literature review from the research paper by Seeram et al. (Seeram et al., 2016) is as follows:

The literature is sparse regarding the use of EI as part of an optimization strategy in digital radiography, and further research is needed to understand its relationship to exposure techniques and patient exposure. With respect to exposure techniques, manipulation of the operating kV cannot stand alone even with digital systems, and concomitant compensation of the applied mAs, together with adequate scatter control are necessary. One concern in digital imaging is the inverse relationship between mAs and image noise. As a result, optimization must consider image quality along with the dose per image. Increasing the dose per image decreases noise, thus improving image quality.

The literature review will be described in detail in Chap. 3.

1.5.3 *The Research Purpose Statement*

The purpose of the research is expressed as an objective of the study and usually identifies important elements, for example, variables, the site of the study, and the study population. In the paper by Seeram et al. (2016), the purpose statement is expressed as follows:

The purpose of this study was to investigate optimization of the EI of a Computed Radiography (CR) imaging system as a radiation dose management strategy, in keeping with the ALARA (as low as reasonably achievable) principle and to compare the optimized EI with the manufacturer's recommended values in an anthropomorphic phantom for the anteroposterior (AP) pelvis and AP lumbar spine projections.

The purpose statement can be translated into objectives, as listed in the next subsection.

1.5.4 *Research Objectives, Questions, and Hypothesis*

Keeping in mind the practical problems described previously and the needs that are apparent in the current literature; the objectives of this study (Seeram et al., 2016) are the following:

1. To correlate the mAs and associated exposure indicator with the entrance skin dose (ESD) using a range of mAs settings while holding the kVp constant.
2. To determine an optimum mAs and corresponding exposure indicator for the AP pelvis and AP lumbar spine of an anthropomorphic phantom and to compare these with the Fuji CR manufacturer's recommended values.
3. To determine a dose-image quality optimization strategy using the mAs and corresponding exposure indicator as an option for better implementation of the ALARA philosophy on the Fuji CR imaging system.

The purpose statement can also be expressed as a *research question* or a *research hypothesis*. As noted by Creswell and Guetterman (2019), "research questions are questions that focus the purpose of the study into specific areas of inquiry." For example, the above three objectives can be expressed as the following research questions:

1. What is the correlation between the mAs (and associated EIs) and the ESD?
2. What is the optimum mAs and corresponding EI for the AP pelvis and AP lumbar spine of an anthropomorphic phantom, compared with the manufacturer's recommended values?
3. What dose-image quality optimization strategy using the mAs and corresponding EI can be used as an option for better implementation of the ALARA philosophy on the CR imaging system?

Hypotheses are used in research to limit the extent of the purpose statement and to make predictions about the relationship between two variables or among three or more variables. The details of using the hypothesis are not within the scope of this chapter; however, the following is noteworthy as stated by Gray et al. (2017): “The scientific method rests on the process of stating a hypothesis, testing it, and rejecting or accepting the hypothesis. The hypothesis-testing process involves several steps, the first two of which are identification of the research hypothesis and construction of the corresponding null hypothesis. Even if a hypothesis is not identified in a research report, when a study is experimental or quasi-experimental, a hypothesis is present.”

A *null hypothesis* requires the use of statistics not only to test it but also to help with the interpretation of the results. In this case, the null hypothesis is referred to as a *statistical hypothesis* (Gray et al., 2017), as opposed to a *research hypothesis* or *alternative hypothesis* to the null hypothesis. For example, the null hypothesis will state that there will be no statistically significant relationship between the independent variable and the dependent variable. The research or alternative hypothesis on the other hand will state that there will be a statistically significant relationship or a difference between two or more variables (Gray et al., 2017). An *independent variable* is feature or a characteristic that has an effect on the outcome, the *dependent variable*. It is the variable that is manipulated by the researcher. The dependent variable on the other hand is the result or outcome that is predicted and measured in the research study (Gray et al., 2017).

1.5.5 Research Methodology and Research Design

The *research design* involves several steps, and “it is the single most important component in producing a study that is appropriate to the discipline, well grounded, credible, precise, and useful“ (Gray et al., 2017), and it demands a good deal of attention on the part of the researcher. It requires a focus on the research methodology and on the research design. While the former refers specifically to two approaches, namely, quantitative methods and qualitative methods, the latter refers to the specific procedures use in data collection, data analysis, and the reporting of the results of the study (Creswell & Guetterman, 2019). The research design focuses on the data collection process, the development of the tool or instrument, which will be used to record the data, and the sampling process (Bhattacharjee, 2012). Equally important are key characteristics that play a role in, for example, the quality of the research design internal, external, and construct validity. Generally, validity refers to the importance and well-grounded conclusions reached on the basis of evidence and reasoning from a sample or population. For more details of internal, external, and construct validity, the reader should refer to Creswell and Guetterman (2019) and Gray et al. (2017)

Research methodology can be defined by two popular approaches used in research studies, namely, quantitative methods and qualitative methods. A

quantitative method is a “formal, objective, systematic study process that counts or measures, in order to answer a research question. Its data are analysed numerically” (Gray et al., 2017). A *qualitative method* on the other hand is “a scholarly and rigorous approach used to describe life experiences, cultures, and social processes from the perspectives of the persons involved” (Gray et al., 2017).

Quantitative research methods are generally placed into two categories, namely, interventional research and non-interventional research. *Interventional research* is intended to investigate cause and effect relationships, as in an experiment, where the object to do conduct some sort of manipulation to the experimental group (interventional group) but nothing to the control group. *Non-interventional* research on the other hand is a descriptive process that examines variables or the association between variables (Gray et al., 2017). Categories of quantitative research approaches include descriptive research, correlational research, experimental research, and quasi-experimental research. The study by Seeram et al. (2016) is an example of a non-interventional research that uses a correlational research design.

Qualitative research “are based on a wide range of philosophies and traditions, such as phenomenology, symbolic interactionism, and hermeneutics, each of which espouses slightly different approaches to gaining new knowledge” (Gray et al., 2017). It is not within the scope of this book to discuss elements of philosophy; however, it is important in the context of research to understand that philosophy describes science, guides methods, and guides criteria of rigor (Gray et al., 2017). The approaches used in qualitative research are phenomenological research (describes experiences and gather “lived” experiences of the research subjects), grounded theory research (provide results “grounded” on the data obtained from the research subjects), ethnographic research (examines research on cultures), historical research (learns from the past to apply to the present and future), and narrative inquiry and case study (Gray et al., 2017).

While a general overview of these methods, including major characteristics, will be described in Chap. 2, Chap. 5 will elaborate the elements and mechanics of these methods.

1.5.6 Data Collection

The outcomes of research sought by the research objectives, questions, and hypothesis are obtained through the process of *data collection*. There are several important elements of data collection; the purpose of which is to obtain information in a systematic and precise manner. Data collection therefore will differ in a number of ways for quantitative and qualitative research approaches and especially their research designs.

In quantitative research, data collection in general requires development of *tools or instruments* (described in the methods and procedures section of the research) to measure specific variables or to gather relevant data, for example, an instrument that can be used to gather demographic data from a sample of the population under

study. The instrument can also be used for other purposes such as collecting numeric (quantifiable) data, as well as data from a large sample size, or as many data readings as possible. The dose optimization research by Seeram et al. (2016) describes tools used in this research. These include the x-ray imaging equipment, an anthropomorphic phantom from which dose data are collected using defined methodology for dose collection. Furthermore, image acquisition for each dose value is described, as well as the image quality evaluation for all images recorded at specific doses, and the statistical analysis performed on the data collected.

In qualitative research, on the other hand, data collection involves the development of forms referred to as protocols expressed as questions and may be formulated as interview protocols and observational protocols (e.g., the behaviors of participants are observed and recorded) (Creswell & Guetterman, 2019).

1.5.7 Data Analysis and Interpretation

After data collection, data analysis and interpretation are the next important steps in conducting research. These steps involve making sense of the data collected. For quantitative data, it may involve creating tables, charts, graphs, and *statistical analysis* to help in summarizing and explaining the conclusions obtained as a means of addressing the research objectives, questions, and hypothesis. This requires that the data must be arranged in a systematic manner and be prepared carefully for examination and reviews and in the case of quantitative research be organized for statistical analysis (Creswell & Guetterman, 2019).

The use of statistical analysis is vital in quantitative research, since this approach uses mainly numeric data sets, which can be used to describe variables, to examine relationships, to predict, and to determine differences (Gray et al., 2017). In medical imaging research, statistics such as descriptive statistics; probability; inferential statistics (hypothesis testing, p-value, effect size, and confidence intervals); and statistical tests such as t-tests, analysis of variance (ANOVA), correlation, regression approaches, and so on measure diagnostic accuracy and reliability (Anvari et al., 2015). Essential statistics will be covered in detail in Chap. 6.

1.5.8 Research Report and Evaluation

The *research report and evaluation* are the final steps in the cyclical process of conducting research. This is prepared after the research has been completed. One of the first considerations in preparing a quantitative or qualitative research report is to consider the intended audience, which will differ for, for example, dissertations or theses, conference papers, and journal article. Most research reports include the following characteristics, namely, abstract, introduction (includes the literature review), methods, results, and discussion.

The *abstract* provides a summary of the elements of the study and generally includes a brief description of the nature and problem to be investigated, leading to a purpose statement, how the research was conducted, the results, and conclusion of the outcomes of the research. The *introduction* features a description of the background relating to the topic under study, significance of the research, a summary of the main elements of the literature review, and finally a purpose statement. The *methods* section summarizes how the research was conducted, the tools and instruments used to collect data, and the statistical analysis used. Reporting the results will differ for quantitative and qualitative research. Generally, the *results* will include descriptions in the form of diagrams, texts, and tables (quantitative study) and major themes (qualitative study) emerging from the participants, regarding each of the parameters outlined in the methods section. The *discussion* section will first restate the research question, purpose, or hypothesis; subsequently link the results of data collection not only to previous related studies but also to the present ones; demonstrate how the results explain the purpose of the research; and subsequently provide a solution to the research problem. This section should also identify limitations of the study and suggest any need for future research. Furthermore, it is important to not only include a conclusion statement but also provide a list of references. Finally, the research report must conform to the requirements of the vehicle (say journal) for presentation, in terms of format, citations, and so on.

1.6 Research Ethics

Ethics in research is a mandatory requirement and activity. It is a complex topic and is characterized by a set of guiding principles that relate to the “respect for persons, beneficence, and justice” (Gray et al., 2017). It is not within the scope of this book and in particular this chapter to describe ethics in research to any full extent; however, it is important to understand that ethics in research has a significant history, which has a major effect on research. Two such notable historical accounts are the *Nuremburg Code* and the *Declaration of Helsinki*. For a thorough account of historical events, the interested reader should refer to the work of Gray, Grove, and Sutherland (2017) who also point out that research ethics is essential “because of (1) the complexity of human rights; (2) the focus of research in new, challenging arenas of technology and genetics; (3) the complex ethical codes and regulations governing research; and (4) the variety of interpretations of these codes and regulations” (Gray et al., 2017).

In a similar vein, Fouka and Mantzourou (2011) identify the following as major ethical issues to consider when conducting research: informed consent, beneficence (do no harm), respect for anonymity and confidentiality, respect for privacy, consideration for vulnerable groups of people (such as prisoners, students, cognitively impaired individuals, and children), and the skills of the researcher.

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Chapter 2

Quantitative and Qualitative Research: An Overview of Approaches



Euclid Seeram

In Chap. 1, the nature and scope of research were outlined and included an overview of quantitative and qualitative research and a brief description of research designs. In this chapter, both quantitative and qualitative research will be described in a little more detail with respect to essential features and characteristics. Furthermore, the research designs used in each of these approaches will be reviewed. Finally, this chapter will conclude with examples of published quantitative and qualitative research in medical imaging and radiation therapy.

2.1 What Is Quantitative Research?

Quantitative research makes use of the scientific method (Chap. 1) through the application of a defined number of specific steps in order to establish new knowledge. These steps involve not only the collection of numerical data but also more importantly the analysis of such data, for the purpose of explaining, predicting, and/or controlling variables relating to the problem being studied. Data analysis is achieved through the use of statistics to obtain objective results. These results enable the research to draw reasonable and dependable conclusions. These elements ensure that the research may be replicated to support the results (Creswell & Guetterman, 2019; Gray et al., 2017; Anvari et al., 2015; Solomon & Draine, 2010). Furthermore, Gray et al. (2017) state that “replication of an existing study is a respective way to generate worthwhile, applicable research findings.”

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The keywords in the paragraph above describing the nature of quantitative research place an emphasis on the following: defined number of specific steps, numerical data, analysis of the data, explanation, prediction, control, variables, and statistical analysis. These will become clear throughout the rest of this chapter.

2.1.1 Types of Quantitative Research

Several authors (Creswell & Guetterman, 2019; Gray et al., 2017; Bhattacharjee, 2012) have identified the types of quantitative research designs or approaches. These types fall into two major categories, namely, *intervention research methods* and *non-intervention research methods*. While intervention research methods “examine cause-and-effect relationships,” non-intervention research “does nothing to the research subjects except for what occurs in the process of measuring them, such as having them fill out a survey or submit to a blood draw” (Gray et al., 2017). Research designs for interventional research include *experimental* and *quasi-experimental* research designs. Non-interventional research (non-experimental) designs include *descriptive research*, *correlational research*, and *survey research*. These methods will be described in some detail in Chap. 5; however, a brief overview of these methods is noteworthy here, since it lays the foundation for the more elaborate descriptions presented in Chap. 5.

2.1.1.1 Non-interventional Research Designs

Descriptive Research

The major features of a *descriptive research* approach are to explore and describe “ideas, which in research are called phenomena, in real life situations” (Gray et al., 2017), examples of which include a simple descriptive design, a comparative descriptive design, a longitudinal descriptive design, and a cross-sectional descriptive design. An example of a longitudinal research in medical imaging is one by Gibson and Davidson (2012) entitled *Exposure Creep in Computed Radiography: A Longitudinal Study* in which the researchers explored the phenomenon of exposure creep in computed radiography over 43 months in three departments from one hospital using the exposure indicator to determine if exposure creep exists and if measures can be applied to stop or reverse exposure creep trends. The interested reader should refer to this study for further details.

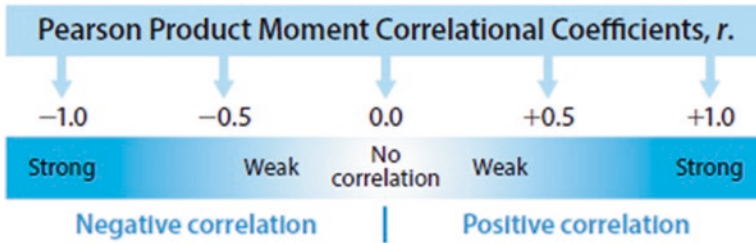


Fig. 2.1 An illustration of the direction, degree, and strength of the association indicated by the Pearson product moment correlation coefficients

Correlational Research

The major goal of *correlational research* is to allow prediction and explanation of the relationship among variables. Researchers use a correlational research design to measure two or more variables to investigate the extent to which the variables are related. Coyle (2012) summarized that correlational research can uncover variables that are interacting and the type of interaction that is occurring, which allows the researcher to make predictions based on the discovered relationships. Furthermore, a statistical test such as a correlational statistic can determine the relationship objectively. The Pearson product moment correlational coefficient, r , shows a linear relationship between two variables as illustrated in Fig. 2.1. If variables are continuous, then r can range from -1 to $+1$.

There are at least three types of *correlational research designs*: descriptive or explanatory, predictive, and model testing (Gray et al., 2017). A *descriptive design* emphasizes an explanation of the relationships between and among variables. A *predictive design* “attempts to predict the level of a dependent variable from the measured values of the independent variable” (Gray et al., 2017). The *model testing design* focuses on testing theoretically proposed relationships.

There are several important features of correlational research. These include correlation between two or more variables, collection of data at one point in time; the use of all scores on a continuum (e.g., 15–95) collection of at least one score for each variable, using the appropriate correlational statistic, and making an interpretation to obtain a conclusion from the results of the statistical test (Gray et al., 2017). For a quality study, researchers should focus on these key features. Other significant correlational research characteristics include display of scores, associations between scores, and multiple variable analysis (Gray et al., 2017). As illustrated in Fig. 2.2, scatter plots are used to display the results of a correlational study. These plots can show a positive correlation (Fig. 2.2a), a negative correlation (Fig. 2.2b), or no correlation (Fig. 2.2c). In a positive correlation, a *positive gradient*—in which variable x increases and variable y increases—is present. In a negative correlation, a *negative gradient*—in which x increases as y decreases, is present. Data points are scattered if no correlation is present between x and y (Fig. 2.2c).

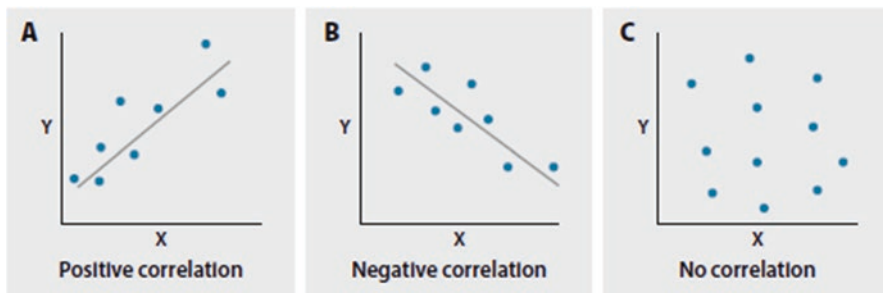


Fig. 2.2 Schematic view of correlational data, which shows a positive correlation (a), a negative correlation (b), and no correlation (c)

There are several advantages and disadvantages of correlational research as well as limitations (Gray et al., 2017; Battistelli et al., 2013). Curtis et al. (2016) encouraged health-care professionals to perform correlational research and also noted that correlational research results can be used to develop hypotheses to be tested in an experimental design. An example of a descriptive correlation research design in medical imaging is one by Seeram et al. (2016). This study investigated optimization of the exposure indicator of a computed radiography imaging system as a radiation dose management strategy, in keeping with the as low as reasonably achievable principle. The study is described further in Chap. 8.

Survey Research

Survey research is another example of non-interventional (non-experimental) approaches to conducting research. A notable characteristic of survey research is to “administer a survey or questionnaire to a small group of people (called the *sample*) to identify trends in attitudes, opinions, behaviours, or characteristics of a large group of people (called the *population*)” (Creswell & Guetterman, 2019).

There are several types of survey designs including *cross-sectional survey designs* (characterized by data collection at one point in time) and *longitudinal survey designs* (characterized by data collection over time). The latter designs include trend design studies, cohort design studies, and panel design studies (Creswell & Guetterman, 2019). A good survey study should include the following important characteristics: sampling from the population, data collection using questionnaires and/or interviews, design of the instruments or tools for data collection, and getting a high response rate. An important point that warrants consideration is to pilot test the data collection instruments, such as the questionnaire and the interview questions. An example of a non-interventional quantitative survey design is a study by Seeram et al. (2015) entitled *Education and Training Required for the Digital Radiography Environment: A Non-interventional Quantitative Survey Study of Radiologic Technologists*. This study is reviewed in detail in Chap. 8.

2.1.1.2 Interventional Research Designs

As mentioned earlier in this chapter, interventional research addresses cause and effect relationships. There are two major research designs in interventional research: *experimental research* and *quasi-experimental research*. The major characteristics of each of these will be reviewed briefly and elaborated in Chap. 5.

Experimental Research

Experimental research is a quantitative research method that deals specifically with numbers. Specifically, an experiment is designed to investigate if a causal relationship exists between two variables (Gray et al., 2017; Price et al., 2015). These variables are the independent variable and the dependent variable. The definitions of these two variables are as follows:

- *Independent variable*: “In interventional research, the treatment, intervention, or experimental activity that is manipulated or varied by the researcher, to create an effect of the dependent variable”
- *Dependent variable*: “Response, behaviour, or outcome that is predicted and measured in research.”

The research process then looks at whether changes in the independent variable cause changes in the dependent variable. With respect to variables, a researcher using the experimental method must focus on (a) manipulating or varying the level of the independent variable and (b) control or reduce any extraneous variable that influences or affects the relationship between the independent and dependent variables. Such a variable is called a *confounding variable*.

The *key features of experimental research* are random assignment, control over confounding or extraneous variables, manipulation of the treatment conditions, outcome measures, group comparisons, and threats to validity (Creswell & Guetterman, 2019). These are features in experimental designs, which include true experiment, quasi-experiment, factorial design, time series design, repeated measures design, and single subject design. Furthermore, experimental research requires what Gray et al. (2017) refer to as rigor and control. While *rigor* “implies a high degree of accuracy, consistency, and attention to all measurable aspects of the research”, *control* “consists of design decisions made by the researcher to decrease the intrusion of the effects of extraneous variables that could alter research findings and consequently force an incorrect conclusion” (Gray et al., 2017). Experimental designs will be further elaborated in detail in Chap. 5.

Quasi-Experimental Research

Quasi-experimental research approaches belong to the category of quantitative research. This approach allows the researcher to investigate the cause-and-effect relationship between the independent variable and the dependent variable. A major difference between this approach and the experimental approach is that quasi-experimental research does not require random assignment of subjects to a group and does not require the research to manipulate the independent variable (Gray et al., 2017). Furthermore, control groups are not necessary (but may be used frequently), and subjects are assigned to groups on the basis of non-random criteria (Thomas, 2020).

There are several types of quasi-experimental designs; however, the more common types include non-equivalent groups design, regression discontinuity, and natural experiments (Thomas, 2020). It is not within the scope of this chapter to outline the details of these approaches; however, the interested reader may refer to brief descriptions provided by Thomas (2020).

2.1.2 Steps in Quantitative Research

The steps in conducting research (the research process cycle) were described in general in Chap. 1. These steps apply to quantitative research; however, there are definitive steps that are mandatory and involve both rigor and control. Gray et al. (2017) emphasize that in research, iteration is vital in the conduct of the research study. The term iteration as stated in Merriam Webster's Dictionary means "a procedure in which repetition of a sequence of operations yields results successively closer to a desired result." The process of iteration is an essential activity in the quantitative research process.

Gray et al. (2017) outline the essential steps as follows: formulate the research problem and purpose, use a theory or a framework (if needed), state any assumptions very clearly, formulate research objectives, questions, or hypotheses, and define study concepts and variables. Furthermore, the steps must include the research design used and the choice of which will demand the following: definition of population and sample, selection of measurement tools, development of plan for data collection and analysis, and implementation of research plan. The latter may require a *pilot study*, which is intended to "determine whether the proposed methods are effective in locating and consenting and in collecting useful data" (Gray et al., 2017). Finally, it is important that the researcher communicates the research findings through presentations at relevant conferences and publication in relevant journals. An example of a quantitative research study that incorporates most of the steps identified in the above paragraph is one by Seeram et al. (2016), which is described in Chap. 8.

2.2 What Is Qualitative Research?

While quantitative research essentially deals with the collection of numerical data to address a research problem and involves rigorous statistical analysis of the data to provide meaningful results, *qualitative research* deals with the collection of non-numerical data (e.g., words) to explore the experiences and knowledge of living from the point of view of people living in the environment. A rather clear notion of what qualitative research is one from Gray et al. (2017) who state that qualitative research “is a scholarly approach used to describe life’s experiences, cultures, and social processes from the perspectives of the persons involved...Qualitative researchers focus on ‘naturally occurring, ordinary events in natural settings’ (Miles et al., 2014)...allows us to explore the depth, richness, and complexity inherent in the lives of human beings. Insights from this process build nursing knowledge by fostering an understanding of patient needs and problems, guiding emerging theories, and describing cultural and social forces affecting health (Munhall, 2012).”

Qualitative research methods are guided by the philosophy of science. Furthermore, this philosophy also ensures stringency of the research process. Additionally, data collection involves open-ended approaches such as observations, interviews, focus groups, careful assessment of documents, Internet-based data, images, and electronic-based communications (Gray et al., 2017).

2.2.1 Types of Qualitative Research

Several types of qualitative research methods and *major* examples include *phenomenological research*, *grounded theory method*, *ethnographic methods*, *explanatory–descriptive methods*, *historical research methods*, *action research*, and *mixed methods research* (Gray et al., 2017; Creswell & Guetterman, 2019). It is not within the scope to describe these methods in any detail, since they will be addressed and elaborated in Chap. 5; however, the following themes of each of them are provided in Table 2.1.

2.2.1.1 Examples in Medical Imaging

The interested reader should refer to the following examples of qualitative research in medical imaging to gain a further insight into the specific research problems and methodologies:

- Munn, Z., & Jordan, Z. (2011). The patient experience of high technology medical imaging: A systematic review of the qualitative evidence. *JBIC Library of Systematic Reviews*, 9(19):631–678. <https://doi.org/10.11124/01938924-201109190-00001>. PMID: 27820215.

Table 2.1 A brief summary of the types of qualitative research and quoted from the authors who have provided their meaning at a glance (see References)

Types of qualitative research	Meaning at a glance	Authors
Phenomenological research	To describe experiences from the perspectives of the participants and to capture the lived experience. Phenomenology is the philosophy guiding these studies, a philosophy that began with the writings of Husserl	Gray et al. (2017)
Grounded theory research	To generate a general explanation (called a grounded theory) that explains a process, action, or interaction among people. The procedures for developing this theory include collecting primarily interview data, developing, relating categories (or themes) of information, and composing a figure or visual model that portrays the general explanation. In this way, the explanation is “grounded” in the data from participants. From this explanation, you construct predictive statements about the experiences of individuals	Creswell and Guetterman (2019)
Ethnographic research	The investigation of cultures through an in-depth study of the members of the culture	Gray et al. (2017)
Exploratory–descriptive research	Elicits the perceptions of participants to provide insights for understanding patients and groups influencing practice and developing appropriate programs for specific groups of people. In addition to the naturalistic orientation common to all qualitative research, exploratory–descriptive studies may be guided by the philosophy of pragmatism with a focus on problem solving	Gray et al. (2017)
Historical Research	To analyze the interaction of people, events, and social context that occurred in the remote or recent past	Gray et al. (2017)
Mixed methods research	Incorporates both quantitative and qualitative methods into one research study. The convergence of technology with health disparities and the complexity of the health-care system has given rise to several research problems that cannot be answered completely with either type of research	Gray et al. (2017)
Action Research	Action research is seen to differ from other research methodologies in three fundamental ways. First, its primary goal is rooted in social change. Second, participants in action research studies accept responsibility for helping solve issues around a focus of inquiry. Third, relationships between the researcher(s) and study participants are more complex, often less hierarchical. Most often, action research is viewed as an approach in which theory and practice are explored by posing questions, collecting data, and testing hypotheses through several cycles of action. The most common purpose of action research is to guide practitioners as they uncover answers to complex problems in disciplines such as education, health sciences, sociology, or anthropology	University of Lethbridge (2020)

- Suchsland, M. Z., Cruz, M. J., Hardy, V., Jarvik, J., McMillan, G., Brittain, A., & Thompson, M. (2020). Qualitative study to explore radiologist and radiologic technologist perceptions of outcomes patients experience during imaging in the USA. *BMJ Open*, *10*, e033961. <https://doi.org/10.1136/bmjopen-2019-033961>
- Munn, Z., Pearson, A., Jordan, Z., Murphy, F., & Pilkington, D. (2013). Action research in radiography: What it is and how it can be conducted. *Journal of Medical Radiation Sciences*, *60*(2), 47–52. <https://doi.org/10.1002/jmrs.8>
- O'Regan, T., Robinson, L., Newton-Hughes, A., & Strudwick, R. (2019). A review of visual ethnography: Radiography viewed through a different lens, *Radiography*, *25*(Supplement 1), S9–S13.

2.2.2 Steps in Qualitative Research

The steps in qualitative research basically follow those in quantitative research and include the following:

1. Identification of the research problem
2. Review of the literature
3. State the purpose of the research
4. Data collection
5. Data analysis and data interpretation
6. Report and evaluate the research

In conducting qualitative research, a further elaboration of the steps is provided by Chenail (2011) and published in *The Qualitative Report*, and in order to gain a further insight into the nature of the various steps, the interested reader may refer to the article entitled *Ten Steps for Conceptualizing and Conducting Qualitative Research Studies in a Pragmatically Curious Manner*. In summary, these steps (Chenail, 2011) are as follows:

1. Reflect on what interests you.
2. Draft a statement identifying your preliminary area of interest and justifying its scholarly and/or practical importance.
3. Hone your topics focus.
4. Compose your initial research question or hypothesis.
5. Define your goals and objectives.
6. Conduct a review of the literature.
7. Develop your research design.
8. Conduct a self-assessment in order to determine what strengths you have that will be useful in your study and what skills you will need to develop in order to complete your study.
9. Plan, conduct, and manage the study.
10. Compose and submit your report.

In the discussion of his report, Chenail (2011) concludes with the following statement:

Although I have presented these steps in particular order, it is important to remember that the conceptualization and conduct of qualitative research is a circular, recursive, and reflective process. The decision-making process in research can best be understood as an integrated system in which choices influence choices so although a particular procedural choice is made at one point in the research process; this choice may need to be re-considered as other issues arise or as new insights arise in the research undertaking. This iterative aspect of qualitative research means you should continuously check and re-check the decisions made for these ten steps and judge and re-judge their effectiveness and coherence.

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Chapter 3

Planning Your Research



Rob Davidson

Albert Einstein (1879–1955) once stated that:

If I had an hour to solve a problem I'd spend 55 minutes thinking about the problem and 5 minutes thinking about solutions.

This simple statement from one of the world's most recognized thinkers stresses the importance of defining the problem and then planning how you could solve the problem. According to Einstein, and many other people, planning is the most important aspect of finding a solution to the problem.

For many of us, solving a problem can mean undertaking research. Undertaking health-related research can be exciting and rewarding. For some people, research is their career, and they are involved in research on a daily basis. For others, undertaking research may just simply be a means of overcoming a small local issue in their daily clinical practice and hence rarely done. In both examples, formal planning is needed so the research outcomes can be seen as having validity in relation to the objectives of the research, which as suggest, might be creating new knowledge or simply overcoming that local issue.

A researcher or a clinically practicing radiographer/radiologic technologist may have identified an area of concern or an issue that needs investigation. Relevant information around the area should then be found by searching for and reviewing the current literature. Chapter 4 provides details on how this is done. If answers relevant to the topic or area of concern aren't found, then further investigation may be needed, and this is the research itself.

Undertaking such research requires appropriate planning before starting and undertaking the research project. The planning process has multiple steps, and while the steps may be typical for most research, the details within each step will vary

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depending on the type of research needed to address the concern or overcome the issue at hand.

This chapter will review the general steps needed in most research planning.

3.1 Formulating a Research Question

“What is your research?” is a question that is often asked both informally and formally. For example, the question of “What is your research question?” may be asked by statisticians who may be helping with your statistical analysis, people whom you have asked for assistance in developing the project and when that answer is needed to be completed on forms such as ethics or research funding applications. To answer such people or complete those forms, a formal understanding is needed, and the explanation will be different to the question of “What is your research about?”. Colleagues, family and friends may ask this question. Knowing what your research is about does not always mean that you fully understand or can explain the research question.

Explaining the purpose of your research is an important aspect of the research itself. Research needs to be undertaken with a purpose and to answer a question. When you complete an ethics application, there will be a response that is required about the benefit of the research. Ethics committees need to ascertain that a participant who will provide their time in the research, whether that is someone undergoing additional tests over and above standard clinical practice or someone simply responding to a survey questionnaire, can be assured that the research will potentially lead to a beneficial outcome, most probably not a direct benefit to the participant.

In some research, where there are no participants, there is no need for ethical approval; however, this does not mean that ethical issues do not need to be considered. There will be more on ethics later in this chapter, though thinking about a project, its potential ethical issues and research questions is an important part of this process.

Questions from colleagues, family, or friends about your potential or actual research project are sometimes like these: “so what?,” “why bother?” or “is that important?”. Similar to the discussion above, for you to be able to answer and overcome such questions, formulating a research question and understanding the research question both formally and informally are important parts of research itself.

3.1.1 Broad and Narrow Research Questions

When considering answering a research question, often clinicians will already have a specific narrow question in mind that needs answering due to their direct involvement in a clinical issue. However, many research projects start from a broad

question that is often too big to answer. The broad question then should have a focus on narrowing the research question to try answering a part or parts of the broad question, so that eventually the broad question will be answered. Importantly, time and other resources are finite, and trying to answer a broad question may be impossible over a short time given such constraints.

Broad research questions often need narrowing. Some examples of very broad questions are “Can cancer be cured?”, “Does having a CT scan improve diagnosis?” or “Can ionizing radiation dose be reduced and image quality be improved?”. Some examples of narrowed or more focused research questions are “Can human epidermal growth factor receptor 2 (HER2) positive breast cancers be reduced using XXXXXX treatment?”, “Does CTCA have an improved diagnosis of coronary arterial stenosis compared to coronary angiography?” and “Can the radiation dose in planar abdominal X-ray examinations be reduced without compromising image quality?”. Even these later questions can be considered as “broad”, and some more focused or narrowed questions can be asked before the research is started.

Think about your research question. Is it a broad research question, or even if you think it is a narrow question, can it be more focused? A narrow, focused question can be a part, even a small part, of answering a broad question. The quote “Without taking many small steps, one cannot complete a journey of a thousand miles. Without collecting many drops of water, one cannot form a river or sea” was written by a famous Chinese philosopher, Xunzi (Hsün Tzu, 31–0220 B.C.E.), and then converted and contextualized for western reading. Taken in the context of research, to answer the broad question, many small questions need to be answered, so the broad or broader question can be answered. Going back to the early discussion and questions of “so what?”, “why bother?” or “is that important?”, understand where your project fits in the broad questions and be prepared to put your research question into that big picture because that can help you in answering the bigger question.

Research however is rarely done by just asking one simple question. Many sub-questions are often needed to answer the broad research question. A focused or narrow question is often easier to answer, the research project itself is easier to manage and the outcomes can be easier to analyse and explain. That small research step may help in completing the broad research journey, so don’t be put off in doing your small research project to answer a small research question.

3.1.2 Types and Characteristics of Good Research Questions

There are many types of research questions, even more than the types of research. The two very broad categories of research are quantitative research and qualitative research, and then of course, there is mixed methods research, a combination of both quantitative and qualitative research. You need to understand what type of research you are planning before you can formulate the type of research question that is needed to be posed and before you endeavour to try and answer the research

question. However, in stating that, the question itself may often lead you as a researcher to the type of research – quantitative, qualitative or mixed methods – that is needed to answer your question.

Descriptive research is typically about trying to describe or define a sample or subset of a population that is being studied, or it can be about trying to describe the phenomenon that is being studied. Descriptive research questions often start the research question statement with the word “what”, “when”, “where”, “who” or “how”. Questions that start with such words are typically quantitative research, though questions commencing with “how” can be qualitative research. In comparison, a “why” question tends not to be descriptive and is more often not to be a quantitative research question.

Some examples of descriptive research questions are as follows:

- What percentages of patients were diagnosed with XXX pathology after having a YYY test in the ZZZ radiology practice/department?
- Where do patients spend most of their time in the ZZZ radiology practice/department?
- How are patients admitted to a ward after having a YYY test in the ZZZ radiology department?

A qualitative example of a “how” question to a participant can be, though not necessarily a descriptive research question, as follows:

- How was your experience after having a YYY test in the ZZZ radiology practice/department?

When you pose a question such as “What are the differences between?”, you are asking a comparative research question. To answer such questions, typically a quantitative research project needs to be defined. You will need to measure one or more variables; hence quantitative research will be undertaken. While this is typically quantitative research, a “what ...” question still could be a question that is put to participant in a qualitative research project. Note the differences here: the first aspect is about a research question, something that you are trying to answer, versus a question that is posed in an interview. Such question that is posed in an interview is trying to obtain people’s opinions, not stating a question to try to answer or address a research issue.

Health and medical research clinical trials are considered as the highest level of research to determine the efficacy of new treatments or diagnostic methods. The World Health Organisation (WHO) defines a clinical trial as “any research study that prospectively assigns human participants or groups of humans to one or more health-related interventions to evaluate the effects on health outcomes”. Clinical trials may assign a group of participants in a group that has a placebo group, something that has no therapeutic or related effect. The research question in clinical trials will pose a comparative research question.

An example of a comparative research question is as follows:

- In the geriatric population, which imaging modality, AAA scan or BBB test, has the highest sensitivity in detecting XXX pathology?

Another type of question that could be asked is relational research questions. Here you are not looking at the differences, you are trying to determine if there is a relationship between influencing factors or variables. A question could be posed “does student attendance in class result in an increased mark?”. Here there are two variable that need to be measured, attendance in class and the student’s marks. The analysis of this data will be different from the questions previously discussed, so different types of questions will lead to different statistical analysis. A common approach in health and medical research is to use a control group. A control group is typically a group of participants, or alternative sample from the same population, that do not have the treatment or intervention applied to them. The researchers will then compare the results or outcomes between the two, or more, groups. Here the question will be similar in which something like “is there a difference in outcomes between the control group and those who received GGG treatment?” will be asked.

A relational research question can also be asked when comparing the same group or sample of the population before and after an intervention. An intervention is something that is applied to the group with an expectation that this intervention will change an expected outcome. An example of such a relational research question is, “Will patients’ weight be reduced after the implementation of the new diet?”

In the next type of question, the researchers are seeking a causal relationship. A causal relationship can be explained as seeking to determine “If X is done, will Y happen?”. Here the researcher will extend beyond just posing a question; they will develop and present a hypothesis. Formulating a hypothesis is discussed in more detail later in this chapter. Simply though, a hypothesis is a formal question, or series of formal questions, to endeavour to prove that given event X has occurred, Y only happens by chance. Such statement is a null hypothesis, and it may appear to be a negative approach; however, this approach is the basis of the scientific method. When null hypothesis is disproved, the alternate hypothesis can be stated as valid. In this example, if the event X occurs, Y, on a high probability, will occur. The word “probability” is important in this statement because a “certainty” can’t be guaranteed. There will be more of this in Chap. 6, about determining probabilities of events and understanding their p-values.

An example in medical imaging could be “What is the effect on the visibility of the CCA during CTCA when the rate and volume of an injection of iodinated contrast agent is changed?” Here the researchers are seeking to determine a causal relationship between rate and volume of the contrast agent and the visibility of the artery in the CCA examination.

3.1.3 *Research Aim or Objective*

When planning research, having a single focused research question can be very useful in ensuring focus of the research project and ensuring the research stays on track. Similar to a broad research question, a research aim or objective can provide focus and direction. However, the aim or objective of the research goes beyond a question and can state more precisely what the researchers want to find out. The research aim or objective provides the intent or aspirations of the research project. The research aim or objective is commonly stated in one sentence.

Some examples using some of the previous research questions and the related aims or objectives are as follows:

Research question	Research aim or objective
What percentage of patients were diagnosed with XXX pathology after having a YYY test in the ZZZ radiology practice/department?	To investigate the prevalence of the findings when patients undergo YYY test in the ZZZ radiology practice/department and have been diagnosed with XXX pathology
<i>A subquestion of a larger project:</i> Where do patients spend most of their time in the ZZZ radiology practice?	<i>The aim of the larger project</i> To investigate whether patient waiting times in the ZZZ radiology practice can be reduced
Does student attendance in class result in an increased mark?	To compare the success rate of students given their attendance rates in class

Having well-stated research questions and aims or objectives is vital when planning the research project itself.

3.2 **Research Planning**

3.2.1 *Theoretical and Conceptual Frameworks*

Often, when thinking about and planning a research project, especially when discussing the project in a group or team environment, ideas flow and the project gets expanded beyond what is needed to answer that research question. While it is a good approach to start thinking broadly and then to narrow the focus of the project, it is useful to have a planning framework that can set boundaries and help the focus.

There is a lot of discussion in the literature about theoretical and conceptual frameworks. As a very brief overview, both are used in research planning to help understand the problem leading to the research and to guide the research process and the analysis of the outcomes, the research data. Theoretical frameworks are more often used in quantitative research projects, and conceptual frameworks are more often seen in qualitative research. Such approaches used in quantitative and qualitative research are discussed in details in Chap. 5.

What is important is to have some sort of framework to help guide the quantitative and/or qualitative research planning.

3.2.2 *Questions Within the Research*

The discussion above has focused on the research question or questions and the aims or objectives and how these can help researchers to have a strong focus in what they are trying to do. This section however has a focus on the research itself, so the researchers can determine what they need to do within the research to answer the question. Well, that might be obvious, that is, to just do the research, get some results and analyse the results. That is true, but what do you have to do to get those results? There are lots of resources and answers in this textbook; however, this section is about research planning and what questions you need to ask to help you plan your research project.

In planning your research, you will need to look at multiple factors within your research. Some such areas or factors include what are you going to do, is this relevant or interesting, what are the ethical considerations, what outcomes will you be working towards and what is your timeframe to get this completed. Some of these areas we have seen earlier are important in establishing research question and the aims or objectives; however, these areas are as important as planning your research. Before you get lost and say this is too hard, there are several frameworks in health and medical research that can help you with this planning. These frameworks were established to make this aspect of the research easier and to provide steps for the researchers to follow in a systematic manner.

There are two main frameworks for health and medical research and are as follows:

- The PICOT or PICO framework
- The FINER framework

3.2.3 *PICOT Framework*

The PICOT framework has a shortened version that is also often used, the PICO framework. Both are valid, but the PICO framework does not consider the timing/ the time period of the project or the type of study or questions being considered. For completeness, the PICOT framework will be discussed as the PICO, which is a part of the PICOT framework, is essentially the same.

The PICOT framework stands for the following:

- Population or Patient group or Problem
- Intervention
- Comparator or Control

- Outcome
- Timeframe or Type of study or question

Under the “P”, a researcher should consider “who is the population that will be included?” This can include the patient’s or person’s age, gender, ethnicity, socio-economic status, or any other demographic variable. The P might also include the patient’s problem. In this case, the PICOT framework may include the health or medical condition that is being considered in undertaking the research.

The “I” stands for invention. To answer your research question, the project may not need an intervention. However, an intervention may be needed to test if a change in outcomes has occurred. Such a research methodology includes evaluating the current situation; seeing that this needs to be changed; trying something different, that is, the intervention; and then evaluating the post-intervention results. If a descriptive research project has identified an issue, then evaluating any changes after an intervention may provide evidence that includes the new or changed practice that is based on the intervention that might provide an improved clinical outcome as a better alternative to the preintervention approach. In Chap. 8, an intervention by Gibson and Davidson is discussed. They considered and used the PICOT framework, and the timeframe was important when planning their research project.

Under the “C” for comparison or control in the PICOT framework, comparative and/or relational research questions are used. The “C” question can be “What comparators (or comparators groups) are you going to use?”. Prior to asking this question, as a researcher or research group, the research methodology must be considered and decided. The types of research methods are discussed in Chap. 2, so review that again at this stage of your research planning.

The “O” for outcome has many meanings. The first and most important is the research’s beneficence. This will be discussed under ethics later in this chapter; however it is a concept that states that researchers should consider and also show to an ethics committee that the welfare of the participant, essentially to do no harm, is the goal of research study.

“Outcomes” also means that in the planning stage of the research, consideration is also made about the following:

- Type of data that is collected.
- What is the validity of the data?
- What is the reliability of the measures taken?
- How the data is stored?
- How the data is analysed?
- How are the outcomes going to be disseminated to the broader community, whether that be the profession or to the general public?

The timeframe, “T”, can be considered in several ways. For example, if an intervention is being proposed, at what point in time is the intervention to be implemented? Other examples are how long is the project to be run, or over what period will the data be collected or how long will the participants be observed?

An alternative “T” is the type of study or question that needs to be answered. Here the researchers should consider what research approach or methodology is needed to answer the question. As mentioned, there are two very broad categories of research, quantitative and qualitative research and a mix of these research methods. A very broad overview of the quantitative research methods are as follows:

- Surveys or questionnaires
- Observational methods
- True or quasi-experimental research
- Clinical trials

A very broad overview of the qualitative research methods are as follows:

- Interviews
- Focus groups
- Oral history or life stories

The examples of research questions discussed above can be considered under the PICOT framework where P, I, C, O and T have been added to show where these are considered in each question that follows:

- What percentage of patients (*P*) were diagnosed with XXX pathology after having (*T*) a YYY test in the ZZZ radiology practice/department?
- What is the effect on the visibility (*P*) of the CCA during CTCA when the rate and volume of an injection of iodinated contrast agent is changed (*C*)?
- Will patients’ weight (*P*) be reduced (*O*) after (*T*) the implementation (*I*) of the new diet (*C*)?

3.2.4 FINER Framework

The FINER framework stands for the following:

- Feasible
- Interesting
- Novel
- Ethical
- Relevant

The focus of the FINER framework is not on the “how” or “what” of developing the research; it is more about getting the researchers to think about the bigger picture aspects of the research. The FINER framework will help answer questions such as whether the research question passes the “so what” question, will the outcome of answering the research question have an impact on clinical practice or improve patient outcomes, or will the participants have their anonymity and confidentiality maintained during the project and after the results are released.

When thinking about the “feasibility” of the project and when designing the research question, some examples of what the researchers need to consider are as follows:

- Can the project be completed with the time frame and budget of the project?
- Are the materials and other resources adequate for the project design?
- Is the sample size appropriate for determining the desired effect?
- Have similar research methods been successfully used before?
- Will the participant recruitment process be suitable in gaining enough participants for the project?

Some examples of what researchers need to consider in the “interesting” aspect of the FINER framework are as follows:

- Will this pass the “so what” question put by professional colleagues?
- Is it likely that the outcomes of the research will be published in a peer-reviewed journal?
- Will others, e.g., staff or participants, be willing to put in time to assist in gathering the data?

The “novel” aspects that researchers need to consider when developing their research questions are as follows:

- Is there a “gap” in the literature that should be addressed?
- Has this work previously been done on this population group?
- Will the outcomes of the work change clinical practice?
- Are there any other variables that could be changed to improve the diagnostic value of the test?
- Will this work make a meaningful contribution?

Ethics will be discussed in more details later; however, when designing research question, some “ethical” issues that should be considered are as follows:

- How will informed consent be obtained?
- What are the risks of participation?
- How will the participants have their anonymity and confidentiality maintained?
- Where will study data be stored, and who will have access to the data?

The “relevance” aspect that researchers need to consider when developing their research relates to the broad overview of the question. This can be thought of as the big picture “so what”. This encompasses the four FINE points, however looking more holistically. There are many such questions that could be included here, and these all include broader-based questions from above. Earlier in this chapter, a section discussed the broad and narrow question, and answering a small question might lead to answering the bigger question. One of the “relevance” aspects might include whether this work will assist in answering that bigger question.

3.2.5 Which Framework?

Both frameworks are used for differing purposes. The PICOT framework is more logistical, in other words, looking more at what needs to be considered practically in the planned research. The FINER framework look more holistically, that is, it considers the bigger picture of the research and where it fits into developing and building knowledge. As such, researchers, when developing and considering questions within their proposed research, should use and consider both frameworks.

So, which framework should be considered first? That question can be considered as a “chicken or egg” type question. Many researchers will consider that the broader of these two frameworks, that is, the FINER framework, should be done first. The reasoning for this is when considering the FINER framework, researchers are looking more broadly than when considering the PICOT framework, which tends to be more practical focused. However, to consider the broader question, some knowledge is needed. This can be gained from a literature search and review, and the PICOT framework can help define and refine that search. So, there is no right or wrong answer to this. Most researchers will consider and answer question from both frameworks together.

3.3 Hypotheses

As mentioned above, a hypothesis is a formal question about research. Not all types of research need a hypothesis; however, when researchers are seeking to determine if a causal relationship exists, then testing the hypothesis is a vital part of such research. A strong, well-defined and well-developed hypothesis is needed, otherwise determining if a causal relationship exists can be flawed. An analogy that can be used to explain this is to ensure that a solid foundation is built (the hypothesis), otherwise the house that is built on the foundation may have weaknesses.

Briefly discussed above, a causal relationship can be explained as seeking to determine “If X is done, will Y happen?”. In this example, a hypothesis would be proposing a relationship between X and Y. In this and other types of research, X and Y are known as variables. There can be more than two variables; however, they will fall into two broad categories of independent and dependent variables. An independent variable is something than can be changed, manipulated or controlled by the researchers. An independent variable is also known as the experimental or controlled variable. In this example, the independent variable is X. A dependent variable is something that “depends” on the independent variable(s). It can also be stated that the dependent variable responds to or is the outcome of changes of the independent variable(s). The dependent variable is something the researchers will measure or observe. In this example, the dependent variable is Y.

Words often used as alternatives to the word hypothesis are assumption, presumption and postulate. When undertaking scientific research, the use of such word can lead to confusion and misunderstanding.

The Cambridge English dictionary defines assumption, presumption and postulate as follows:

- Assumption as “something that you accept as true without question or proof”
- Presumption as “a belief that something is true because it is likely, although not certain”
- Postulate as “an idea that is suggested or accepted as a basic principle before a further idea is formed or developed from it”

The Cambridge English dictionary defines hypothesis as “an idea or explanation for something that is based on known facts but has not yet been proven”. Here the important words are “not yet been proven”. The other words of assumption, presumption and postulate differ around this important point that a hypothesis can be tested and possibly be proven. The result of a proven hypothesis is a scientific theory. A scientific theory is an explanation for why or how something has happened; though caution must be taken here, the hypothesis must be tested repeatedly until it become widely accepted. If a hypothesis is scientifically proven, well accepted, and well established, it might become a scientific law. An example of this is Einstein’s theories of special relativity and general relativity. There is a gathering of physical evidence and support for these theories, so in studying these theories, hypotheses would have come after the scientific theory. Given Einstein’s incredible ability to think well ahead of his time, he can be forgiven for going outside of the usual steps of hypothesis to scientific theory to scientific law.

Medical research rarely gets to the level of being a scientific law. So then, let’s consider the main differences between hypotheses and theory. A hypothesis is decided or determined, based on previous information, before the research is conducted. A theory is typically formed later after many research experiments or studies are conducted. Some other differences are that a hypothesis is single statement and a theory typically a collection of research outcomes. A theory is based on evidence such as on multiple research outcomes and hence more likely to be true than a hypothesis. A hypothesis is a specific statement about a single research experiment or observation, while a theory is a general principle that can be applied in multiple instances.

Some common thoughts are that a hypothesis is an educated guess. The word “guess” is not the best term. Hypotheses need to be based on known information that can be used as the basis of argument for research.

3.3.1 *Falsifiability*

In research that uses the scientific method, falsifiability is an important part of developing a hypothesis. In order to test a hypothesis, the scientific approach is to prove that the hypothesis cannot be false. “Cannot” can be a strong statement, so as briefly mentioned above, a better statement to use is “on a level probability, the statement is false”. The concept or idea of falsifiability does not mean that the something is false; it means that it is possible to prove that the something is false.

Karl Popper (1902–1994), prominent science philosopher, introduces the principle of falsification. According to Popper, a hypothesis cannot conclusively be affirmed, but it can be conclusively negated. In describing this principle, Popper proposed the notion: “Are all swans white?” If you were in the northern hemisphere and conducted a study based on this question, then observed and recorded the colour of tens of thousands of swans, you could come to the conclusion that all swans are white. To disapprove this, you just need to observe and record one black swan, e.g., travel to Australia, and that would disprove the theory that “all swans are white”.

3.3.2 *Null Hypothesis*

A lot of students and some seasoned researchers get or are confused about the null hypothesis. Adding to the confusion are the concepts of type I and type II errors that can result from analysis of the null and alternative hypotheses. Associated with this are the p-values; however, there will be more on p-values in Chap. 6. As mentioned previously, the null hypothesis is a negative statement or position that can be taken about the proposed research that is trying to determine a causal relationship. The concept of using a null hypothesis in research is to try and disprove the null hypothesis, though at a level of statistical significance.

First, let’s look at the definition of a null hypothesis. The null hypothesis is usually given the symbol H_0 and read aloud as “H-naught”, or in some places as “H-zero”. There are many small variations of the definition of a null hypothesis; however, a general statement can be that a null hypothesis is a statement used in research and hence research statistics, which proposes that there is no change in the dependent variable when the independent variable is change. In other words, there is no change in outcomes when the research variables are altered or changed. This then becomes generalized from the sample taken in the research to the population of the sample and that the sample relationship has occurred by chance.

Not yet discussed is the alternative hypothesis. The alternative hypothesis is usually given the symbol H_1 . This is essentially the opposite of the null hypothesis in that an alternative hypothesis proposes that there is a relationship between the variables in the population and that the relationship between the variables in the sample reflects this relationship in the population.

As seen here, when undertaking research to determine a causal relationship, it is important that researchers know the population and know that they can show that the sample they are using is the representative of the population. This later part is about showing that the sample comes from that population and that can demonstrate the power of their sample in relation to the population. Some basic concepts that need to be considered are as follows:

- First assume that the null hypothesis is true and that there is no relationship between the dependent variable and the independent variable(s) in the population.
- Then determine how likely this relationship has given that the null hypothesis is true.
- Then if this sample relationship is extremely unlikely, researcher can then reject the null hypothesis in favour of the alternative hypothesis, though as mentioned, only on the basis of some level of probability.

Some notable examples of where the null hypothesis has been used are the following:

Kern S. (2011) in the book *The Disappearing Spoon: And Other True Tales of Madness, Love, and the History of the World from the Periodic Table of the Elements* has used an example of null hypothesis from Roentgen's work when discovering X-rays. Roentgen noticed a fluorescent glow while working with a Crookes tube, a cathode ray tube, external to the Crookes tube. Some "ray" must be extoling the tube, and it was known that cathode rays (electrons) could not escape through the glass and not to any real distance through air. Roentgen then found that he could see the bones of his hand when this invisible light, X-rays, passed through his hand. Before announcing this as a scientific discovery, he locked himself away in his laboratory in an attempt to disconfirm what he had found. Roentgen's null hypothesis was that there is no invisible light that can pass through a human hand. During this period, Roentgen went on to determine many of the known properties of X-rays. He and many other scientists successfully replicated these experiments, and as such, the alternate hypothesis, which is X-ray can pass through solid objects such as bone and flesh, was confirmed. The result of Roentgen trying to falsify his findings instead of proving them has lead to us to know that his discovery of X-rays was more than just a simple observation.

A further example provided by Grant (2006) and other authors was that many scientists, including Copernicus, Aristotle and others, set out to disprove a null hypothesis that the world is flat. This eventually led to the rejection of the null hypothesis and the acceptance of the alternate hypothesis that world is round or a sphere. Most people in the world now accepted this alternate hypothesis, though there is still a very small minority that are still convinced that the world is flat. Copernicus, Aristotle and others had to change people's thinking, so they proved that their thinking was wrong.

3.3.3 Formulating a Hypothesis

As discussed above, a hypothesis is a formal question about research. There are characteristics of a good hypothesis and some of these are the following:

- Is the hypothesis based on previous evidence about the research topic?
- Can the hypothesis be tested?
- Does the hypothesis provide a brief explanation of the research event and provide a brief explanation of measured outcomes? A more formal statement of this is: Does the hypothesis include some details on both the dependent and independent variables?

As previously mentioned, a hypothesis is a formal means of stating a research question that can be tested by scientific research. In developing or formulating a hypothesis, there are steps that need to be taken. Some of these that should be considered are the following:

- Can the population and the sample of the population be fully described and detailed?
- Can the appropriate number of samples, tests or observations be made so that the result can be meaningfully statistically assessed?
- Are the selected dependent and independent variables the most appropriate?
- Are there alternative possible explanations that need to be considered, e.g. alternate way to measure the dependent variable?
- Are there any other influencing, moderating or mediating variables?
- Can the expected causal relationship or the correlation between the independent and the dependent variables be fully defined?
- Are there alternate ways that the hypothesis is formulated for this experiment so that the outcome could be confirmed or disproved?
- Are the expected outcomes of the planned research fully stated?

Depending on the type of research being conducted to try and solve the same or similar problem, the hypothesis will be constructed differently. Earlier, a research question was posed: “Does student attendance in class result in an increased mark?”. This research question can be altered to form different hypotheses if the research is looking for a causal relationship versus comparative research versus determining a correlation between variables.

An approach that can be used for research that is trying to determine a causal relationship is an “if then” statement. If trying to determine a causal relationship, this earlier research question could be restated to “if student attendance at class increases, then the class mark will increase”. Such a hypothesis provides both an understanding about the research to be undertaken and the type of research that will be used. Similarly, if you are trying to determine a correlation between attendance and the class mark, then the hypothesis could then be “the attendance rate of students has a positive effect on the class mark”. Further, if you are comparing subgroups of the sample of the population, then the hypothesis could be “students who have the greatest attendance in class will have better marks than those students who attend the least number of classes”.

While a hypothesis is mainly used when trying to determine a causal relationship, a hypothesis can be used in other types of quantitative research.

3.4 Research Ethics

All good research practice involves consideration of all potential ethical issues, whether the research needs formal ethics committee approval or not. As such, all researchers need to understand ethical principles. Essentially, without understanding ethical principles, how can any health or medical researcher proceed in their research without potentially breaching ethical principles and importantly without potentially causing harm to those who may or may not be involved in the research?

There are many types of research, such as fundamental or basic research, applied quantitative research, applied qualitative research, and applied mixed method research. In health or medical research, which is generally applied research, ethical considerations can differ between quantitative, qualitative and mixed methods research. For example, if a researcher is using quantitative methodology to determine if the amount of radiation that is measured from scatter radiation from an anthropomorphic phantom at varying distances varies under changing X-ray exposure factors, then the main ethical considerations are the use of ionizing radiation and whether the researchers will obtain an increased personal radiation dose reading during the project. An opposite example is a clinical trial where participants are recruited and are randomly placed into two groups and where one group undergoes a given X-ray examination for determination of a diagnosis and the other undergoes a different type of examination. The outcome of such research could determine which examination procedure provides the best diagnosis. In this later example, there are clear, potentially high-level ethical issues. For example, one group in the research project could potentially miss out on not having a correct diagnosis made for their medical condition. A further consideration for one group must also be the use of ionizing radiation that is needed in one group compared with the other group.

According to the World Health Organisation, and many other organizations, there are four general ethical considerations that need to be in all researchers' thoughts and consideration when planning to undertake any research project that involves human participants. They are as follows:

- Respect for the person or persons
- Beneficence
- Non-maleficence
- Justice

The importance or weighting of these four areas can and will vary depending on the type and application of the research.

3.4.1 *Respect for the Person or Persons*

Respect for the person or persons must be considered under several general themes. The first of these themes is autonomy. For example, is the potential participant in the research capable of being able to make an informed decision of their involvement in the project? Have the researchers provided enough information to potential participants so these participants can understand any potential risks to themselves and the potential benefits that may be an outcome of the research? In providing such information to the potential participants, the potential participant can then determine if they want to be involved in the research project. This is the notion of informed consent. Informed consent can only be gained if:

- The participant's information is written so potential participants can understand the information, that is the information is not written in technical language or jargon that only other researchers or professionals in the field can understand.
- The potential participants can assess the potential risks and benefits of the project.
- The participant can make a voluntary decision from the information provided.

In providing such information to potential participants, there must be an opt-out statement. Potential participants must be able to feel safe that at any time if they change their minds they are free, without any consequences, not to continue in the project.

The next of these themes is protection of people or potential participants with impaired or diminished autonomy. For example, children or those mentally handicapped, as participant groups generally are not able to consent to involvement in a project. Researchers must consider if such groups are needed in the research. Human Research Ethics Committees (HERC) will generally put research that involves such groups as "high risk" and try to ensure the researchers are cognisant of the individuals from such groups and ensure there is a potential benefit that overcomes any disadvantage that the individual may experience or to the group generally. HREC will generally not approve any research that involves such groups unless there is a potential benefit to the individuals from such groups.

Another area under this theme is minority groups. The researchers of potential research projects that involves participants from minority groups must consider any potentially negative impact on both the individual and group as a whole. In such cases this goes beyond whether a person from such a minority group can consent; it goes to whether there may be a social, emotional or any other impact on the individual or on the group as a whole.

A further theme under the topic of *respect for the person or persons* is privacy of the individual and of their personal information. Topics under this area that need to be considered are as follows:

- Personal dignity.
- Is sensitive information needed? If yes, is the disclosure of that information needed beyond the immediate project?

- De-identification of data.
- Security of stored data and timeline of data storage.

3.4.2 *Beneficence*

The notion of beneficence, according to the Cambridge Dictionary, is helping people or doing good acts. Such acts can be being kind, being generous or being merciful. In research ethics, broad notion is more defined as a principle so that researchers must try to maximize possible benefits from the research and minimize the possible risk or harm to a participant or to the public more generally. This principle of beneficence requires researchers to ensure they have considered the following:

- The risks of the research be reasonable or small given the expected benefits of the research.
- The research design is sound, well-constructed and based on evidence.
- The researchers themselves must both knowledgeable and experienced in conducting such research projects.
- The researchers can assure others of the well-being of the research participants.

3.4.3 *Non-maleficence*

Non-maleficence, as an ethical research concept, is thought to have originated from the concept of *primum non nocere* (first do no harm), which is considered to be part of the Hippocratic Oath in the medical profession. The notion of non-maleficence requires researchers to consider the possibility of inflicting harm on others. If there are such risks in conducting the research project, researchers need to consider if it would be better not to undertake the project or that aspect of the project, rather than to take risk, which can cause more harm than good.

Such potential harm, under notion of non-maleficence, is all encompassing. It is not just limited to the participants or volunteers in the project; it needs to consider, but not limited to, the following:

- The broader community
- The environment
- Participant animals if in the research project
- Future generations
- Etc.

3.4.4 Justice

Justice, in terms of research ethics, has many similarities to the notion of justice in a legal sense and in other areas. Justice, as an ethical consideration, is the newest of the four ethical considerations. According to Sims (2010), the Belmont report, which was developed in 1979 by the US National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, was where the notion of justice came into being as an ethical consideration. A significant concern at that time was the use and the benefit of research outcomes in higher economic status countries when the data was obtained from lower and middle economic status countries who did not get the same benefits.

The notion of justice in research ethics is still being debated and defined and can mean different things depending on the context and circumstances. Some statements include ensuring against the exploitation of participants, yet they now include a specific section about the respect for the person or persons. Others include discussion that justice goes beyond respect. One thing that is common to all discussion is about the fairness in relation to the burdens and costs of undertaking the research and where the benefits be gained from the research outcomes.

3.4.5 Broader Ethical Areas for Consideration

Some research funding organizations have research ethical statements that provide detailed statement about guiding principles on the conduct of ethical research. While these statements generally incorporate the broad four areas discussed above of respect for the person or persons, beneficence, non-maleficence, and justice, the organizations can provide detailed areas of focus that researchers must consider when applying for funding from or conduction research within such organisations.

An example of these organisations is the US National Institutes of Health (NIH), which has published seven main guiding principles on the conduct of ethical research. They are the following:

- Social and clinical value
- Scientific validity
- Fair subject selection
- Favourable risk-benefit ratio
- Independent review
- Informed consent
- Respect for potential and enrolled subjects

3.4.6 *Writing Ethics Applications*

Human Research Ethics Committees (HREC) are established in all universities, major hospitals and other organisations where research may be conducted. Approval from an HREC is required for all research that involves human participants. Other research involving animals, genetically modified organisms (GMOs) and ionizing radiation will need approval from similar organisations in most countries. For example, the approval for the use of ionizing radiation may be required before an application to an HREC can proceed. The need for these later organisations will differ between countries and organisations, so importantly, check the local requirements.

Typically though, an HREC anywhere in the world will require similar standard information on which to base their decision to ascertain if the project has considered and addressed all ethical issues. Such information are as follows:

- Information about the project, including
 - Where the research will be conducted
 - Who are the researchers and information about their previous research experience

This information includes evidence-based background information, for example, a concise literature review around the project to show relevance of the research topic. Given that the HREC members are unlikely to be experts in the research field, this must be written in a language style without an expectation that the HREC members will understand the jargon used in the field.

The place where the research will be conducted is information to the HREC around potential risk. For example, if the research is to be conducted in an aged care facility, the HREC will want to see later that any such risk, which involves the elderly people, has been considered and addressed.

Details of the researchers and information about their previous research experience are important to HREC, so they can be assured that the researchers have the ability to undertake, collect and analyse the data and to potentially provide evidence-based outcomes.

- The funding, administration and details of prior reviews of the project.

Funding can provide conflicts of interest. For example, if a drug company provides research funding to a university, is there an expectation that the results will favour that drug company? As such, this information is important for an HREC to have so they can review potential conflicts.

Administration information can also help the HREC. If funding is being administered by a reputable organisation, such as a university or major hospital, then the HREC can have more confidence about the fairness of the cost of the research.

Details of prior reviews of the research project can assist the HREC. It cannot be expected that all HREC members are experts in all types of research. Typically, an HREC will have a range of people with experience in a variety of research and

lay or members of the general public. A review by experts in the field can assist the HREC's understanding and evaluation of the project.

- The aims and objectives of the project.

The aims and objectives and, if needed, the hypotheses will be sought to be gained in undertaking the project. These need to be clear as the HREC members will assess the other aspects of the HREC application against these. If the HREC think that the project cannot meet its stated aims or objectives, or if the hypothesis cannot be met, they will seek more information from the researchers or reject the application.

- The research design and methodology.

Research planning and development of research questions has been discussed above. HREC will want to be assured that the research questions, research planning and the design and proposed methodology are appropriate to the project and can potentially deliver the expected outcomes. Without this detailed understanding, an HREC cannot determine whether the benefit of the project outweighs the risks to the participants and others.

- Details about the participants, any risks to the participants and methods of gaining informed consent.

Under this section, the researchers will describe the population, and the sample of the population they expect will be the participant group. They will also need to detail the means of recruiting the participants.

The HREC will also need details on how consent will be obtained from potential participants to participate in the research project. Consent is normally obtained in writing, either by signing a consent form or by agreeing to details that are provided prior to undertaking an online survey. The researcher will need to develop and provide both the HREC and potential participants, the participant information form (PIF) and the participant consent form (PCF).

The information on the PIF needs to include the following:

- The title of the research project
- A plain language statement about the project that clearly explain the research project at the level of understanding of the prospective participants including the following:
 - Aims and objectives of the project
 - Purpose of the research
 - Potential benefits of the research
 - Research methods that will be used
 - What will be required of the participants including any demands on their time, need for travel, etc.,
 - The potential risks including any minor discomforts, areas where their dignity may be at risk and all other potential risk factors
 - The recruitment process of the participants
- A clear statement that participants can withdraw from the project at any time
- Some details of when and where research outcomes may be available

- Contact details of principal researchers and brief information on others involved in the project, including the funding details of the project
- HERC approval details and contact details

The PCF will include the following:

- The title of the research project
- Researchers' information
- A statement about reading the provided PIF
- A statement that participants can withdraw from the project at any time
- Area for attesting their agreement by signing the form

Most commonly, the HREC forms and submission processes are available online. If the project is to be conducted through more than one organisation, multiple HREC application will be needed. The most common approach is to submit a form to one organisation, have their approval and submit to the other organisations including details of the first approval. While this does not guarantee the later organisation's ethics approval, it does show that ethical issues have been considered and may speed up the process.

3.4.7 Ethics and Manuscript Publication

The main output of research is the publication of a manuscript in a peer-reviewed journal. Most health-related journals are affiliated with international organisations about promoting quality and professionalism in publishing and ensuring that ethical research leads to such quality manuscripts.

The two main such organisations are the World Association of Medical Editors (WAME) and the Committee on Publication Ethics (COPE). Of these two organisations, COPE is more focused on ethical research. Both WAME and COPE provide statements on ethical practices, including publishing ethics; however, COPE has more detailed core practice statements that member journals and publishers should have publicly documented practices in many areas including the following:

- Ethical conduct of research
- How to handle allegations of misconduct

3.5 The Research Proposal

Enabling the readers of this book to develop a research proposal is an expected outcome of reading this book. There are a lot of details in other chapters about the nature and scope of research, research methods, the literature review and of data collection, analysis and interpretation. An understanding of all these areas is needed in writing a research proposal.

How the research proposal is written will depend on the type of research that is proposed and on who is the audience of the proposal. Some typical examples of the research proposal audience are as follows:

- An ethics committee. As discussed above, HREC needed detailed information about the proposed research project. As such, an ethics application has a lot of similarities to a research proposal.
- A funding body. Each funding organisation has its own format for a research proposal, so the organisation's guidelines must be closely followed and importantly adhered to.
- There are many examples of where the funding organisation's initial review of submitted research proposals will look at the guideline compliance and reject those proposals that don't meet the guideline requirements.
- Universities. Research projects are undertaken by higher degree research students and other university students. Each university will require the submission of a proposal and has defined requirements for the differing types of university student projects. Similar to other areas, it is important to read, understand and follow research proposal requirements when developing the proposal.
- Health organisations. Medical, allied health or nursing staff who wish to undertake research within their clinical role will need organisational approval and ethics approval, prior to commencing the research. As mentioned previously, not all projects require ethical approval; however, for all such proposed research, health organization will require organizational approval prior to commencing the project. While there will be lots of similarities to the ethics applications, the focus of organisational applications will typically have a greater focus on organisational benefit, organisational impact such as impact on patients and other staff, time frames and costs.

While there are differences depending on where the proposal will be submitted, all research proposals will have common areas that need to be included and discussed in the documentation. These areas are the following:

- The background to the research including the research problem and the significance of undertaking the project
- The research aims and objectives, the research questions and hypotheses if needed
- A review of literature to provide details of research area and problem
- The type of research, design and framework
- The timeline including a Gantt chart
- A statement on ethical considerations
- The expected outcomes and potential benefits
- How and to who the results will be disseminated

There will be other areas of detail needed depending on the audience of the research proposal.

3.5.1 *Timelines and Gantt Chart*

Many of the areas discussed in the research proposal section above are included in various chapters and sections of this book. Research timelines, and visually displaying the timeline with the use of Gantt charts, need to be considered in all research proposals.

Timeline statements are an important management process in any project. Research timeline statements are an important management process in any research project. Timeline statements of when each phase of the research project and when the overall project will be completed are needed in the research management process.

The easiest way to provide timeline information is visually. A Gantt chart is a visual display of the research project phases that are proposed and when they expect to be undertaken and completed. A Gantt chart will also display the chronological order of the research phases and the aspects with each phase. Gantt charts were first invented by Henry Gantt (1861–1919) as part of his work in project planning. They are now used as a planning in many management and project areas.

Gantt charts are used in many other areas other than research. As such, there are many dedicated software applications that can be used to assist in providing the timeline information visually. For many small to medium research projects, spreadsheets and/or tables in documents can and do suffice to provide the readers with an easy overview of the timeline information. For long and more complex research projects, such as clinical trials, dedicated software that are used in other project management areas are often used.

The common aspects of all Gantt charts include an initial column of information about the research project phases and sub-phases and then multiple other columns with date or time period headings. Part of the research planning is to ensure that the phases and subphases of the project will be identified for the timeline of the project and as such, then easily to a Gantt chart. The intersection point or cells in the chart of the research project phase or subphase and the date/time period are highlighted to show when the phases or subphases will be undertaken and completed. An example of a Gantt chart for a dummy research project can be seen in Fig. 3.1.

3.6 Final Words

Remember Albert Einstein's words that are stated at the beginning of this chapter. There are many other examples of discussion in the literature and on the web about the need for proper planning. A common adage that commenced in the military about planning and is now used more widely is the "7Ps". There are many versions of the 7Ps, some more of the commonly stated versions (one without one of the Ps) are as follows:

Prior Proper Planning Prevents Painfully Poor Performance

Prior Preparation and Planning Prevents P*** Poor Performance

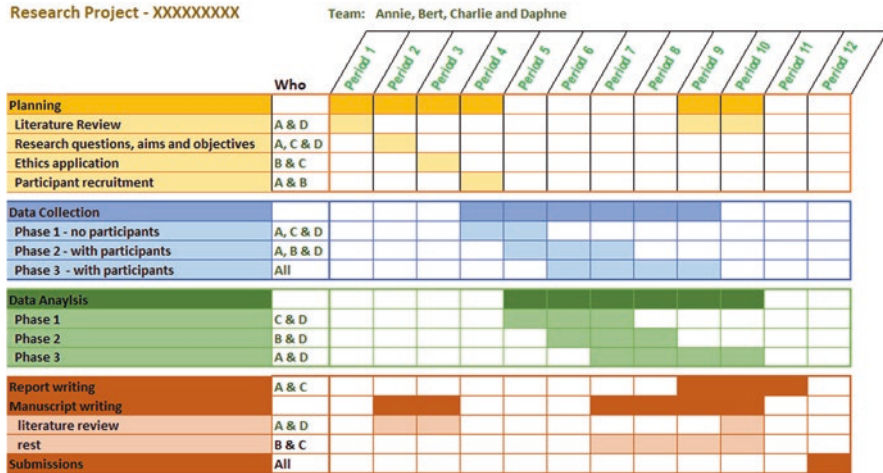


Fig. 3.1 Example of a Gantt chart for a research project

To sum up, keep in mind the words of Benjamin Franklin (1706–1790) who many think said it the best, “If you fail to plan, you plan to fail”.

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Resources

- Some current, as of January 2021, links to organizations web sites on ethics and ethics resources.
- World Health Organization. <https://www.who.int/health-topics/ethics>
- USA. Department of Health and Human Services, National Institutes of Health. <https://clinicalcenter.nih.gov/recruit/ethics.html>
- UK. National Health Services. <https://www.hra.nhs.uk/about-us/committees-and-services/res-and-recs/>
- Canada. <https://www.canada.ca/en/health-canada/services/science-research/science-advice-decision-making/research-ethics-board.html>
- Australia. <https://www.nhmrc.gov.au/research-policy/ethics/human-research-ethics-committees>
- South Africa. <http://www.hsrc.ac.za/en/about/research-ethics/code-of-research-ethics>
- New Zealand. <http://www.hrc.govt.nz/ethguid4.htm>

Chapter 4

Literature Searches and Reviews



Rob Davidson

4.1 Literature Searches and Reviews: Overview

When undertaking research or when wanting to find out more about a topic, either as a student or as a professional radiographer/radiologic technologist, evidence-based information is needed. All professions, including medical imaging/medical radiation science, must use evidence-based information, not hearsay. Also, clinical and research decisions should not be based on approaches such as “that is the way we have always done it”. The patient is at the center of the medical imaging/medical radiation science role. These clinical professions need to ensure that practices are evidence-based to provide the best outcome for the patient.

Scientific- or evidence-based information is typically classified as being available in primary, secondary, tertiary, and gray literature. Primary literature is found in peer-reviewed journal articles. Secondary and tertiary literature combines information from primary literature (Streefkerk, 2019). An example of secondary literature is a textbook that combines and references mainly primary information. Tertiary literature is typically written more for the general public. It can be found in non-peer reviewed magazines and websites. Gray literature is an information from other non-peer reviewed sources such as government documents, white papers (e.g., x-ray equipment manufacturers often release white papers on the use of their latest imaging unit), conference proceedings, and other sources (Godin et al., 2015).

Evidence-based information can be broadly classified further into new or mature information. Mature information is typically found in secondary and tertiary literature. A lot of mature information can be found from a search of the web, in Wikipedia, or, for profession of medical imaging/medical radiation science, in wiki-Radiography. Caution though must be taken with web- or wiki-based evidence as it may not be evidence-based and it also may not be scholarly or peer-reviewed. On

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the web, false information and conspiracy theories can be found. An example is that there are many websites stating that the earth is not round, rather it is flat. Clearly, there is overwhelming evidence that the earth is round, yet these websites exist and will provide their reasons as alternative “evidence.”

Textbooks are often a collective overview of scientific literature and are put in a suitable form for the intended reader. For example, a textbook on computed tomography (CT) for radiography/radiologic technologist students and experienced medical physicists will have differing levels of information and differing levels of treatment of the information, based on their needs. Authors of profession-based textbooks will base their information on real evidence. They will provide references to that evidence, typically journal articles from peer-reviewed journals, and have their textbook peer reviewed.

The second broad classification source of evidence-based information is new or more recent information. This is generally found in primary and gray literature. Several cautions must be kept in mind when sourcing and reading such information. The first level of caution should be asking the question of where the information is published. If obtained from a journal, a further question should be asked as whether the journal is “peer reviewed”? Gray literature and not all primary literature are peer-reviewed. A peer-reviewed journal will provide details about the editor, the editorial team, and the peer review process. Often, a journal, maybe on an annual basis, will acknowledge and thank the reviewers and the people who have undertaken the peer reviews of the previously published articles. Checking this information about the journal, the peer review process and past reviewers can then provide information on the quality of the journal itself.

A peer review process is a process where experts in the field will review the paper submitted by the authors for publication in the journal (more details on this process are provided in Chap. 7). The reviewer will examine the background information, the methods used in the article to collect information or data, how this information or data is evaluated and interpreted, and if the findings and conclusions are accurate and valid. More than one expert will review a submitted paper. The editor will review and check if the reviewers’ findings and comments are valid and if the paper is to be accepted for publication, needs more work or changes, or is rejected. Some of the best scientific journals have very high standards and, as a result, have very high rejection rates. A high rejection rate in itself is an indication neither of the quality of the journal nor of the quality of papers in the journal. All peer-reviewed journal articles should be read with the second of these cautions in mind.

Information obtained from any non-peer reviewed source must have the same level of cautions as discussed previously for web- or wiki-based information. Again, this does not mean that the information from articles in non-peer reviewed journals, the same as web- or wiki-based information, is weak or false and caution levels just need to be high. Importantly any such information should be verified from other sources, and such information from these sources need be to be read with another series of cautions in mind.

These additional cautions are based on the quality of the information. These are also applicable to primary information in peer-reviewed journal article. Some questions that should be asked are: How was the information in the article found and assessed? Another way of stating this is, Was the authors' methodology correct? What approaches were used by the authors to review and analyze the information? Was the information in the peer-reviewed articles presented correctly? Were the authors' conclusions based on evidence provided in the article?

4.2 Searching the Literature

The first step in finding evidence-based information needed for an assignment, undertaking a research project, or writing a journal article is to look for appropriate sources of the required information. As mentioned, textbooks are a source of mature information, and good textbooks will reference primary sources of information. When planning a research project, information from textbooks can be a useful part of the background information, though when finding information for a research project, it is important to have the most recently published information. Textbooks for students in programs or courses will be prescribed or recommended for use; however, newer information may often need to be found.

When looking at other more recently published information, typically, there will be hundreds of articles or publication from both primary and gray literature that could be relevant. Students and researchers need to be able search for the relevant information that is published—but that is easier said than done!

4.2.1 Getting the Search Terms Correct

The first step in any search is knowing what to search for. Let's say an assignment on image quality and dose in CT angiography needs to be undertaken and the information required needs to be recent. What search terms would be used? Most universities and colleges have online library access. To find articles in any library, a database search is needed. Searching online database uses search engines—they will be discussed in more details later. To find information relevant to an assignment on "*image quality and dose in CT angiography*," a very simple approach would be to enter those exact words into the search engine. An example of an online interface of a search engine can be seen in Fig. 4.1. Using this simple approach, all of the relevant journal article details and information from other sources needed would be found; however, there will also be many irrelevant journal articles and other information returned in the search results.

To limit the search results to relevant information, the first thing that is needed is to select the appropriate terms that will be used in the search. These are then entered into the appropriate fields in the database. Typical search engine fields that are used

Fig. 4.1 A screenshot of the University of Canberra’s library combined search engine user interface showing multiple search fields

for searching are the title of the article, the keywords, and the article’s abstract. In Fig. 4.1, the title is the search field shown. Note that not all journal articles are written using these terms so the returned search results from journals may vary. As an example using the terms from above, in the fields that were selected to be searched, the authors may not have used the term “CT angiography,” instead, the authors may have used the term “CTA.” Searching by just using one of those terms may not find articles that only included the other term. A simple solution could be to include a search on both of those terms; however, the resultant list of journal articles will include many clinically based articles that are not related to image quality or dose. The two terms of “image quality” and “dose” could be included in the search. A radiographer or radiography student will understand that the term “dose” relates to ionizing radiation, but the search results could also find articles on drug or contrast agent dosages. Importantly, searching for journal articles is not an exact science. There will be some missed articles, and articles that will also be found are not relevant to the topic. After finding a number of possible relevant articles, the abstracts of the articles should then be read to then select the appropriate articles for further in-depth reading and delete the inappropriate ones.

To have more appropriate articles selected by the search and to aid in limiting the number of articles returned by the search, “inclusion” and “exclusion” criteria terms can be chosen. The use of inclusion and exclusion wording is done by using Boolean search terms or operators. As seen in Fig. 4.2, most search engines will have the Boolean operators ready for ease of use.

The main Boolean operators are AND, OR, and NOT. These Boolean operators are used to organize a search by including or excluding search words. For example,

Fig. 4.2 Boolean search terms in use – a screenshot of the University of Canberra library user’s interface of their combined search engine

in Fig. 4.3a, searching for CT will include all the articles that have the term CT in the search fields. If the OR Boolean operator with CT and “angiography” is used, the search will return all articles that have those terms. A Venn diagram of the results is shown in Fig. 4.3b. This OR search will result in many articles that may not be specific to CT angiography, as all CT and all angiography articles will be found. A considerable amount of time reviewing and finding appropriate articles will be needed.

The AND Boolean operator will only return articles when both the terms CT and “angiography” are found in the search fields. An example is seen in in Fig. 4.3c, with the shaded section in the Venn diagram showing the search results. This will narrow the search and assist in finding relevant articles where both terms are needed. If, for some reason, the term angiography needs to be excluded from CT articles, then use the NOT Boolean operator. Such a result can be seen in the Venn diagram in Fig. 4.3c.

For a better search, think of alternative search words for the terms that need to be found. As previously mentioned, CT angiography can be written as the term CTA. Including CT and angiograph in quotation marks in the search field will combine those words in the search. Using the OR Boolean operator will then return articles that have CT angiography and CTA in the search fields. An example of the results is seen in Fig. 4.4. The results returned will include both terminologies for CT angiography.

For the example provided above of a search for recent articles about “*Image quality and dose in CT angiography*,” more complex search terms will be needed. For example, it will be best to include the term “radiation dose” and possibly exclude

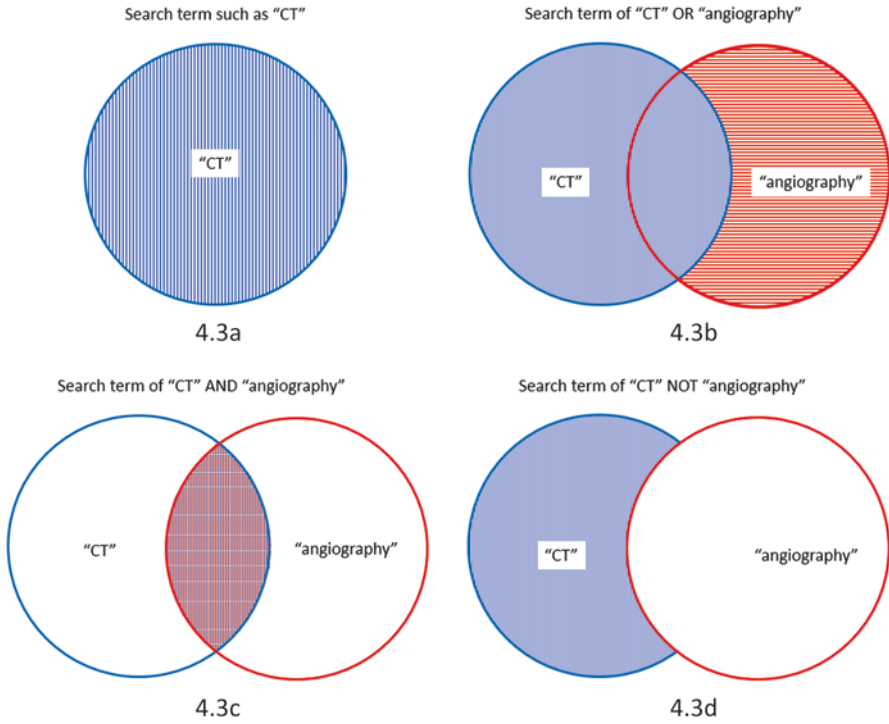


Fig. 4.3 Venn diagrams of searches: (a) using a single term, (b) using the Boolean terms of OR, (c) using the Boolean terms of AND, and (d) using the Boolean terms of NOT. The output of the use of the Boolean terms is shown in the shaded sections of each Venn diagram

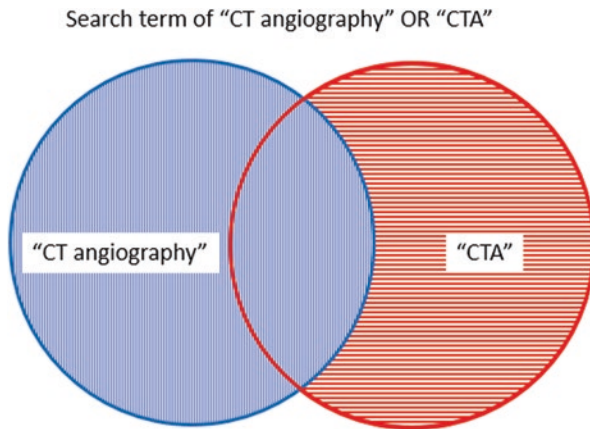


Fig. 4.4 Venn diagrams of the results of a search for CT angiography and CTA

“drug doses.” Figure 4.1 shows an example of a search engine where multiple search lines have been added and each line can target various fields in the search. A search of primary information may vary in the terms used to that when undertaking a search of the gray literature. Figure 4.1 also shows the ability to select just journals or to have a wider search for other information as well.

Some search engines only allow a single line of input terms. In such search engines, the terms will need to be nested. An earlier example of single line search nesting terms was using quotation marks to join CT and “angiography” together into a single search term of “CT angiography”. In single line search engines, brackets can also be used where multiple lines would be used on other search engines. Search engines with multiple lines do the nesting. An example of this would be (“CT angiography” OR CTA) AND (“radiation dose”). Other search options that most search engines allow are the use of truncations (an asterisk, *) and wildcards (often a question mark, ?, or sometimes an exclamation point, !). A truncation asterisk can be placed at the end of a term such as “CT*”. This search will include results for “CT”, “CTA”, “CTCA”, and others. Using a question mark (or in some search engines, the exclamation point) in “ioni?ing” will include both US and UK spelling of “ionizing” and “ionising.”

4.2.2 Journal Databases and Search Engines

Search engines and databases can be found outside of library websites. Library search interfaces will often use multiple other search engines and combine the results. A comprehensive list of journal databases and search engines can be found in Wikipedia, at the time of writing this is at https://en.wikipedia.org/wiki/List_of_academic_databases_and_search_engines. Many of the journal databases and search engines in this site have a focus that is not relevant to health and medical fields. As such, using some of those search engines may not find the information needed. Some of the more health and medical focused databases and search engines are the following:

CINAHL (Cumulative Index to Nursing and Allied Health Literature),
MEDLINE (Medical Literature Analysis and Retrieval System Online),
MedlinePlus, service is provided by US National Library of Medicine,
PubMed, which primarily accesses the MEDLINE database.

Other relevant databases and search engines are the following:

ScienceDirect has sections on Health Sciences, Life Sciences, Physical Sciences
and Engineering, and Social Sciences and Humanities;
Scopus;
Web of Science;
Google Scholar.

4.3 A Literature Review Versus Annotated Bibliography

When undertaking early higher education studies, most students have previously been taught the basics of searching for evidence. As previously discussed, there are several different types of evidence that can be considered to use in an assignment or as background for a research article to be submitted to a journal. The student or researcher needs to select appropriate articles, or other sources of information, based on their inclusion criteria. Importantly, the information from these sources needs to be presented in their work.

The approach many people take, after undertaking the search and collecting the articles or other information, is to read the information and make notes about the important aspect of the article or information. As mentioned previously, all information must be read with cautions in mind. The first of those cautions was where was the information found, that is, was it found in primary, secondary, tertiary or gray literature. The second of these cautions is about the quality of the information read. When reading and making note, ask questions about the quality of the information (Pyrzczak & Tcherni-Buzzeo, 2019). Some of the question areas are as follows:

Currency

Some things to consider are: What is the year of publication? Is the information outdated? For example, an article on CT angiography from 1990, would it still be clinically relevant today?

Coverage

Some things to consider are: Is this an overview of the subject or an in-depth review of a subsection of the topic? Does the information covered meet the needs for assignment or research?

Authors' authority

Some things to consider (but may be harder to ascertain) are: Has/have the author(s) declared any conflict of interest? Is/are the author(s) affiliated with a reputable organizations or universities in the field of the information? Have authors published previously in this field?

Accuracy and objectivity

Some things to consider (but may be harder to ascertain) are: What is the intended purpose of presenting/publishing this information? Is the research method appropriate? Is the information error-free? Have the authors correctly evaluated and presented their results? Is/are the statistical method(s) appropriate to analyze the data? Are the authors' conclusions based on the data presented?

After collecting and noting the relevant information from each source, a further question on each of the articles or other information is as follows:

Can the information in that article be verified against other reliable sources?

Note thought, answering this question may not always be possible as at some stage the information was new and there was no other information about this specific topic.

There are two common ways of presenting the information that has been found. These are through an annotated bibliography or through a literature review. Discussion on each of these follows. For both of these approaches, some critical thinking is needed. Critical thinking is an integral part of evaluating research literature and undertaking research. It involves analyzing the information that has been read, interpreting the information, making inferences about the information including inferences in relation to other similar information about the topic, being able to explain the information in alternative words, and being open-minded about the topic and prepared to take on further information about the topic at a later date that could change the thinking about the topic.

4.3.1 Bibliographic Information

A bibliography is a list of details of the works, such as a journal articles, gray literature, book chapters or websites, that were consulted, reviewed, and then provided background or other information on a topic for writing an assignment or journal article. The work that is cited in the assignment or journal article then becomes a reference list.

There are many and varied ways to manage bibliographic information. Bibliographic information is more than details of the information name and source, it is also should includes brief notes. The minimum bibliographic information is the citation (full details of the authors, title of information, and where the information can be found) and keywords. When undertaking an annotated bibliography or literature review, further details, discussed later, should also be kept.

There are many means of managing bibliographic information. Manual input methods include using software such as Microsoft Word®, Microsoft Excel®, or Microsoft Access®. When using such bibliographic information management methods, ensure that there are consistent fields and keyword layouts for later search. When searching for and finding information, especially journal articles, it is often possible to download a citation of the article directly into reference management software.

Reference management software, like most software applications, are many and varied. The one used in writing this chapter was Clarivate Analytics' EndNote®. The online version of the journal, where the article was found, will often provide the citation in a format suitable for each main reference management software application, in formats of EndNote, RIS, BibTeX, and others.

While the main citation details can be downloaded into the reference management software, many further details such as keyword may need to be manually added. Most reference management software applications now are more than citation managers. The applications allow for manual inputs of notes and other details and can be linked to a PDF document of the journal article. The reference management software application can build either bibliographies or reference lists at the end of the assignment or journal article. Importantly, the use of reference

management software applications allows for searching for the information on author names, titles of the information, keywords, and on nearly all of the fields of information.

When selecting a reference management software application, ensure that it can be directly linked and used from within the software being used to write the assignment or research article, such as Microsoft Word®. Get to know and practice using the selected reference management software application.

4.3.2 *Annotated Bibliography*

An annotated bibliography is essentially notes or the details about the information that has been collected following the database search. Following finding relevant information and evaluating the relevance and quality of the information, notes should be made of the main points of the articles. As previously mentioned, such note can be stored in a variety of ways including reference management software applications. An annotated bibliography will include a full citation of the article including details such as the names and details of the authors; the title of the work; the journal name, volume, issue, date, and page numbers; and the brief information about the article's content.

This brief information or notes, from sources such as a journal article, gray literature, book chapter or web site, in an annotated bibliography can take several forms. These are descriptive annotated bibliography, summary annotated bibliography, and a critical annotated bibliography.

A descriptive annotated bibliography is a description of the content of the information found. A descriptive annotated bibliography, other than the citation, only provides the main points made in the information such as a brief overview of the content or scope of the information (CSU, 2020; UNSW, 2020).

A summary annotated bibliography provides a summary of the key points of the information content including those in the descriptive annotated bibliography. Further details should be included such as the following:

- The research method or approaches taken in presenting the information
- The main points including those highlighted in figures, plots, and tables
- Conclusions made

A critical review of the information is needed to provide the next type of annotated bibliography, that of a critical annotated bibliography. A critical review takes the above approaches used to create descriptive and summary annotated bibliographies several steps further. The general areas are as follows:

- Significance and contribution of the information to the field or topic area. In this area, things to be considered are as follows:
 - The intended reading audience
 - The authors' aim(s) in presenting this information and was this achieved

- Was there information missing and is this problematic in their work
- Approaches or methods used and presented. In this area, things to be considered are as follows:
 - Is the research method used appropriate?
 - The objectivity or biases in the information.
- Information collected and analysis of that information. In this area, things to be considered are as follows:
 - Strengths and limitations of the information
 - Reliability of the information
 - The conclusions based on the data and analysis of that information and justified

Additional details that should be considered and included in a critical annotated bibliography are as follows:

- The relevance of the information and how it relates to the themes or concepts being searched for
- Thoughts/reflections on how this information fits into the overall topic area of this information

The main skills needed to develop an annotated bibliography are being concise and succinct. Depending on the style of annotated bibliography needed and its use, the word length will typically vary between 50 and 150 words. Being able to condense a 4,000 word journal article down to such word lengths and importantly provide the essential points about the information needs practice and development.

An annotated bibliography has several uses. When searching for and finding information, annotated bibliography notes or details are a useful way to collate and, at a later date, review the information that has been previously collected. For such use, manual methods or reference management software applications can be used.

Typically, an annotated bibliography is often a prescribed assignment in a course of studies. Here, the format will vary depending on the lecturing/tutoring staff's requirements. It will more likely take the form of a summary or critical annotated bibliography. Such an annotated bibliography, as detailed above, contains information about the individual piece of information. When critical appraisal and comparison between information is needed, a literature review is then undertaken.

4.3.3 Literature Review

A literature review goes beyond an annotated bibliography, though the review should use the information collected in the first use of an annotated bibliography described above. The role the writer of the literature review is to critically evaluate the information from various sources about a topic. In doing so, the writer must

carefully analyze each source of information, compare and contrast all the found information in the search, and develop a synthesis of the sources of information found on the topic (Baker, 2016).

This type of literature reviews is usually used to address broad questions such as those in assignments or to provide more focused background that may be needed when preparing journal articles or writing dissertations or theses. Typically, no clear method for the selection, analysis, and synthesis of the information is used (Hong & Pluye, 2018). The method of selection, analysis, and synthesis is what is needed for the purpose and that of the person undertaking this. For example, the previously given topic on *image quality and dose in CT angiography* for a student assignment will provide a wide range of information found, analyzed, and synthesized. All hopefully will find current and relevant articles and gray literature and provide comprehensive analysis and synthesis. However, it is doubtful all students will use exactly the same articles nor will the students provide a comprehensive review and analysis of the literature and information available on the topic. To provide such a review, more systematic approaches to literature reviews are needed.

The authors of the textbook *Seven Steps to a Comprehensive Literature Review* (Onwuegbuzie & Frels, 2015) suggest there are three phases incorporating seven steps to undertaking a literature review. The first phase is an exploratory phase, similar to those discussed in sections above, the second phase is analysis and synthesis of the information, and the final phase is communicating that information.

4.3.4 Advanced Types of Literature Reviews

According to Grant and Booth (2009), there are 14 types of literature reviews, and each has differing approaches to or frameworks of search, appraisal, synthesis, and analysis (SALSA) used. The literature review process discussed above is more commonly known as a narrative or traditional type of review. It has some drawbacks, especially when trying to pull all the primary literature together to provide a detailed review of all of the work or evidence on a specific topic. A more formal and rigorous literature review is a systematic review. While undertaking a systematic review is not typically needed in undergraduate studies, a brief overview here will help with the understanding of the limitations of narrative literature reviews.

When undertaking a narrative or traditional literature review, not all primary information is typically included. The person undertaking the search for the information selects the articles based on their inclusion and exclusion criteria. This introduces a bias into the results that are presented. For a narrative literature review that is used in a student's assignment or to provide background in a research article, such a bias is expected and can be reviewed and considered by the examiner or reader of the article. A systematic review, however, must include all of the literature based on the search criteria. No bias is acceptable in a systematic review. There must be stringent inclusion and exclusion criteria that are applied. These criteria must be

provided to the reader so, if the reader wants, they can replicate the search and check for any bias (Clarke, 2018; Clarke & Chalmers, 2018; Gough et al., 2017).

Systematic review approaches are now formalized, and guidelines have been developed. Various groups have developed approaches in statements such as the Quality of Reporting of Meta-Analyses (QUOROM) statement and the now accepted Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (Hutton et al., 2015). Various organizations have established guidelines to ensure correct approaches are undertaken in systematic reviews. These include the Cochrane Handbook for Systematic Reviews of Diagnostic Test Accuracy (Leeflang et al., 2013) and guidelines in other organizations such as the Joanna Briggs Institute in the University of Adelaide (Campbell et al., 2015). Further information about PRISMA statement are detailed in several journal articles (Beller et al., 2013; Hutton et al., 2015; Liberati et al., 2009).

Seven key principles of a systematic literature reviews have been described (Pittway, 2008). They are as follows:

- Transparency
- Clarity about the search process and the inclusion and exclusion criteria
- Integration
- Focus
- Equality
- Accessibility
- Coverage of the review itself

Meta-analysis, a means of objectively summarizing all of the information from the search question, is often undertaken to combine results from multiple research project that has been presented in multiple journal articles. Meta-analysis is, for example, undertaking when combining the sensitivity and specificity or receiver operating characteristic (ROC) results of particular radiology test to find a specific pathology (Campbell et al., 2015; Leeflang et al., 2013). Such analysis will provide an objective analysis of all the research done in this specific area.

4.4 Writing the Review

When writing up the literature review, providing details and evidence of the literature review is needed. The report or literature review must provide the following:

- The details of the search terms used
- The details of the search engines used
- The number of publications that met the search terms criteria
- The type of publications found, e.g., refereed journal articles or from non-peer reviewed sources and the number in each type
- The number and details of any excluded publications
- The final number of publications use in the literature review

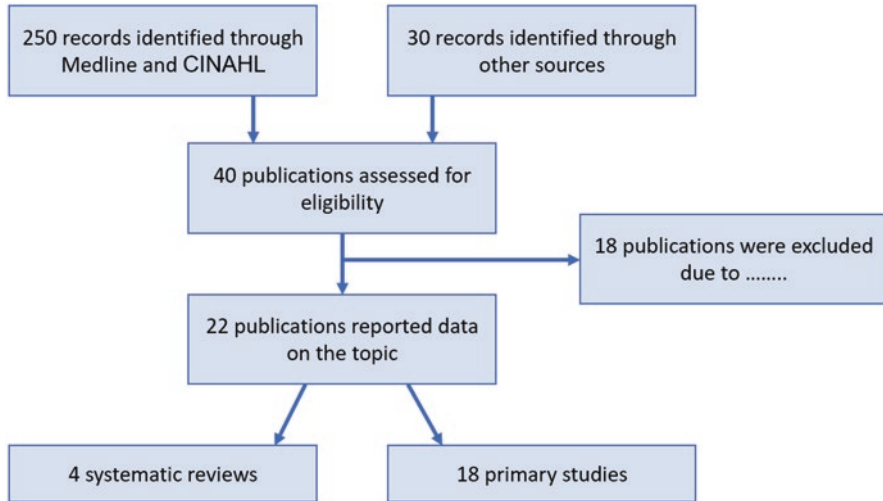


Fig. 4.5 Flowchart of article search and inclusion details

A diagram of the process and typical of what could be included in the literature review write up can be seen in Fig. 4.5.

Differing approaches are needed when writing an annotated bibliography than the approaches needed when writing a literature review. Both approaches however should have some commonality to the structure of the assignment. In both the annotated bibliography and the literature review, there should be an introduction section. Typically, this section is not given a title such as “Introduction”; however, it commences the assignment or journal article. The introduction section presents an overview of the topic and approaches used, including whether the work being presented is annotated bibliography or a literature review. The other common section for both annotated bibliographies and literature review is the conclusion. This section should have the title of “Conclusion(s)”. The conclusion will draw together the main points made in the body of the assignment/article. Importantly, this should be done more concisely using differing phrases from those used in the main body of the text and reiterate any opinions that have been formed. The conclusion will also be comments on future work, if needed, to be done in the topic or field of the assignment or journal article that is being written.

The approach used in an annotated bibliography will depend on the structure required for the assignment and, however, should differ depending on the annotated bibliography approach used being descriptive, a summary or a critical review. The main sections of the annotated bibliography will, in an appropriate order, present the details of the following:

- A citation of journal article or other information
- Keywords of the article or information
- The 50 and 150 words narrative of the annotated bibliography

In a literature review, the main body or text of the assignment can have multiple sections. These sections and subsections should be given appropriate titles, so the reader has an understanding about the topic being presented. These sections and subsections will provide a critical appraisal by comparing, contrasting, and synthesizing the relevant information found in the search on the topic of the assignment.

When writing both an annotated bibliography and a literature review, the concepts that have been read in journal articles or other sources of information need to be discussed by comparing, contrasting, and synthesizing the authors' information. Importantly, any concepts need to be understood, interpreted, and put in context of the assignment. In other words, those concepts need to be written in words of the writer, not as a direct copy of the author's wording in their article. There are however a few exceptions to this rule. Putting other peoples' words into a document in alternative words is called paraphrasing.

Paraphrasing is making an alternative statement that expresses the ideas or concepts that was written in the article or other information. Paraphrasing uses different words to those written in the article or information, and importantly, the source of that information is provided by citing the details of the information. Paraphrasing also shows the reader, or the person marking the assignment, that the original author's words are understood well enough to rearrange them and rewrite them. It takes practice to be able to paraphrase well, and it is a skill that needs to be developed. When starting to paraphrase for assignment, the important aspect is that the concept that is being discussed in the journal article is well understood. When there is a good understanding of what is written in the article, expressing that concept in alternative words becomes a relatively easy task.

There are only a few times that direct quotes or direct copies of words into an assignment are acceptable. These times are when the words are of such a high level of importance that paraphrasing the words would not do the author's words any justice. Such as example is the words spoken by Winston Churchill after the Dunkirk evacuation on British and Allied soldiers in World War II, which were:

We shall fight on the beaches, we shall fight on the landing grounds, we shall fight in the fields and in the streets, we shall fight in the hills; we shall never surrender. Delivered by Winston Churchill, the Prime Minister of the United Kingdom on 4 June 1940 in the House of Commons (Churchill, 2013).

Other direct copies of words show a lack of understanding and, especially with many digital-based sources of information where copy and paste techniques are available, shows laziness. In assignment, these are two things that need to be avoided.

4.5 Acknowledgement of Sources

Previously discussed were citations and the methods of citing. A citation is an acknowledgement of the work the authors have made in getting the information available for others. To not acknowledge the source of the information is plagiarism. Plagiarism is using someone else's ideas or concepts and passing them off as their own ideas or concepts and is cheating. Whether the ideas or concepts are paraphrased or quoted directly, without acknowledging the work of the original authors, the writer of that assignment or article is plagiarizing.

In all good universities and colleges, plagiarism is considered a serious offence. Plagiarism in a submitted article for publication can mean rejection of the article and refusal to consider further articles from those authors. Plagiarism, in this digital age, is easily detected.

Following the practices described above of collating information from articles and other sources, including the authors' and journal or source of information details, means that plagiarism should never happen.

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Chapter 5

Quantitative and Qualitative Research Methods



Andrew England

5.1 Quantitative Research Methods

Quantitative research uses methods that seek to explain phenomena by collecting numerical data, which are then analysed mathematically, typically by statistics. With quantitative approaches, the data produced are always numerical; if there are no numbers, then the methods are not quantitative. Many phenomena lend themselves to quantitative methods because the relevant information is already available numerically. Examples include the changes in the numbers of radiographers and radiologic technologists holding doctoral level qualifications or a comparison of the incidence of contrast-induced nephropathy between countries or institutions. It is important to note that phenomena that are not obviously number-based can still potentially be examined using quantitative research methods.

Within medical imaging and radiation therapy, there will be a variety of methods in which to collect quantitative data. The most common source of quantitative data includes the following:

- *Questionnaires/surveys*: could be conducted in person, by telephone or video call or asynchronously online. Such techniques rely on the same question set being asked in the same way to a large number of people. Within health care, such approaches will typically involve study samples within excess of 100 participants. Typical examples might be patient satisfaction surveys (Fig. 5.1) or the scoping of ideas around a potential service improvement project.
- *Observations*: these could involve the counting of the number of times that a particular phenomenon occurs, for example, the incident of an adverse reaction following the administration of an iodinated contrast agent (Fig. 5.2). This could also potentially extend into a qualitative dimension by counting the number of

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EXAMPLE OF SURVEY / QUESTIONNAIRE BASED RESEARCH	
Rosenkrantz, AB., Pysarenko, K. The Patient Experience in Radiology: Observations From over 3,500 Patient Feedback Reports in a Single Institution. <i>J Am Coll Radiol</i> 2016;13:1371-1377.	
AIM:	To identify variables that relate to the experiences of patients attending the X-ray Department.
MATERIALS & METHODS:	The study institution provides contact information for patients to provide comments on their recent imaging examinations. Feedback was recorded and 3,675 comments were reviewed over a three-year period. Key themes were identified. Employee type was also reviewed against each patient comment.
RESULTS:	The behavior of staff members and waiting times were dominant comment themes. Less common were issues around exam comfort, medical records, privacy, the formal report and reimbursement. Comments predominantly related to the technologist or receptionist and much less to radiologists.
CONCLUSIONS:	Comments from patients largely reflected staff behaviors and communication. Other comments related to waiting times. Radiologists were encouraged to promote their visibility to patients.

Fig. 5.1 An example of survey-/questionnaire-based research. (Adapted from Rosenkrantz et al., 2016)

times a word or phrase is used by study participants. Observational methods may also rely on the coding of data into numbers.

- *Secondary data*: this would typically include pre-collected data, which will be in abundance within medical imaging and radiation therapy. Such pre-collected datasets will be stored on a hospital information system (HIS) or radiology information system (RIS). Previously collected data can provide opportunities to investigate changes to practice or provide valuable benchmarks from which to define standards. Opportunities to use such data can exist when generating regional and national radiation dose audits (Fig. 5.3).

5.1.1 Descriptive Research

Descriptive research is a process whereby the researcher would have no control of research variables. Such studies will typically aim to determine, describe or identify what is going on with a particular phenomenon. Descriptive research does not seek to establish reasons why or how events or phenomena have come to be.

EXAMPLE OF OBSERVATIONAL RESEARCH	
Dillman, JR., Ellis, JH., Cohan, RH., Strouse, PJ., Jan, SC. Frequency and Severity of Acute Allergic-Like Reactions to Gadolinium-Containing IV Contrast Media in Children and Adults. <i>Am J Roentgenol</i> 2007;189(6):1533-8.	
AIM:	To ascertain the frequency and severity of acute intravenous reactions to gadolinium-based contrast agents in pediatrics and adults.
MATERIALS & METHODS:	Over a six-year period patients who experienced a potential reaction to intravenous gadolinium-based contrast agents were reviewed. Parameters evaluated included past medical history, prior exposure to radiological contrast media and any previous reactions. Data were obtained from hospital-based patient electronic records.
RESULTS:	65,009 adults and 13,344 pediatric gadolinium-based contrast examinations were performed during the study period. Acute reactions were reported after 54 contrast administrations (0.07%). The majority (n=48) involved adults and six occurred in children. Three-quarters were classified as mild. 19% moderate and 7% severe. Half of the patients with a reaction had an identifiable risk factor for contrast media administration.
CONCLUSIONS:	Contrast media reactions involving gadolinium occur infrequently. The majority are mild but moderate and severe reactions were noted in the study.

Fig. 5.2 An example of observational research. (Adapted from Dillman et al., 2007)

An important feature of descriptive research is that it can evaluate many variables. It is, however, important to state that for a descriptive research study to be conducted, there is in fact only one variable to be under investigation. Descriptive research can be closely associated with observational research studies; it is important to note that descriptive research is not limited to only observational data. Descriptive studies can include case studies and also information acquired using surveys.

Research questions involving descriptive studies are typically formulated using 'What'. Several examples of descriptive research studies, which may be undertaken within radiography and medical imaging, could include the following:

- What is the current impact of the COVID-19 pandemic on radiographer/radiologic technologist recruitment?
- What are the characteristics of radiographers/radiologic technologists leaving the profession before the national retirement age?

EXAMPLE OF A STUDY INVOLVING SECONDARY DATA	
Hart, D., Hillier, MC., Wall, BF. National reference doses for common radiographic, fluoroscopic and dental X-ray examinations in the UK. <i>Br J Radiol</i> 2009;82:1-12.	
AIM	To report national reference doses for common X-ray images in the United Kingdom.
MATERIALS & METHODS:	Over a 5-year period 316 hospitals submitted data to a National Patient Dose Database (NPDD). For single projectional radiographs the data submitted amounted to 23,000 entrance surface dose measurements and 57,000 dose-area product (DAP) values. For fluoroscopy examinations there were 208,000 DAP values and 187,000 exposure times submitted. Doses from dental X-ray examinations were also included.
RESULTS:	Third-quartile dose values (adult and pediatric) were generated for 30 diagnostic X-ray examinations and 12 interventional procedures. Reference doses were around 16% lower than those reported in 2000 and substantially lower than those reported in the mid-1980s.
CONCLUSIONS:	Using digital equipment has been found, based on study findings, not to have had a significant effect of reducing the radiation dose.

Fig. 5.3 An example of a study involving the collection of secondary data. (Adapted from Hart et al., 2009)

- What is the incidence of patients failing to attend for outpatient imaging appointments?
- What are the characteristics of women failing to attend for breast cancer screening mammography? (See insight.)
- What is the average radiation dose delivered for patients undergoing trauma full-body CT examinations?

INSIGHT – Comparison of various characteristics of women who do and do not attend for breast cancer screening (adapted from Banks et al., 2001).

In 2001, Banks and colleagues undertook a study to determine the characteristics of women who attended and did not attend for breast cancer screening. Of the 1064 women invited for screening, 882 (83%) attended. Study conclusions confirmed that women who routinely attend a national breast cancer screening programme in the United Kingdom typically come from less deprived areas and were more likely to have a current prescription for hormone replacement therapy than non-attenders.

5.1.2 Correlation Research

Correlation research is a type of research that attempts to measure a minimum of two variables and compares their relationships statistically. The term ‘correlation’ focuses on establishing a mutual relationship or connection between two or more things.

Researchers are often interested in investigating correlations for several reasons. The first is that they believe that there is no causal relationship between two variables, an example being a patient’s body habitus and the radiation dose required to produce a diagnostic X-ray image (see insight). The second and opposite reason is that the researcher believes that there is a causal relationship between variables. An example of this might be that there is a relationship between the length of a hospital stay and the time needed to achieve a full recovery from the illness. A distinct weakness of correlation research is that the researcher does not have the ability to manipulate the variables under examination. A caution must exist when interpreting correlation research in that two variables can be shown to correlate yet one does not necessarily cause an effect on the other. When investigating correlations, it is of the utmost importance to consider theoretical explanations for any correlations. A simplistic example would be when considering the relationship between tube current time (mAs) and effective dose. A correlation between these two variables would undoubtedly exist, and the theoretical basis would be that the tube current time product would equate to an approximation of the number of X-ray photons leaving the X-ray tube. This in turn would provide a proxy of the radiation dose to the patient and as such demonstrate a relationship with the effective dose.

INSIGHT – Impact of body part thickness on AP pelvis radiographic image quality and effective dose (adapted from Alzyoud et al., 2019).

Alzyoud and colleagues undertook a study to determine the impact of body part thickness on AP pelvis radiographic image quality and effective dose. An anthropomorphic pelvis phantom was imaged with additional layers (1–15 cm) of animal fat as a proxy for increasing body part thickness. Unsurprisingly, a strong positive correlation ($r = 0.97$; $P < 0.001$) was found between body part thickness and effective dose.

The presence and strength of any correlation, i.e., the numerical relationship between two variables, can be quantified statistically (correlation coefficient) and are also typically displayed graphically (Fig. 5.4). The type of correlation statistic will depend on the distribution of the variables under analysis. For variables that are approximately normally distributed, then a common correlation statistic used is Pearson. For variables that are not normally distributed, then an appropriate correlation statistic would be Spearman. It is a common convention that correlation analyses are presented as a scatter plot illustrating the relationship between the two

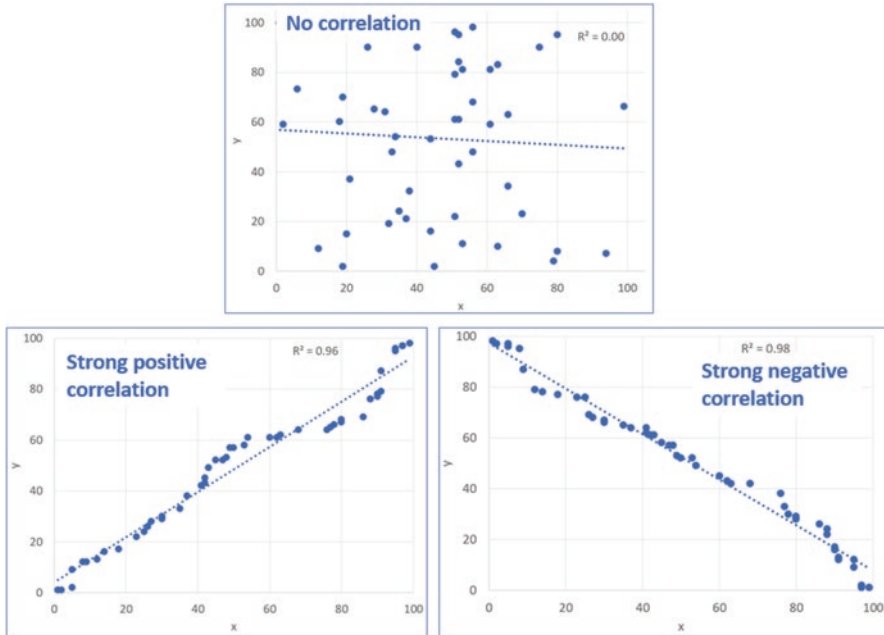


Fig. 5.4 A series of correlation scenarios illustrated using scatterplots. The R^2 value provides a numerical indication of the statistical strength of the correlation

variables. A correlation trend line is then inserted and presented alongside the correlation statistic (coefficient). Methods have been published within the literature for interpreting the resultant scatter plots and for categorising correlation coefficients. A further correlation test is often described within the literature. Kendall's Tau is a correlation statistic used to compare two ordinal variables. Ordinal variables are items that can exist in categories but where there is a normal order to the structure. Several examples of ordinal variables can include university degree classifications and disease severity scores. An example of the use of Kendall's Tau could be when two college tutors are comparing their ranking of ten radiography students (Table 5.1). This hypothetical scenario resulted in a correlation coefficient between the two tutors of 0.833 ($P < 0.001$).

5.1.3 *Quasi-Experimental Research*

Quasi-experimental research is a type of methodology that attempts to establish a *cause and effect* relationship. Similar to true experiments, quasi-experimental research aims to establish a relationship between an independent and dependent variable. Within a research context, the *independent variable* refers to a parameter

Table 5.1 Example ranking data of the perceptions¹ of two tutors regarding student competency

Student initials	Tutor A	Tutor B
AC	1	1
DF	2	3
PT	3	2
AD	4	4
IJ	5	4
ZB	4	5
GM	6	7
BC	7	6
DT	8	8
GL	9	10
NB	10	9

whose variation does not depend on that of another. Conversely, a *dependent variable* refers to a parameter whose values do depend on that of another, in some instances this is called the *response variable*. Some examples of independent and dependent variables commonly experienced within medical imaging and radiation therapy are described within Table 5.2.

One key difference is that quasi-experiments do not rely on a random assignment of subjects or participants. For example, in a true experiment, a researcher would typically randomly assign a patient to a treatment or imaging protocol. In quasi-experimentally designed studies, the researcher would not have control over the allocation of treatment or imaging test. In such studies, the patient or subject would have already been assigned to pre-existing groups, and the effect of the prescribed intervention can then be determined (cause and effect). Differences between the two designs are illustrated in Fig. 5.5 and discussed within the *insight*.

INSIGHT – If a radiology department were interested to understand whether image quality was higher and radiation doses were lower for X-ray Room A, when compared with X-ray Room B.

True experimental design

Half of the patients attending for X-ray imaging would be randomly assigned to X-ray Room A and the other half to X-ray Room B. After a period, a selection of images and dose records from X-ray Room A and X-ray Room B would be compared to answer the research question.

However, for practical reasons, if managers in the hospital do not want to wait for the results and ask whether the information is already available on the organisation's computer systems. If this were the case, then one option would be to use a quasi-experimental design.

Quasi-experimental design

You know for the past 12 months that patients have been imaged in both X-ray Room A and X-ray Room B. You know that the allocation of two rooms is likely based on which room was available at the time and that equal patient types will have been spread between the two rooms. You know that the patient's images between X-ray Room A and X-ray Room B were not randomly assigned. You know it is likely that the computer data can help determine which room delivers the higher quality images with the lowest radiation dose. You acknowledge that this would be an accepted research methodology, but that any confounding variables must be considered within the analysis.

Table 5.2 Examples of independent and dependent variables

Study or project area	Independent variable(s)	Dependent variable(s)
Digital radiography radiation dose	Exposure factors (kVp/mAs) Patient size	Entrance surface dose Absorbed (organ) dose Effective dose
Adverse effects from iodinated contrast media administration	Existing renal function Contrast media volume Contrast media concentration	Post-administration renal function Image contrast enhancement
Patient satisfaction/experience	Examination type Socioeconomic characteristics of the patient Waiting times	Patient satisfaction score
Severity of side-effects following radiation therapy	Tumour location/size Technique Radiation dose	Side effect Severity Duration

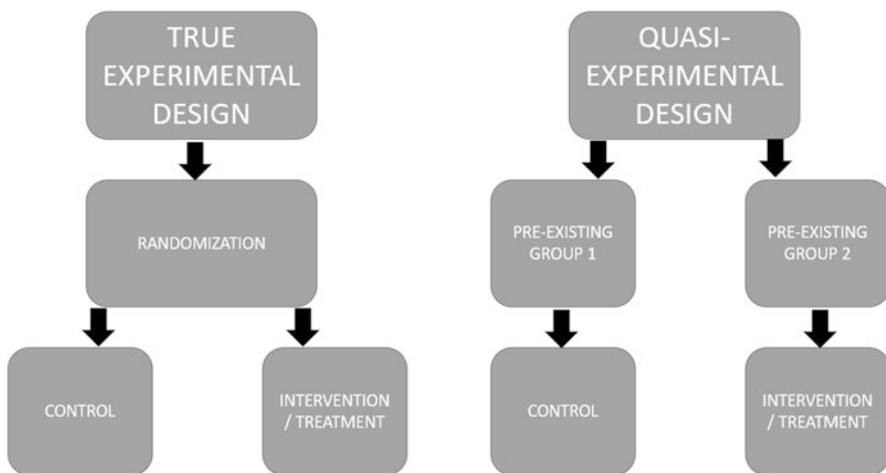


Fig. 5.5 An illustration of the broad differences between true experimental and quasi-experimental designs

It should be noted that there are a number of subtypes to quasi-experimental studies. The three commonest are *non-equivalent groups design*, *regression discontinuity* and *natural experiments*. Each of these will now be discussed in detail and relevant examples are provided.

5.1.4 *Non-equivalent Groups Design*

In this subtype (most common), the researcher selects pre-existing groups but where there is one distinct difference. An example of this might be in the comparison of different arterial stents used in the treatment of peripheral vascular disease. A hospital may opt to use several different stent types in the treatment of arterial disease. It is possible to compare the outcomes (patency, freedom from reintervention and freedom from lower limb amputation) in groups of patients that have had different stents implanted. Although not the preferred methodology, such an approach can provide an indication of the clinical performance of the different stents. In such study, it would be important for the researchers to try and account for any confounding variables. A *confounding variable* is an unmeasured variable that influences the cause and effect. One method to achieve this would be to select the two groups to be as close as possible, ideally with the stent type being the independent variable. A non-equivalent research design may be useful if comparing a new stent with an older/discontinued stent; in this case, the patient types and covariables are likely to be similar. If upon review the two stent groups had significantly dissimilar covariates, this would then be an unfair comparison. Such a situation could arise if one brand of stent was used in favour of the other, for example, in cases of more severe disease or where early restenosis would be anticipated. The underlying status of the patients within the two groups is likely to be different, and it would be very difficult to understand the effects of the covariates versus the effect of the individual stent types.

5.1.5 *Regression Discontinuity*

The instigation of medical therapies (treatments) can be based on arbitrary cut off values. If a patient is above a threshold, then they will receive the treatment, and if they are below, then they do not. At the junction of this threshold, the differences between the two groups are often very minimal, so minimal that some people could describe the differences as being non-existent. Researchers can use patients just below the threshold as the control and above as the treatment group. Remember such a methodology differs from a true experiment in that there is *no randomisation*.

Such an example within radiology would be the use of iodinated contrast agents in patients with renal impairment (Fig. 5.6). Prophylactic treatment, for example, hydration, may be used as a tool to minimise the incidence of contrast-induced nephropathy in patients undergoing computed tomography. Criteria for determining the need for

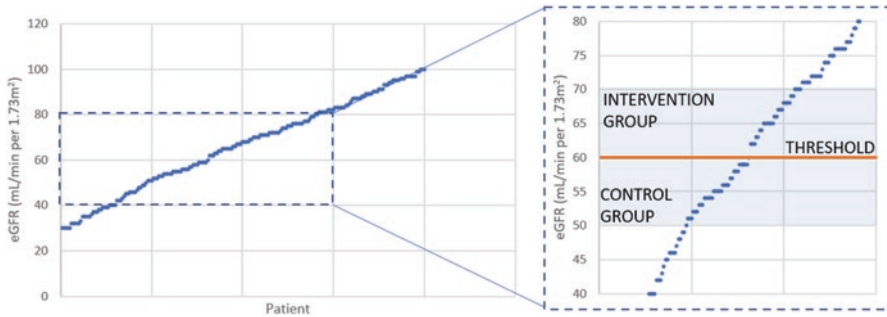


Fig. 5.6 A fictitious example of the use of regression discontinuity in research design. Patients pre- and post-threshold were selected to compare the effects of hydration prior to contrast-enhanced computed tomography

and type of hydration regimen would be based on the estimation of a patient's glomerular filtration rate (GFR). A group of patients, close to but not over the GFR threshold, could be identified as the control group, and those patients who have just exceeded the threshold could be defined as the intervention (or treatment) group. The effectiveness of any hydration regimen could be compared between the two groups.

5.1.6 Natural Experiments

In medical research, subjects are normally deliberately assigned into either a treatment or a control group. In natural experiments, subjects determined by an external event or situation are assigned into different groups. Although this might be a genuinely random process, this approach is still not considered to be a 'true' experiment because they are observational in nature and thus are compared with pre-established groups.

An example of this could be where a smoking ban has been introduced in all public spaces for a period of time. If the area was only served by a single hospital, then the cardiovascular event rate dropped during the ban. If the ban was lifted and the cardiovascular event rate reverted, then this could provide evidence of cause and effect. It would also need to be accepted that there could be other reasons for some fluctuation in the cardiovascular event rate.

There are instances when a quasi-experiment design would be advantageous over other methodologies. Ethical justification can exist for some situations or disease areas in that it would be unethical to provide or withhold treatment on a random basis. This would be true if there was evidence that the data had already been collected. Radiation dose comparisons could be such situations where there would be data collected, thus allowing comparisons between imaging modalities, protocols and imaging rooms. It would be unethical to compare computed and digital radiography by means of a randomised controlled trial if data were already available. In many healthcare systems, such data would be routinely collected and stored on radiology information systems. As such comparisons could be undertaken

EXAMPLE OF A QUASI-EXPERIMENTAL STUDY DESIGN USING PREVIOUSLY COLLECTED DATA	
Mercer, CE., Hogg, P., Lawson, R., Diffey, J., Denton, ERE. Practitioner compression force variability in mammography: a preliminary study. <i>Br J Radiol</i> 2013;86(1022):20110596.	
AIM:	To investigate whether the absolute amount of breast compression force applied during mammography differs between and within practitioners.
MATERIALS & METHODS:	488 clients underwent mammography by 14 practitioners. Data collection included BI-RADS breast density, breast volume, compression force applied and practitioner code.
RESULTS:	Breast compression force was statistically different between the BI-RADS classifications. Practitioners applied compression forces either as low, medium or high. Only six practitioners demonstrated a correlation between breast density and compression force. A general trend of higher compression for larger breast volumes was noted.
CONCLUSIONS:	Practitioners vary in the amount of compression force applied to the breast tissue during routine mammography.

Fig. 5.7 An example of a quasi-experimental study using previous collected data. (Adapted from Mercer et al., 2013)

retrospectively and answer the research question without the need for a prospective experimental study. A caveat would be that the researchers would need assurances regarding the quality of the data stored and also that significant confounding variables were not present.

Practically, true experimental designs are often logistically too complex or too expensive. In such instances, quasi-experiments allow the research to be undertaken using previously collected data (Fig. 5.7). Quasi-experimental designs are likely to be attractive to radiography and radiologic technology students. In such instances, access to pre-collected data or pre-existing groups would facilitate study within the constraints of a training programme, for example, a final year dissertation

In the above study (Mercer et al., 2013), 488 clients underwent mammography by one of 14 practitioners. Data collection included BI-RADS breast density, breast volume, compression force applied during the examination and a practitioner code. Study conclusions suggest that practitioners are shown to vary in the amount of compression force applied during routine mammography.

As with any research methodology, there will be merits and limitations of quasi-experimental research. These are identified and discussed in the table below (Table 5.3).

Table 5.3 Summary of the advantages and disadvantages of quasi-experimental research designs

Advantages	Disadvantages
External validity (often involving real-world interventions) and internal validity higher (better control of confounding variables)	Lower internal validity than experiments with randomisation
Logistically easy to manage. In many cases data will have been collected retrospectively, i.e., radiation dose data.	Sometimes difficult to verify that all confounding variables have been accounted for
Control group comparisons possible	Use of retrospective data can be challenging. Often difficult to confirm accuracy or gain access, i.e., imaging datasets/patient case notes
Useful when it is unethical to manipulate the intervention/treatment	Non-equivalent groups may extend beyond the intervention being studied

5.1.7 Experimental Research

Experimental research is commonly used in many disciplines, including medicine and medical imaging. Experimental research is not a single entity but a collection of research designs, which use manipulation and controlled testing to understand processes. In experimental research, it is common for one or more variables to be manipulated to determine their effect on a dependent variable or variables.

Experimental research studies are less at risk of confounding variables because the researcher controls who receives and who does not receive the prescribed intervention. Experimental research is typically used when the research has a specific question or hypothesis, and in medicine, such methods are often cited as the *gold standard*.

As previously stated, experimental designs typically use randomisation, careful manipulation of an independent variable and strict study controls. Randomisation is a term used to confirm that each subject had equal chance of being assigned into either the control or experimental group. The use of randomisation is a mechanism to attempt to eliminate systematic bias. It is important to note that randomisation is different from random sampling. Random sampling is when the sample for a study is based on a random selection from the population under investigation.

Several different types of randomisation exist within experimental research. *Simple randomisation* is the most common and basic method. This method is analogous with flipping a coin in which heads could imply allocation to the control group and tails the treatment or intervention group. Other methods can include throwing a dice; numbers 3 or lower would equate to the control group and numbers larger than 3 the treatment group. A risk of this approach is that there may not be equal numbers within the two experimental groups (Table 5.4).

Block randomisation is a method designed to randomised subjects into groups with equal sample sizes. The block size is determined by the researcher and should be a multiple of the numbers of the number of groups. For example, if there was a control and a single treatment and the desired sample size was 100, then there this study would need 50 blocks. Two patients would enter each block and then be randomised to either the control or the treatment (Fig. 5.8).

Table 5.4 A fictitious example of *simple randomisation* where numbers of subjects in the control and treatment groups could be unequal

Patient	Dice Score	Group
1	5	Treatment
2	3	Control
3	4	Treatment
4	6	Treatment
5	6	Treatment
6	3	Control
7	5	Treatment
8	3	Control
9	1	Control
10	4	Treatment
11	4	Control
12	6	Treatment

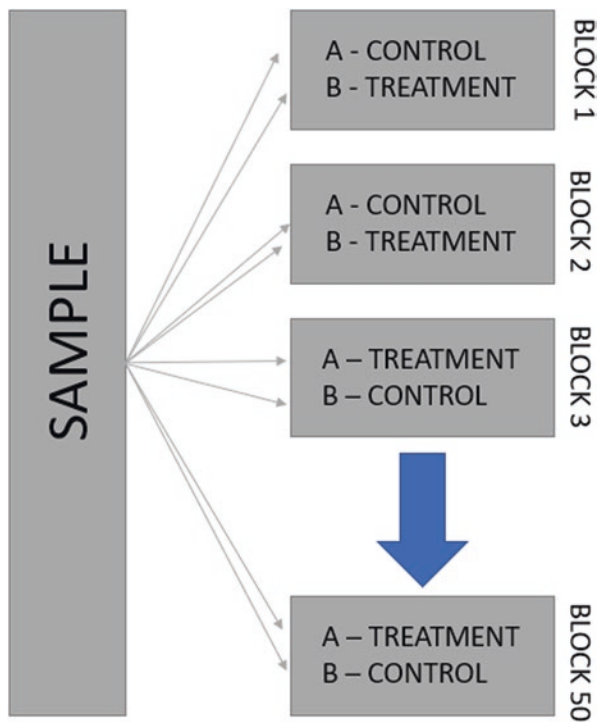


Fig. 5.8 Illustration of a *block randomisation* process

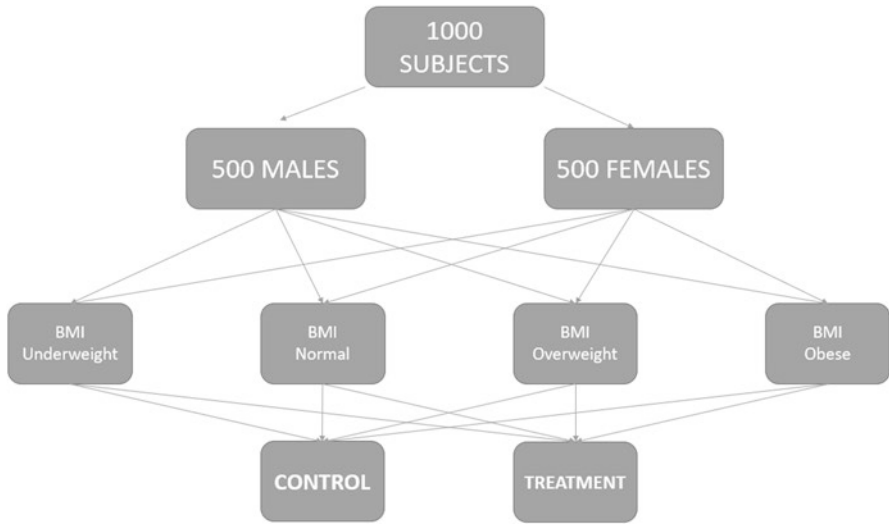


Fig. 5.9 An illustration of an approach to stratified randomisation

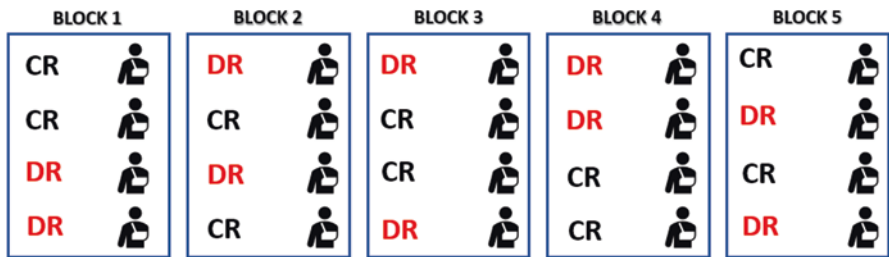


Fig. 5.10 An illustration of a *permuted block randomisation* method for patients in five hospitals being assigned to either CR or DR

Stratified randomisation is an alternative method for controlling and balancing the influence of covariates. Individuals are grouped into strata and then randomised into either the control or treatment group (Fig. 5.9). Stratified randomisation is important for small trials in which treatment outcome may be affected by known clinical factors that have a large effect on prognosis. Stratification can also be useful in large trials where interim analyses are planned or for non-inferiority studies.

Permuted block randomisation is a technique that can be used to randomly assign subjects to a certain intervention within a block. For example, we want to test whether or not digital radiography or computed radiography leads to a lower radiation dose for a total of 20 patients across five different hospitals (Fig. 5.10). From a research design perspective, the ‘treatments’ or interventions are *computed radiography* and *digital radiography*. The blocks would be the different hospitals.

Permuted block randomisation maintains each block as the same number of individuals with each imaging modality (CR/DR). There would be equal number of

individuals assigned to the respected imaging modality at any point in the study. This would be useful for interim analyses and if the study were to end early. There are problems with this approach, for example, if for a given hospital the first two patients were randomised to CR, then the researchers would know that the next two patients would be receiving a DR examination. This could generate problems, and as a result, a process of *blinding* can be introduced so either the researchers or subjects are not aware of the treatment assignments. These concepts are better described as either single or double blinding.

Several subtypes to experimental research designs exist. The *posttest-only control group design* is a setup with at least two groups, one of which does not receive the treatment or intervention (control). In this design, data are collected on the outcome measure after the treatment or intervention. With the COVID-19 pandemic, the relevant vaccine trials could be considered a posttest-only control group design in that subjects are randomised to either *placebo* or the active treatment (vaccine) and the incidence of SARS-CoV-2 virus is measured as the post-treatment outcome. Within such a design, the term *placebo* is used to define a substance or treatment, which is designed to have no therapeutic value, for example, inert tablets or injections.

In experimental studies, an additional step can be added where data is collected prior to delivery of the treatment or intervention. Such a situation may be useful, for example, in a trial of a new antihypertensive medication. Subjects will be randomised into either the control or the intervention (treatment) group, and then both will undergo a *pretest*. Within this example, the pretest would be the assessment of systemic blood pressure. Those in the treatment group would then undergo a period of treatment, and both groups would then be subject to a *posttest*. Treatment success would typically be defined as the difference between the groups. This process of a pretest/posttest control group design is illustrated in Fig. 5.11.

INSIGHT – If a radiology department were interested to understand whether pre-hydration prior to contrast-enhanced was an effective strategy in reducing the incidence of contrast-induced nephropathy, then the following pretest/posttest control group design could be used (*based on Nijssen et al., 2017*).

Clinical Trial Overview

The authors undertook a prospective randomised controlled trial for patients at risk of contrast-induced nephropathy. Patients were recruited if there were deemed at high risk (eGFR 30-59 mL/min/1.73 m²) and who were undergoing an elective procedure requiring iodinated contrast media administration at a single centre.

Randomisation

Patients were randomised (1:1) to receive either intravenous saline (treatment) or no prophylaxis (control).

Pre-test

Immediately prior to iodinated contrast media administration, all patients had their serum creatinine measured and their eGFR calculated.

Post-test

Serum creatinine was measured, and eGFR was calculated at 2–6 days and 26–35 days after contrast exposure in all patients.

Outcomes

The primary study endpoint was the incidence of contrast-induced nephropathy defined as a pretest/posttest difference in serum creatinine of more than 25% or 44 $\mu\text{mol/L}$. The authors confirmed that no prophylaxis was non-inferior to saline prophylaxis in the prevention of contrast-induced nephropathy.

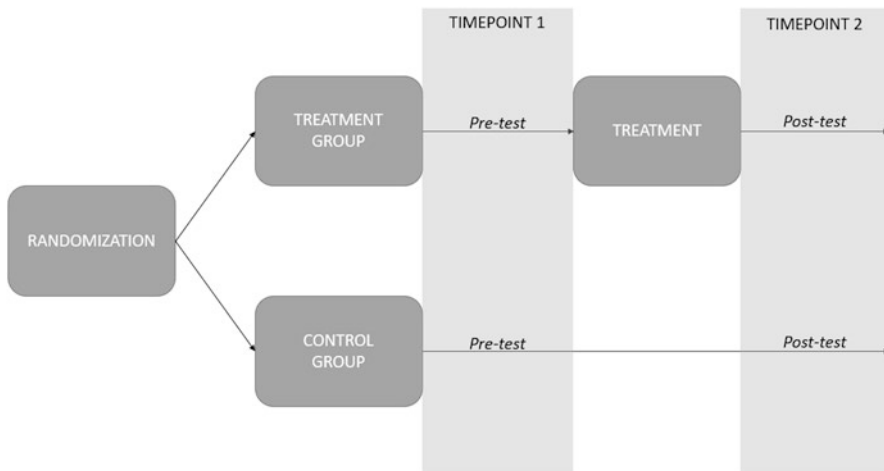


Fig. 5.11 Illustration of a fictitious *pretest/posttest control group* study design

In situations where treatment might be sensitised by a pretest, there is the option of conducting a *Solomon four-group study design*. This design contains additional control groups, which seek to help reduce the influence of confounding variables and allow researchers to understand the effects on any pretests. This is a complex research methodology but can reduce some of the internal validity issues plaguing research. For a study testing a treatment or intervention, a Solomon four-group design would enlist two control groups. One of these would undergo both the pre- and posttest, and one would only undergo posttesting, without any intervention (Fig. 5.12).

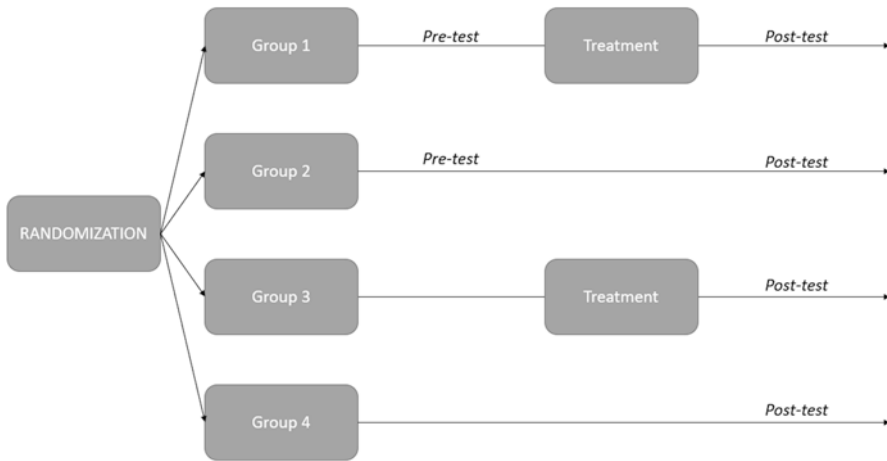


Fig. 5.12 An illustration of a typical *Solomon four-group* study design

INSIGHT – A Solomon four-group study design would be useful if there was a concern that the pretest could by itself induce some therapeutic benefit. An example of this could be the evaluation of an intervention to support radiation therapists who are frequently involved in the care of the terminally ill. To understand the issues and provide a baseline in which to test the intervention and pretest questionnaire could theoretically encourage participants to consider methods for improving their health and well-being outside of the trial. Such methods could be unconscious to the subject and as such may not be identifiable within any eligibility criteria or strict study protocol.

The use of a four-group study design would allow testing of the intervention alongside understanding the effect of the baseline questionnaire on the subjects.

A final consideration in experimental research is the introduction of *crossover*. Crossover can be deliberate or unintentional and is defined as the study switching from the control to the treatment group. It is useful for evaluating two treatments, but there must a washout period where the patient is theoretically allowed to return to baseline (Fig. 5.13). Crossover designs can be useful in area where there is limited access to subjects, for example, rare diseases.

INSIGHT – An example of a crossover study could refer to asthma .

In a cohort of asthma patients, who were followed up for a period of eight weeks prior to randomisation, they were assigned to either the active drug or a placebo. They were then tapered off the active treatment and given a washout period of between 2 and 4 weeks. Following the washout period, they were either titrated onto the alternative treatment (either placebo or active drug).

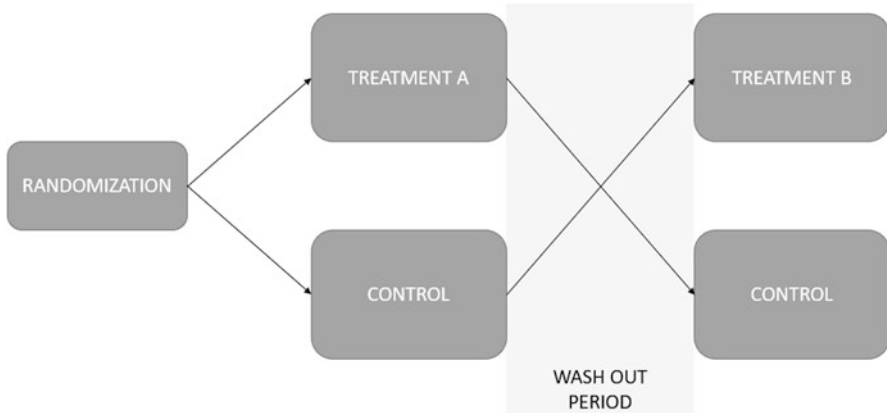


Fig. 5.13 An illustration of a *cross-over* study design

An advantage of crossover studies is that the subject acts as their own control; this results in the need for a smaller sample size than with a parallel group study. Such an approach can only be used in areas where a patient is likely to rebound back to their original health state, i.e., asthma or diabetes. Disadvantages that also exist in that crossover studies typically require a longer duration and can be difficult to trial multiple dosages and manage dropouts. To some degree, blinding can also be an issue if the subject experiences benefit with the first randomisation; some will also be reluctant to withdraw treatment and move into the control arm.

Although undesirable, in some trials, it is ethically important to allow crossover (patients switching from the control to the experimental treatment). An example where this is common practice is in oncology trials and as such makes it difficult to detect and attribute improvements in overall survival with the experimental treatment. Statistical techniques are available, which can help mitigate the effects of crossover.

INSIGHT – In a phase 3 trial (Sternberg et al., 2013) of pazopanib versus placebo for patients with advanced renal cell cancer, around 51% of the control group crossed over to the active treatment during the study. The hazard ratio for overall survival of the pazopanib in the intention-to-treat population was 1.01 (95% CI 0.72–1.42), indicating no benefit from the active treatment. Study researchers undertook a post hoc statistical adjustment using the rank preserving structural failure time (RPSFT) method and confirmed that pazopanib was associated with a survival benefit (hazard ratio 0.5).

5.2 Qualitative Research Methods

Qualitative research methodologies are becoming increasingly more popular in medical imaging and radiation therapy research. Qualitative research, by definition, covers research that produces results that are not based on numerical quantification or statistical analysis. Qualitative research, in its broader sense, aims to describe, explore and understand phenomena through non-numerical based inquires and predominantly focuses on meanings, understandings and experiences.

Qualitative research can be undertaken as a standalone study or when combined with quantitative research as a *mixed methods study*. Typically, methodologies within qualitative research focus around observations, interviews, focus groups and case studies.

Before attempting to understand the different approaches to qualitative research, it would be useful to consider the thought processes (*paradigms*) around the development of the key qualitative approaches. A paradigm is essentially how a researcher would view the world and what they believe is possible to gain understanding on. A research paradigm is also moulded by how a researcher believes it is possible to know something and their relationship with knowledge, including whether the world is independent of, or affected by, the research being undertaken (Table 5.5).

5.2.1 Phenomenological Research

Phenomenological research seeks to describe a phenomenon or phenomena from the experiences of many, essentially revealing what lies hidden. Such studies can be longitudinal or at a single time point and can involve interviews, focus groups and/or direct observations. Phenomenology seeks to describe the structures of experience as they present themselves to consciousness, without any recourse to theory, deduction or assumptions from other disciplines. To reiterate, such an approach is not to define a theory or develop a model. An example of such is the work by Cuthbertson (2019) who investigated the journey of radiographer advanced practice using phenomenology (Fig. 5.14).

Table 5.5 Summary of the key principles in the formation of a research paradigm

Principle	Description
Ontology	Focuses on the nature of being and existence and seeks to classify and explain entities. Ontology is based around the object which is the focus of the inquiry
Epistemology	It is the process concerned by how we gain knowledge and how we get to know something
Methodology	Refers to the overarching strategy and rationale of the research project
Methods	The precise processes and steps whereby research is conducted or a subject or topic

Adapted from Bristowe et al. (2015)

Phenomenological research study data is primarily collected through interviews, stories or observations within the people who have had the ‘relevant experience’. Within Cuthbertson’s work (Fig. 5.14), this was from diaries and interviews with radiographers moving into advanced practice. Data collection then typically results in transcription and interpretation. The result is generally a series of themes or issues that are common to many of the research participants. This form of methodological approach is useful in that it considers an individual’s experience and data collection can often be in the form of interviews which can favour the skillset of healthcare professionals. Two main approaches to phenomenological research exist (descriptive and interpretative; Table 5.6). Descriptive phenomenology focuses on a ‘pure’ description of an individual’s experiences and was developed from the work of Edmund Husserl. More recent approaches have focused on the interpretation of such experiences and are considered interpretative phenomenology, following the work of Martin Heidegger.

EXAMPLE OF A PHENOMENOLOGICAL RESEARCH STUDY	
Cuthbertson, LM. The journey to radiographer advanced practice: a methodological reflection on the use of interpretative phenomenological analysis to explore perceptions and experiences. <i>J Radiother Prac</i> 2019;19:116-121.	
AIM	To explore the experiences and perceptions of radiographers in their journeys to advanced practice.
MATERIALS & METHODS:	A two-phase qualitative research design was utilized. The first phase reviewed a series of reflective diaries based on the educational phase of 12 practitioners. The second phase was based on one-to-one, semi-structured interviews for six practitioners. Interviews were analyzed thematically.
RESULTS:	Key diary themes informed the interview content. Following the interviews and analysis 12 sub-themes were generated and three superordinate themes.
CONCLUSIONS:	Radiation therapists work in an everchanging workplace. Changes result from developments in technology, treatments and patient expectations. Interpretative phenomenological analysis can be used to evaluate perceptions and experiences from a range of stakeholders and provides an opportunity to conduct effective research.

Fig. 5.14 An example of phenomenological research relating to radiographic advanced practice (adapted from Cuthbertson, 2019)

Examples of phenomenological research questions that could arise within medical imaging and radiation therapy may include the following:

- How do cancer patients cope with the side-effects from radiotherapy?
- What is it like to undergo uterine artery embolisation?
- What are the experiences of carers of family members with a serious physical disability undergoing frequent medical imaging examinations?

5.2.2 *Grounded Theory Research*

Grounded theory research seeks to develop theory arising from the data. Such studies can be longitudinal or at a single time point and can involve interviews, focus groups and/or direct observations. Grounded theory methods are typically used to gain an understanding of the social and psychological processes that characterise an event or situation. An example of this is the work by Benfield et al., 2021 who investigated the perceptions of dose creep among student radiographers (Fig. 5.15). A grounded theory approach comprises of a series of carefully planned steps, which if performed correctly are believed to guarantee a high-quality theory as the outcome. The basic approach to grounded theory is to read and re-read a textual database (field notes, interview transcripts, etc.) and to identify relevant variables and their relationships. Data collection and analysis are simultaneous, with one informing the other, and is often described as cyclical and reflexive in process. Grounded theory is useful to attempt to explain a process but not for hypothesis testing.

Open coding is part of the analytical process of grounded theory and is focused on the identification, naming, categorisation and describing of phenomena found

Table 5.6 Similarities and differences between descriptive and interpretative phenomenology

Descriptive	Interpretative
Possible to suspend a researcher’s personal opinion	Accept that an endless number of realities are possible
Able to arrive at a single description of the phenomena	Interpretations are the only thing that is possible from experiences
Accept that there is unlikely to be more than one reality	Describing ‘description’ experiences is an interpretative process
Multiple realities would introduce doubt and lack of clarity	
Typical sample size (10–15)	
Methods include observation, interviews, conversations and focus groups. Written records such as diaries and journals can also be examined	
Powerful method for understanding subjective experience. Gain insight on actions and motivations of an individual or individuals. Can help develop new theories and change policies	
Such an approach does not suit all research questions. Potential issues with language barriers and cognition. Data collection time consuming	

EXAMPLE OF A GROUNDED THEORY RESEARCH DESIGN	
Benfield, S., Hewis, JD., Hayre, CM. Investigating perceptions of ‘dose creep’ amongst student radiographer: A grounded theory study. Radiography	
AIM	To explore the perceptions of ‘dose creep’ amongst student radiographers.
MATERIALS & METHODS:	A Grounded Theory qualitative based research study was undertaken. Six participants were recruited and took part in semi-structured interviews. Data on the perceptions of dose creep were analyzed using constant comparative analysis (CCA).
RESULTS:	Insights were obtained regarding the term ‘dose creep’ and related clinical decision making. Important learning needs and actions (academic and clinical) were identified help improve X-ray exposure practices.
CONCLUSIONS:	This publication seeks to describe some of the challenges surrounding optimal X-ray exposure selection and the term ‘dose creep’. Study findings have highlighted the importance of teaching and learning around appropriate exposure factor selection.

Fig. 5.15 An example of research into ‘dose creep’ undertaken using Grounded Theory (adapted from Benfield et al., 2021)

Table 5.7 A summary of the elements making up the basic frame of generic relationships in Grounded theory research

Element	Description
Phenomenon	Is the concept that holds the bits together, sometimes called the outcome of interest or subject
Causal conditions	These are the events of variables that can lead to the occurrence or development of the phenomenon
Context	Typically, is hard to distinguish from the causal conditions. It is the specific locations (values) of background variables. A set of conditions influencing the action/strategy
Intervening conditions	Very similar to context. Context can be identified as having moderating variables and intervening conditions with mediating variables
Action strategies	The purposeful, goal-orientated activities that agents perform in response to the phenomenon and intervening conditions
Consequences	These are the consequences of the action strategies, intended and unintended

within the acquired data. Following an open coding process, the next step is general axial coding; here, pre-established codes are related to each other, via and combination of inductive and deductive thinking. The result is a basic frame of generic relationships based on the elements described in Table 5.7.

Examples of grounded theory research questions that could arise within medical imaging and radiation therapy may include the following:

- How do radiographers foster a culture of patient safety within MR scanning?
- What are the barriers to accessing breast cancer screening for women within ethnic minority groups?

5.2.3 Ethnographic Research

Ethnographic research seeks to describe the characteristic of a culture and its community members. Such studies are longitudinal and typically require emersion in the culture and an extensive period of data collection (observation and interviews) and fieldwork. Simply, ethnography focuses on the sociology of meaning through close observations of sociocultural phenomena. It is a process whereby understanding is generated relating to a group's beliefs, values and practices and how they adapt to change. Subdivisions of ethnography exist, and it is possible to investigate one's self, and this is given the term 'auto-ethnography'. A recent example of ethnography within medical imaging and radiation therapy was described by O'Regan and colleagues in 2019 (Fig. 5.16).

Examples of ethnographic research questions that could arise within medical imaging and radiation therapy may include the following:

- What expectations and beliefs do people within non-native English-speaking communities hold about the options for undergoing medical imaging?
- What expectations and beliefs do people undergoing gender transformation hold about the processes for establishing pregnancy risk during medical imaging and radiotherapy?

5.2.4 Explanatory–Descriptive Qualitative Research

Explanatory research is often conducted to help understand a problem more efficiently. It does not aim to provide a final answer to the research questions but allows the research team to explore the research in depth. With such an approach, the researcher seeks to lay down the groundwork for future studies. Explanatory research is typically conducted in an area that has not received much attention and can be used to outline priorities, provide essential definitions and help establish a relevant research model. Essentially, this type of research will help provide the building blocks for the work of others.

Methods for explanatory research include reviews of the literature (Fig. 5.17), interviews, focus groups and an analysis of cases.

Further opportunities to undertake explanatory research in medical imaging and radiation therapy could be to attempt to answer the following research question:

- Has radiographic image quality for trauma cervical spine examinations reduced because of the widespread availability and utilisation of computed tomography?

EXAMPLE OF ETHNOGRAPHY AS A RESEARCH DESIGN	
Hayre, CM., Blackman, S., Carlton, K., Eyden, A. Attitudes and perceptions of radiographers applying lead (Pb) protection in general radiography: An ethnographic study. <i>Radiography</i> 2018;24(1):e13-e18.	
AIM:	To investigate the attitudes and perceptions of radiographers utilizing lead rubber protection during general X-ray examinations.
MATERIALS & METHODS:	The study included participant observation and semi-structured interviews. Observation was used to evaluate whether lead rubber shielding remained an essential tool for diagnostic radiographers. Semi-structured interviews was used to support or refute the theory of limited use of lead rubber protection in clinical practice and to enable the construction of phenomena.
RESULTS:	Radiographers identified a dichotomy of applying lead rubber protection and that this was underpinned by personal beliefs and values. The restriction in the use of lead protection may be linked to culture, word-of-mouth and not existing research evidence. Radiographers outlined that the shielding of pregnant patients was primarily personal choice.
CONCLUSIONS:	There are well-established complexities in the application of lead rubber protection in clinical departments. It is likely that the use of lead rubber protection may become increasingly more fragmented in use in the future.

Fig. 5.16 An example of ethnography as a research method used in radiography (adapted from Hayre et al., 2018)

5.2.5 *Historical Research*

The purpose of a historical research design is to collect, verify and synthesise evidence from the past to establish facts and defend or refute a hypothesis. A wider and broader aim of historical research is to investigate the past in which to help inform the future. Such approaches make use of archived documents, oral recordings and interviews. Although it is a valid research method, it can be limited by the availability of primary sources, and as such triangulation can be difficult. An example in radiography comes from the work of Sola Decker who presented an oral history of radiography by examining the lived experience of newly qualified radiographers between 1950 and 1985 (Fig. 5.18).

Further opportunities to undertake historical research in medical imaging and radiation therapy could be to attempt to answer the following research questions:

EXAMPLE OF AN EXPLANATORY QUALITATIVE RESEARCH DESIGN	
Booth, L., Henwood, S., Miller, PK. Leadership and the everyday practice of Consultant Radiographers in the UK: Transformational ideals and the generation of self-efficacy. <i>Radiography</i> 2017;23(2):125-129.	
AIM:	To report the role of consultant radiographers in the United Kingdom with specific focus on the leadership aspect of the role.
MATERIALS & METHODS:	A qualitative-thematic approach was used. Using six consultant radiographers, their leadership-related experiences were explored together with individual reflections on self-efficacy.
RESULTS:	Many elements of consultant radiographer leadership practice are aligned with the Transformational Leadership Model.
CONCLUSIONS:	Study findings may help consultant radiographers in the context of leadership. Study findings can also be used as a guide regarding the value of professional self-efficacy.

Fig. 5.17 An example of a potential explanatory qualitative research study (adapted from Booth et al., 2017)

EXAMPLE OF AN HISTORICAL RESEARCH STUDY	
Decker, S. The lived experience of newly qualified radiographers (1950-1985): An oral history of radiography. <i>Radiography</i> 2009;15:e72-e77.	
AIM	To report on the lived experiences of newly qualified radiographers between 1950 and 1985.
MATERIALS & METHODS:	Analysis of the written materials generated from informants’ oral history accounts.
RESULTS:	Oral history accounts suggested that radiographers perceived their training as “fit for purpose” and that the general norm was to “get on with it”.
CONCLUSIONS:	The oral historical accounts of radiographers’ lived experiences can be useful for highlighting lessons learned within the profession.

Fig. 5.18 An example of historical research into the lived experiences of newly qualified radiographers between 1950 and 1985 (adapted from Decker, 2009)

- How has the attitude to radiographer-led justification changed over the last 20 years?
- How has the role of the radiographer and radiologic technologist changed over the past 20 years?

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Chapter 6

Data Collection, Analysis, and Interpretation



Mark F. McEntee

6.1 Data Collection

Often it has been said that proper prior preparation prevents poor performance. Many of the mistakes made in research have their origins back at the point of data collection. Perhaps it is natural human instinct not to plan; we learn from our experiences. However, it is crucial when it comes to the endeavours of science that we do plan our data collection with analysis and interpretation in mind. In this section on data collection, we will review some fundamental concepts of experimental design, sample size estimation, the assumptions that underlie most statistical processes, and ethical principles.

6.1.1 Preparation for a Data Collection

A first step in any research project is the research proposal (Sudheesh et al., 2016). The research proposal should set out the background to the work, and the reason of the work is necessary. It should set out a hypothesis or a research question. Crucially, a research proposal should include a proposed research methodology. In research that involves data collection, it is crucial that the population you wish to investigate is identified and the mechanism by which you will sample that population is clearly set out.

Based on the hypothesis, or the research question that you have identified, you will need to decide whether you are going to observe or measure and how you are going to go about that. A proper interrogation of a research hypothesis or question should identify the information that you will need to answer your question and

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conclude on your hypothesis. As you know, hypotheses are statements that you seek to prove or disprove. So, if one sets out a hypothesis that 70 kVp is better for the visualisation of kidneys than 110 kVp, then you know that the type of information required to answer this question is going to involve some measure of visualisation of the kidneys and some measure of the dose received by the kidneys and other organs in the region. Thus, before we begin data collection, we should have a clear picture of what it is that we need to measure and the tools by which we will measure it. We might also wish to estimate the sample size needed; sample size calculation is discussed later in this chapter.

6.2 Common Tools for Data Collection in Medical Imaging

As with other areas of science, methodology for data collection in medical imaging can be broken into the following three broad areas:

- Quantitative research
- Qualitative research
- Mixed methodologies

The barriers between quantitative and qualitative research or sometimes argued to be artificial and mixed methodologies attempt to use the benefits of both to come to a greater understanding of truth. In reality, the methodology chosen should be appropriate to the hypothesis or to the research question being asked. The question of whether qualitative methods and quantitative methods are better is moot, as the important issue is whether you have chosen the correct methodology for your research.

6.2.1 *Quantitative Methods*

6.2.1.1 Dose Measurement

Increasingly dose measurement devices are built into the imaging equipment that we use. Before you begin data collection, understand what dose measurement devices are available to you. Many x-ray tubes will have a dose area product metre built into the system and will give you a measurement of the dose at the tube multiplied by the area of the collimation. All CT scanners will give you some measure of dose length product (DLP) or computed tomography dose index (CTDI). Fluoroscopic dose units will give dose area product (DAP) over time. Although there are many measurements of dose, there is only one measurement of dose that can estimate the risk to the patient. So, if you are interested in estimating the risk to the patient, you must use the Sievert.

Sieverts (Sv) take into account the dose measurement that you receive from your imaging device (dose area product, dose length product, and computed tomography dose index) and the area of the body being exposed (chest, head, and pelvis) and use the international commission of radiation protection's (ICRP) tissue sensitivity index to give an estimate of the risk to the patient. It is generally assumed that there is a 5% risk of a fatal cancer from every Sievert of radiation. At the beginning of a data collection, decide on the dose unit and understand how you are going to convert this to Sieverts. The absorbed dose is multiplied by the tissue weighting factor, and this creates a risk for each organ; then all the organs are added together to create the effective dose (McCollough & Schueler, 2000).

6.2.1.2 Image Quality Measures

There are many measurements of image quality. These can be broken down into physical measures, psychophysical measures, and observer performance measures, and these will be discussed later in this chapter.

6.2.1.3 Assessment of Knowledge or Attitudes

Surveys are a common way of testing knowledge and attitudes. Increasingly these are carried out over the Internet using freely available tools. Although the technique of administering surveys has changed, the principles have not:

1. Survey design.

Modern web-based survey tools allow the researcher to select different question styles from true/false, multiple choice questions, short answer questions, and matching style questions as well as many others.

- (a) It is important to note that just because there are many options available, not all options need to be chosen. The survey should be kept as simple as possible, but not simpler.
- (b) Questions should be unambiguous and should be mutually exclusive.
- (c) The reader should not be confused by the answers that are selectable, for example, if there is a rating scale, the rating scale needs to be explained.
- (d) It is best to keep rating scales consistent throughout the survey so that the responder is not confused by changing scales as they proceed. For example, if a scale of 1–5 is used, 1 can mean very poor, 2 can mean poor, 3 can mean fair or neutral, 4 can mean good, and 5 can mean very good. Changing the direction of this could mean that your responder does not correctly interpret your question and responds in the inverse.
- (e) If rating scales are not used and instead descriptive statements are allowed to be chosen, the difference between descriptions should remain consistent. For example, the question “how would you rate your experience” could be followed by something like excellent, very good, good, fair, poor, very poor;

this gives three positive ratings and three negative ratings, provided you believe that fair is a negative rating. However, if the responder believes that “fair” is quite a positive thing to say, then you have four positive ratings and only two negative ratings, and your scale is biased.

- (f) In as much as possible, you should simplify the process for the responder; this will ensure higher levels of completion of the survey. Dropdown menus of choices provide more consistent responses than typed responses.
 - (g) In web-based surveys, do not rely on too many short answer questions or open questions; participants typing on phones, tablets, or other small devices may find it difficult to give large complex answers. Where qualitative data is important to your hypothesis or research question, a survey might work, but interviews or focus groups might provide you with a greater richness of data.
 - (h) It is always useful to pilot your survey. When piloting a survey, be clear about the questions you want to be answered; don't just get the pilot participants to respond to the survey, but rather get them to give you a critical analysis of the questions and the chronology as well as the ease of use. A good technique would be to sit with your pilot participants as they complete the survey and get them to think out loud as they proceed.
2. Ethics.

As surveys are completed by humans, surveys will require approval of an ethics committee before administration. There should be a statement at the beginning of the survey indicating the terms and conditions of the data collection and the ethical approval for the collection and asking the participant to indicate in some way that they have read and understood the terms and conditions. Only when a participant has given some indication that they understand their responsibilities and rights and relation to the survey, should they proceed.

3. Distribution of the survey.

Increasingly we are seeing surveys distributed via social media and email. Distribution via social media has many advantages and some disadvantages. The advantages are that it is free, that it can be snowballed, that it increases the likelihood that the target population will receive the request, and that the survey can be amplified by people that are active on social media with many followers. The primary disadvantage is that you do not know the sample size. Many people may see the link and scroll past it; many people will open the link and not complete the survey. One way to deal with this is to be very clear in your social media advertising as to who the survey is appropriate to. You might, for example, say the survey is open to all registered technologists in the state of Utah, with 5 years of experience or less. This gives you some estimate about the potential sample size, but will not allow you to generate numbers around your response rate because you will not be able to verify how many people in the sample received the request for completion via social media.

4. Most survey tools give an indication to the responder as to how much they have completed in the survey; this is a useful tool to aid completion.

5. Many of the tools for collecting data via electronic surveys also have the additional advantage of providing you with some analysis of your results, particularly descriptive statistics. These should not be taken at face value, as some data cleaning may be necessary.

The use of the Internet has greatly reduced the cost and the difficulty of getting the survey to the participants, but it has brought some extra complications. It is often difficult to know how many people this survey has reached; particularly if social media is used for the delivery of surveys to participants, this is missing data. Where a response rate is required, it is advised that email, or postal solicitation, should be used first, with a link to the survey rather than generalised distribution into the whole population (Good & Hardin, 2012). However, with every new tool comes a new problem; early research into the use of web forms for surveys demonstrated that many of the issues in survey design are maintained or exacerbated by the web form. Changes in the number of options, the layout of options, and the order of options can all be seen to change the responders choices (Couper et al., 2001).

There are plenty of books to help you with the wording of questions in surveys (Iarossi, 2006), but the principles are that the questions should be clear and unambiguous; the question should be tested on a sample of participants before dissemination to the wider sample. You should be sure that your introduction or your questions do not reveal your hypothesis, or your research question, otherwise you run the risk of participants adjusting their answer.

An important consideration with any survey is bias and particularly bias in the sample. When using Internet surveys, it is clear that only those who have access to the Internet will be able to respond, and although this is an increasingly small part of the developed world, it remains a large part of the developing world. Beyond the obvious bias of using web-based surveys, the use of social media for distribution creates a further bias. Only those that have social media accounts will be able to access the survey. Even when using email, there will be a propensity for some to check their email more often than others. Therefore, it is important to describe exactly how you have distributed your survey and be aware of the biases that your method introduces. Beware of falling into the trap of thinking that your sampling method is random; random selection is a process of its own that is discussed elsewhere in this text. Convenience sampling has inherent biases, and they're not truly random.

Proper sampling of the target population may not be possible, and often compromises will be needed. For example, the list of all registered radiographers with the health-care professions council in the United Kingdom is publicly searchable, but does not contain details such as email addresses or home addresses. Such details are protected by law and are not shared by registration bodies; therefore, a full list of all registered radiographers would not be available to the researcher, and only compromised methodologies of contacting a sample of the population will be available.

6.2.2 *Qualitative Methods*

Qualitative methods are an extremely powerful mechanism of understanding the behaviour, the knowledge, and the attitudes of human beings, systems, and organisations. There are seven groups of very powerful tools used under the heading of qualitative methods, and these include interviews, focus groups, ethnographic research, action research, and content analysis in case study research to name but a few.

6.2.2.1 Interviews

Interviews are one of the most common methods of qualitative research and involve a personal interview with a single respondent; multiple single respondents might be used, but they do not interact with each other. Interviews provide an opportunity to collect rich data about a person's behaviours, beliefs, or motivations. They allow you to use the same questions on multiple individuals, but not have those individuals interact or bias each other's answers. Interviews are typically organised in similar ways to surveys, in that they have proper prior planning, ethical approval, and a set of pre-approved questions and pre-approved explorations of those questions. The interviews are recorded, and the responses are transcribed and are then assessed using thematic analysis. Interviews take time to organise and take time to analyse; they might often place the researcher in close proximity to the interviewee. Human interactions are hard to predict, and there can be biases introduced by the interpersonal interaction between the interviewer and interviewee. Some of these can be reduced by interview over the phone or by video calls (King et al., 2018).

6.2.2.2 Focus Groups

Focus groups are probably the second most common type of qualitative research method. The focus group usually involves a small number of 5–7 participants. The participants are gathered together, and there is interaction between the groups. Like the interview there is proper prior preparation, questions are carefully designed, and ethical approval is gained. The interaction between the groups is recorded, and the recording is then transcribed and analysed.

The researcher leads to discussion among the group but does the least talking. Focus groups rely on the interaction between the participants to gain deeper answers or to gain insight into areas of agreement or disagreement. One question might be asked to the group; while every person in the group might answer, some people in the group will respond to other answers or clarifications. Typically, the conversation builds and continues until the same responses begin to emerge. This is sometimes referred to as saturation. Focus groups can result in a large amount of data in a very short period of time. They can be hosted on the Internet, although this can reduce the amount of interaction (Morgan, 1996).

6.2.2.3 Ethnographic Research

Ethnographic research is an in-depth observational method. In this type of research, the researcher embeds themselves within the organisation, the culture, or the structure that is being investigated. The idea is that the participants under observation begin to act naturally around the researcher and their true behaviour can be observed from a viewpoint within the culture or the organisation. In this type of research, instead of relying on an interviewee giving their perspective, or a focus group discussing the issue, the researcher gets to witness their natural behaviour and thoughts first hand. This type of research is most useful for gaining a detailed description of everyday life and seeing events from the viewpoint of the participants. Typically, ethnography can last several days up to a few years. Anthropological research frequently relies on ethnographic methodology to understand complex relationships between people, culture, language, and the environment (Gusterson, 2008).

6.2.2.4 Action Research

Action research is a type of qualitative methodology that seeks to solve our problem by involving the community that has researchers and participants in the research. Action research is a collaborative endeavour that works on the assumption that people working together will find the best solution and that knowledge sharing activities will lead to improvements. Action research would have a hypothesis or research question, but the methodology has the potential to lead the project in directions that might not be predicted. Action research can also involve elements of other qualitative research such as interviews, focus groups, and observation (Avison et al., 1999).

6.2.2.5 Content Analysis

Content analysis seeks to derive meaning from the interpretation of multiple sources of information such as documents, music, painting, poetry, movement, and dance. Conclusions drawn from content analysis might synthesise information about an organisation, or a culture, from multiple sources, and are not restricted to written and oral resources. Content analysis seeks a more holistic understanding and attempts to address the problem from multiple cultural and linguistic perspectives (Neuendorf & Kumar, 2016).

6.2.2.6 Case Study Research

Case study research seeks to draw conclusions from an in-depth analysis of a single case. However, it is not a single sample, rather an attempt to use an example to draw wider conclusions. A case study of a student's progress through education, for example, might be used to draw conclusions about the barriers and enablers to learning.

6.2.2.7 Mixed Methods

Mixed methods are a group of approaches or methodologies in research that focus on real-life or contextual learning from multiple perspectives. Mixed methods refer to the inclusion of both quantitative and qualitative research methodologies. Mixed methodologies use quantitative research to assess, for example, the size and variability of a problem and then use qualitative methodologies to understand the impact and the meaning of that problem on an organisation, society, or culture. Mixed methodologies intentionally use both methodologies harnessing the strengths and benefits of both in an attempt to more fully understand the issue (Meissner et al., [n.d.](#)).

6.3 Descriptive Statistics

On a very broad level, the analysis of research data is broken up into the following two categories:

- Descriptive statistics
- Inferential statistics

Descriptive statistics focuses on mathematical ways of organising and summarising raw data. They tend to focus on measures of central tendency and variability; both can also include characteristics such as percentages and proportions.

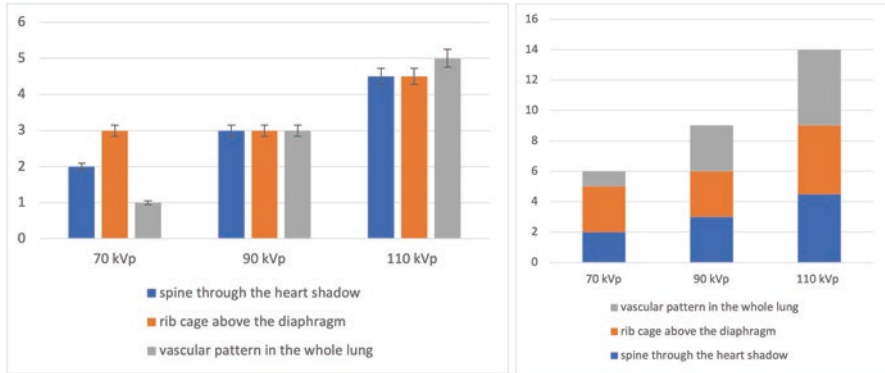
The measures of central tendency include mode, median, and mean. The measures of variability include range, interquartile range, and standard deviations. Using a measure of the central tendency combined with a measure of the variability gives us a lot of information about the sample. Using these descriptive statistics, we can draw conclusions about the distribution of the data (Fisher & Marshall, [2009](#)).

6.3.1 Presentation of Data

Aligned with descriptive statistics is the important issue of data presentation. Data presentation is not necessarily statistics, but can provide us with an important insight into the data using a mechanism other than mathematics or linguistics. For the visual learner, data presented as bar charts, pie charts, maps, infographics, scatter plots, curves, or matrices can add understanding and colour to the presentation of results.

6.3.1.1 Bar Charts

The bar chart is a convenient diagram that shows the measure of central tendency as a bar whose height is equal to the median, mean, or mode. These bars are often accompanied by error bars, which can show the interquartile range, the standard deviation, or the error of measurement (Figs. [6.1](#) and [6.2](#)). Bar charts can show



Figs. 6.1 and 6.2 Example of bar charts showing the changes in image quality for three image quality criteria across three energy ranges of the beam. Both are generated from the same data

information on multiple criteria at the same time and can include information on central tendency and variability in the one figure.

6.3.1.2 Pie Charts

A pie chart is a diagram of a circle divided into segments to represent the proportions of the total achieved by each segment. Although I use some mechanism for visualising proportions, pie charts can only show one criteria at a time and are not useful for showing measures of central tendency with their associated variability (Fig. 6.3).

6.3.1.3 Histograms

A histogram is a graphical representation of the distribution of numerical data in a sample. The histogram displays the values in the sample in groups or range that is sometimes referred to as bins or buckets. The histogram then presents this data with the height of each column representing the number of values in each bin or bucket. The bins are usually mutually exclusive and consecutive intervals. They are typically of equal width. Histograms can give us a visual representation of the patterns in the data. Figure 6.4 shows a symmetrical, unimodal distribution of data, Fig. 6.5 shows that data is skewed to the right, and Fig. 6.6 shows that data is skewed to the left. From histograms we can also determine whether our data is bimodal, multi-modal, or symmetrical.

6.3.1.4 Scatter Plots

Scatter plots are a visual representation of two variables for a set of data, set out using Cartesian coordinates to display the values. The data points are presented in a chart with coordinates X and Y . Scatter plots can be used to suggest relationships

Fig. 6.3 A pie chart showing the proportions of scores given to each of the three kVps for one of the image quality criteria. From this pie chart, the reader can estimate that roughly half of the total score given for these criteria were given to 110 kVp

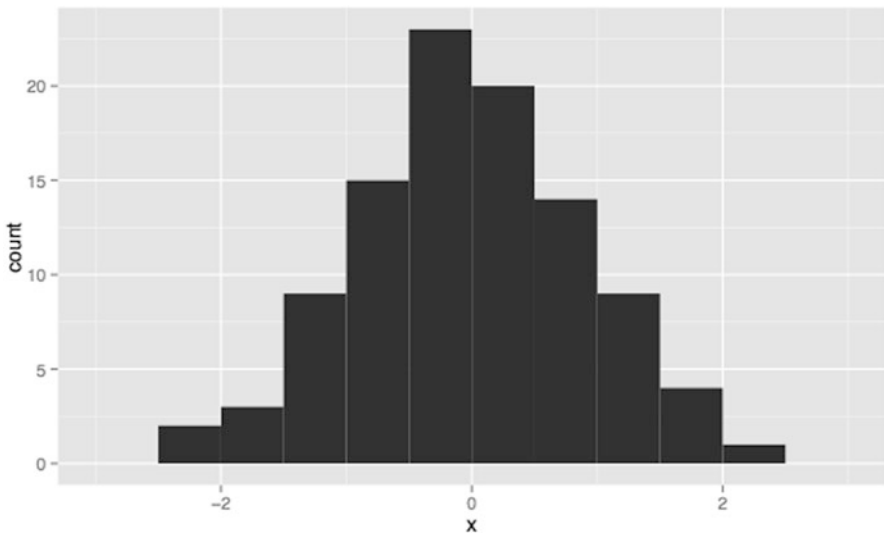
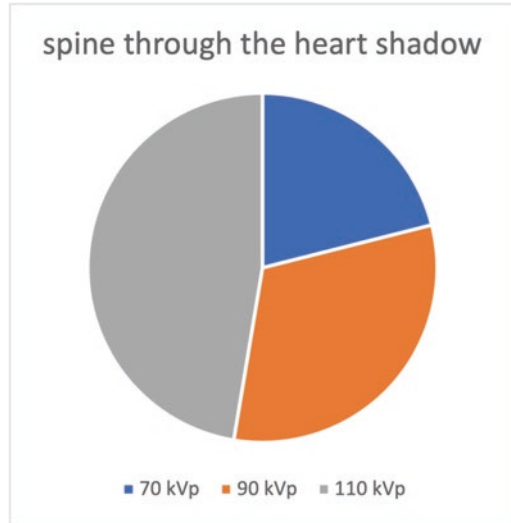


Fig. 6.4 A histogram with asymmetrical, unimodal distribution. (<https://en.wikipedia.org/wiki/Histogram#/media/File:Symmetric-histogram.png> Attribution-ShareAlike 4.0 International)

between various types of data, for example, the relationship between weight and height in a population or between the eruption interval and the duration of an eruption as shown in Fig. 6.7.

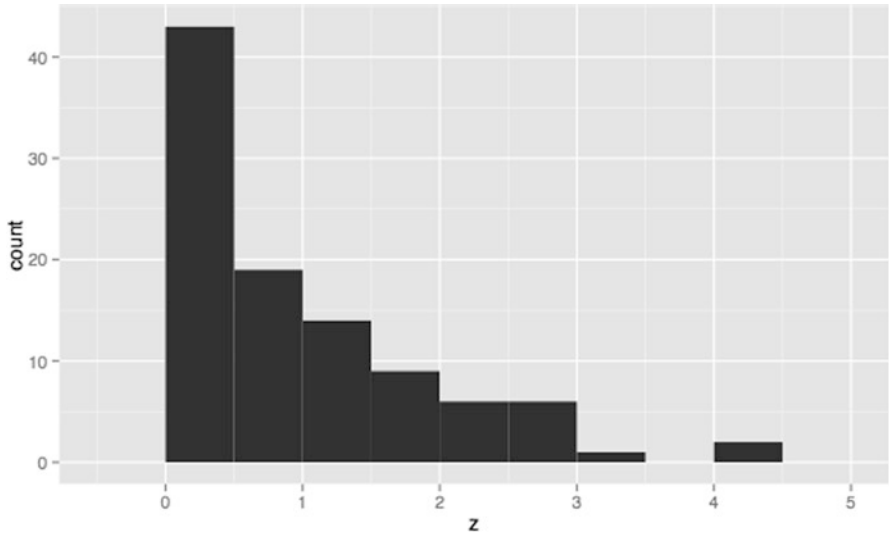


Fig. 6.5 A histogram showing data that is skewed to the right. (<https://en.wikipedia.org/wiki/Histogram#/media/File:Skewed-right.png> Attribution-ShareAlike 4.0 International)

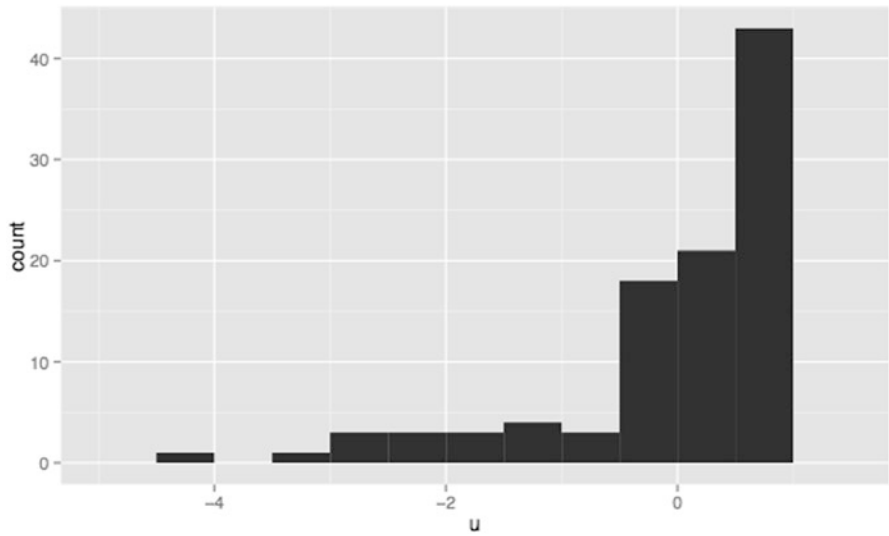
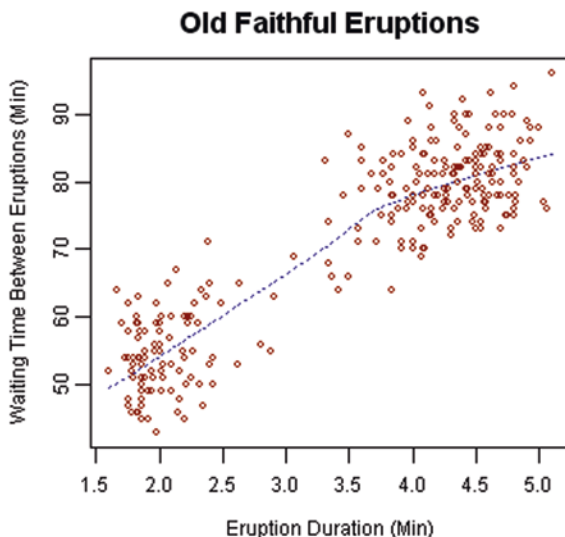


Fig. 6.6 A histogram showing data that is skewed to the left. (<https://en.wikipedia.org/wiki/Histogram#/media/File:Skewed-left.png> Attribution-ShareAlike 4.0 International)

Fig. 6.7 <https://commons.wikimedia.org/wiki/File:Oldfaithful3.png#filelinks> (Public domain image) Waiting time between eruptions and the duration of the eruption for the Old Faithful Geyser in Yellowstone National Park, Wyoming, USA. This chart suggests there are generally two types of eruptions: short-wait-short-duration and long-wait-long-duration



6.3.1.5 Box Plots

A box plot is a method of showing multiple descriptive statistics at once. They show the minimum, the maximum, the sample median, and the first and third quartiles and any outliers. Reading the box plot from the top:

- The uppermost whisker is the maximum data point excluding any outliers.
- The top of the box is the third quartile.
- The central line of the boxes the median.
- The lower line of the box is the first quartile.
- The lower whisker of the plot is the minimum point excluding any outliers.
- Outliers are often shown as an asterisk beyond the maximum or minimum points.

Figure 6.8 is an example of a box plot that demonstrates the results of five experiments measuring the speed of light; each experiment has its own maximum, minimum, median, and first and third quartiles. In experiment three, we can see that there are outliers beyond the maximum and beyond the minimum. Box plots are particularly useful for comparing distributions between several groups or sets of data; they also give us a good indication of what the histogram of the sample might look like. Box plots can be taught of as an alternative way of visualising histograms.

6.3.1.6 Tables

In many instances, the best way to depict several descriptive statistics at once is through the use of a table. Table 6.1 demonstrates the mean and standard deviations of ratings given to image quality criteria across 3 kilovoltage peaks. This is the same

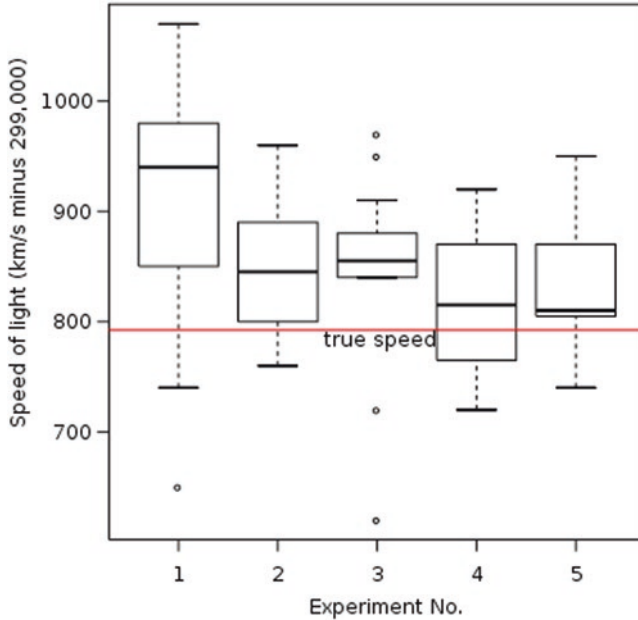


Fig. 6.8 A box plot presenting the results of five experiments to measure the speed of light. (Source <https://commons.wikimedia.org/wiki/File:Michelsonmorley-boxplot.svg#filelinks> (Public domain image))

data that is shown in Fig. 6.1. It is important to choose either a table or a agraffe, infrequently is it warranted to use both. Comparing Table 6.1 and Fig. 6.1, it is clear that a bar chart is the better way of showing this data.

6.3.1.7 Graphs

Graph plots the magnitude of one variable on the horizontal axis called the x -axis against the magnitude of another variable plotted on the vertical axis called the Y -axis. The position of each point along the graph is defined by its coordinates on the X - and y -axes. The X - and Y -axes intersect in the bottom left-hand corner of a graph; this is typically at the point where X equals zero and Y equals zero, although not always.

There are multiple mathematical equations that result in linear and logarithmic graphs. The classic mathematical formula for allowing is $Y = a + bX$, where X and Y are the variables and a and b are the constants; a is the point where the line intercepts with the Y axis and b is the slope of the line.

Table 6.1 demonstrates the mean and standard deviations of ratings given to image quality criteria across 3 kilovoltage peaks

	70 kVp (mean)	90 kVp (mean)	110 kVp (mean)
Spine through the heart shadow	2	3	4.5
Rib cage above the diaphragm	3	3	4.5
Vascular pattern in the whole lung	1	3	5
	<i>sd</i>	<i>sd</i>	<i>sd</i>
Spine through the heart shadow	0.2	0.3	0.4
Rib cage above the diaphragm	0.3	0.3	0.4
Vascular pattern in the whole lung	0.1	0.3	0.4

6.3.2 Measures of Central Tendency

Just before we get into detail about measures of central tendency, it is important to reorientate ourselves with the three broad levels of measurement that are available to us. These are nominal (categorical), ordinal, and continuous (interval/ratio). You will find as we progress through this chapter that many of the tools used in descriptive and inferential statistics rely on some baseline assumptions. It is really important to note the type of data you are using, because some of the statistical tools are not appropriate for use with certain types of data. Before you begin any statistical tests, please note whether your data is nominal, ordinal, or continuous.

6.3.2.1 Nominal (Categorical) Data

Nominal data is also sometimes called categorical data; it is used when scoring cases into broad categories such as gender (male, female, and other). When creating categories for nominal data, the categories must be exhaustive, allowing each participant to fit into their own mutually exclusive category. It is also clear that there is no hierarchy between the categories. For example, we may wish to categorise people into religion, or a speciality of practise, but there is no sense in which the number representing those categories have any hierarchy; category 5 (Christian) would not be higher in the hierarchy than category 1 (Pagan).

6.3.2.2 Ordinal Data

Ordinal data is for categorising responses into hierarchies or ordered categories. It is used where the variables being examined cannot be easily measured, for example, levels of stress, feelings of love, sense of anger, and level of hunger. Although there is a hierarchy between the levels of hunger, for example, there is no internationally agreed numerical measurement of this. Therefore, it makes sense to collect this as

ordinal levels that categorised the levels of hunger into a hierarchy. An example of a hierarchy would be extremely hungry (1), very hungry (2), no sense of hunger (3), full (4), and very full (5). We often measure satisfaction in a similar way; however, the principle of ordinal data requires that the categories are exhaustive, and mutually exclusive; these are criteria that are often unfulfilled.

6.3.2.3 Continuous Data (Interval/Ratio Data)

Continuous data is often what is thought of as natural numbers, they are directly measured, they have infinite scales, and there are equal differences between the increments on the scale. Continuous data is all around us in measures such as height, temperature, weight, and light levels. There are two categories within continuous data: interval and ratio data. With ratio data 0 means the absence of the measure, for example, if you are 0 cm, or have 0 weight, you do not exist. However, with interval data such as temperature, reaching 0 does not mean the absence of temperature, rather 0 is just another point on the scale.

6.3.2.4 Mode, Median, and Mean

In the previous sections of this chapter, we discussed how data can be gathered and displayed. Many of these methods of display use two important characteristics of the data, a measure of the central tendency and a measure of the variability. The measure of central tendency is a way of explaining the most typical or the most representative scores in a distribution.

Measures of variability are statistics that represent the dispersal of the sample data or how it is spread. In this next section, we will discuss the various measures of central tendency and variability and when they are appropriately used.

Many statistical texts will provide you with numerous formulae related to the calculation of means, modes, medians, interquartile ranges, variants, standard deviations, and interquartile range. In the following sections, I will attempt to explain these concepts in simple language without the use of formula. This is a break from the traditional method of explaining statistical concepts but is based in the reality of modern-day use of statistical software packages. It is rare, and indeed not advised, to calculate your statistics by hand. It certainly is a worthwhile exercise if your area of speciality is mathematics or statistics; however, the reader of this text is more likely to be entering the data into a statistics package and selecting the appropriate calculation. Therefore, it is more important to understand the difference between these measures than the formula for them. However, clearly, statisticians and mathematicians may not agree with this approach to learning statistics and mathematics.

6.3.2.5 Mode

For categorical data the most appropriate measure of central tendency is the mode. Categorical data is data that is essentially formed from the categorisation of things. For example, in categorising vegetables, category 1 is a carrot and there are 5 carrots in category 1; category 2 is a lamb and there are 5 lambs in category 2; and category 3 is paintings and there are 10 paintings in category 3. This collection of things does not have an average; there is no sense in which you could average lambs, paintings, and carrots. However, it does have a category that is most frequently occurring, paintings. Paintings are the mode. It is very important to recognise when data is grouped into categories, because normal mathematical principles do not apply; you cannot necessarily add or subtract categorical data. If we added these three categories together, we would have 15, but 15 what? 15 things? The mode can be easily recognised by inspection of group data; the largest group is the mode. Where you are to groups of data that are of equal size, distribution is said to be bimodal. Take for example the group of numbers below. Each number represents a category of thing:

1,1,1,2,2,**3,3,3,3,3**,4,5,6,7,**8,8,8,8,8**,9,10,11,12

Here we can see that the most common numbers are three ($n = 5$) and 8 ($n = 5$); therefore, this distribution of numbers is bimodal.

In the following group of numbers, now we can see that there is one less 8, making 3 the mode:

1,1,1,2,2,**3,3,3,3,3**,4,5,6,7,8,8,8,8,9,10,11,12

From this example, you can see that it is essential to use the mode when talking about categories, but that the mode can shift greatly with the change of a single number. Because the mode only takes into account the most frequent score in a dataset, it is not generally considered to be a satisfactory way of describing the central tendency. Very different distributions of data can have the same mode.

6.3.2.6 Median

The median is the point that sits at the middle of a distribution; it splits the distribution in half with 50% of the values above and 50% of the values below. The median should be used for ordinal data and continuous data (interval ratio scale). There are 23 numbers in the list below; there are 11 below five (5 is the 12th number) and 11 above five; therefore, 12 is the median. When there are a lot of numbers in a sample, it may not be feasible to count in order to find the middle number, so use the formula $(n + 1)/2$. In this case $n = 23$, so, $(23 + 1)/2 = 12$.

1,1,1,2,2,3,3,3,3,3,4,**5**,6,7,8,8,8,8,8,9,10,11,12

The median is a useful value that divides the distribution into equal halves; however, it is more appropriate to use the mean or average when dealing with continuous (interval or ratio) data because this better takes account of all of the data in the sample.

6.3.2.7 Mean

We are all familiar with the average, average height, average weight, and average score on a test. Another word for average is mean. The mean is the total of all of the scores divided by the number of scores. The mean is the average and can be calculated by adding all the numbers in the dataset and dividing by the total number of data points in the set.

1,1,1,2,2,3,3,3,3,3,4,5,6,7,8,8,8,8,8,9,10,11,12

There are 23 data points in the sample below and when we add all of the data points together, we get 126.

$$126 / 23 = 5.58$$

Clearly we cannot average ordinal data or nominal (categorical) data (where numbers are used to represent discrete categories, such as excellent (6), very good (5), good (4), fair (3), poor (2), very poor (1)). There is no sense in which excellent is 6 times better than very poor and 6 times worse than excellent, these numbers are simply being used to represent a category. However, for continuous data, the mean should be used.

6.3.2.8 Comparison of the Mode, Median, and Mean

It is important to consider which measure of central tendency is appropriate to your dataset. The median and the mode are less sensitive to extremes in the data, while the mean will be pulled or skewed towards extreme data. Some datasets are more prone to extremes than others. In medical imaging and radiation science, very large patients can have very large radiation doses. In these cases, the median or the mode might be more useful measure of central tendency, as they ignore the extreme cases.

For example, consider a computed tomography examination of the abdomen. If 100 patients are examined, each receiving of 10 mSv of radiation, the median, mode, and mean are all equal at 10 mSv. Now consider an additional 5 extremely large patients are added and they receive 100 mSv. The mode will remain at 10 mSv, the median will be 10 mSv, while the mean will be $1500/105 = 14.3$ mSv.

The position of the mode, median, and mean can also tell us about the skewness of the distribution. If the mode and median are lower than the mean, then the data is said to be skewed to the left and contain more data in the lower end of the graph

(Fig. 6.5); if the mode and median are higher than the mean, then the data is said to be skewed to the right (Fig. 6.6).

6.3.3 Measures of Variability

Measures of central tendency alone are insufficient to describe a dataset and to understand the distribution of the dataset properly and have some estimate for how much the data is spread out; we need a measure of its variability. We generally accept that measurements will be different from one patient to another; we don't expect that all patients receive the same dose, and we don't expect that all images will be rated with the same image quality. Therefore, no measure of central tendency should be reported without a measure of variability as well. There are several measures of variability that are commonly used, and these include the range, interquartile range, variance, and standard deviation.

6.3.3.1 Range

Range is perhaps the simplest measure of variability, where we look at the highest and the lowest measurements in the dataset and calculate the difference between them. Although the range is easy to calculate, it is susceptible to extremes. Taking again our example from above, if 100 patients underwent abdominal CT and received 10 mSv, the range is from 10 to 10. By adding one patient who receives 100 mSv, the range becomes from 10 to 100.

Therefore, it is often recommended to average the last five points at the extremes of a dataset when calculating the range. It is obvious from the above example that a range of 10–100 gives no indication of the homogeneity of the sample. It does not indicate that there are no data points between 10 and 100. One might expect from this range that there are data points ranging across the values from 10 to 100, when in fact there were none. Therefore, range has limitations as an explanation of the variability of sample.

6.3.3.2 The Interquartile Range

As we have seen above, the range gives us an estimate of the variability of the data, but it does not tell us much about what is happening between the maximum and minimum data points. To get more information about this, we use the interquartile range. The interquartile range is the distance between the scores representing 25th percentile and the 75th percentile. The 25th percentile represents 25% of all the scores and a range, in other words the first quarter of the data. The 75th percentile represents a point in the data that includes 75% of all of the data; in other words, any data point above the 75th percentile is in the top quarter of the data.

The interquartile range is the most appropriate measure of variability when the median is used as the measure of central tendency. For ordinal data, or interval ratio data, which is highly skewed, the median is the most appropriate measure of central tendency, and thus the interquartile range would be the most appropriate measure of variability:

- The first quartile contains 25% of all of the data (Q1).
- The second quartile includes all the data above 25% up to and including the median at 50% (Q2).
- The third quartile contains all of the data above 50% up to and including 75% (Q3).
- The fourth quartile contains all of the data above 75% (Q4).

Like other measures of variation, the interquartile range allows us to make some assumptions about the distribution. If the distance for Q2 and Q3 is the same, then we can make the assumption that the distribution is not skewed. If the distance for Q3 is greater than Q2, then we can say that the data is skewed to the right, and vice versa; if the distance for Q2 is greater than that of Q3, then we consider data is skewed to the left. Also, the larger the interquartile range, the wider the spread of data.

6.3.3.3 Mean Deviation

Perhaps a better measure of the variability is something that will average out the variation on either side of the mean and will give some estimation of how closely individual data points are clustered around the mean. Mean deviation of a set of observations is the mean of the absolute deviations from the mean. In a dataset that has the values 1, 2, 3, 4, 5, it is clear that the mean is 3:

- 1 deviates from 3 (the mean) by 2
- 2 deviates from 3 by 1
- 4 deviates from 3 by 1
- 5 deviates from 3 by 2
- The mean of the deviations is $(2 + 1 + 1 + 2)/4 = 1.5$.

Mean or average deviation benefits from the fact that it uses all of the data to calculate the measure of variability and is easy to compute. However, this does not indicate the direction of the variance whether it is in the positive (+1, +2, etc.) or negative direction (-1, -2, etc.). Numbers ranging across 0 from -1 one to +1, for example, will cancel each other out and, therefore, it is not easy to calculate mathematical models for average deviation. As computation is no longer a problem, mean deviation is not frequently used. In preference, variance or standard deviation is used instead.

6.3.3.4 Variance

Variance is similar to mean deviation in that it attempts to estimate how closely the data points are clustered around the mean. However, it deals with the need to remove negative numbers, by squaring all of the deviations from the mean. In other words, variance is the average of the squared deviations from the mean:

- 1, 2, 3, 4, 5, it is clear that the mean is 3.
- 1 deviates from 3 by 2, $2^2 = 4$
- 2 deviates from 3 by 1, $1^2 = 1$
- 4 deviates from 3 by 1, $1^2 = 1$
- 5 deviates from 3 by 2, $2^2 = 4$
- The meaning of the variance is $(4 + 1 + 1 + 4) / 4 = 2.5$.

Variance uses the squaring of the difference between a data point in the mean, to deal with the problem of negative values (-1 , -2 , etc.). However, this sometimes makes it harder to understand what the size of the variance is, in comparison with the actual data points. It would therefore be very useful to have a measure of the variability that is expressed in the same units as the data points, rather than being the squares of the deviations. That is where standard deviation comes in.

6.3.3.5 Standard Deviation

Standard deviation is a measure of variability that attempts to solve the problems of mean deviation and variance. Standard deviation is the positive square root of the variance:

- 1, 2, 3, 4, 5, it is clear that the mean is 3.
- 1 deviates from 3 by 2, $2^2 = 4$
- 2 deviates from 3 by 1, $1^2 = 1$
- 4 deviates from 3 by 1, $1^2 = 1$
- 5 deviates from 3 by 2, $2^2 = 4$
- The meaning of the variance is $(4 + 1 + 1 + 4) / 4 = 2.5$
- Taking the positive square root of this $\sqrt{2.5} = 1.58$.

We can now see that standard deviation takes account of positive and negative values, while resulting in a measure of variability that is closer to the natural result of mean deviation. It is there a more representative of the spread of the dispersion of the frequency in the data. Larger standard deviations mean that the data is more spread out on either side of the mean. Calculation of variance and standard deviation is extremely tedious by hand, and statistics textbooks will provide you with equations for the calculation of variance and standard deviation; however, these have been superseded by the calculation via statistical packages.

6.4 Correlation

We often hear statements like “there is a correlation between life expectancy and diet” and “there is a correlation between heart disease and body mass index”, but what does this mean? Correlation seeks to express quantitatively the relationship between variables and the direction of that relationship. Correlation, therefore, has two components, a measure of the extent of the relationship and a direction, either a positive correlation or a negative correlation.

The positive or negative aspect of the correlation indicates the direction. Saying that there is a positive correlation between weight and radiation dose means that as a patient’s weight goes up, so too will their radiation dose (Alhailiy et al., 2019). Saying that there is a negative correlation between the time spent viewing a radiograph and the accuracy of the decision means that the longer the radiologist spends looking at the radiograph, the more likely they are to be incorrect about their decision (Ganesan et al., 2018).

The direction of the correlation is relatively straightforward, what is more important however is to understand the magnitude of the correlation. If two variables were 100% correlated, this would mean that there are no other factors impacting the relationship; if one goes up, the other variable goes up also in a predictable way described by a straight line. Although there are some such correlations, we very rarely find them in biological systems due to the complexity of biological organisms. For example, although we know that radiation damages biological tissue, we also know that biological tissue can repair this damage. Individuals may be able to repair this damage in different ways depending on their genetic makeup and a number of genetic mutations they have. So, if we try to measure the correlation between radiation damage and radiation dose, we might find that these two things are poorly correlated, because there are multiple other factors at play (Nguyen et al., 2015). Nguyen et al. found a positive correlation between dose in the mSv and the percentage of cells with damage to their DNA with a correlation coefficient of 0.48, but what does this mean?

Due to the desire to express the numerical relationship between two variables, a statistics called the correlation coefficient has been developed; it expresses the magnitude of the relationship and its direction. Correlation coefficients are appropriate for quantifying linear relationships, but there are also some special instances of correlation coefficients that can be used in non-linear relationships. There are two common correlation coefficients used for indicating linear relationships: Pearson’s “*r*” and Spearman’s “*p*” (ρ).

Pearson’s *r* is appropriately used continuous data (both interval and ratio scales) that are linearly related. It is most widely described as a parametric test and is used to measure the relationship between variables that are linearly related. There is no assumption of normality in the correlation test, but there is a normality assumption underlying the test of significance; therefore it is frequently said that the data must be normally distributed; there is no such assumption in the test. Pearson’s *r* is the most powerful test to use and should be used for all continuous data.

Then Spearman's ρ is used. This assumes that at least one of the variables on the X - or Y -axes was on an ordinal scale. This is a version of the Pearson's test that can deal with ordinal or continuous variables and assumes in monotonic (linear) relationship between the two variables. It uses the ranks of the given variables instead of their values.

Where the sample sizes are small or there are many ranks that are tied during the Spearman's test, there is an alternative test called Kendall's tau. This has all of the same assumptions as Spearman's correlation.

Nominal data cannot be appropriately applied to either Pearson's or Spearman's correlation coefficient, perhaps Cramer's V is an option but consult a statistician (Mathematical methods of statistics / by Harald Cramer | National Library of Australia, [n.d.](#))

Like the scatter plots referred to earlier in this chapter, we can visualise the relationship between two variables X and Y by plotting them on a graph. We could attempt to fit a line to the scatter plot as shown in Fig. 6.7; through a process of trial and error, we might find the best fit. Finding the best fit mathematically is referred to as linear regression. In reality there might be multiple relationships between the data on the scatter plot, so fitting a line should only be done when it can be reasonably assumed that the relationship is most likely linear.

Correlation coefficients can vary between -1 and $+1$. A correlation coefficient of -1.0 is a perfect negative correlation, while a correlation of $+1.0$ is a perfect positive correlation. In general, the closer the correlation is to ± 1.0 , the more precisely the data fits along the line.

It is often useful to add descriptors to the numbers resulting from correlation coefficients to help us describe the finding. However, the reality is that the descriptor of the correlation really depends on the area being researched. In some areas, with lots of interactions such as socioeconomics or biological science, it would be rare to see correlations above 0.6; therefore, the researcher might report such a correlation as strong. In medical radiation science, however, where the number of interactions can be reduced or controlled, it is common to see the following descriptors:

- $+1$ and -1 are often referred to as perfect.
- 0.8 is referred to as a strong positive relationship.
- 0.6 is referred to as a moderate positive relationship.
- 0.4 and below is referred to as a weak positive relationship.
- 0 zero is referred to as no relationship.

It is important to note that although the tests above will give you a measure for the correlation of two variables, the significance of the correlation is also an important measure. So, the correlation coefficient is often associated with a p -value. This p -value gives an indication of how likely it is that this result (the correlation coefficient) is due to chance. Like any other statistical tests mentioned elsewhere in this book, we tend to report that findings are significant if the chance of them being real is greater than 95% and the likelihood of the results being purely as a result of chance is less than 5%; in other words a p -value is less than or equal to 0.05.

So, a statistical test showed us that there was a strong positive relationship of

$r = 0.8$ with a p -value of 0.3.

We would conclude that our result was not significant, because it is likely to be as a result of chance. In this situation, we might decide to gather more data and retest the correlation coefficient. With more data, we might find that the strong positive relationship remains constant at

$r = 0.8$, but p -value decreases to 0.03.

This is indicative of a strong positive and statistically significant relationship between the two variables. It is a common error to report correlation coefficients alone without their p -values, thus rendering the correlation coefficient useless.

6.4.1 *Correlation and Causation*

It is crucial even at this point to separate correlation from causation. Just because two things are correlated does not mean that one thing happened because the other. A classic example is the correlation between hospital visits and illness. There is a very strong positive correlation between being ill and visiting the hospital, but clearly visiting the hospital is not what made you ill. The cause of this correlation lies elsewhere and can be explained by the causes of illness which are multitudinous. There are many examples of spurious and unhelpful correlations that are often shared as a joke but sometimes misunderstood. For example, almost everybody who is in a car crash is found to be wearing shoes, but removing shoes would not solve the car crashes, rather it might in fact even worsen them. This is because there is no causal relationship between shoe wearing and car crashing; correlation is not causation.

In medical radiation science, there is a correlation between the use of iodinated contrast agents and acquired kidney injury (Faucon et al., 2019). However, the causation is continually debated.

To establish a causal relationship, there are typically three criteria used:

1. The cause must precede the effect.
2. The cause and effect vary together; if the cause varies, the effect varies.
3. If the cause does not occur, the effect does not occur.

So, does the correlation between iodinated contrast agents and acquired kidney injury meet the test of causation?

1. The cause must precede the effect. Some would argue that the patient is undergoing the radiological examination because they have a kidney problem already, so it is the kidney problem that precedes imaging rather imaging preceding the kidney problem.

2. The cause and the effect vary together; if the cause varies, then the effect varies. This seems to hold true that there seems to be a relationship between the amount of contrast agent delivered and the impact of the acquired kidney injury (Fähling et al., 2017).
3. If the cause does not occur, the effect does not occur. This does not seem to hold true; patients still have acquired kidney injuries with or without the use of iodinated contrast agents (Gilligan et al., 2020). There may be an association, but iodinated contrast agents do not appear to be independently associated with acquired kidney injury.

6.5 Inferential Statistics

Descriptive statistics are very useful in many situations and can provide helpful insights into the data and even in some cases allow you to draw some conclusions. However, if you wish to draw inferences about the population from a sample, then you are going to need to use inferential statistics.

Most research in social sciences and in health sciences requires the use of samples rather than entire populations; this is at once expedient and essential, as the scale of working at population level would render research almost impossible. Through a combination of powerful mathematical tools and assumptions about data, we can make very strong inferences about the population from relatively small samples. In doing so we must be very aware of the data type (nominal, ordinal, or continuous) and the sampling procedure. Differences between two samples can be as a result of sampling error rather than differences between samples. Size of the sample is something that will require closer attention later on in this book.

Earlier on in this chapter, we described a sample of 100 patients who underwent computed tomography abdominal examinations, each of which received a dose of 10 mSv. Does this seem likely? Our own instincts about the variability of patients in terms of gender, age, weight, and height makes us feel like it is highly unlikely to be an appropriate sample of the population. Populations vary, so therefore, we would expect to see variation in a sample of the population. A result like this either is highly unlikely to be a rare fluke (the probability of finding such a result is infinitesimally small) or is more likely a sampling error.

To create a sample of 100 patients all of which received 10 mSv would have required us to filter the population of patients and sample only those that received a dose of 10 mSv. This is not a sample of the population of CT patients, but rather a sample of the population of CT patients who received 10 mSv during their CT abdominal examination. From this sample, we can only make inferences about those patients who undergo CT abdominal examinations and receive 10 mSv; we can say nothing about all of the other patients. This points to a simple fact; our sample must reflect the population that we are sampling.

If my population contains males and females across the normal range of weights and heights, then my sample should contain all of that variation in the same

proportions as the population and, therefore, my doses should vary in a similar way. Well-chosen samples are crucial to harness the power of inferential statistics; it is an underlying principle, which if ignored, renders any inferences useless. Even with very well-chosen samples, they are never exact representations of the population; therefore, all inferences based on samples involve the possibility of sampling error. This is why when we report inferential statistics, we report them with a p -value, an indication of the probability of the result being real, rather than as a result of chance.

6.5.1 The Normal Distribution

We mentioned the normal range of weights and heights. What does it mean to say with the normal range? Well, there is a range of normality. Normality has a central tendency, but it also has variability. While the average height of males in the Netherlands is 183.8 cm (Krul et al., 2011), there is a normal range of heights either side of this that are considered normal. So, what is abnormal? Statistically speaking there are several definitions, the most common of which is that if a measurement is outside three standard deviations of the mean, then it is not in the normal range.

The standard deviation of male height in the Netherlands is roughly 3 inches, or 7.5 cm. Any male outside of three standard deviations ($7.5 \text{ cm} \times 3 = 22.5 \text{ cm}$) would be considered to be exceptionally tall (above 206.3 cm) or exceptionally small (161.3 cm) for the Netherlands. You might think that it is a huge assumption to make. It can be made only because of our knowledge of probability and sampling distributions.

In nature we find that many measurements are normally distributed. This means the frequency distribution of the data creates a bell-shaped curve. We find this normal distribution in so many natural measurements that we thus named it “normal”. There is a normal distribution for the heights of men and women, there is a normal distribution for the neonatal birth weight of children, and there is a normal distribution of the weight of adults. To say, there is a normal distribution that indicates that we have an expectation that there is a mean and that the other measurements are equally distributed either side of it. There are some people that are smaller than the mean, but there are an equal number of people that are taller than the mean, that’s normal. If we were to say to you then that my friend was Dutch and 210 cm tall, what would you say? Are the chances of that being true? Probable or improbable?

Probability is a central concept in understanding inferential statistics. As you know, probability is normally expressed as a proportion, somewhere between zero and one. A probability of one means the event is certain to happen, a probability of zero means the event is certain never to happen. In reality, if we are using sampling of the population, will never be able to say with absolute certainty whether an event will happen or not. This is unfortunate and leads to those who do not understand inferential statistics and probability saying “ah, but you can be certain!”, To which you reply, “I am 95% certain”.

If you are to say you are 95% certain, it means that if you are to carry out your experiment 100 times, you will get the result that you have reported 95/100 times, in a different result 5/100 times. We often use the p -value of 0.05 to indicate the statistical significance of the result. It means what we have said above that result would be the same, 95/100 times. If you were to say that you were 99% confident, result would be different only, 1/100 times, or $p < 0.001$.

We can calculate the likelihood of many events in advance if we know the number of occurrences of the event and the total number of possible occurrences. The classic example is the coin toss. The probability of tossing ahead is calculated easily because we know there is one head and the possibility of two occurrences (head or tail). Does the probability of tossing ahead is 50%, every time. Likewise, we can calculate the probability of winning our local raffle. If one winning ticket will be drawn and 10,000 tickets are sold, your chances of winning are 1 in 10,000 and probability of 0.0001. In the case of something you would not like to win, we can calculate the probability of dying from cancer. Say average life expectancy is 80 years of age and 1 in every 2 people get cancer by age 80, then your probability of getting cancer in your lifetime is the percentage chance of dying from cancer (50%) divided by the percentage chance of dying from something (100%). Fifty percent divided by 100% gives a probability of 0.5. This is of course a very rough estimate and ignores individual factors and socioeconomic factors such as obesity, income, and smoking.

We can also calculate the probability of slightly more complicated things that are normally distributed and measured using continuous data, such as height and weight. The basis of our calculation of probability is our understanding of the normal curve. The normal curve is characterised as follows:

1. It is symmetrically distributed around the mean; the same number of cases fall above the mean as far below the mean. The mode is equal to the median and is equal to the mean.
2. The number of cases is smaller at the extremes, with most cases being closer to the mean.
3. It has a Gaussian appearance.

In this text we are not going to cover the formula for the normal curve, rather the principle that we are trying to take away is that all normal curves have the same mathematical form whether they are displaying the distribution of male heights in the Netherlands, neonatal birth weights, the weights of the population of adults undergoing CT abdomen examinations, or the amount spent and sandwiches at lunchtime. Figure 6.9 demonstrates for normal distribution probability density functions (normal distributions), three of which have the same mean but varying standard deviations. Although they seem to vary in shape and size, they all follow the principles of the normal distribution.

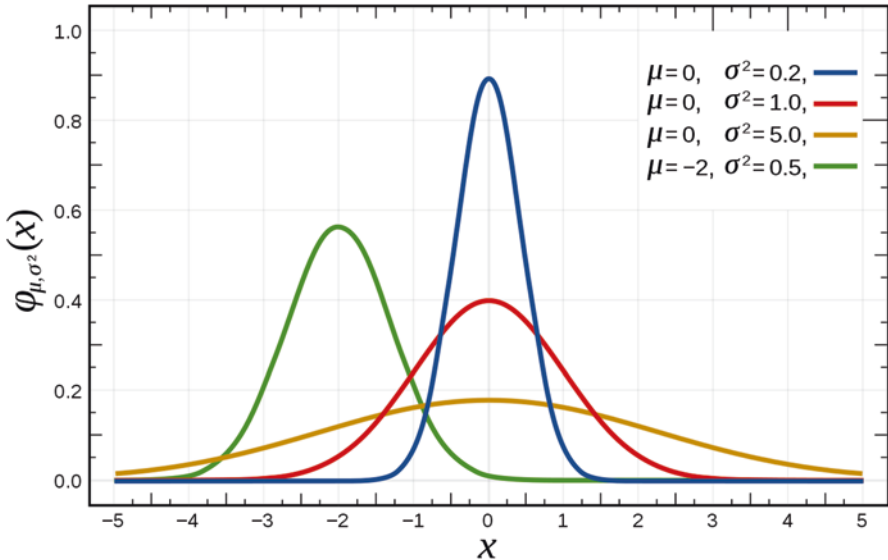


Fig. 6.9 A selection of normal distribution probability density functions. Both the mean, μ , and variance, σ^2 , are varied. The key is given on the graph. (Source https://commons.wikimedia.org/wiki/File:Normal_Distribution_PDF.svg (Public Domain image))

6.5.1.1 The Standard Normal Curve

It can be very useful for the purposes of statistical comparison to transform raw normally distributed scores from the data collection onto a standardised normal curve. By transforming the mean and standard deviation onto the standard normal curve, we removed the only two distinguishing characteristics of non-standardised normal curves. It is important to note here that in reality, no distributions are exactly normal but approximate the normal curve.

The standard normal curve has the following characteristics by convention:

1. The mean is transformed to 0. Whatever method is used to transform the mean to 0, the same method is used for all other data points in the sample.
2. The mean, median, and mode are equal, at 0.
3. The standard deviation is $1 \sigma^2$.
4. The area under the curve is 1.
5. Fifty percent of the area under the curve is below the mean, and 50% of the area under the curve is above the main.
6. Assuming all of the above, we can use statistical tables to estimate the area under the curve at any given score for z .
7. The area above the curve at any given scores z is directly proportional to the percentage of cases in the non- standardised normal curve. In other words, we can use the area under the curve of the standardised normal curve to make

estimates about the percentage scores at that same point in the non-standardised normal curve.

8. The percentage area under the curve is standardised for each standard deviation. The first positive standard deviation plus the first negative standard deviation results in 68.2% of the area under the curve, two standard deviations results in 95.45% of the area under the curve, and three standard deviations results in 99.73% of the area under the curve. Now we can see why it is possible to say that if a value is outside three standard deviations, then there is less than 1% chance of it being normal.

We say that something is statistically significant if the probability of it happening due to chance is less than 0.05. Thus, it is useful to know where on the standard normal curve 0.05 sits. These are sometimes referred to as critical z scores on the standard normal curve. Most statistics books reproduce a table of the z scores and their associated area between z and the mean and beyond.

- A z score of 1.65 results in an area beyond the of 0.0495. Thus, this z score means that 95% of the area is under the curve since the left of this point and less than 5% of the data sits to the right. This is a useful z score to remember if we are testing for statistical significance at 95%.
- A z score of 2.33 results in an area under the curve of 0.0099, meaning that 99% of the area under the curve sits to the left of the z score and less than 1% of the datasets to the right.
- A z score of 3.10 results in an area beyond z of 0.0009, meaning that 99.9% of the area under the curve sits to the left of the sea score and lasting 0.1% of the datasets to right.
- A z score of 3.73 results in an area beyond z of 0.0009, meaning that 99.99% of the area under the curve sits to the left of the sea score and lasting 0.01% of the datasets to right (Fig. 6.10).

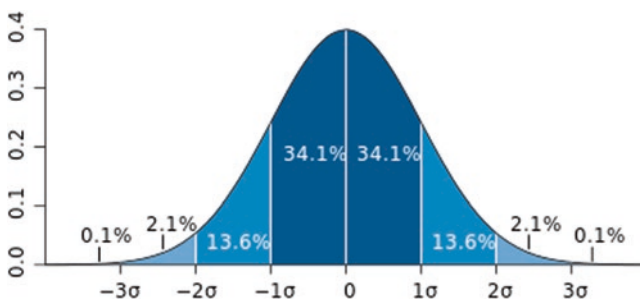


Fig. 6.10 Normal distribution curve that illustrates standard deviations. Each band has 1 standard deviation, and the labels indicate the approximate proportion of area (note: these add up to 99.8% and not 100% because of rounding for presentation). (Source: https://en.wikipedia.org/wiki/Normal_distribution#/media/File:Standard_deviation_diagram.svg Rights CC BY 2.5)

6.5.1.2 Using Standardised Normal Curves to Compare Distributions

We can use to standardise normal curves to compare completely different distributions of data. For example, we can compare the diagnostic accuracy of computed tomography of the abdomen, in 200 patients, to the diagnostic accuracy of chest x-rays in 100 patients. Please note that these data are completely made up just for the purposes of demonstrating how to use standardised normal curves to compare distributions.

Let's say the diagnostic accuracy of CT has a mean of 0.8 and the standard deviation of 0.15, while the diagnostic accuracy of a chest x-ray (CXR) has mean of 0.6 and a standard deviation of 0.1.

To calculate the percentage of CT scans that had higher diagnostic accuracy than CXR, we subtract the diagnostic accuracy CXR from the diagnostic accuracy of CT:

$$0.8 - 0.6 = 0.2$$

Then we divide this by the standard deviation of the diagnostic accuracy of CXR, 0.1:

$$0.2 / 0.1 = 2$$

This gives us a z score of 2. Looking at other statistical tables, this indicates that there is an area to the right of this 0.0228.

This means that approximately 2.3% of CT scans had higher diagnostic accuracy than CXR.

On the other side of the curve, we can calculate the percentage of CXR that have lower diagnostic accuracy than the CT scans. We subtract the diagnostic accuracy of the CT scans from the CXR:

$$0.6 - 0.8 = -0.2$$

Then we divide the standard deviation of the diagnostic accuracy of the CT scan, 0.15:

$$-0.2 / 0.15 = -1.33$$

This gives us a z score of -1.33 ; looking at our statistical tables, this indicates that there is an area to the left of the curve of approximately 0.0918, indicating that 9.2% of the CXRs were of lower diagnostic accuracy than the CT scans.

So, can we say that the CT scans are significantly better than the ultrasound scans? In this case, yes, because the area to the right of the curve is less than 0.05. We can say with greater than 95% confidence that CT scans are more accurate and ultrasound in this made-up case.

6.5.2 *Hypothesis Testing and Interpreting Outcome of Statistical Tests*

In Chap. 3, we discussed the process of formulating a hypothesis. In this section we will discuss hypothesis testing. As previously discussed, a hypothesis is a statement that you seek to prove or disprove.

Taking an example from earlier in this chapter, we might state and hypothesise that 110 kVp is better for the visualisation of the kidneys than 70 kVp. There are two possibilities, either the statement is true, the alternative hypothesis (H_a), or this statement is false the null hypothesis (H_0).

The steps in testing this hypothesis are as follows:

1. State the alternative hypothesis (H_a). “110 kVp is better for the visualisation of the kidneys than 70 kVp”.
2. State the null hypothesis (H_0). “110 kVp is not better for the visualisation of the kidneys than 70 kVp”.
3. Set the decision level. By convention we typically set the decision level at 95%, meaning that we will accept the result as statistically significant if the probability of the result being purely chance is less than or equal to 0.05. This is referred to as alpha. Alpha can be set at a level desired by the researcher. If 99% certainty is required, then alpha is set at 0.01; if 99.9% certainty is required, then alpha is set at 0.001.
4. Then we calculate the probability of the null hypothesis being true. In this calculation, also calculate the probability of finding the null hypothesis by chance.
5. Make a decision about the null hypothesis based on this decision level stated:
 - (a) If the probability of the null hypothesis being true is less than 0.05, then we reject the null hypothesis and accept the alternative hypothesis.
 - (b) If the probability of the null hypothesis being true is greater than 0.05, then we accept the null hypothesis.

Let us take, for example, a paper assessing image quality and dose reduction using high kVp and additional filtration for abdominal digital radiographs. In this work they compared 80 kVp with 92 kVp when imaging the abdomen. Their hypothesis was that higher CVPs would result in lower dose, with no change in image quality.

6.5.2.1 Step 1

They stated their alternative hypothesis. Their alternative hypothesis was that “92 kVp produces lower dose to the patient while maintaining image quality”.

They stated their null hypothesis: “92 kVp does not produce lower dose to the patient while maintaining image quality”. The image quality measurement scores they chose were image quality criteria and signal-to-noise ratio and

contrast-to-noise ratio. The dose measurement score they chose was dose area product, which was converted to effective dose.

6.5.2.2 Step 2

They state their alpha “A 2-sided P value less than 0.05 was considered to indicate a statistically significant difference”.

6.5.2.3 Step 3

They calculated the probability of the null hypothesis being true. In this paper there were several measures of image quality and two measures of dose. So, they calculated the probability of the null hypothesis being true for each of their measures of image quality and each of their measures of dose.

6.5.2.4 Step 4

Make a decision about the null hypothesis based on the decision level stated. In this work, they found that the effective dose was lower when using 92 kVp compared with 80 kVp and they stated that the probability of this being a result of chance was less than 0.001. This was lower than the alpha they had chosen, so they concluded that 92 kVp was lower dose.

When it comes to the image quality criteria, they found that there was a difference in the image quality demonstrated in two image quality criteria and only in patients that were imaged once under 80 kVp and once under 92 kVp. When patients were unpaired, there was no statistical difference in the image called the criteria. When it came to signal-to-noise ratio and contrast-to-noise ratio, there was no significant difference between the two kVps. They concluded: “Dose reduction for abdominal digital radiography can be achieved with comparable image quality by performing abdominal digital radiography using 92 kVp”.

So, we can see that they have accepted the alternative hypothesis and rejected the null hypothesis.

This paper is one of many examples that demonstrate a common difficulty that arises from medical radiation science experiments. There are multiple measures of image quality, and the same pattern was not seen when patients were paired compared with when patients were unpaired. So, in drawing their conclusion, there are two potential errors that the authors can make.

Type 1 error occurs when we incorrectly reject the null hypothesis. What are the chances that they have made a type 1 error in this paper? The answer is quite straightforward and is stated in the methodology that alpha is 0.05 probability that the conclusion in this paper incorrectly rejects the null hypothesis.

Table 6.2 A generalised confusion matrix of decisions

	Ho actually true	Ho actually false
Decision: Ho true	True positive (TP)	False negative (FN) (type II error, beta)
Decision: Ho false	False positive (FP) (type I error, alpha)	True negative (TN)

Table 6.3 A confusion matrix of decisions generated from (Jang et al., 2018). The conclusion drawn by the authors is denoted by *

	92 kVp actually worse	92 kVp actually better
Decision: 92 kVp worse	True positive (TP)	False negative (FN) (type II error)
Decision: 92 kVp better	False positive (FP) (type I error)	True negative (TN)*

Type II error occurs when we incorrectly accept the null hypothesis. The probability of this type of error is denoted by beta.

While we attempt to ensure that our experiments are sound through multiple processes that are of proper prior planning and preparation, combined with appropriate use of data types and inferential statistics, we cannot eliminate the probability of error. The interplay of alpha and beta can be shown in a confusion matrix (Table 6.2).

In applying these principles to the example paper above, remember that they stated their null hypothesis as “92 kVp does not produce lower dose to the patient while maintaining image quality”; for the purpose of the table below (Table 6.3), I’m going to summarise this as “92 kVp worse”;

6.5.3 *Sampling Distributions: Parametric (Normal) and Nonparametric (Non-normal)*

Although the normal distribution is by far the most important distribution in statistics, it is not the only distribution that we need to be aware of. The normal distribution is the “bell shaped curve” and is most common distribution in nature and the most important distribution in statistics. See Fig. 6.9. The normal curve is considered parametric. There are several other distributions of data that, thanks to the central limit theorem, can be considered to estimate as a normal distribution (the binormal distribution, the Poisson distribution, the chi-squared distribution, and the student’s t-distribution). All other distributions are considered non-parametric.

Knowing whether your sample is parametric or nonparametric is an important piece of information in deciding the types of statistics that you will use. Parametric statistics make assumptions of normality, while nonparametric statistics make few or no assumptions about the distribution. As a general rule of thumb, you apply

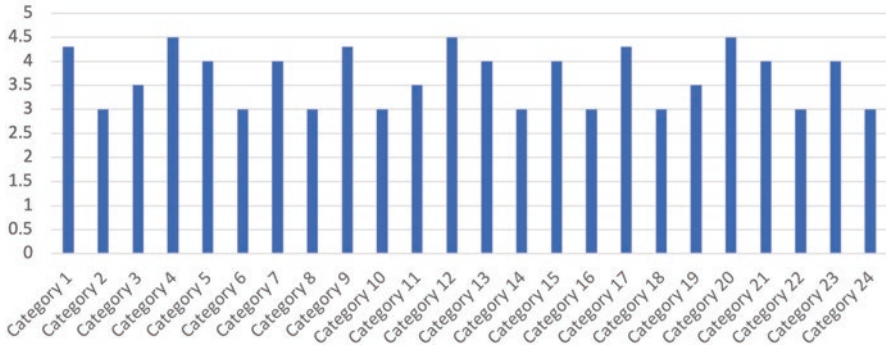


Fig. 6.11 An example of a uniform distribution

parametric statistics when you know that the population from which your sample has taken has a normal distribution. If the population from which your sample is taken does not have a normal distribution, then nonparametric statistics are used. There are tests that can be performed to determine whether or not your sample is normal. These are referred to as normality tests. Nonparametric distributions are described below.

6.5.3.1 The Uniform Distribution

Uniform distributions are not common in nature, but they may occur in certain circumstances. We came across a uniform distribution earlier when we discussed the hypothetical sample of 100 patients who underwent an abdominal examination and received 10 millisieverts each. The distribution of doses across these 100 patients would result in a rectangular distribution, or a uniform distribution. We might also see this rectangular distribution in a frequency distribution of random numbers. As the numbers are truly random, there is likely to be an equal chance of each number appearing; thus the distribution will be roughly rectangular (Fig. 6.11).

6.5.3.2 The Exponential Distribution

The exponential distribution is particularly important in nuclear medicine. The key feature of an exponential distribution is that each subsequent variable decreases from its predecessor. When we think of the half-life of a nuclear medicine radioisotope, for example, we know that the radioactivity of the radioisotope will reduce by half, over its half-life. This is referred to as exponential decay. The half-life of radioisotope is the time required for the radioactivity of the isotope to decay two half of its initial value (Fig. 6.12).

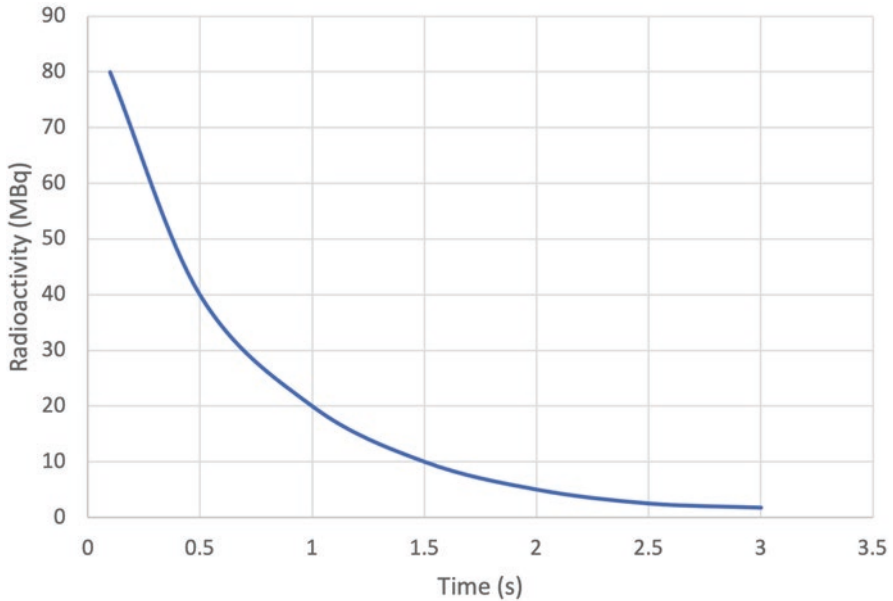


Fig. 6.12 An example of an exponential decay in radioactivity. In this fictional case, the radioactivity is decreasing by half every 0.5 seconds

Interestingly it can be shown that if we sum two or more exponential variables, this would lead quite naturally to the third and most important distribution, the normal distribution.

6.5.3.3 Central Limit Theorem

The central limit theorem postulates that in many, fairly common situations when independent random variables are added together, there are some will tend towards the normal distribution. This is an important theorem because it means that even when the original variables themselves were not normally distributed, the addition of these variables has a normal distribution. The most important implications of the central limit theorem are that when your data is formed from the combination of multiple random variables, the distribution of this data will be normal. In medical imaging, for example, if you create an image quality figure, from the combination of multiple image quality criteria, then the distribution of your data sample will be normal, even though the distribution of the scores for each individual image quality criterion would not be normally distributed.

Another important application of the central limit theorem is that it implies that certain other distributions can be approximated by the normal distribution; these include the binomial distribution, the Poisson distribution, the chi-squared distribution, and the student's t-distribution.

6.5.4 Making Decisions About Which Statistical Test to Use

To provide some guidance as to which statistical test to use, we have created a decision tree as shown in Fig. 6.13. This is a decision tree and should not be used as a definitive guide to statistical tests, as there are other possible tests that are not listed in the decision tree. However, the majority of situations are covered.

6.5.4.1 Step 1

The basic principle for deciding which statistical test is appropriate is to begin with your hypothesis. Is your hypothesis asking questions about relationships, categorisation, or the differences between groups?



Fig. 6.13 A decision tree for statistical tests based on a combination of guidance given by Field A. (2013). *Discovering statistics using IBM SPSS statistics*. Sage and Pirk, C. W., et al. (2013). Statistical guidelines for Apis mellifera research. *Journal of Apicultural Research*, 52(4), 1–24 and (Neill Howell 2008 Inferential Statistical Decision Tree - StuDocu, n.d.)

6.5.4.2 Step 2

The next point in your decision tree will be about the number of groups that are involved; this will be 1, 2, or multiple.

6.5.4.3 Step 3

Following that, if relevant, you will need to decide whether your groups are dependent or independent; to understand these, we simply need to think of cause and effect.

- Independent variables are those that cause an effect. It is typically the variable that the researcher is adjusting in the experiment. This is the cause.
- Dependent variables are those variables that are impacted upon by the independent variable (the variable that the researcher is adjusting). This is the effect.

So, in the example of the impact of kVp on image quality, kVp is the independent variable, and image quality is the dependent variable.

6.5.4.4 Step 4

Finally, you will need to decide whether your groups are parametric (normally distributed) are nonparametric.

- Nonparametric statistical tests assume little or nothing about the distribution of the data. They are very useful when your data sample is small, or your probability distribution is not known, or cannot be demonstrated to be normal. It is important to understand that the term nonparametric is not supposed to imply that there are no parameters associated with the data, but rather that no parameters are assumed in the analysis of the data. Once the data has been analysed, the parameters will be known. This is self-evident from the key difference between parametric and nonparametric statistics. There are no prior assumptions of the distribution at all in nonparametric statistics.
- Parametric statistics assume in normal probability distribution, or one that can be estimated as normal. Therefore, they have a prior assumption of normality.

These four steps should then bring you to a point in which you can decide which statistics are appropriate. There are multiple versions of statistical decision trees available, none of which are exhaustive; however, a good example is presented in the last page of Field A. (2013). *Discovering statistics using IBM SPSS statistics*.

6.5.5 *Sample Size (Power) Calculation*

Significance testing is an important part of inferential statistics, and a lot of research and effort has gone into designing appropriate statistical tests above in Fig. 6.13. The goal of each of these statistical tests is to give the researcher an estimate of the probability of their finding being true. These are called power calculations or sample size calculations.

It is important to note that we can calculate the sample size required prior to a study but often there are ethical, time, and cost considerations involved in deciding how many people to sample. Pretest (ad hoc) calculations of sample size are important and often play a part in research proposals and methodological planning. It is also important to note that in randomised control trials, it is a requirement of many quality statements such as CONSORT (<http://www.consort-statement.org/>) and PRISMA (<http://prisma-statement.org/>) that the sample size calculation should be reported and justified.

However, retrospective calculation (post hoc) of sample size is often reported giving us a measure of the power of the sample. This allows the reader to decide whether a larger sample would have played an important role. However, power should always be calculated prior to a study since it is the prestudy probability that the study will detect the effect. Sample size calculations that are done after the study has been carried out are actually better described as calculations of the 95% confidence interval.

We already know that there are two major types of error, the error of incorrectly rejecting the null hypothesis (type I error, alpha) and the error of incorrectly accepting the null hypothesis (type II error, beta). When designing, experiment researchers often want to know what the probability of type II error will be. To estimate the probability of type II error, various sample size calculations have been created. These are also called power calculations, and they attempt to give us a measure of how well a test will be performed given certain sample sizes. A power calculation will give us the probability of accepting the alternative hypothesis when it is actually true (1 – type II error) and requires an estimate of four things:

1. Alpha (type I error), the probability of falsely rejecting the null hypothesis, i.e., the chance of a false-positive result.
2. Beta (type II error), the probability of falsely accepting the null hypothesis, i.e., the chance of a false negative result.
3. Smallest effect size of interest, the minimal difference between the groups that the investigator considers clinically relevant.
4. The variance, the variability of the outcome measure, expressed as the SD in case of a continuous outcome (Noordzij et al., 2010).

Alpha and beta can sometimes be estimated based on the hypothesis. For example, if we want to say with a certainty of 95% that the null hypothesis can be rejected, we know that our alpha is 0.05. Conventionally, the beta is set at 0.2, meaning that

the researcher desires less than a 20% chance of a false-negative conclusion and 80% chance of a true positive (the power).

The smallest effect size of interest is the smallest clinically relevant difference between the samples being compared that the researcher is interested in detecting. This is often established based on clinical needs and could be a difference in the measures of radioactivity in radionuclide imaging, or a 10% difference in contrast-to-noise ratio of a nodule in CT scanning, or potentially a whole number on an ordinal scale of a visual grading analysis. The smallest effect size of interest is determined by the research or based on the hypothesis and might be decided empirically on measurement or previously published evidence or could be chosen as the best guess from previously published papers.

The variability of the population is the final piece of information we need to calculate a sample size. However, the variance of the actual population is rarely known, and this is often replaced in the calculation by a best guess, either from previously published information or from a pilot sample of the population. The standard deviation of and normally distributed pilot sample or the interquartile range of a non-parametrically distributed pilot sample might be used as a measure of the variability. Sometimes a standardised difference or effect size can be calculated. This is done by dividing the difference between the means of the two sample groups, by the population standard deviation (if these are known).

Hopefully it is evident to you that there is a large amount of imprecision in the calculation of sample sizes; in the above paragraphs, we talked a lot about guessing and estimating. The sample size calculation is very sensitive to these choices, and sometimes these choices are based on convention or estimates from small pilot samples. In large expensive randomised control trials, it would be essential to first carry out a thorough investigation of the sample size requirement using as few estimates or guesses as possible.

Let us take for example our comparison of two kVps for chest radiography. We carry out a pilot sample to investigate the image quality produced by 70 and 125 kVp. The table below shows the absolute scoring of image quality criteria against the definition for three different image quality criteria. Although this is just a small pilot survey of 10 images and three radiologists, we can estimate the anticipated difference between the two groups (Table 6.4).

This pilot sample gives us a measure of the performance of the 70 kVp group achieving 33% of the total possible score and the 125 kVp achieving 75%. Now if we use a typical alpha of 0.05 and a typical beta of 0.08, we use a sample size calculation tool such as [Clincalc.com](https://clincalc.com/stats/samplesize.aspx) (<https://clincalc.com/stats/samplesize.aspx>).

Assuming that these are two independent samples, gathered from two separate groups of patients and not from the same patients being X rayed twice, the sample size calculation gives us a sample size of 124 participants with 62 in each group needed to be able to demonstrate a significant difference between these two kVps with 95% confidence.

Table 6.4 A demonstration of absolute scoring of anatomical image quality criteria resulting in an absolute score

Anatomical image quality criteria	Absolute scoring (against a definition) Score: 1, 2, 3, 4, 5	
	70 kVp	125 kVp
Visualisation of the spine through the heart shadow	1	3
Reproduction of the whole rib cage above the diaphragm	2	4
Visually sharp reproduction of the vascular pattern in the whole lung, particularly the peripheral vessels	2	5
Percentage increase	5/15=0.33	12/15 = 0.75

6.6 Image Quality Measurement and Comparison

Image quality is a wide topic with several approaches taken by several disciplines. Each approach addresses the needs of their discipline. Most image quality measurements seen in radiology and radiography literature tend to sit within the technical efficacy and diagnostic efficacy of Fryback and Thornbury's hierarchy of assessment methods as shown in Table 6.5 (Fryback & Thornbury, 1991).

When radiographers assessed the quality of an image, they used many more criteria than just image quality. The typical checks that a radiographer carries out on a radiograph are listed in Table 6.6. These include a combination of factual checks such as the identity of the patient and the correctness of the marker, as well as some qualitative assessments of the image quality. Ultimately Table 6.6 is a typical checklist that combines quantitative and qualitative characteristics of a radio graphic image and allows the radiographer to synthesise this information into two final decisions: (1) Is the image diagnostic? (2) Is any further imaging required?

This next section will outline three fundamental image quality metric and three evaluation methods for measuring technical efficacy and diagnostic accuracy. The three fundamental image quality metrics are as follows:

1. Signal-to-noise ratio (noise)

Noise, information that is not part of a desired signal, is present in all electronic systems and originates from a number of sources including electronic interference.

2. Spatial resolution (sharpness)

Spatial resolution refers to the ability of an imaging modality to differentiate two adjacent structures as being distinct from one another. Spatial resolution is expressed in line pairs per mm (lp mm). Its opposite is blurry.

3. Contrast resolution (contrast)

Contrast resolution in radiology refers to the ability of any imaging modality to distinguish between differences in image intensity.

NOTE: These three properties are not separable from each other

These three fundamental measures of image quality can be measure by three fundamental image quality assessment methods:

Table 6.5 A hierarchical model of efficacy, typical measures of analyses adapted from Fryback and Thornbury's hierarchy of assessment methods

Level	Name	Focus	Measurement tools
1	Technical efficacy	Concerns technical quality of the images	Sharpness: Resolution of line pairs and modulation transfer function (MTF) Contrast and noise or mottle (SNR, CNR)
2	Diagnostic accuracy	Addresses diagnostic accuracy, sensitivity, and specificity associated with interpretation of the images	Number of normal and abnormal diagnoses Diagnostic accuracy (ACC), positive predictive value (PPV), and negative predictive value (NPV) Sensitivity and specificity, receiver operating characteristics (ROC)
3	Diagnostic thinking efficacy	Focuses on whether the information produces change in the referring physician's diagnostic thinking	Percentage of cases judged "helpful" to making diagnosis Empirical subjective log likelihood ratio for test outcome
4	Therapeutic efficacy	Concerns effect on the patient management plan	Number of times image is judged to be helpful in the planning and management of a patient's case Percentage of times a medical procedure is avoided due to image information Number of times planned therapy is changed due to image information
5	Patient outcome efficacy	Efficacy studies measure (or compute) effect of the information on patient outcomes	The percentage of patients who improved with the imaging tests compared with those without the imaging test Morbidity avoided due to the imaging information Expected value of test information is measured in quality-adjusted life-years (QALYs)
6	Social efficacy	Analyses examine societal costs and benefits of a diagnostic imaging technology	Cost benefit analysis from a societal viewpoint Cost-effectiveness analysis from a societal viewpoint

Table 6.6 A typical 10-point image quality check used by radiographers and radiologic technologists

1	Identification	Name ID number DOB Exam date/time
2	Area of interest	Is all required anatomy included?
3	Anatomical markers	Correct marker used – correct side/position for projection? Not obscuring any relevant anatomy Annotation required? (e.g. supine/portable/trolley)
4	Correct projection (assess each projection)	Correct position? Correct centring? Central ray alignment? Any evidence of rotation? Are joints of interest adequately demonstrated, if appropriate?
5	Exposure	Have optimal exposure parameters being used? Any evidence of under or over exposure? Evaluation of exposure index? If AEC used – has it had appropriate impact?
6	Image quality	Evaluate: Noise Contrast Density Sharpness (geometrical, movement, and photographic) Are relevant anatomical image quality criteria achieved?
7	Collimation to ROI	All relevant anatomy included. Examine superior/inferior/lateral/medial limits of the image. Are four collimation borders visible? Is the exposed field of view optimal/too large/too small? Electronic collimation should be used to improve viewing conditions only – not a substitute for collimation of radiation field
8	Artefacts	Review for all artefacts: Clothing/jewellery Medical device Mechanical artefact Any avoidable artefacts? Any unavoidable artefacts?
9	Need for repeat or further projections	Is a repeat projection required? If yes, why? What improvement is required? Is it related to patient position and radiographic technique? exposure? Is there a need for further projections? If yes, why? – improve demonstration of area of interest/pathology? What projection is necessary? Would another modality potentially demonstrate the anatomy/pathology better? Consider guidelines (iRefer and appropriateness)
10	Anatomical variations/ pathological appearances	Is normal anatomy identified? Any anatomical variations? Any pathology appearances evident?

1. Physical measures
2. Psychophysical measures
3. Observer performance methods

6.6.1 Physical Measures

Physical measures of image quality do not require an observer to decide about the outcome. Typically, they measure input and generate a ratio of that value to the output. An example of a physical measurement would be signal-to-noise ratio. As no imaging system can create a perfect image of the object, the signal in and the signal out will be different. Where you want a measure of physical image quality, signal-to-noise ratio, contrast-to-noise ratio, modulation transfer function, and detective quantum efficiency are all potential measures of image quality that might be useful. They are particularly useful in determining the degradation of the imaging chain, where your hypothesis is not concerned with the interpretation of the observer or the interpretation of the image. Physical measures of image quality are excellent for comparing different devices under the same conditions or as a baseline measurement for comparison over time (Jessen, 2004). Physical measure requires no observer judgement and is based on input and output ratios. Comparisons of these measures are frequently done using descriptive statistics. Comparing the means and reporting the standard error of measurement.

- Sharpness can be physically measured by MTF.
- Noise can be physically measured by NPS.
- Noise across frequencies can be physically measured by DQE.

6.6.2 Psychophysical Measures

Psychophysical measurements are not subjective, rather they adapt physical measurement for psychophysical sensations such as seeing (Kundel, 1979). For example, spatial resolution can be measured by a line pair test tool such as the Hutner line per test object. An observer assesses the degree to which the actual line pairs of the test tool are faithfully preserved in the image of the test tool (Huda et al., 1997). The contrast detail resolution assessment device assesses how the low contrast detail in the actual object is preserved in the image. Both of these test tools are used by human observer to interpret the outcome of the test; thus, they are more closely aligned to the processes typically in radiology. They are useful in that there is a known truth, the tools are relatively cheap, and the observer does not need to be an expert in either anatomy or pathology to use the devices.

Psychophysical measures of image quality are excellent for measuring the performance of an imaging device over time, to observe any degradation; they are also

excellent for comparing different devices under the same conditions (Martin et al., 1999).

Sharpness can be psychophysically measured in lp/mm. The spatial resolution of an imaging system is a measure of its ability to display two unique (high contrast) objects, closely separated in space, as distinct features in the image. This should be referred to as high contrast spatial resolution; resolution of moderate and low contrast objects is also important, and these will generally be more difficult to see. This is referred to as contrast resolution. There are several tools for measuring spatial resolution, but it is measured in lp/mm.

Contrast and noise can be psychophysically measured by contrast resolution tests such as the CDRAD test tool. The ability to detect an object is dependent upon the contrast of the object and the noise in the image. This test tool is a square piece of Perspex divided into 15 Roseanne columns, designed with 15 exponential steps of depth and size of drilled holes in the Perspex. It can be used to generate a contrast detail detectability curve and is excellent for measuring low contrast resolution. The tool comes with instructions for scoring the reader's evaluation of the images and allows for corrections of mistakes and the generation of an image quality score. There are also software packages available to analyse the image quality score of the image produced automatically. Studies have investigated the validity of using such tools for both optimization and image quality assessment and have concluded that they are suitable (Al-Murshedi et al., 2018).

6.6.3 Observer Performance Tests

“Since an image is, by definition, a means for visually representing the clinical information captured by the X-ray equipment, at some stage quality must be based on the judgement of a human observer” (Martin et al., 1999). Observer performance studies used anatomy and pathology to determine whether the image has sufficient image quality to achieve its goal. Observer performance tests use an observer to decide about the visibility of either visual grading of anatomical structures or pathological criteria within the image resulting in sensitivity, specificity, and ROC measures.

6.6.3.1 Visual Grading Analysis (VGA)

The principle of using anatomy as a measure of image quality is based on the idea that if the anatomy can be demonstrated, then the pathology can be demonstrated. When measuring image quality using anatomical image quality criteria, it is important to choose anatomical criteria that are consistent with the hypothesis or research question. For example, if you are trying to determine whether an imaging technique or imaging device is adequate for demonstration of an osteoblastoma, then it would be important to use anatomical image criteria based on the structure of the bone,

such as the sharpness of the cortex, or the visibility of trabecular lines. Guidelines on image quality criteria for clinical radiographs have been developed by the Commission of the European communities back in 1995 (European Commission European Guidelines on Quality Criteria for Diagnostic Radiographic Images EUR 16260 EN, 1995); these were developed when film was primarily used for imaging and are in need of updating. However, they contain some useful principles. For example, they define the visibility of anatomical criteria at different levels. For example:

- “Visualisation” was defined as meaning that the characteristic features are detectable but details are not fully reproduced in other words the features are just visible.
- “Reproduction” means that the details of anatomical structures are visible, but not necessarily defined, in other words the details are emerging.
- “Visually sharp reproduction” means that the anatomical details are clearly defined and the details are clear.

With these three definitions in hand, the researcher is free to choose anatomical criteria that are relevant to the research question. In the guidelines, there are a set of image quality criteria for the chest, skull, lumbar spine, pelvis, urinary tract, and breast. However, researchers can follow the principles set out in these documents to create anatomical image criteria for other areas and to adapt and amend these image quality criteria to their research question (Table 6.7).

Table 6.7 An example of image quality criteria for the chest is given in the *GUIDELINES ON QUALITY CRITERIA FOR DIAGNOSTIC RADIOGRAPHIC IMAGES* (p. 20) These are broken down into Image criteria and important image details

1. Diagnostic Requirements
1.1. Image criteria
1.1.1. Performed at full inspiration (as assessed by the position of the ribs above the diaphragm— either 6 anteriorly or 10 posteriorly) and with suspended respiration
1.1.2. Symmetrical reproduction of the thorax as shown by central position of the spinous process between the medial ends of the clavicles
1.1.3. Medial border of the scapulae to be outside the lung fields
1.1.4. Reproduction of the whole rib cage above the diaphragm
1.1.5. Visually sharp reproduction of the vascular pattern in the whole lung, particularly the peripheral vessels
1.1.6. Visually sharp reproduction of (a) the trachea and proximal bronchi, (b) the borders of the heart and aorta, and (c) the diaphragm and lateral costophrenic angles
1.1.7. Visualisation of the retrocardiac lung and the mediastinum
1.1.8. Visualisation of the spine through the heart shadow
1.2. Important image details
1.2.1. Small round details in the whole lung, including the retrocardiac areas: high contrast: 0.7 mm diameter low contrast: 2 mm diameter
1.2.2. Linear and reticular details out to the lung periphery: high contrast: 0.3 mm in width, low contrast: 2 mm in width

Table 6.8 A demonstration of relative and absolute scoring of anatomical image quality criteria resulting in an absolute score and a relative rank

Anatomical image quality criteria	Relative scoring (against a test image) Score: -2, -1, 0, +1, +2		Absolute scoring (Against a definition) Score: 1, 2, 3, 4, 5	
	70 kVp	125 kVp	70 kVp	125 kVp
Visualisation of the spine through the heart shadow	0	+2	1	3
Reproduction of the whole rib cage above the diaphragm	0	+1	2	4
Visually sharp reproduction of the vascular pattern in the whole lung, particularly the peripheral vessels	-2	+2	2	5
Absolute score	-2	5	5	12
Relative rank	2	1	2	1

Anatomical image quality criteria can be used without reference to a standard image (relative) or with reference to a definition (absolute) (Table 6.8).

- *Relative grading*
- The observer compares the test image to a *reference*, and there is a scale across 0. It can have 3, 5, or 7 points (i.e. -2 to +2).
- *Absolute grading*
- The observer states their opinion on the visibility of a certain features *without a reference* image (1-5).

VGA studies can be used to evaluate the detectability of anatomical or pathological structures. They mainly use anatomical structures (because these have a known truth). The underlying theory is that the ability to detect anatomy correlates well with pathology. It is important to note that the data generated by visual grading analysis is ordinal and should be reported by descriptive statistics such as the median and the interquartile range. It is inappropriate to use mean and standard deviation to describe ordinal data. Likewise, when it comes to the statistical comparison of a visual grading analysis, it is important to use statistics that are appropriate to ordinal data, such as nonparametric statistics.

The use of anatomical image quality criteria has several advantages over the use of pathology for measuring image quality:

1. Firstly, the vast majority of clinical images are normal and, therefore, images without pathology are easy to find.
2. Secondly, the reader does not have to have the same level of expertise to search for anatomical image quality criteria compared with searching for pathology. Knowledge of anatomy and some training in radiographic anatomy is sufficient to allow someone to rate image quality criteria. Therefore, radiographers and other non-radiologist medical staff can be used to rate image quality criteria.

3. Thirdly, anatomical image quality criteria can be used to generate a visual grading characteristic, which is very helpful in determining which imaging modality or technique best displays the anatomical criteria.

6.6.3.2 Visual Grading Characteristics (VGC)

Although the use of evaluating image quality criteria has become established, they may seem a quite simplistic measure. However, they have become established because they are a valid unreliable measure. The image quality criteria are based on clinically relevant structures that should correlate with the visualisation of clinically relevant pathology. Visual grading of image quality criteria have also been shown to correlate with methods of measuring visualisation of pathology such as receiver operating characteristics (ROC). Image quality criteria are also much more freely available than pathological images. The majority of images taken in the clinical setting are actually normal, most, or all of the patients have the required anatomy, and anatomical criteria can be visualised by a range of professionals that do not require the training or experience of a radiologist. When grading image quality criteria, it is common that trained students, radiographers, radiologic technologist, anatomists, or academics in the field can be used to evaluate the visualisation of the image quality criteria. The presentation of this data as descriptive statistics is useful, and inferential statistics can be used to drive a conclusion about the likelihood of significant differences.

However, there are strong arguments against transforming image quality criteria grading results into numerical values (continuous data). As discussed previously, rating an image as better than another image does not mean that it is twice as good or 10 times good; it just means that it is better. What an observer means by better, much better, or was an observer means by worse, are much worse, cannot, and should not be translated into continuous numbers as they are an ordinal scale. Researchers often fall into the trap of converting grading results into a continuous scale. This is a mistake, because in a continuous scale, four is twice as good as two. Likewise, the calculation of means or standard deviations would be forbidden for an ordinal scale, and medians and interquartile ranges would be more appropriate. Therefore, a more appropriate mechanism of presenting the analysis of image quality criteria and interpreting the results without making any assumptions about the distribution has been developed. This method called visual grading characteristics (VGC) takes the strength of the visual grading analysis of image quality criteria and combines it with the strengths of receiver operating characteristics (ROC) analysis and creates hybrid methods.

The method handles visual grading data in similar fashion to ROC-data (Båth & Månsson, 2007). “The resulting measure of image quality is the VGC curve, which--for all possible thresholds of the observer for a fulfilled criterion--describes the relationship between the proportions of fulfilled image criteria for the two compared modalities. The area under the VGC curve is proposed as a single measure of the difference in image quality between two compared modalities. It is also described

Table 6.9 Number of decisions in each rank

Grade	Number of decisions given grade	
	70 kVp (modality A)	125 kVp (modality B)
1	10	30
2	40	50
3	30	15
4	15	5
5	5	0
Total	100	100

how VGC analysis can be applied to data from an absolute visual grading analysis study”.

Take, for example, a comparison on the image quality of two kVps;

- *Step 1:* We have 100 images taken at 70 kVp and 100 taken at 125 kVp.
- *Step 2:* We ask five observers to score them against the image quality criteria for the chest on a scale of 1–5. The modal (consensus) decision for each criterion is recorded.
- *Step 3:* Summarises number of decisions in each rank (Table 6.9).
- *Step 4:* Create a cumulative table from 0 to 100 (Table 6.10).
- *Step 5:* Plot modality A against B as in Fig. 6.14.

The Area Under the VGC Curve

The area under the VGC curve can be calculated using software developed for calculating the area under the ROC curve. ROCKIT and LABMRMC (<http://metz-roc.uchicago.edu/MetzROC/software/software>) are two examples of software that can be used. In the same way that the area under the ROC curve can be used as a figure of merit for determining which modality is better, the area under the VGC curve (AUC_{vgc}) can be used in the same way. The validity of using ROC software for analysing visual grade characteristics has been investigated and found to be valid (Hansson et al., 2016).

6.6.3.3 Receiver Operating Characteristic (ROC) Methods

Recent research has indicated that medical error is now the third leading cause of death in the United States (Makary & Daniel, 2016). Errors in diagnostic imaging form an important part. However, it is true and will likely remain true that no test is 100% accurate. When we diagnose a patient from a really logical image, we’re only looking at a small part of the information about that patient. Other examinations, blood tests, physical examination, and surgical interventions, will all form part of the diagnosis of the patient.

Table 6.10 A cumulative table of scores from 0 to100

Number of decisions given grade	
70 kVp (modality A)	125 kVp (modality B)
0.00	0.00
0.1	0.3
0.5	0.8
0.8	0.95
0.95	1.0
1.0	1.0

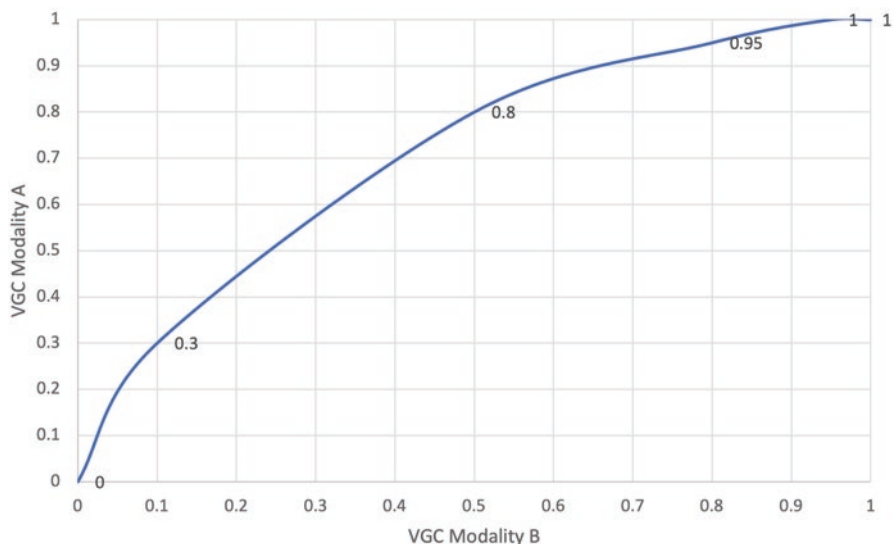


Fig. 6.14 A VGC curve plotting modality A against modality B

One way of deciding whether one method of diagnosis is better than the other is to have two or three experts decide together, or combine their results. This seems sensible, until you realise that there is large in-jure observer variability. Observers will vary so much in their decisions, but any difference between the accuracy of one method of diagnosis over the other gets hidden in the measurement error. There are two problems here; the first is that often the actual diagnosis is not known, so we do not have a measure of the truth, and the second problem is that there is variability between the observers (interobserver variability) and also variability within observers (intraobserver variability).

The solution presented in the 1960s was the receiver operating characteristic (ROC) curve, which is a plot of true positive responses (sensitivity) against false positive responses (1—specificity), is based on the assumption that sensitivity and specificity are covariates. The methodology requires that the investigator knows the

truth of the diagnosis. It allows the generation of a single figure of merit by which the performance of a method of diagnosis can be judged. ROC method in radiology is a specialist subject of its own; for a proper treatment of this subject, please see observer performance methods for diagnostic imaging, foundations, modelling, and applications with R-based examples (Chakraborty, 2017).

In ROC methodology, several expert observers report on a carefully selected set of images that contain a known number of abnormal cases, a known number of normal cases. Observers can be asked to make a decision about the case, being positive or negative (ROC), or can be asked to mark multiple areas of suspicion and rate their level of suspicion (Free-response ROC or FROC) and the location ROC (LROC). In the FROC model, the observer marks each part of the image that they believe are suspicious, and they give a rating for their level of suspicion. In the LROC paradigm, the observer only marks the area that is most suspicious and gives an overall rating to the image.

In ROC the observer makes a single decision per image, and this is usually recorded in a binary scale of either positive or negative or diseased or not diseased. It is useful also to provide the observer with a confidence scale, usually a scale of 1–5 in which they indicate the confidence they have in their own decision. Once this data has been collected, the performance of the observer can be plotted using the false positive fraction (FPF) on the X-axis and the true positive fraction (TPF) on the Y-axis. When these two parameters are plotted against each other, they create a curve; the area under the curve (AUC) is the figure of merit (FOM) for the ROC. The investigator can then average the areas under the curve for multiple observers to create an average figure of merit.

This is very useful for giving us the performance of one system, but how do we compare two systems against each other? This is where the statistical part comes in, and we generate a significance test and generate AP value for the observed difference between two FOMs. Like in previous statistical tests, we can determine if one FOM is greater to another with a certain level of confidence, and typically we take a p -value of less than or equal to 0.05 as being a statistically significant difference between two FOMs.

The Confusion Matrix

Clinical decisions are often complex, with multiple possible outcomes available to the observer. For the purpose of understanding ROCs, we're going to assume in the following section that all decisions are binary. Ratings can either be positive or negative or diseased or not diseased. This approach of asking observers to rate an image as positive or negative is more common in the laboratory setting, or in the university setting, rather than in the clinical setting. A decision made about an image in a clinical setting might include, for example, to request further imaging, to request a biopsy, or to request that the patient returns in a number of years for further imaging and follow-up. Rarely if ever, is the clinical decision purely binary.

Table 6.11 A confusion matrix or contingency table of 2×2 binary decisions against binary truth

	Actual condition determined by gold standard or the truth	
	Patient actually has disease	Patient is actually well
Test indicates disease (positive)	True positive (TP)	False positive (FP) (<i>Type I error, alpha</i>)
Test indicates no disease (negative)	False negative (FN) (<i>type II error, beta</i>)	True negative (TN)

It is true, however, that the truth, the real truth, sometimes is never actually known and is binary. The patient either has the disease, or they do not. Knowing that truth is very difficult, sometimes our gold standard for truth has its own flaws. Radiology often uses pathology as the gold standard; however, the literature on pathology interobserver variation and intraobserver variation also demonstrates that the decision can be hugely impacted by the observer. It is for this reason that the ROC methodology requires a high level of certainty in which the truth of the image is shown to the observer. Often experimenters will go to great lengths to verify whether a patient truly has the disease or not. Some examples of truth that are used in radiological experimentation in mammography might be cancers visible on an image, verified by two observers agreeing and verified by pathology from biopsy, lumpectomy, or mastectomy.

Image test sets with known binary truth of normality and abnormality are incredibly valuable. There are many freely accessible image datasets with known fruit available on the Internet, e.g., publicly available datasets LUNA16 (Home – LUNA16 – Grand Challenge, [n.d.](#)) and LIDC-IDRI (Armato et al., [2011](#)).

Once the observers' decisions are binary and the truth being used is also binary, we can create two 2×2 confusion matrices or contingency tables summarising the outcome of an experiment or a comparison of two systems (Table 6.11). From this confusion matrix, we can calculate a large number of other metrics for the efficacy of the diagnostic examinations such as sensitivity and specificity.

It is important to note for most of the calculations listed below that none of the cells in a contingency table can be empty. If one cell contains a 0, many of the ratios cannot be calculated. Some authors have discussed adding 0.5 to contingency table to replace any zeroes (Moses et al., [1993](#)), this should not be thought of as a correction, but more like a hack, that introduces bias into the results a better solution would be to increase the sample size until each cell contains a result.

Sensitivity and Specificity

The term sensitivity derives its name from physiological concepts like pain. We all have a certain sensitivity to pain. For example, if I touch something extremely sharp, I will feel the pain of it piercing through my skin, and if I touch something extremely hot, I will feel the pain of it burning my skin. Sensitivity refers to the idea of being able to detect something, in this example, a sensation. Now, imagine that I could

feel the sensation, but I could not differentiate between it being sharp or hot. I would still be sensitive, but I would not be very specific about the type of pain.

So, sensitivity is the idea of being able to detect something, while specificity is the idea of being able to differentiate what it is. A radiologist who is extremely sensitive to nodular structures in the chest will detect all of the circular round nodules in the chest, with 100% sensitivity. However, some of those round nodules in the chest are just normal end-on veins and arteries, some are little contortions in the veins, and others are in fact benign while some are malignant. The radiologist who is 100% sensitive will detect all of these. The radiologist who is 100% specific will be able to differentiate all of these. Of course, the ability to detect is in a large part affected by the quality of the imaging modality and the imaging technique. The ability to differentiate is impacted by several factors too, some of which might be the technology and the technique, while others might be knowledge and experience.

Calculating Sensitivity and Specificity

We can calculate the sensitivity and specificity other given diagnostic examination by counting the numbers of true positives and true negatives and false positives and false negatives resulting from that diagnostic examination (Table 6.6).

The ratio of the number of TP decisions to the number of actually diseased cases is termed sensitivity or the true positive rate (TPR) or sensitivity. It is also sometimes called the recall rate, or the probability of detection, or power.

$$\text{Sensitivity} = \text{True positive rate (TPR)} = TP / TP + FN$$

Likewise, the ratio of the number of TN decisions to the number of actually non-diseased cases is sensitivity or true negative rate (TNR), sometimes called selectivity.

$$\text{Specificity} = \text{True negative rate (TNR)} = TN / FP + TN$$

The complements of TPR and TNR are termed false negative rate (FNR) and false positive rate (FPR), sometimes called fallout.

$$\text{False negative rate (FNR)} = FN / TP + FN$$

$$\text{False positive rate (FPR)} = FP / FP + TN$$

Positive and Negative Predictive Values

The probability that the patient who is diagnosed as having the disease actually has the disease is called the positive predictive value (PPV). Likewise, the probability of the patient being diagnosed as being normal when they are actually normal is called the negative predictive value (NPV). These predictive values are only relevant to the clinical scenario, in which the prevalence of the disease in the population is known,

but the truth of the case in front of the observer is not known. Predicted values like these are not relevant to laboratory-based experiments that are investigating the ability of an observer to detect an abnormality. Laboratory-based experiments or university-based experiments typically increase the prevalence of abnormalities to allow for a satisfactory calculation of sensitivity and specificity. Typically, laboratory-based experiments do not report predicted values, while clinical audits and reports on the efficacy of a service use PPV and NPV.

High positive predictive value and negative predictive value are given great importance in discussions of diagnostic accuracy. A higher positive predictive value means fewer unnecessary biopsies, or further tests. Biopsies have a cost, in terms of patient comfort and hospital resources. Radiologists with higher positive predictive values will request biopsies that turn out to be positive more often than not.

$$\text{Positive predictive value(PPV)} = TP / TP + FP$$

A high negative predictive value (NPV) means fewer cases of patients returning with worst disease in later years or leaving with undiagnosed diseases. These are the types of cases that often make the news and are sometimes referred to as misdiagnosis. They have serious consequences for the patient, as they might delete treatment, increased the need for medical interventions, and even reduced life expectancy.

$$(\text{NPV}) = TN / FN + TN$$

The compliments of positive predictive value and negative predictive value are false omission rate (FOR) and false discovery rate (FDR).

$$\text{False omission rate (FOR)} = FN / FN + TN (\text{or } 1 - \text{PPV})$$

$$\text{False discovery rate (FDR)} = FP / TP + FP (\text{or } 1 - \text{NPV})$$

Two further ratios that can be calculated from sensitivity and specificity are the likelihood ratios. They are used to determine whether the results of a test are useful prediction of the probability of the patient having a condition. They are called the positive likelihood ratio and the negative likelihood ratio.

$$\text{Positive likelihood ratio(LR +)} = \text{TPR} / \text{FPR} (\text{or Sensitivity} / 1 - \text{specificity})$$

$$\text{Negative likelihood ratio(LR -)} = \text{TNR} / \text{FNR} (\text{or } 1 - \text{sensitivity} / \text{Specificity})$$

From these, a “diagnostic odds ratio” can be calculated. It is defined as the ratio of the odds of the test being positive if the subject has a disease relative to the odds of the test being positive if the subject does not have the disease.

$$\text{Diagnostic odds ratio(DOR)} = \text{LR +} / \text{LR -}$$

Accuracy

Accuracy as a measure simply tries to summarise the proportion of correct decisions in the population. So, this is the total number of true positives, plus the total number of true negatives in the whole population.

$$\text{Accuracy} = \text{TP} + \text{TN} / \text{Total population}$$

Table 6.12 shows the calculation of other measures of the efficacy of an examination.

Imagine an experiment where we wish to determine whether CT images of the chest are an accurate method of diagnosing lung cancer in a population. We take 100 images of patients with known cancer, proven at biopsy and 100 images of patients who underwent a CT scan for other (say cardiac) reasons, but who have no lung nodules and no cancer proven by outcome and subsequent normal chest CTs. Let us assume in this experiment that we are 100% certain about the truth, we know those 100 smokers definitely had lung cancer, and we know that those 100 patients with cardiac issues definitely did not have lung cancer. The confusion matrix for this example is set out in Table 6.13.

Plotting the ROC curve

“In a Receiver Operating Characteristic (ROC) curve the true positive rate (Sensitivity) is plotted in function of the false positive rate (100-Specificity) for different cut-off points. Each point on the ROC curve represents a sensitivity/specificity pair corresponding to a particular decision threshold” (ROC curve analysis with MedCalc, n.d.).

The ROC curve is derived from the confusion matrix and is created by plotting the true positive rate (TPR) (aka sensitivity) against the false positive rate (FPR) (aka 1-specificity) at various threshold settings. The ROC curve is generated for each instance of the confusion matrix. The TPR (0.8) and FPR (0.1) in the table above would generate one point on the curve.

If a system had 100% sensitivity and 100% specificity, the area under the ROC curve (AUC) would be 1. A system that was no better than a coin toss would generate an AUC of 0.5. If a diagonal line was drawn between the origin at 0, 0 and the endpoint at 1, points above that diagonal line would represent a good result, better than random, and points below that line represent a poor result, worse than random. It is important to note that if a system scored a perfect zero, it would still have great discriminatory value, but its results need to be inverted (negative becomes positive and vice versa).

More points on the ROC curve can be created by asking the observers to rate the confidence of their decision for both positive and negative cases. Counting how the cumulative ratings add up allows us to calculate the FPR and TPR at different levels of confidence. Table 6.14 gives an example of how to create the table, and Fig. 6.15

Table 6.13 A worked example 200 patients undergoing CT for nodules on a smoker population

Test results	Actual condition determined by gold standard or the truth		Patient is actually well 10 (FP)	Patient is actually well 90 (TN)	Patient is actually well True negative rate (TNR) = TN / (TN + FP) = 90/100 = 0.9	Patient is actually well False positive rate (FPR) = FP/FP + TN = 10/100 = 0.1	Patient is actually well Positive predictive value (PPV) = TP/ TP + FP = 80/90 = 0.88*	Patient is actually well False omission rate (FOR) = FN/ FN + TN = 20/110 = 0.18*	Patient is actually well False discovery rate (FDR) = FP/ TP + FP = 10/90 = 0.11*	Patient is actually well Negative predictive value (NPV) = TN/ FN + TN = 90/110 = 0.81*	Patient is actually well Diagnostic odd ratio (DOR) = LR+/LR- = 8/4.5 = 1.77
	Test indicates disease (positive)	Patient Actually has disease 80 (TP)									
Test indicates disease (positive)	80 (TP)	10 (FP)	90 (TN)	True negative rate (TNR) = TN / (TN + FP) = 90/100 = 0.9	False positive rate (FPR) = FP/FP + TN = 10/100 = 0.1	Positive predictive value (PPV) = TP/ TP + FP = 80/90 = 0.88*	False omission rate (FOR) = FN/ FN + TN = 20/110 = 0.18*	False discovery rate (FDR) = FP/ TP + FP = 10/90 = 0.11*	Negative predictive value (NPV) = TN/ FN + TN = 90/110 = 0.81*	Diagnostic odd ratio (DOR) = LR+/LR- = 8/4.5 = 1.77	
Test indicates no disease (negative)	20 (FN)	90 (TN)	True negative rate (TNR) = TN / (TN + FP) = 90/100 = 0.9	False positive rate (FPR) = FP/FP + TN = 10/100 = 0.1	Positive predictive value (PPV) = TP/ TP + FP = 80/90 = 0.88*	False omission rate (FOR) = FN/ FN + TN = 20/110 = 0.18*	False discovery rate (FDR) = FP/ TP + FP = 10/90 = 0.11*	Negative predictive value (NPV) = TN/ FN + TN = 90/110 = 0.81*	Diagnostic odd ratio (DOR) = LR+/LR- = 8/4.5 = 1.77		
Accuracy = TP + TN / TP + FP + TN + FN											

Table 6.14 Adapted from (Chakraborty, 2017) p.60, demonstrating the cumulative ratings of positive and negative cases. Observers rated positive cases on a scale of 1–5, with five beings

Rating	Confidence ratings given to case by observer				
	1	2	3	4	5
For actually normal cases ($n = 60$)	30	19	8	2	1
For actually disease cases ($n = 40$)	5	6	5	12	12
	Operating points				
	Ratings \geq	Ratings ≥ 4	Ratings ≥ 3	Ratings ≥ 2	Ratings ≥ 1
FPR	0.017	0.050	0.183	0.50	1
TPR	0.440	0.680	0.780	0.90	1

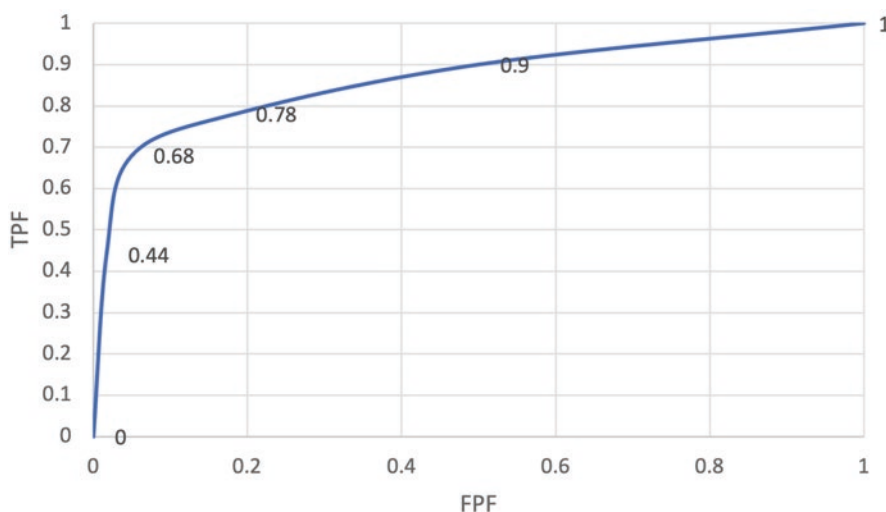


Fig. 6.15 A plot of FPF again TPF to create an ROC curve

shows how that same table is plotted to create the ROC curve. As the confidence values here are actually measured from the observer, they are referred to as empirical ROC data. The data points for an ROC curve can also be estimated by estimating the sensitivity at a fixed specificity and the specificity at a fixed sensitivity.

Calculating the Area Under the ROC Curve (AUC)

Creating the receiver operating characteristic curve is not the end of the process. The figure of merit in an ROC experiment is the area under the curve (AUC). The area under the curve can be interpreted as the value of sensitivity for all possible specificities or conversely the value of specificity for all possible values of sensitivity. It can also be a measure of the probability of an individual sample test having

greater suspicion than that of a randomly chosen test (Rudolfer, 2003). The area under the curve is normally reported with a 95% confidence interval that indicates the upper bound and lower bound of the area under the curve with 95% confidence.

Where the points on ROC curve are connected by straight lines, the area under the curve can be calculated by calculating the area of the trapezoids underneath each of these straight lines. The trapezoids would be generated by dropping a vertical line directly from each point on the ROC curve. We can intuitively understand how the area of a trapezoid can be calculated, and therefore might be tempted to do this manually, but you should be advised against it, as the area under the curve is exactly equal to a particular statistic known as the Mann-Whitney Wilcoxon statistic on his calculation easily using software.

The area under the ROC curve can be calculated using software developed for calculating the area under the ROC curve such as ROCKIT and LABMRMC (<http://metz-roc.uchicago.edu/MetzROC/software/software>). The area under the curve can also usually be calculated mathematically using software such as SAS (https://www.sas.com/en_us/software/university-edition.html) or R (<https://www.r-project.org/>) or MedCalc online (<https://www.medcalc.org/calc/index.php>). Most models used nonparametric analysis of the empirical area under the curve. This removes any assumptions about the underlying distribution of the data points.

Sample Size Calculation for ROC

The power of an area under the curve estimation is driven by the sample size. Typically the more images that the readers have to read, the higher the power; however, this has a cost. Expert readers are typically radiologists or physicians with the qualifications and experience to interpret the image. Their time is often fully used in the clinical setting dealing with patients, administering departments, researching, teaching, etc. So, although from an experimental design setting we might want to have 1000 images, this is very uncommon in the literature. Large sample sizes have been used in ROC methodology, with volunteer observers typically reaching 2–300.

Extremely large sample sizes require research funding to pay for the time of the readers involved. The Digital Mammographic Imaging Screening Trial (DMIST) is an example of a large, state-funded trial that used ROC methodology in which 49,528 women underwent screening mammography at 33 different sites across the United States and Canada having both digital and film mammograms. In this study, they calculated the difference between the area under the curve as 0.03 with 95% confidence (−0.02–0.08) with a p -value of 0.18 (no significant difference). However, when the population was substratified into those over the age of 50 (difference in the area under the curve, 0.15; 95% confidence interval, 0.05–0.25; $P = 0.002$), women with extremely dense breasts (difference, 0.11; 95% confidence interval, 0.04–0.18; $P = 0.003$), and premenopausal women (difference, 0.15; 95% confidence interval, 0.05–0.24; $P = 0.002$), there was a difference (Pisano et al., 2005). In this case, the ROC methodology was used to create a single figure of merit for deciding between 2:00 diagnostic imaging devices, film screen mammography, and digital

mammography. Because the conclusion was of public health interest, I would have an impact on the population of the country; it was therefore government funded, and readers involved were paid for their time. This is a good example of how ROC methodology can be used to make complex decisions using what ultimately looked like simple metrics.

From the above examples, it is clear that decisions about sample size are not driven simply by statistical requirements, but often by the funding requirements and the infrastructural and professional arrangements in place. Therefore, it is common for sample size calculations to be done retrospectively, although this is not best practise.

Calculating the sample size necessary to make a decision about the area under the curve requires inputs on the following:

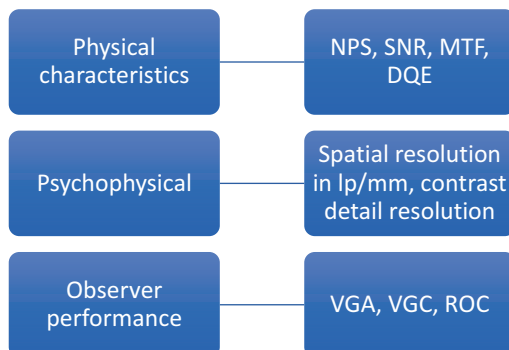
- The level of probability of making a type I error (alpha), two-sided, in other words the probability of incorrectly rejecting the null hypothesis.
- It also requires the input of the desired type II error, (beta), the probability of incorrectly accepting the null hypothesis required power.
- The area under the curve predicted or calculated from the actual study.
- The ratio of sample sizes of the negative and positive groups.

(https://www.medcalc.org/manual/sampling_ROC1.php)

6.7 Conclusion

I hope the reader will find this chapter useful in understanding some of processes used in medical radiation science research. This chapter has set out data collection methods, descriptive statistical methods, and inferential statistical methods. Of particular significance in medical imaging research is the collection of knowledge and attitudes via a combination of quantitative and qualitative methods. Many research studies in medical radiation science require some measure of image quality; these are summarised in Fig. 6.16 and should be chosen based on the hypothesis or research question.

Fig. 6.16 A summary of physical, psychophysical, and observer performance image quality measures



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Chapter 7

Communicating Research Findings



Rob Davidson and Chandra Makanjee

7.1 Method of Communicating Your Research Findings

Research is a scholarship activity and a collective endeavor, and as such, its finding should be disseminated. Research findings, often called research outputs, can be disseminated in many forms including peer-reviewed journal articles (e.g., original research, case reports, and review articles) Meyers and conference presentations (oral and poster presentations). There are many other options, such as book chapters, educational materials, reports of teaching practices, curriculum description, videos, media (newspapers/radio/television), and websites. Irrespective of the approach that is chosen as the mode of communicating, all modes of communication entail some basic organizational aspects of dissemination processes that are common. These are to define research project objectives, map potential target audience(s), relay target messages, define mode of communication/engagement, and create a dissemination plan.

Choosing the desired media and format of your communication strongly depends on your communication objectives, i.e., what you want to achieve. Start by asking yourself what you want to achieve with your dissemination. This first strategic step will make all other subsequent steps much simpler and guide how you define the success of your activities.

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7.1.1 *Create a Profile*

Whether communicating as an individual researcher, for a research project, or for a research organization, establishing a prominent and unique identity is an important start. This can be achieved by the use of personal or organizational websites, social media accounts, researcher identifiers, and academic social networks to help make you and your research visible. Using researcher identifiers like ORCID (<https://orcid.org/>) when disseminating outputs will ensure that those outputs will be unambiguously linked back to the individual researcher (and even automatically updated to their ORCID profile). An online presence maintained via personal websites, like social media accounts (e.g., Facebook, Twitter, LinkedIn, ResearchGate, and institutional researcher profiles), can be a personal calling card, where you can highlight your experience, demonstrate your expertise in certain topics, and naturally develop your ability to be not only an effective and impactful communicator but also gain insights from other field experts on your topic.

7.2 Audience

7.2.1 *Map your Audience*

Specify who exactly you want your research results to reach, for which purposes, and what their general characteristics might be (e.g., policy makers, patient groups, under or post graduate students, non-governmental organizations, academics, practitioners, and general public). Target and frame the key messages that you want to communicate to specific groups. Get an understanding of your target audiences and their interest, needs and expectations, and preferred medium of communication rather than what you want to tell them. Here is your opportunity to align your messages and media accordingly with their needs and priorities.

Within medical imaging, the audience is wide and diverse consisting of health and other associated healthcare professionals such as medical, nursing, or allied health professionals; medical physicists; and engineers and IT software technicians. Myers (2018) suggests that there are five main audiences as shown in Table 7.1. These are academics, students, interprofessional and multidisciplinary teams' members, institutions/organizations, and regulatory bodies/professional societies and the general public.

According to Myers (2018), what most people understand or learn from your research project is when it is written in some form. A written account of a research project will be available for reading long after the project has finished. An important consideration though is that once the research is disseminated, you as the researchers have little to no further influence on how the work interpreted by others. Good writing techniques are needed so that the reader interprets the research message the way you want it to be interpreted. Creative writing techniques are also needed to

Table 7.1 Five main audiences of research outputs

Audience	Subgroups	Preferred outputs	Other
Academics	Researchers and lecturers	Journal article, conferences, and book thesis	Social media platforms
Students	Undergraduate and postgraduate	e-textbook, case studies, and journal article	Social media platforms
Professionals	Clinicians—Medical imaging and non-medical imaging	Journal article, conferences, and case studies	Social media platforms
Other professionals	IT and X-ray engineers	Journal article, conferences, and magazines	Social media platforms
General public			Newspaper article, magazine, book, and social media platforms

Adopted from Myers (2018)

ensure that the writing about the research not only is providing full details of the project but also is engaging.

As writing itself is a creative process, there needs to be a decision about how the research “story” is told. According to Richardson and St. Pierre, 2005, when anyone writes, they create a particular view of reality and decide what or what not they are going to say (Corley and Giona, 2011). The research story that is to be told and the style used vary depending upon the audience. For example, when research findings are presented at a conference, in a seminar or in a lecture, those people who have attended will learn about the research without having to read it. That information though is short term, and most people will not remember much about the topic of the presentation. While researchers need to consider the audience, they also need to consider the medium of dissemination.

7.2.2 *Students*

An important audience of research outputs is students. The students can be undergraduate students, postgraduate students such as PhD candidates, or other professional students. Most outputs written for students tend to be teaching oriented such as textbooks and teaching cases. Textbooks tend not to be a direct method of dissemination of research, rather they are a later synthesis of research by someone who is actively involved in teaching at the appropriate level and understands what students at that level need for their studies.

However, higher degree by research (HDR) students such as masters by research and PhD candidates are researchers themselves and need to understand the field

they are researching in, and that means the most current knowledge which is gained mostly through peer-reviewed journal articles.

7.2.3 Clinical Professionals

The main audience of most health research is the health professionals working in the clinical setting. The term “evidence-based practice” is well known (Hoffman et al., 2017). We as health professionals should not base our clinical decisions and our clinical practice on what has been done in the past without clinical evidence. For example, a statement by a senior clinician such as “well, I have always done it that way, so that is the way we will do it in the future” is not necessarily evidence-based practice. That senior clinician may have based their decision on evidence; however, they also may not. Clinical practice and decisions, based on more recent evidence, may have moved on since that person’s understanding of their clinical practice.

Clinicians also need to maintain their clinical currency through undertaking professional development. Reading and reviewing current research outputs is a part of professional development. As discussed in previous chapters, there are many types of research. The outcomes from some types of research will have greater validity in determining clinical decisions and practice. In terms of clinical practice and decision-making, make sure you have a good understanding of the implications of those types of research and research outputs that you read.

7.2.4 Other Professionals

An alternative professional audience is people who are working in related professional fields. For example, we as diagnostic radiographers/radiologic technologists work closely with medical professionals such as radiologist and non-medical professionals such as medical physicists and IT teams. Each of our professions should keep up to date with the research in these related fields.

7.2.5 Institutions/Organizations

Another audience for researcher is institutions/organizations. These may be public or private organizations. A specific outcome of the research may be a report that may or may not be allowed to be made publicly available. Since most researchers want to publish their research results, not making the research outputs or findings publicly available can go against their principles of undertaking the research project. However, many research projects can be privately funded and as such, the research outputs may be protected intellectual property.

7.2.6 *General Public*

The general public is anyone who is not an expert in field of the research. It is not often that research outputs are written for the general public; however, the public press may determine that some research is in the broader interest of the public and hence invite either verbal or written comments about the research.

7.2.7 *General Comments*

Writing of the research outputs or finding is more than just presenting results and conclusion. It is a creative process that involves telling a story about the research that is relevant and of interest to the selected audience. The researchers when writing about their outputs or finding need to have an understating of that audience so they can tailor the writing style and highlight and promote the relevant findings to that audience.

7.3 Research Output Types

The research audience is the one who is going to read about or listen to the “research story,” and the output type is how the “research story” is presented. Regardless of the “research story’s” audience or the output type, good planning for telling and presenting the story, like a research plan, is always needed. Myers (2013) suggests having a checklist such as in Table 7.2.

As listed in Table 7.2, there are many methods and means of communicating research once outcomes of the research are finalized. These are discussed in detail in the following sections.

7.4 Journal Articles

The process of taking the research and research outcomes to journal publication can be a long process. It is often stated that the hardest part about writing a journal articles is writing. Making the time to sit down and compose a report of research findings is a very difficult first step. Within universities and other research organizations, there are often support processes to help researchers write. If the research is conducted outside of these organizations, then dedication is needed. Researchers have faltered at this stage; it is important to remember that if the outcome of the research is not communicated, then the research itself and the efforts of the researchers and participants were wasted.

Table 7.2 The research story template

Areas	Description
Title	Needs to reflect the research, be simple and clear Is it catchy so to draw attention? Should not have been used before Abbreviations and jargon are best avoided
Purpose	Describe the purpose of the research in one sentence
Authors	Who are the authors? What have been their contributions? What is the order of listing multiple authors?
Audience	Who will read or listen to the “research story”? Are they clinical professionals in the same field, other professionals in a related area, students, general public or if the output is a thesis, the examiners? Keep in mind what Danny Iny (2012) wrote in his blog, <i>Sure, content is king—but without an audience, the king can get awfully lonely</i>
Method	What research method has been used? Quantitative/qualitative and mixed methods are discussed in other chapters. A description of the research methodology with these methods will be required
Publication outlet	If a journal, which journal? What are the journal’s requirements in submitting a manuscript? These will be available on the journal’s website and failure to fully comply may mean rejection of the manuscript If a conference, which conference? A conference presentations or poster? What are the presentation requirements, e.g., length in minutes and number of slides? Is there a need for refereed proceedings or an abstract to be published? What are the poster requirements? Hard copy or electronic? If hard copy, what size, font size, word number, etc.? If electronic, what format, e.g., PowerPoint, what is the number of slides, etc. for both, are their requirements to be present at the poster and/or give a brief oral description? If a newspaper article, what are their requirements for word length, etc.? A thesis, what is the page layout, word number, font size, single or double line spaced, printed on one side of the paper or both, binding requirements, and reference list style? See more detail below
Theoretical and practical contributions	What are the theoretical and practical contributions that flow from the research?
Material included	This will depend on publication outlet, the audience, and word count limit If a thesis, full details of all aspects of the research will need to be included If another publication outlet, the prime consideration will be word, figure, and table limits. Here ensuring that the “research story” is told to that audience is the main consideration

Adapted from Myers (2013)

7.4.1 Journal Selection and Criteria for Evaluating a Journal

Journal selection for submission of the research manuscript can be vital. The selection of the journal should be based on several factors with the first of these being the readers of the journal. The audience of the research will be the readers of the journal. Other factors are often considered by experience researchers, and these are based on various metrics such as quality ranking of the journal including impact factor of the journal and citation rates. Some of the key journal ranking metrics are the journal impact factors (JIF), Q index, h5-index, and SCImago journal rank (SJR).

Reputable journals will include on their website details about the editor and the editorial board members and provide details about expectations of authors in addressing ethical issues and other areas such as plagiarism, conflicts of interest, and publication fraud. The journal's website will also provide details about the peer-review process such as the criteria used for peer review, selection of reviewers, the type of peer review, and time frames for the peer-review process. Reputable journals will also have clear statements that endorse best and practices guidelines that have been established for journals and publishers by organizations such as the World Association of Medical Editors (WAME), the International Committee of Medical Journal Editors (ICMJE), and the Committee on Publication Ethics (COPE).

7.4.2 Journal Article Writing

All research manuscripts, name of the document before publication, will common elements that are needed for publication. Tress et al. (2014) in their work titled *How to write a paper for successful publication in an international peer-reviewed journal* have defined several steps in writing the manuscript. These steps are the following:

Step 1: Define audience and select correct journal.

Defining the audience and journal selection should be done early; this has been discussed in more detail earlier in this chapter. The manuscript can be written before or after the selection of journal but should not be done before knowing the audience. There are some advantages of selecting the journal before writing the manuscript. They are knowing their word limit, ethics statement requirements, referencing style, table and figure requirements, etc., of that particular journal. However, if the manuscript is rejected by one journal, it is not a difficult task to suggest changes to the original journal, and then change the manuscript to the requirements of the new journal.

Step 2: Define the objective, type, and title of the manuscript.

Approaches to undertaking the research are discussed in other chapters of this textbook. While the research project may have several research objectives, a research

paper, and hence the manuscript, should ideally focus on one objective. The title of the proposed paper must be clear and must reflect the objective of the research, which is the focus of the manuscript. The title should also be able to give the reader a clear understanding of the focus of the research. The type of research that was undertaken also needs to be clearly stated. This can be indicated in the title; however, this needs to be clearly stated in the abstract and early in the many body of the manuscript.

Step 3: Decide on co-authors.

Ideally, prior to undertaking any research when determining the research team, the co-authors and the order of the co-authors on the manuscript should have been decided. Issues such as conflicts of interest can arise during the research and then later when writing for a journal.

All authors listed for a journal article must have made a substantial intellectual contribution to at least one major aspect of research project such as the project conception, design, data collection, analysis, and writing of a manuscript. Team writing can occur; however, this requires clear agreements of roles, responsibilities, and timelines. Typically, the first listed author will have management responsibility of the writing process and then also of the journal submission process. However, all authors must agree with the final documents and then later sign off on their agreement during the journal submission process.

Step 4: Write for readers.

The audience of the intended journal article is known, and the manuscript should be written with the audience in mind. The aim of the intended journal article is to inform readers about the research that has been done, which often in health areas is to inform clinical practice. The manuscript should have a clear message and be expressed in a language that is suitable to the audience. The intended journal article should not only be informative but also be interesting and easy to read, with clear and concise messages that the author wants to convey.

Step 5: Write in short, but regular sessions.

For many researchers, writing can be the most daunting aspect of the research. A common approach then for some people is to avoid writing in long blocks of time to write a paper and instead write in short sessions at regular intervals, e.g., daily. Make writing a routine task. Short writing sessions, such as 30–60 minutes of writing a day can be very productive. Such an approach can provide a feeling of regular success and hence reduces fear of failure. Other people may prefer to block a significant amount of time and complete the writing task as soon as possible. The first author should understand these differing approaches and not expect that all co-authors who are tasked with writing will have the same style.

Step 6: Set out a clear structure for the manuscript and write the sections.

The structure of a proposed journal article is often defined by the journal. The structure will depend on the type of research that has been undertaken and will

differ between quantitative, qualitative, and mixed methods research. If the structure is not defined by the journal, authors should review structures for their type of research that are typically used in journal article writing. A journal's structure will define the major sections that are needed. For example, the sections may be, though the names of the sections will vary, an abstract, an introduction, the method section, results, discussion, conclusions, acknowledgements/conflicts of interest, and references.

Having a clear structure or a skeleton of the manuscript allows a writing to follow that framework. Journal articles are limited in word number, and using such an approach helps reduce repetition and overlap of information.

The abstract is a short overview of the proposed paper. Most readers will read the abstract and decide from the abstract whether to read the entire paper or not. Writing an abstract that entices the interest of the reader is a skill that needs practice. The abstract will have a word limit and may also have further subsections that are required by the journal. This section should also align with manuscript's sections and summarize those sections in a few sentences.

The introduction should commence with setting the research scene about the project. This can be a concise overview of the earlier completed literature review. Also need is why the research was undertaken by defining the gap in knowledge or addressing the significance of and need for the research project.

The research methods section should provide details of the methodology used and include details of the data collection and analysis methods. In this section, any ethically issues that were faced should be detailed, and ethical approval information should be provided. In this section, subheading should be used to help the reader with the content that is included in the subsection and to potentially go back to that subsection easily. The experimental or data collection methods that were chosen should have been based on evidence and as such fully referenced as to the appropriate use for the type of research that was undertaken. If the method used in the research has not been previously used before, then more detail information and description of the methods needs to be provided. Similarly, for data analysis methods, these should be fully referenced as to their appropriate use for the analysis of the data collected.

The results sections should only present the results that were relevant to answering to the research question and which address the objective and the purpose of the proposed paper. The results must only be those of the experimental methods used in the research project. The results should not be discussed in this section. Figures and tables can be used so the reader can gain an understanding of the results. Some brief explanation of the figure or table is needed, but full details of the information in figures and tables should not be also written in the text of the results section. It is important in this section to present only the facts that support the objective.

The discussion section is where the results are interpreted and placed in context with other relevant work that has previously been undertaken, that is research that is already published. For example, the results may agree or disagree with previous work that has been reported. The results can also be discussed in context of implications for clinical practice. Importantly, the results should not be generalized beyond

the scope of the population that the research was conducted with. Also, the discussion should not speculate beyond the known facts supported by the results of the research or other referenced similar work. During the research, there may be unexpected results or factors that have impacted on the data collection or results themselves. Discussion of such things is needed to provide the reader with information of such issues and their impact on the research undertaken.

At the end of the discussion section, future directions and suggestions for further research should be discussed. This tells the readers that the authors understand the area of research, acknowledge their research as part of answering the bigger research question, and understand that their research will not solve all the problems in this research area. Authors should also discuss the limitations of the project. This further tells the readers that the authors understand their own research project at a high level and they have assessed the strengths and weaknesses of the project.

The conclusion section is one of the most important areas to write in the manuscript. This section should not present new facts, repeat what is in the manuscript, or continue any of the discussion. While the abstract provides an overview and entices the audience to read more, the conclusions are take-home messages of the journal article. This, along with the abstract, is the most important section of the document. As such, the wording of this section must provide the take-home message that the authors want from undertaking the research.

The acknowledgement section is where you list the people who were not authors but contributed in the research project or in the writing of the manuscript. Also, any sources of funding or others that have contributed to the research should be acknowledged.

The references must comply with the journal's guidelines. All in-text reference must also comply with the guidelines. Importantly, the references tell the reader that you know the area of the research, you have considered other sources of information, and you provide the reader with information that may not be fully discussed in the manuscript.

In all sections of writing the manuscript, authors must ensure that they are plagiarizing the work of others. All reputable journals will check for plagiarism during the review process. Plagiarism, as all students and researcher should understand, is using the words of others without acknowledging the source of that information (Nikolian and Ibrahim, 2017). It is expected that authors of research will have read widely and knowledgeable good practice states that concepts written but other should be written in the author own word and understanding the concept and of course the source of that information is acknowledge through referencing. Failure to do this will mean the journal will reject the manuscript.

Step 7: Review and edit the manuscript.

Once the manuscript is finalized, all authors should review, critically appraise, and comment on all section of the document. When rereading your own work, one suggested method is not to reread for at least a week, preferably more, as many people are known to read in their mind what they meant to write, not what they actually wrote. A gap of a week or more means that what was written previously should

not still be in the forefront of their mind and they can pick up areas that needed correction earlier. New researchers and manuscript authors should find and get someone with research writing experience to review and comment on the draft manuscript. Importantly, when doing this, be open and do not be sensitive to suggestions that come from such a person.

At this stage, all references should be rechecked for their currency; the correct reference detail requires style by the journal.

Step 8: The submission.

Most journals have an electronic paper submission process that guides authors easily through the required steps and separate documents. Normally a cover letter, a separate title page with all of the authors contact details as well as qualification, a separate document for the abstract and key words, a document with the main content but without the abstract and author details, a separate document for figures and table content, full content document with all of the content from title, author details to references, a separate document for funding, permission from authors to contribution of drafting the manuscript and a separate permission to publish document. The system allows you to reorder the submitted documentation in a chronological order (Tress et al., 2014).

A covering letter addressed corresponding author to the journal's editor or editor-in-chief as per the journal guidelines, which include the name and address of the corresponding author and may include co-authors details as well. The content generally includes the title with a short statement about the key message and relevance of the paper. Other information may relate to ethical approvals, declarations regarding funding, and potential conflicts of interest (Tress et al., 2014).

Some journals ask for suggestions for suitable reviewers. If so, people with a sound knowledge of the field should be suggested. This list should not include anyone with whom the author has published or anyone from the same research team or close associates. Authors may also request that particular people are not asked to review the manuscript. If seeking to exclude anyone, valid reasons for the exclusion must be given. If the editor uses one of the suggested reviewers, they will first check the academic credibility of that person. Under no circumstances should a manuscript be submitted to more than one journal at the same time (Tress et al., 2014).

After completion of all these steps, a PDF version of the document is generated, which will require approval. It is important to thoroughly read through this document and at the same time to ensure that all of the requirements as stipulated by the journal have been fulfilled before submitting to the journal (Tress et al., 2014).

Step 10 Review and revision.

The review process will vary depending on the journal and its focus. However, the review process has many common processes. A typical path through the review process for a manuscript from submission to acceptance, or maybe rejection, can be seen in Figs. 7.1a and b.

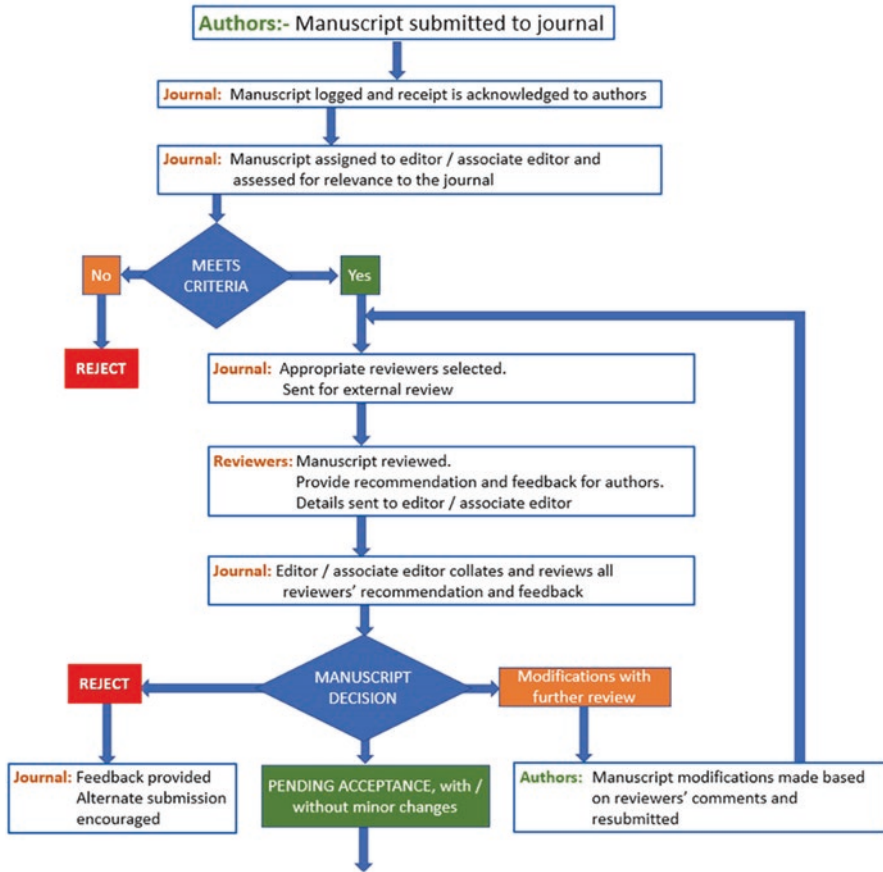


Fig. 7.1 (a) Part A of a typical flow diagram of the review process from submission to acceptance. (b) Part B of a typical flow diagram of the review process from submission to acceptance

7.4.3 Review and Revision

The aim of the peer-review process is to assess whether the submitted manuscript is in line with the aims and objectives of the journal—this is typically done by an associate editor of the journal—and with suitability and quality of the manuscript potential for publication in the journal.

The typical submission and review processes are detailed in Fig. 7.1a and b. The typical process is that an associate editor is assigned to the manuscript, who undertakes a brief review to assess whether it meets the journal’s aims and objectives. Peer reviewers are assigned and who provide detailed responses to the associate editor about the content, the quality of the research that has been undertaken, whether the aim and objectives of the research are addressed and met and

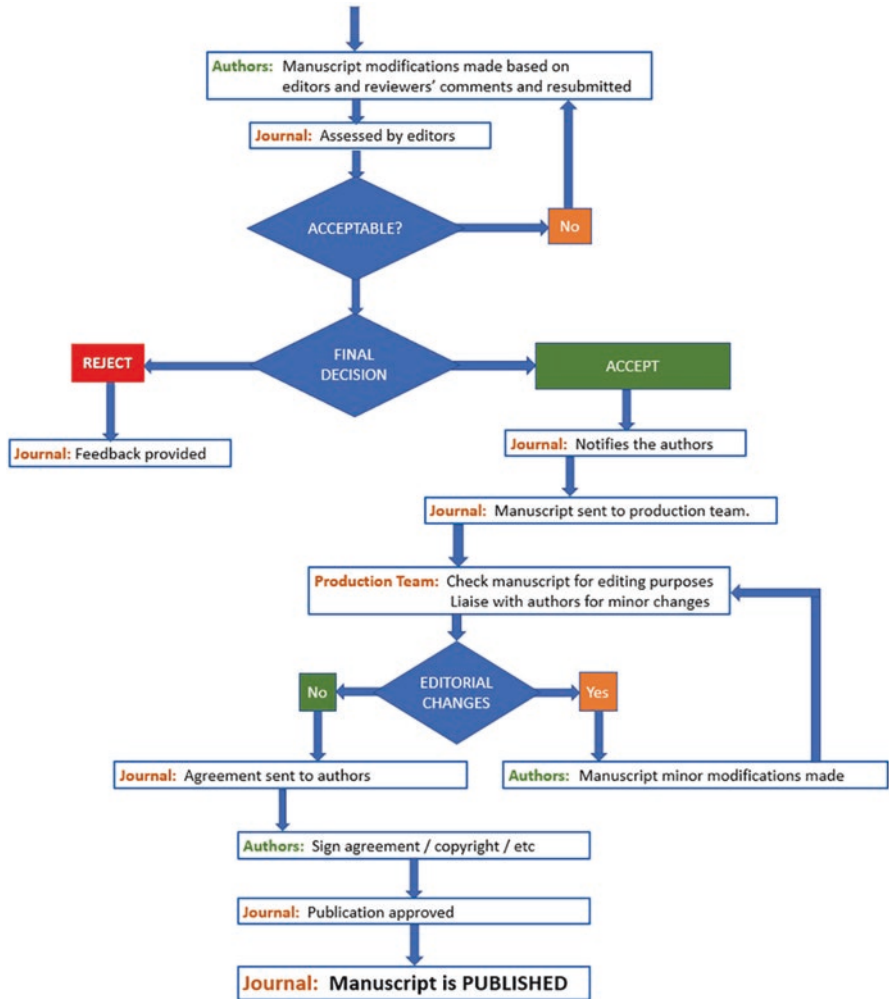


Fig. 7.1 (continued)

including ethical considerations. The reviewers also recommend whether the manuscript should be accepted, or it needs minor or major revisions, or whether it should be rejected. The associate editor collates the reviewers' comments and recommendations, assesses and provides the decision with reviewers' comments back to the authors.

If the outcome is accepted with minor or major corrections, authors will typically have to undertake modifications based on the reviewers' comments. This point in the review process can be frustrating to new authors; however, the best approach is to critically and impersonally respond to every point in the reviewers' comments. List the comments in chronological order and make the changes or factually

comment, preferably with justification supported with scholarly references, where reviewers' suggested changes are considered not appropriate.

The review process continues until the reviewers are satisfied and editorial team approves the manuscript. The manuscript is then sent for publication and the publication team liaises with the authors with proof read opportunity. Here there still may be some minor grammatical or spelling changes to be suggested to the authors. This process to the point of final publication of the printed article may still take several months; however, typically an e-copy may be published earlier.

If the outcome is rejected, the authors will be provided with reviewer comments. At this point, the journal relinquishes any rights for publication. The authors are then able to revise the article and start the submission process with the same journal as a new submission as some journals do provide that option or another journal.

Some journals are "open access" journals. This means that the published articles are freely available for anyone who has access to the Internet to read. Prior to open access, journals made their money by selling the journal volumes typically to universities and libraries. The open access approach now means that the authors may need to pay for their accepted article to be published. This cost shifting by the journals has a benefit of allowing the research paper to be more widely read. It is something that needs to be considered and factored into the cost of undertaking the research.

7.5 Conference Presentations

Conferences are forums for discussing ideas, presenting and learning about the current state of research, and becoming part of a community through meeting with clinicians and academics in the same or related fields. They also serve as a networking opportunity including gaining new research ideas and teams (Bavdekar et al., 2017; Verde Arregoitia and González-Suárez 2019).

In terms of research communication, conferences are often the first place where research is presented. Given conferences are mainly face-to-face events, though now becoming online events as well, there are opportunities to the audience to ask questions about the research, for researchers gain feedback, and to build collaborative research links. Conferences also present an opportunity to present research findings at various stages through the research process and gain further ideas, suggestions, comments, and even support to complete the research project (Rowe and Ilic, 2015). With conferences being mainly face-to-face events, many such research discussions are often informal over coffee or lunch breaks.

There are other advantages of presenting research finding at conferences. There are often less rigorous requirements for acceptance of a conference presentation than there is for a peer-reviewed journal publication. The lead-up and preparation times can be shorter, and conference presentations develop other skills in the researchers such as presentation and public speaking skills (Verde Arregoitia and González-Suárez 2019). The disadvantage is that conference presentations, even

refereed conference proceedings, have less research output weighting in the scientific community. A further disadvantage is that a conference is usually at a point in time and hence has limited reach to audiences, whereas a journal article has the potential to reach a wider audience and for a longer period of time.

There are two main approaches at conferences for presenting research finding. These are through oral presentations and poster presentations. The higher ranking of these is a conference presentation, and most of a conference's time is devoted to oral presentations. Often the scientific committee of a conference, those who review and approve conference presentations, when rejecting an oral presentation may accept the abstract as a poster.

7.5.1 Oral Presentations

Research oral presentations or talks can take several different forms; however, at health conferences, the most commonly used form is that of a lecture. Lecture format, other those than that are presented by specifically invited experts known as keynote addresses, has a limited time duration, commonly 12 minutes with 3 minutes for audience questions or 17 minutes with 3 minutes for audience questions. The presentation length will be determined by the conference's scientific committee, as well as the presenting format of the slides to be used. The most commonly used presentation format is Microsoft PowerPoint®; however, other formats such as Prezi® are becoming more commonly used. All such details will be provided on the conference website for potential presenters.

7.5.1.1 Presentation Submission

Prior to the oral presentation being accepted, there is a submission process for potential presenters to undertake. This process usually consists of a submission of an abstract and presenters' names and affiliations (Gopal et al., 2017). The conference website will provide abstract guideline including details such as the format and length of the abstract and submission timelines and will indicate if the presenters should submit an oral or poster presentation or be considered for both.

As with all abstracts, the key is to engage the audience engagement. In this case, the conference's scientific committee members who decide on acceptance are the first audiences, and the other audiences, if the journal is accepted, are the delegates of the conference. Keeping both the audiences in mind when writing the abstract will enhance the likelihood acceptance of the presentation, which will attract more delegates to the conference.

7.5.1.2 Preparing the Presentation

As with most things, preparation is the key to a successful outcome of the presentation. The key elements of any presentation must be kept in mind when preparing the presentation. The main key element of all presentations is to ensure audience engagement. Including such element for audience engagement can be commenced when developing the presentation slides themselves. Some areas to consider are the following:

- Keep the slides simple.
Use a consistent and simple theme for the slides' background. Organizations' logos that have assisted in the research should be highlighted on the first slide and then consistently displayed on all other slides (Gopal et al., 2017).
- For the written points on the slides, use a font type and size that will be clear and visible from the back of a large venue. In a PowerPoint® presentation, this typically plain style font such Arial or Times New Roman and a font size of 26–30. Keep the number of written points on each slide to a maximum of four or five points or short statements.
Where possible use graphics such as images, charts or simple tables to help explain concepts. Videos embedded in the slides can also be considered.
- Presentation content.
Ensure that the number of the slides needed for the content will not exceed the time limit of the presentation. A basic rule of thumb, but double check when practicing the presentation, is one slide per minute of the presentation.
The title slide is one of the most important slides as it will be visible to the audience while the session chair introduces the presenter(s). The title of the presentation on the title slide must convey a message to the audience about the research being presented. All names, titles, and organization affiliations of the authors should be included on the slide whether they are presenting or not. Also, on this slide, any information such as the research funders and supporting organizations should be displayed.
- Content slides, or the main body of the presentation, should follow a typical format used in research articles. Such a format should provide information on the research that was undertaken including the background and research questions; the research methods, data collection methods including ethical considerations and analysis methods; results; discussions; and conclusions. Given the time limits of the presentation, these areas will need concise information; however, the content and message still must be captivating and engaging to the audience. This is one of the more difficult aspects of preparing a conference presentation, what should be included and what should be left out.
- Figures, such as images and charts, and tables must be relevant to the section. All figures and tables will need to be discussed in the presentation during that slide's display, so ensure that the important aspects of the figure or table are highlighted for ease of the audience recognition.

- Videos can be engaging; however, ensure they are brief and relevant to the point being made on that section of the presentation. With the use of videos, ensure that they play on multiple different computers prior to the conference and then check them again at the conference and have a backup plan if the video fails.

The concluding slide should have the take-home message included. This is the important outcome statement that you want the audience to remember. A time limited conference presentation is not the place for multiple take-home messages so limit the presentation to and focus the presentation on the main take-home message that should be conveyed from the research. If there are multiple outcomes from the research, present these in separate conference presentations.

References must be included. These should not be a reference style that only includes the reference details in a final section or slide. The style, whether a number or author-date system, must include the reference information in the footer section of the slide where the reference is made. A full reference slide must be included; however, this is often only visible for a few seconds, and the audience may want take note of the reference details as the relevant slide is being displayed.

Importantly for all slides, ensure that the research story and message are told and important aspects are emphasized throughout the oral presentation.

- Practice the presentation.

Most beginning researchers are not accomplished public speakers. Practicing the presentation multiple times is important to help develop this skill. First, practice with the research team to get the timing and message correct. Once this is done, give the “finalized” oral presentation to a broader audience, for example, at a departmental meeting or education day. During these practice sessions encourage questions and seek feedback, especially from those who have previously given many conference presentations. Another method to practice is to record the presentation as a YouTube recoding. Upload this and provide the link to colleagues, family, and friends. Presentation evaluation forms can also be used for specific types of feedback that the presenters feel they need. Following any feedback, refine the presentation and practice again.

Don't read from the slides or from handheld written notes. When talking about the content of that slide, use different wording than that which is written on the slide. The slides should provide cues to the discussion topic, and use the slide's wording to ensure that a topic or section is not missed. As the researcher and presenter, you are topic expert so demonstrate this expert knowledge by not reading. Reading from written notes also means that your eyes are looking down at the notes, not at the audience. Audience engagement can be lost when the presenter is reading whether that is reading from the slide or notes. When practicing in delivering your presentation, use the slides wording to jog your memory for the point to discuss. The wording of your presentation will change slightly every time you practice and when you give the presentation at the conference. By not reading, the presentation will come across to the audience as more authentic.

- Written presentation information.

Handouts are sometimes allowed at conference; however, most conference organization committees will publish the abstract in a conference proceedings book. The conference proceedings can be refereed or not refereed. If the presentation is to be published as a refereed conference proceeding, more detail is often needed than just the abstract. Typically, this is a one- or two-page summary with more words allowed than an abstract alone. The wording in such a refereed conference proceeding will still need to be concise and engaging and provide enough information about the research to be meaningful. If handouts are allowed, write the handout as if you were writing a one-page refereed conference proceeding.

7.5.1.3 At the Conference

Prior to the scheduled presentation time, most conferences will have room where the presentation can be uploaded and tested to ensure figures and videos are displaying and the presentation can be reviewed. This should be done early and well before the presentation session commences. If there are issues, these can be fixed without the stress of being close in time to the scheduled presentation time.

During early parts of the conference, take the opportunity to read the conference proceedings, and know when and where your presentation session will be held. You should be at the session room about 10–15 minutes prior to the commencement of the session so you can meet the session chairperson. Even if you are the last scheduled presenter in the session, arrive before the session starts. The chairperson will want to ensure the correct details and pronunciation of the authors' names and the title of the presentation. They will also provide you with details on how to move the slides forwards, backward, if needed, how to use the pointer, and how to start a video if there is one as part of the presentation.

During the presentation itself, unless you are an experienced presenter, you will be nervous. If you have practiced the presentation thoroughly, the nervousness will only last a short while and you will soon get into the swing of telling your research story. Remind yourself that you are the expert in this research and that will help you get underway. Some “dos” are as follows:

- Even if you are nervous, try to appear confident by speaking clearly into the microphone, if provided, and at level that the audience can hear.
- Use the pointer or mouse pointer when you look up at the slide so the audience can see what you are emphasizing at the point in time.
- Look back at the audience and try to engage a few people in the front rows with eye contact.
- If you can, get out from behind the podium or computer and use some hand and body gestures.

Some “don'ts” are as follows:

- Try to avoid jargon, speech pauses with “umms” and “errs” and words such as “like,” “so,” or other commonly used everyday language.
- Don not hide or shrink down behind the podium or computer.
- If standing out on the stage away from the podium or computer, don’t wander around aimlessly on the stage and use wild hand gestures – you will distract the audience from your message.
- Try gimmicky things to engage the audience attentions unless you have practiced and tested these previously and have the confidence that such things will deliver the results to a mixed audience.

For the concluding slide, indicate at the commencement of this slide that this is the end of the presentation by using phrases such as “in summary” and “to conclude” and that you are summing up the research. Following this makes any acknowledgements that are needed including co-authors, research colleagues, and other that have assisted you on the research journey.

At the end of the presentation, there will be a time for audience questions. Come prepared for questions; however, no one can predetermine all possible questions. If you don’t know the answer, be honest and state that. If you need more time to get information, state that and advise the person asking the question that you can catch up with them after the session has concluded.

7.5.2 Poster Presentations

The next most common conference presentation type is the poster presentation. There are two types of poster presentations; these are printed posters and electronics posters. Both may be offered as conference options though now with electronics posters being more popular by conference organizers.

Printed poster presentations still have a current advantage in that they are displayed for the duration of the conference. Typically, a room or several rooms are setup for printed posters to be displayed. The authors will have the poster ready printed to the conference dates, and on day one of the conference, hand the poster in its designated place. Commonly, there will be times set aside in the conference schedule for authors to be presented next to their poster so conference attendees can ask questions (Woolston, 2016). There also maybe a scheduled time for the authors to talk to the poster information. While this is not a formal oral presentation and will be shorter in duration than an oral presentation, the details discussed above for oral presentations should be considered when preparing for such a talk.

Electronic poster presentations have the advantage that they are displayed electronically on a large format screen or monitor and in doing so can be multiple slides rather than a single slide printed poster. The disadvantage is that there are typically few screens than posters, so each poster is only displayed for a short period of a few hours to a whole day. Similarly, to printed poster displays, authors are expected to be available for questions and may also need to give a short oral talk on the poster.

Common requirements for both printed and electronics posters.

The audience of both types of posters still must have a high level of consideration in preparing the poster. The authors will have already determined which conference they will present at; however, there will be subgroups of conference attendees in which they need to consider. This will be a factor in the message of the poster and how the information is displayed. Some questions to consider when developing the poster are the depth of the information needed, the number of words versus figures or tables, and the take-home message that is the outcome of the research.

Poster preparations, for presenting research outcomes, mainly come down to what content from the research project is included and what content is left out for another conference presentation or publication. An effective poster should have a single key message, and the information available for the reader should not be overwhelming. The use of figures and simplified tables can reduce the number of words needed. Given the limited space available in both types of posters, getting the wording concise is a major consideration in poster preparation.

Getting the wording concise means identifying the key areas and foci of the research. This typically will not happen in the first draft of the poster. Similar top oral presentations share and present the poster with colleagues and get their feedback. Ask them questions about the key areas, foci, and the take-home message. If your colleagues' feedback differs from your expectations, you have not yet got the wording and message to the audience correct. Revise and try again.

7.5.2.1 Printed Posters

Ensure you have read the conference's scientific committee requirements for size of the printed poster. Once you have that, you can make a single slide in a software program such as Microsoft PowerPoint and set the slide's dimensions to those required by the conference's scientific committee. Often this will be in the metric A0 size which is 841×1189 mm on in imperial measurements, 33.1×46.8 inches. The next decision is to determine if the research information is best presented in landscape or portrait format. This sometimes is decided by the figures or tables that will be used. For example, a figure is higher than its width, and a portrait format might best suit the overall appearance of the poster.

Poster must be designed in such a way so that wording can be read typically from 5 to 10 m/from 15 to 30 feet away. This means that the written sections should be in a minimum of 24 font size, section headers slightly larger, at least 32 font size and in bold font, and the title section of the poster in at least 72 font size. The font style should be a plain style such as Times New Roman or Arial, though for the written text a serif style font, Times New Roman, is easier to read. Figures and tables also must be able to be clearly seen from the above distances.

An increasing practice is that printed posters need to be submitted to the conference via their web site in pdf or PowerPoint format prior to the commencement of conference. In some cases, the conference organizers will print the poster, or

becoming more common, they will display the poster electronically. Such posters differ from electronic posters; see those differences below. However, for many conferences, there will still be a need to print and take the printed poster to the conference. When getting the poster printed, it is advisable to check what electronic format they need, and typically this is in pdf format.

There is a concept in poster and other similar means of communication called “white space.” White space is the gap between written sections and between figures or tables. Visually, there is a need to have some gaps with no information to give the reader some visual relief in the layout of the poster. This is the concept of white space. It helps the reader/viewer of the poster to appreciate the layout of the poster and hence is more likely to read the content. A poster with no white space does not look appealing. The potential audience will be put off reading the poster if the poster is just crammed with writing and figures. However, use white space appropriately as there is a limited amount of words, figures, and diagrams that can be included in a poster.

Like a journal article or an oral presentation, a conference poster needs specific sections that cover the content of the research. Some suggested layouts are shown in Fig. 7.2a and b.

The content areas of a poster are the following:

- The poster title and author affiliations.
As per all research outputs, the title must convey a message to the audience about the research being presented. It is the first thing they will read and must catch their attention for them to read further. Author affiliations enables an opportunity for you to be contacted (Ranse and Hayes, 2009)
- The abstract.
The abstract must be the same as that, which was accepted by the conference scientific committee. As such, this another reason to get the wording of the abstract right when the poster presentation was planned and then originally submitted.
- The introduction.
This section, similar to the requirements of an oral conference presentation, is an overview of the main points that were gained from the literature review and those identifying the gap of knowledge or importance of the research.
- The methods.
The methods section, again similar to the requirements of an oral conference presentation, provides information on the type of research methods, the data collection methods including ethical considerations, and analysis methods.
- Results, discussion, and conclusion.
These sections can be separated out into individual groups, depending on the space on the poster. These sections will be succinct, and a concise overview of the research was undertaken. Here, it is important to carefully consider the importance of what is included and what is left out.

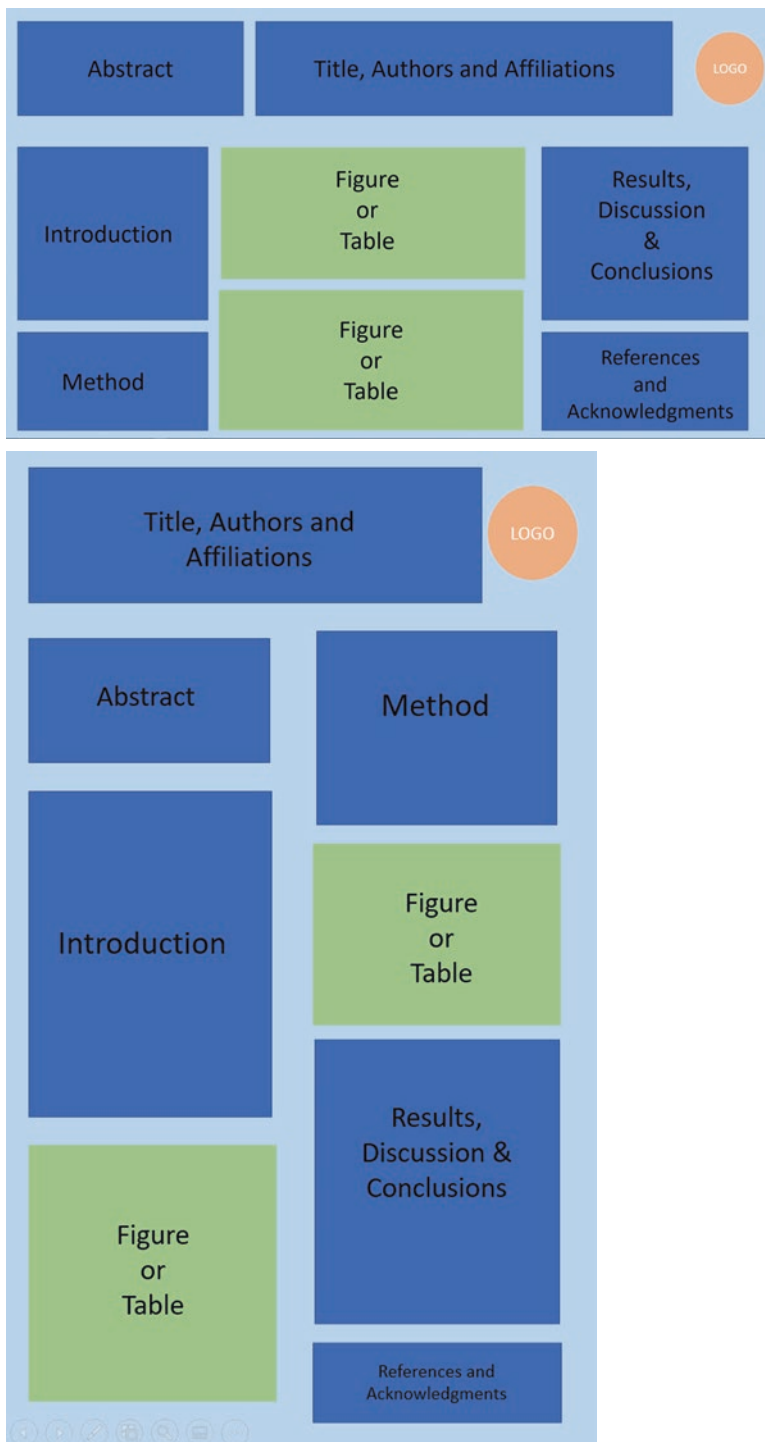


Fig. 7.2 (a) Suggested layout for a poster when displayed in landscape mode. (b) Suggested layout for a poster when displayed in portrait mode

The concluding comments must have a strong take-home message. Again, this is what the reader will remember most, so it is important to put extra effort into getting the wording and message right.

- Figures and tables.

If an image is to be used, ensure that it has a high resolution, at least 300 DPI, before inserting it into the electronic version of the poster. If this is not done, when the poster is printed, the image will be pixelated and distract from the quality of the poster.

Ensure the tables only included the minimum amount of information to convey the message about the results. Highlight or bold the important data in the table so this is easily found by the reader.

- Reference and Acknowledgements

Like all research outputs, you must acknowledge the sources of information that have help in undertaking the research and acknowledge those who have not directly being involved in the research itself but have helped get the research to this stage of communication.

- Further layout considerations.

The text in the written section should be left aligned. It is easier for most people to read written text when the wording is left-aligned compared with when it is justified, that is the words are spread evenly along each line. Try to distribute the written sections, figures, and table in a balanced manner so that the poster is aesthetically pleasing, with an appropriate amount of white space in the poster. Some posters will include a printed border around the edges of the poster and around each section of text. Some people think this is visually attractive and adds to the poster's aesthetic appeal, and other people think this is not needed and white space will do the same thing.

As mentioned, printed posters only provided an opportunity to present concise information on the research project. If more information needs to be conveyed or you want the audience to find related information about other aspects of the project, then a website with such information can be setup. The poster can include the URL of the website or can be linked via an embedded QR code on the poster. Ensure the URL is correct, and the QR code provides the correct link prior to printing the poster.

If the website is extended information on the project, or project related, keep the information brief, and don't overwhelm the reader. If using this approach, be aware that the information is now in the public domain and that can have implications in managing your intellectual property. The URL or QR code could be a link to related work that has already been published in a journal. If using this approach, ensure the published article is freely available to the general public and does not have limited viewing to only those who hold a subscription to the journal.

7.5.2.2 Electronic Posters

Electronic poster can be thought of as a cross between an oral presentation and a printed paper in terms of the amount of information that can be provided in the poster. An electronic poster can have multiple slides and hence have more space for information on the research project. When the electronic poster is displayed on the monitor, it will display each slide for a fixed amount of time and then move to the next slide. As such the number of slides should not be too many that will discourage a person from standing and reading about the research project. An alternative that is also used is computer-based setup for electronic posters. The person will select the desired poster to read and can move through slides at their own timing.

For both display options, limit the written words to a similar number that would be used in a printed poster and increase the number of figures and/or tables.

7.5.3 Online Conference Presentation

Online conferences are growing in popularity, and numbers of such conferences are increasing. There are advantages and disadvantages with the main disadvantage being the reduced opportunity for interaction and networking with other people in the field.

Oral presentations can be synchronous or asynchronous. A synchronous oral presentation is similar to an oral presentation at a face-to-face conference. A time slot for the presentation and the time allowed will be preset. The conference organizers will have a Zoom® meeting or similar already set up. The slides either can be uploaded to their site or can be only on your personal computer. Either way, the screen will be shared with attendees, and you will control the slides similar to that which would be done at a face-to-face conference. An opportunity exists with this approach if you want to use other programs that can, for example, display the data dynamically; a whiteboard can be used, and a drawing is done during the session or anything else that will enhance the delivery of the research story. Questions from the audience can also be asked via the moderator of the session. Typically, the presentation will be recorded so other delegates of the conference can watch the presentation at a later date.

An asynchronous is purely a recorded presentation and is uploaded to the conference website. The disadvantage of this for the audience is they cannot ask direct questions to the presenter.

All aspects of the preparation for such online conference oral presentations are the same as previously discussed for a face-to-face presentation. However, if asynchronous, you can get the opportunity to view the recording before uploading it to the website and redo the presentation if needed. For either approach, practice using a microphone or headset for speaking into a computer – for many people this can be a daunting experience on the first try. If pre-recording the presentation, when

reviewing the presentation, check the quality and volume of the sound (Wellstead et al., 2017).

Another disadvantage of such approach over a face-to-face presentation is that audience can either not see you or can only see your face. As such, non-verbal cues to the audience at best can only be facial expressions. That also means verbal cues such as speaking at an appropriate speed, changing the pitch of your voice, and not talking in a monotone voice and appropriate use of the computer mouse cursor become more important when other non-verbal cues cannot be seen.

7.5.4 Alternate Means of Research Dissemination

What has been discussed up to this point are the traditional methods of research dissemination, with a few modern tweaks. Given the expanding world of communication, there are other means of research dissemination that need some brief mention.

7.5.4.1 Websites

Previously mentioned is that websites can be used to convey information about research projects and the outcomes of the research. Websites can be as simple or complex as desired, providing a brief overview of the research similar to the amount of information in a poster or full details of the project and results that are more detailed than a journal article.

An advantage of such website is that search engines can find the sites and use the keywords in the metadata to help others find that site and information. The main disadvantage of this is that websites are not referee information and as such is classified as gray literature (see Chap. 4 for more details). A more common approach for web use in research projects is to use such a site for detailed information that cannot be included in a journal article. For example, this could be computer algorithms or coding that has been used in the research or the full dataset where only a concise or abridged version of the data could be included in the article, or other project information.

For small clinically based research projects, this approach is typically not used. However, the organization that has supported the research may have research pages on their website, and a brief overview of the project and a link to the journal or conference site can be added.

All these approaches will enhance the dissemination of the work that has been undertaken, and that, the spreading of the research outcomes, should be a major goal of all research.

7.5.4.2 Visual Abstracts

Research project visual abstracts are a brief overview of the research details, an abstract, however with the focus of providing that information primarily in a visual format. Visual abstracts are based on marketing and advertising campaign approaches; however, they are growing in areas like health where the research message needs to get beyond the profession to a wider audience of the general public. To have effective visual abstracts, using external expertise in developing visual campaigns is advised. While using such expertise, those experts still need significant input from the researchers as to what is the main message to deliver to that audience.

Visual abstracts can be static images or videos. Determining which is the best method will depend on the audience, the format for delivery and of course, and the budget for developing and disseminating the visual abstract.

A good visual abstract will still provide the reader, or viewer, with the key information and findings of the project. The title, like which has been discussed previously, must reflect the research findings and the project. Other information will be briefly provided and the take-home message of the research must be the focus of the visual abstract.

Visual abstracts can be a single page of printed information, for example, that is displayed in a pharmacy outlet, to inform the pharmacy customers of new approach that is being used. Visual abstracts can be dynamic and, for example, uploaded to YouTube where their search approaches will help interested people find the YouTube video. A key point when using a visual abstract though is that this information is considered gray literature and a reference to a journal article or other refereed information should be included (Nikolian and Ibrahim, 2017).

7.5.5 *Advanced Methods of Research Dissemination*

The dissemination methods discussed above are the common methods of turning research project information into an output that will be seen, read, and taken on board. There are however long research projects than those focused on this textbook that are conducted over several years such as Masters by Research and Doctor of Philosophy university degrees. The output of such degrees is a thesis, dissertation or in the case of more clinically based programs, an exegesis.

Textbooks, such as the one you are currently reading, are the synthesis of many sources of information of the topic and as such are mature information. While this chapter is not focused on these means of research information dissemination, some brief information should be included to provide a more comprehensive coverage of all methods of research dissemination.

7.5.5.1 Textbooks

Textbooks are written depending on the intended audience, as either an in-depth treatment of a focused topic, or as an overview of the general topic area or, such as this textbook, and are written as an overview of the topic and with a level treatment for students or those beginning in the field. All such textbooks are a synthesis of the relevant information and are based on existing knowledge in that field. As such textbooks should have many references for alternative views or more in-depth treatment of the topic. However, all textbooks should undergo a peer-review process to ensure the information is factual and relevant as well as written for the selected audience.

7.5.5.2 Thesis or Dissertation

Research students who undertake masters or doctorate level research, sometimes called higher degrees by research (HDR), have undertaken supervised independent research over a period of several years. The major output of a masters or doctorate program is a thesis or dissertation, or in the case of more clinically based programs, an exegesis; however, many such students will publish or present sections of their research in journals or at professional conferences. The thesis or dissertation is a highly detailed manuscript that has many sections, typically in chapters of the thesis, that include the following:

- An introduction to the research area.
- A comprehensive literature review of the research area and the research methodology(ies) used and identification of the gap in knowledge.
- Consideration of ethical issues.
- Full details of the data collection methods and how they are linked into the theoretical research methodology approaches.
- Full understanding of the data analysis methods used and a comprehensive analysis of the data collected.
- Linking of the data analysis to that knowledge found in the literature.
- Details of the theoretical and practical contributions that flow from the research.

A thesis or dissertation is only intended to be read by a very narrow audience. That audience is often only the research supervisors, the examiners of the research thesis or dissertation, and other research staff at the candidate's university. Synthesized and narrow aspects of the thesis are often used as the basis for more widely written or present research works.

7.6 Final Thoughts

Undertaking research is a rewarding exercise in that new knowledge is developed, alternative methods are tested, or new or revised methods are tried on new population groups. However, if this information is not made available for critique through a peer-review process nor if it is made widely available for the benefit of others, particularly in health for the benefit of the patients and hence general population, then the research was undertaken in vain. Don't let your research information sit inside a computer that is never seen by others.

If you are not a researcher and, like most health professionals, are a consumer of research information for the benefit of your patients, then please take note of the effort of others and time needed to get this information to you and your colleagues.

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Chapter 8

Examples of Published Research Studies in Medical Imaging: A Selected Review



Euclid Seeram, Rob Davidson, Andrew England, and Mark Mc Entee

The purpose of this chapter is to identify and describe briefly the eight examples of research studies published in the medical imaging literature, with a focus on the steps of conducting research described in this textbook. In this regard, therefore, the research studies identified will first state the title of the research and outline briefly each of the following: the purpose of the research; the research question, objectives, and or hypothesis; the literature review; the research design and methodology including data collection; the results; and conclusions of the study.

8.1 List of Research Studies

- *Study 1*: Example of a Descriptive Correlational Design in Radiography (*Euclid Seeram, PhD*)
- *Study 2*: Example of a Non-interventional Quantitative Cross-Sectional Survey Design Study of Radiologic Technologists in a Computed Radiography Environment (*Euclid Seeram, PhD*)
- *Study 3*: Example of a Literature Review (*Rob Davidson, PhD*)
- *Study 4*: Example of Descriptive Research and Relational Research (*Rob Davidson, PhD*)

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- *Study 5: An Example of a Retrospective Mixed Methods Analysis High Dose Alerts from a Radiation Dose Tracking Software (Mark McEntee, PhD)*
- *Study 6: An Example of Research Using Sensitivity, Specificity and Accuracy to Determine the Performance of a Radiographer Abnormality Detection (Mark McEntee, PhD)*
- *Study 7: An Example of a Randomized Control Trial in Computed and Digital Pelvic Radiography (Andrew England, PhD)*
- *Study 8: An Example of a Non-randomized Control in Digital Radiography and Methods for Managing Heterogeneous Groups (Andrew England, PhD)*

8.1.1 Study 1: Example of a Descriptive Correlational Design in Radiography

Seeram E, Davidson R, Bushong S, Swan H. Optimizing the exposure indicator as a dose management strategy in computed radiography. Radiol Technol. 2016;87(4):380–391.

This study used a *descriptive correlational research design* to investigate the optimization of a of the exposure indicator (EI) of a computed radiography imaging system as a radiation dose management strategy, in keeping with the International Commission on Radiological Protection (ICRP) radiation protection philosophy of as low as reasonably achievable (ALARA). The study compared the optimized EI with the manufacturer's recommended values for the anteroposterior (AP) pelvis and AP lumbar spine projections. One of the study's objectives was to correlate the milliamperere seconds (mAs) and associated EIs with the entrance skin dose using a range of mAs settings while holding the kilovoltage peak (kVp) constant.

The study used a non-interventional research approach to relate or associate variables in a predictable manner as opposed to an interventional approach, which is typical in experiments. The non-interventional approach used a correlational research method to measure the degree of association (or relation) between two or more variables using statistical procedures. Entrance skin dose and EI were the dependent variables, and mAs was the independent variable.

Researchers examined the measurement of the entrance skin dose for the AP pelvis and the AP lumbar spine using exposure technique factors including mAs and kVp that the manufacturer suggested. Researchers obtained the entrance skin dose measurements with a calibrated dosimeter (Unfors Instruments) free in air (i.e., an air environment free of any absorbing or scattering objects) for the AP pelvis and the AP lumbar spine. For all nine of the mAs settings, researchers calculated the mean milligray (mGy) per mAs setting for the AP pelvis and AP lumbar spine.

Descriptive statistics (e.g., such as sample size, mean, standard deviation, and range) was computed for the dosimetry and EI data. In addition, the Pearson correlation was applied to examine the relationship between the entrance skin dose and the EI as well as the dose and mAs. Data was graphed and plotted the mean dose for

the AP pelvis and the AP lumbar spine as a function of mAs. Furthermore, the inverse EI, the mAs, and the dose were compared. The inverse EI shows a strong positive linear relationship ($r = 0.999$) for both the AP pelvis and the AP lumbar spine.

At doses of 5, 10, and 20 mGy, the EIs were 400, 200, and 100, respectively. When researchers plotted the inverse EI as a function of mAs and plotted the dose as a function of the inverse EI, they saw a strong positive linear relationship ($r = 0.999$) in both cases. Instead of displaying the S number on an image (e.g., 100), the inverse S number (e.g., 0.01) should be displayed to better aid technologists in understanding the relationship between the dose and the patient (as opposed to the image plate) as well as the S number.

The results of this study show that technologists can optimize the dose and image quality in computed radiography imaging using the mAs exposure technique factor and associated EIs. Specifically, the dosimetry phase of this investigation showed a strong positive linear relationship ($r = 0.999$) between mAs and dose, mAs and the inverse EI, and the inverse EI and dose for the AP pelvis and AP lumbar spine. Under the controlled conditions researchers used in this study for dose optimization, the EI values were stable. The manufacturer’s reference values of 25 mAs (EI = 86) for the AP pelvis and 50 mAs (EI = 88) for the AP lumbar spine were optimized to 16 mAs for the AP pelvis (EI = 136) and 32 mAs for the AP lumbar spine (EI = 139). Seven expert observers, who have at least 10 years of experience teaching radiographic technique and positioning in classrooms, laboratories, and hospitals, performed an image quality assessment and determined that the manufacturer’s recommended dose can be reduced by 36% for the AP pelvis and AP lumbar spine without compromising image quality.

The study illustrates the use of the correlational research design to investigate a problem in digital radiography. The design is simple and robust. Researchers easily were able to analyze and interpret the statistics of the collected data to obtain results. The design allowed the researcher to objectively arrive at practical conclusions (Table 8.1).

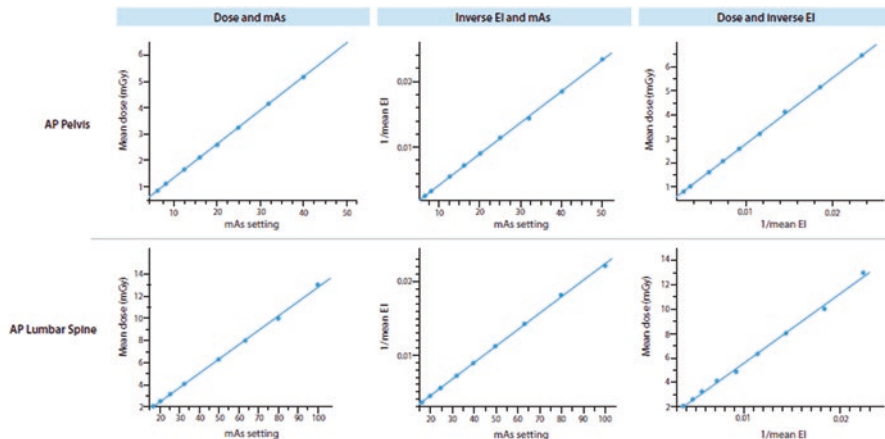


Table 8.1 Anteroposterior (AP) pelvis and AP lumbar spine image acquisition results (Courtesy of Euclid Seeram, PhD)

AP pelvis					AP lumbar spine				
mAs	Mean mGy	Els (S No.)	Mean mGy (S No.)	Inverse mean EI ^a	mAs	Mean mGy	Els (S No.)	Mean EI (S No.)	Inverse mean EI ^a
50	6.45	43	43	0.023	100	13	45	45	0.022
		44					45		
		44					45		
40	5.17	54	54	0.018	80	10	57	55	0.018
		55					55		
		54					55		
32	4.14	71	69	0.014	63	7.98	71	70	0.014
		68					71		
		68					70		
25 ^b	3.24	88	86	0.011	50 ^b	6.36	88	88	0.011
		86					90		
		84					88		
20	2.60	108	108	0.009	40	5.09	110	110	0.009
		108					110		
		108					110		
16	2.09	136	136	0.007	32	4.07	139	139	0.007
		136					139		
		136					139		
12.5	1.63	175	175	0.005	25	3.19	179	179	0.005
		175					179		
		175					179		
8	1.06	277	277	0.003	20	2.56	220	220	0.004
		277					220		
		277					220		
6.3	0.83	357	357	0.002	16	2.05	277	277	0.003
		357					277		
		357					277		

All images were obtained at 81 kVp

^aThe mean exposure indicator (EI) for 3 images obtained at each milliamperere seconds (mAs) setting

^bReference exposure techniques

8.1.2 Study 2: Example of a Non-interventional Quantitative Cross-Sectional Survey Design Study of Radiologic Technologists in a Computed Radiography Environment

Seeram E, Davidson R, Bushong S, Swan H (2015) Education and Training Required for the Digital Radiography Environment: A Non-interventional Quantitative Survey Study of Radiologic Technologists. *Int J Radiol Med Imag* 2: 03. doi: [https://](https://doi.org/10.1155/2015/123456)

doi.org/10.15344/ijrmi/2015/103

The *purpose of this research* was to explore the physics and technology knowledge components of CR, as well as the confidence and attitudes of technologists in using the CR imaging system in clinical practice.

The *literature review* found only two research studies that investigated education and training issues in digital radiography. These studies were lacking specifically in areas relating to CR Physics and Technology knowledge components; the use of CR technology in practice; confidence in using the CR imaging system in practice; attitudes toward CR use in practice and specific use of the EI in practice.

The *ethics approval* for this study was obtained by the Ethics in Human Research Committee, Charles Sturt University (CSU). In addition, the following statement was written on the questionnaire:

... By completing this survey, you will have provided us with your consent to use your responses for this research. Please be ensured that any information or personal details gathered from this survey are confidential, and that neither your name nor any other identifying information will be used, or published without your written permission.

The *research design* used is a *non-interventional quantitative cross-sectional survey design*. The methodology employed *snowball sampling (non-probability sampling)* and an online survey questionnaire which was administered from a *purposeful (convenient) sample* of 103 diagnostic technologists who routinely perform CR imaging in hospitals in British Columbia (BC).

The data collection for the survey study used an instrument to capture data on the degree of knowledge of CR physics and technology and the level of confidence and attitudes of radiographic technologists in using CR systems for imaging adult patients in clinical practice.

The survey questionnaire was pilot-tested and subsequently revised and was prepared for online electronic distribution using the Vovici survey software (www.vovici.com).

Since a questionnaire could not be found in the literature that reported validity, face validity for this particular instrument was obtained by asking three expert digital radiography physicists to review it, and all agreed that it met the validity requirement for this study. To measure the reliability, Cronbach's alpha is used, and it has become the most widely used objective measure of reliability. Cronbach's alpha was used to provide a measure of the internal consistency of the survey instrument used in this thesis. Such consistency indicates the extent to which all items on the instrument measure the same concept or construct and hence it is connected to the inter-relatedness of the items....reliability estimates show the amount of measurement error.... This error is the correlation of the test instrument with itself. If this correlation is squared and then subtracted from 1.00, the result is the index of the measurement error. Cronbach's alpha is expressed as a number between zero and one. Tavakol and Dennick, provides a simple example to calculate the alpha. They note that if a test has a reliability of 0.80, there is a 0.36 error variance (random error) in the scores ($0.80 \times 0.80 = 0.64$; $1.00 - 0.64 = 0.36$) (p 53). Acceptable alpha values may range from 0.70 (acceptable) to 0.95 (excellent). All descriptive statistics were

calculated using the SAS statistical package. Furthermore, the written responses to the last question (number 15) on the survey questionnaire is as follows:

The *results* of the survey study showed that the *response rate* was 69% and that most of the respondents were mostly females above 40 years old, who indicated that their CR education/training was provided by the vendor for less than 2 hours. The *degree of knowledge of CR physics and technology* varied from no information to little information on selected topics listed on the questionnaire. The analysis of variance (ANOVA) statistics showed that there was no significant difference between the variables of *age, education level, years of working in CR, hours and method of CR education received; on confidence and attitudes in using the system in practice*. With respect to the use of the EI in practice, the overall ANOVA test was significant, but the analysis failed to detect a difference between the levels of education/training received.

The third useful insight relates to the knowledge gaps identified in the survey study. The survey results provided a clear view of the various topics needed for an understanding of the physics and technology of CR imaging. These topics could be used to a “curriculum” for CR at the technologist level. The final insight offered by the results of this study is that even though factors such as age, method, and hours of CR education/training and experience in working in CR imaging did not have a statistical significance on the confidence and attitudes in using the CR system, a good understanding of the knowledge components of CR identified herewith can only lead to a wise and effective use of the CR imaging system in clinical practice.

The *conclusions* drawn from this research demonstrate that a knowledge gap in CR education/training is clearly apparent and that variables such as age, method, and hours of CR education received, as well as experience in working CR, did not have a statistical impact on confidence and attitudes in using the system in clinical practice.

8.1.3 Study 3: Example of a Literature Review (Rob Davidson, PhD)

Wilson-Stewart K, Shanahan M, Fontanarosa D & Davidson R, *Occupational radiation exposure to nursing staff during cardiovascular fluoroscopic procedures: A review of the literature, Journal of Applied Clinical Medical Physics*, DOI: <https://doi.org/10.1002/acm2.12461>, 2018

Abstract

Fluoroscopy is a method used to provide real time x-ray imaging of the body during medical procedures to assist with medical diagnosis and treatment. Recent technological advances have seen an increase in the number of fluoroscopic examinations being performed. Nurses are an integral part of the team conducting fluoroscopic investigations and are often located close to the patient resulting in an occupational exposure to radiation. The purpose of this review was to examine recent literature,

which investigates occupational exposure received by nursing staff during cardiovascular fluoroscopic procedures.

Articles published between 2011 and 2017 have been searched and comprehensively reviewed on the referenced medical search engines. Twenty-four relevant studies were identified among which 17 investigated nursing doses comparative to operator dose. Seven researched the effectiveness of interventions in reducing occupational exposure to nursing staff. While doctors remain at the highest risk of exposure during procedures, evidence suggests that nursing staff may be at risk of exceeding recommended dose limits in some circumstances. There is also the evidence of inconsistent use of personal protection such as lead glasses and skull caps by nursing staff to minimize radiation exposure.

Conclusions: The review has highlighted a lack of published literature focusing on dose to nurses. There is a need for future research in this area to inform nursing staff of factors, which may contribute to high occupational doses and of methods for minimizing the risk of exposure, particularly regarding the importance of utilizing radiation protective equipment.

This article is an example of a literature review that was used for the evidence of the need for and the basis of later research. The introduction section of the article provides some background to the issue being reviewed; in this case, the growth of fluoroscopic investigations and the fundamental radiation protection goal of as low as reasonably achievable (ALARA) support staff radiation dose and the specific concern of dose to the orbits during fluoroscopy examinations. This introduction section also provided an overview of concerns that the literature review would address.

Search details, such as date searched, were stated early so the reader was provided with the context of the currency and relevance articles found and reviewed in the literature. As described in Chap. 4, the search strategy, inclusion, and exclusion criteria were discussed and provided as flow diagram. Areas of focus of the search and evaluation were also provided against each selected article as a table. The readers could then easily determine where the relevant information was located and, if needed, integrate those articles at a greater depth.

In this example, the areas of focus were radiation dose monitoring, effects of the equipment and staff location, lead shielding, eye dose, imaging parameters, and staff education. The discussion section brought together these areas and focused on the area that was relevant to the future research.

The article also highlighted area of concern, namely, the lack of research that has been undertaken in the area of radiation dose to nurses during fluoroscopy procedures. While this area of focus was used to justify further research, some initial recommendations from the literature review were made recommending provide adequate shielding departmental management to provide options to ensure that occupational radiation dose is kept as low as reasonably achievable.

8.1.4 Study 4: Example of Descriptive Research and Relational Research (Rob Davidson, PhD)

Gibson D and Davidson R, Exposure Creep in Computed Radiography: A Longitudinal Study, *Academic Radiology*, Vol. 19(4), pp 458–462, 2012

Abstract

Purpose: Exposure creep is the gradual increase in X-ray exposures over time that results in increased radiation dose to the patient. It has been theorized as being a phenomenon that results from the wide-exposure latitude of computed radiography (CR) and direct/indirect digital radiography (DR). This project evaluates radiographic exposures over 43 months to determine if exposure creep exists and if measures can be applied to halt or reverse exposure creep trends.

Methods: Exposure indices were initially recorded over 29 months between August 2007 and December 2009 from the intensive and critical care unit (ICCU) and the emergency department (ED) departments where manual CR exposures were used. The data from this period were then assessed, and the exposure indexes (EI) values from the radiographic images were compared with the radiology department criteria of EI values between 1400 and 1800 as being in the optimal exposure range. EI values below this were considered underexposed and over this as overexposed. An intervention was required to be used in ICCU and implemented in January 2010 to halt a noted trend of overexposure. The EI value for each chest X-ray (CXR) was recorded in the patients' ICCU records and was to be used by radiologic technologists/radiographers to determine exposure factors in subsequent CXR. After the intervention, EI values were recorded and evaluated for an additional 15 months between February 2010 and March 2011.

Results: Between August 2007 and December 2009, 17,678 ICCU CXR images and 69,327 ED X-ray examinations were evaluated for over- and underexposure. A trend was noted in ICCU that showed a significant increase ($P = 0.023$) in EI values from the beginning to the end of the evaluation. No such trend was seen in the ED EI values ($P = 0.120$). After the intervention in ICCU, the overexposure trend was halted.

Conclusions: Exposure creep has been shown to exist. It is surmised that this occurs where judgment to determine the correct radiographic exposure factors is needed when taking into account a large range of patient sizes. It has also been shown that providing radiologic technologists/radiographers with previous EI values for the same X-ray examination can halt a trend of exposure creep.

This is an example of a research project with two phases. The first phase was designed to answer a descriptive research question. The second phase was included to then answer a relational research question. In both phases, the research project was undertaken over an extended period of time, hence the wording of a longitudinal study. The questions in the two phases were as follows:

- Whether exposure creep, when using manual radiographic examination exposures, existed as had been theorized in the literature.

- If exposure creep existed, could it be stopped and/or reversed?

This study was the first to show that exposure creep existed, and could be halted and potentially reversed. Exposure creep, also known as dose creep, is the gradual acceptance over time by radiographers/radiologic technologists of the use of higher radiographic exposure techniques for the same planar X-ray examination projection in digital radiography (DR). The phenomenon means that over time doses, to the patient for that examination, increase and are greater than what is needed for an acceptable diagnostic image. The phenomenon had been theorized by many authors in journal articles principally based on their observation, and that DR systems have a linear response to the amount of radiation reaching the DR receptor.

Gibson and Davidson, in the descriptive phase of their study, showed that exposure/dose creep occurred where manually set X-ray exposure parameters were being used. Prior to the study, they determined the exposure index (EI) range of values for an optimal exposure, an over exposure, and an under exposure. Over 17,000 mobile chest X-ray (CXR) EI from the intensive and critical care unit (ICCU) over a 26 month period were reviewed and categorized. It was shown that over exposure index values for CXR increased over time, and this was shown to be a statistically significant increase. Figure 8.1 shows the monthly optimal, overexposure, and underexposure EI values as percentages of the total monthly figure.

An intervention was then planned and implemented. The intervention was that radiographers were required to document the EI of the CXR and other typically documented exposure parameters of kVp, mAs, and SID. The EI of ICCU CXR was further reviewed for an additional 13 months following the implementation of the

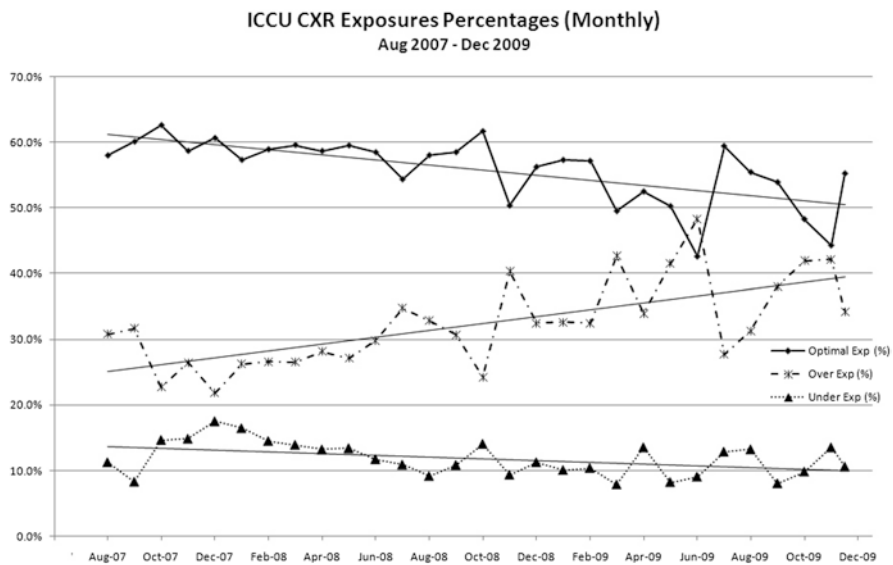


Fig. 8.1 Plot showing the over- and underexposure trend of CXR in ICCU over a 26 month period. (From Gibson and Davidson, 2012, with permission)

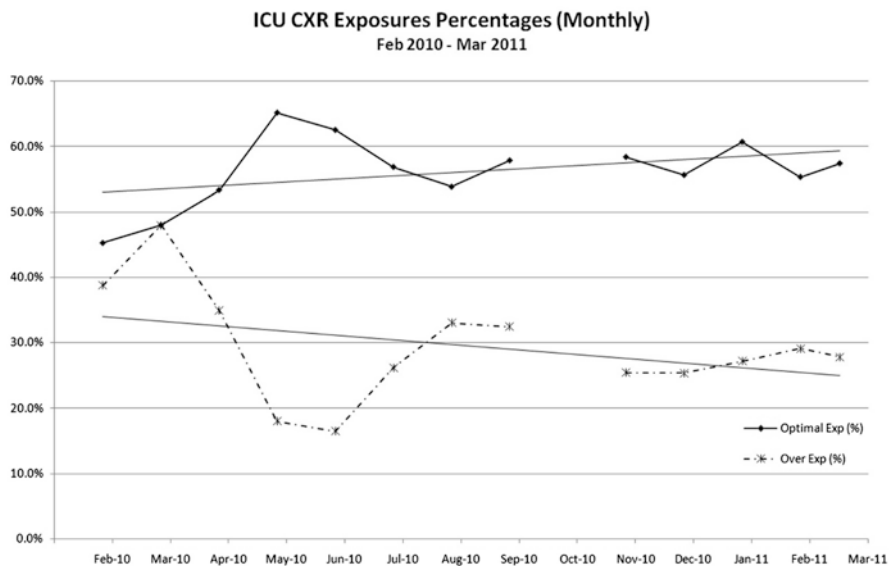


Fig. 8.2 Plot showing the halt of over exposure trend of CXR in ICCU over a 13-month period. (From Gibson and Davidson, 2012, with permission)

intervention. The over- and underexposure trends are shown in Fig. 8.2, while Fig. 8.2 trend plots show an increase in optimal exposure percentages and a reduction of over exposure, changes from the start to the end of the review period could not be shown to statistically significant. The statistics however did show that there was no increase in over exposure and hence the conclusion could be made that the over exposure was halted.

This work is also an example of where a local departmental concern has led to significant research being conducted. At the time of writing this chapter, late 2020, the article by Gibson and Davidson had been cited in 43 later journal articles.

8.1.5 Study 5: Example of a Retrospective Mixed Methods Analysis (Mark McEntee, PhD)

Study 1: An example of a retrospective mixed-methods analysis high dose alerts from a radiation dose tracking software. The study has examples of descriptive statistics, boxplots, true alerts (true positives), false alerts (false positives), and user feedback.

The paper was published in the journal “Radiography” in 2021 and was entitled “Radiation dose tracking in computed tomography: Red alerts and feedback. Implementing a radiation dose alert system in CT” (Crowley et al., 2021).

8.1.5.1 Background

The purpose of this study was to investigate the effect of the implementation of a radiation dose tracking software into the CT department of a large teaching hospital. The study aimed to investigate the causes of red alerts (high dose alerts) issued by the software, determining the veracity of the red alerts. Furthermore, it is to investigate the effect of implementing a radiographer feedback tool on the red alerts in order to assess radiographers' opinions about the veracity of the alert and have radiographers assign a cause to them.

A non-systematic, or *narrative literature review* was carried out. The review established that there are legal imperatives on radiology departments to establish diagnostic reference levels and to use them to help optimize radiation dose to patients. It also established that there are several dose monitoring software that are available on the market; these include dose watch (GE health care), dose wise (Phillips), team play (Siemens), dose track (sector), dose monitor (PACS health), and open-source packages such as open REM.

The review also established that the implementation of these systems into clinical practice is a challenge; an understanding of how information on high doses is fed back into the system and is investigated represents a significant challenge to clinical workflow and hospital governance. The questions that arise during clinical implementation of such systems include the following: (1) Is the dose reported actually accurate? (2) The dose might be high, but what was the cause of this high dose? and (3) What are the consequences of this high dose?

In this study, the authors implemented a system of triaging the alerts from the system into the following:

1. True alerts, unjustifiably high doses. These are likely to be the first sign of a system or protocol error.
2. False alerts high radiation doses that were acceptable once investigated due to clinical reasons such as large patient size, or scanning parameters selected purposely to reduce noise.

Insight

The narrative literature review method is as convenient way of assessing the literature in an area. It does have its advantages in being convenient, efficient, and focused. However, without a systematic method of searching the literature, the literature search can have bias introduced. The authors search for papers that are related to the subject but may choose papers that suit the narrative of their introduction and ignore papers that do not suit. There is also a problem when the literature is not systematically searched, the papers related to the topic might not be found. The danger here is that the researcher can progress with their methodology, not knowing that other researchers have previously published in this area and perhaps answered the research question or hypothesis.

8.1.5.2 Method

The study gained ethical approval from the Human Research Ethics Committee (HREC), and data was collected during two six-month periods, separated by one year. The 1 year of separation was necessary to implement the radiographer feedback system for red alerts.

During the first 6 months of the study, the data was gathered without any intervention from the radiographers. The dose watch system monitors and archives the doses related to the scanning parameters and the associated study descriptions. The software automatically calculates diagnostic reference levels (DRLs), as per the legal requirements in Europe. The red alerts within the system can be established by the user and in this case were triggered when a patient received twice the *median* dose length product (DLP) during a CT scan.

During the second 6-month period, radiographers gave feedback on the red alerts. Radiographers devised a list of potential causes of high-dose and were asked to select a cause for each of the CT red alerts. A radiology lecturer and radiology fellow also assessed the cause of the red alert, and a consensus conclusion was arrived:

- A red alert was considered to be true if the high dose could not be associated with known factors such as patient size, incorrect labeling of the study, required repeated examinations, arms by the side of the patient, or foreign bodies.
- An alert was considered to be false if the high dose could be attributed to a justifiable cause. With the exception of arms by the side, this positioning the patient was not considered a factor that justified a false alert.

The data analysis used both descriptive statistics and inferential statistics. Descriptive statistics was used for continuous variables and for categorical variables. A chi-square test was used to assess if there was a difference in the red alerts before and after the introduction of the radiographer feedback tool.

Insights

When trying to compare two six-month periods in this fashion, it is important to consider whether there were any substantial differences in the patient populations at those two times. Back in 2014–16, the idea of a global pandemic was far from people's minds. In retrospect, this methodology had a risk; the initial 6-month period might have had a very different cohort of patients from the second 6-month period. Thankfully this was not the case. In future work, I do believe it would be methodologically wise to reduce the gap between the periods assessed.

The hypothesis here arose from the clinical insights of the radiographers working with radiologists in the CT Department. The purchase of software is something not to be taken lightly. Software in a hospital has to be tested, it has to be compliant with relevant legislation, and it needs to be supported, so, when the software is introduced, it needs to be used. The red alerts being produced by the system were

critiqued by the radiographers, and because they were producing alerts for doses that the radiographers saw were justifiable, it was possible that the red alerts would begin to be ignored. By introducing a system to allow the radiographers to give their opinion on the red alert and to assign a cause to the red alert, not only the system did become more useful but also it became a tool for reflection on practice. Having the radiographers involved as well, resulted in authorship for the radiographers, one of whom has now moved into the field of academia.

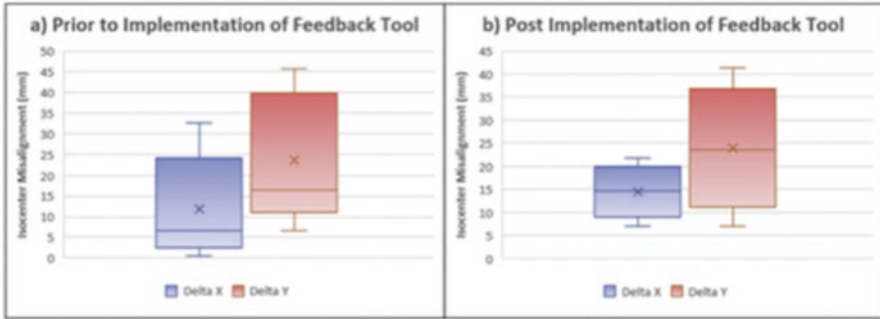
8.1.5.3 Results

As the red alert software is producing dose reports for every examination that takes place, this type of methodology results in a large sample size. There were 11,298 CT examinations included in the study, 4368 in period 1 in 6930 in period 2. During period 1, there were 206 red alerts and 357 during period 2. However, only 17% of these had feedback from the radiographers in the second period. Almost all of the feedback from the radiographers was given via selecting a reason for the high dose from the drop-down menu. Only four radiographers entered any text in the free text box.

An independent samples t-test was used to compare the number of red alerts during the first period and second period. Overall, no significant difference was found between the two groups ($p = 0.3$). However, the large sample size allowed substratification of the sample, and when CT pulmonary angiography and CT brain examinations were investigated, it was found that the number of red alerts had decreased significantly ($p < 0.001$) after the introduction of the radiographer feedback system, while the number of red alerts for the CT thorax and abdomen and pelvis increased significantly ($p < 0.004$).

The analysis of the radiographers feedback on the agreed true alerts for both periods ($n = 10$) allowed for insight into the causes of higher doses. These included patient kyphosis not being accounted for in positioning, patient hemothorax increasing dose modulation, scanning beyond desired anatomy, and increased kVp with no rationale. After discussion with the radiographers, only 1 of the 10 true alerts was unexplained. False alerts from the system could be explained commonly by larger patient size, extra studies, and misalignment with the isocenter.

Box plots were used to explore one of the major causes of true alerts during period 1 and 2. In the box plot below, we get a quick visual of the measures of central tendency and the variance after samples of delta X and delta Y. This finding in the study was one that raised some ideas for further work. There is little evidence to suggest what would be an acceptable margin for error in the alignment of the patient. Although misalignment appears to be related to the number of red alerts, assigning a false alert or true alerts was not possible without some criterion for what the margin of error is. This observation based on the descriptive data is something that would require further study.



Insight

The computed tomography department is always one of the busiest departments in radiology. Even though the radiographers were provided with a dedicated computer for entering the feedback on the red alert system, many did not. A study like this is difficult to perform in the clinical environment, as the patient will always be the priority. There are patients on the table, patients waiting to come into department, phones ringing with clinicians wishing to discuss patients to be scanned, and patients who have yet to be scanned. It is a hive of activity; introducing a new activity into this workflow will always be challenging. There was very little input from the radiographers in the free text format. Thus, it meant only qualitative analysis of the red alert system was not possible. To enhance the mixed methods aspect of this work, a focus group or an interview with the radiographers involved with identifying and classifying red alerts may have added extra insight

Reference

Crowley, C. et al. (2021) 'Radiation dose tracking in computed tomography: Red alerts and feedback. Implementing a radiation dose alert system in CT', *Radiography*. W.B. Saunders Ltd, 27(1), pp. 67–74. doi: <https://doi.org/10.1016/j.radi.2020.06.004>.

8.1.6 Study 6: Example of Research Using Sensitivity, Specificity and Accuracy to Determine the Performance of a Radiographer Abnormality Detection in Singapore (Mark McEntee, PhD)

This paper was published in 2021 in the journal radiography and is entitled "Accuracy of radiographer comment following a 2-month experiential and blended learning in appendicular skeleton X-ray interpretation: The Singapore experience" Del Gante, E. et al. (2021) 'Accuracy of radiographer comment following a 2-month experiential and blended learning in appendicular skeleton X-ray interpretation:

The Singapore experience', *Radiography*. W.B. Saunders Ltd, 27(1), pp. 43–47.
doi: <https://doi.org/10.1016/j.radi.2020.05.010>.

8.1.6.1 Background

In Singapore radiographers began digitally annotating abnormalities on emergency X-ray images, this developed into a radiography abnormality detection service. This is a radiographer's description of the abnormality and is not intended to be communicated to the referring physician and is not intended as a full and final radiologist report. Rather, this written description of the abnormality is communicated to other health professionals in the emergency department. This serves to reduce the chance of a patient being sent home with an undetected injury. The radiographers did not undergo any formal university training but rather undertook a blended education experience with a combination of in-house lecturers, auditing of practice, and experiential learning.

A narrative literature review established the fact that there were many radiographers reporting on radiographs globally, with the United Kingdom leading in regard to this advanced practice. Radiographers in the United Kingdom typically undergo at 12–18 month postgraduate educational program in image interpretation.

This study was carried out to investigate the performance of Singaporean radiographers in abnormality detection and to compare their performance with already established and published statistics from around the world. It also aimed to establish whether radiographers retained their performance over time.

Insight

In the evolution of radiographer reporting, it has been common for practice to emerge from clinical needs. In the United Kingdom, the clinical need often emerged from the lack of radiologists available in the health service. Often advanced practices would emerge in hospitals and health districts that were not in the capital city, or in regional capitals, rather advanced practice established itself first in the regions and in those services that most suffered from the lack of radiologists.

In the case of this study, the need for the radiography abnormality detection service arose from a gap in the service rather than from a lack of radiologists. Radiology has never been under as much pressure as now. Imaging services have expanded hugely; there are new modalities and new demand. The number of images being read by radiologists has increased exponentially. "Hot reporting" or "wet reporting" by radiology is often no longer possible due to demands of other imaging modalities. So, radiographers are stepping into that gap, to provide emergency clinicians who may not be expert in the interpretation of musculoskeletal radiographs, with a comment on the image that may be helpful in determining the path of treatment. Once the practice had emerged, the question of whether or not the radiographers were accurate resulted in this research paper. It is important to note that advanced

practice often precedes the evidence base, but the evidence base supports the ongoing development and sustainability of the advanced practice.

8.1.6.2 Methods

The reporting data from 13 radiographers was assessed. Each of these had undergone a combination of experiential learning, reflection on practice, auditing, in house lectures, online training, and self-directed learning.

These radiographers worked in the emergency department and assessed radiographic images on a diagnostic quality monitor. If they detected an abnormality, they inserted their comment describing the abnormality and save this as a new image to PACS. If no abnormality is detected, the radiographer annotates the image to indicate it has been assessed. These images are then reported by the radiologist. The radiologist report is taken as the truth. All reports are checked against the radiologist report and evaluated for accuracy. For each radiographer, the number of true positives, true negatives, false positives, and false negatives was calculated. For each radiographer and for all radiographers combined, *sensitivity*, *specificity*, *accuracy*, and prevalence and error rate were calculated using MedCal®. Radiographers were grouped into two groups, those that had commented on more than 1200 images and those that had commented on less than 1200 images.

The average sensitivity specificity, accuracy, and prevalence were calculated for each radiographer. The *95th confidence interval* of the mean was also calculated. This gives the reader an indication of the measure of central tendency and also how confident we can be in that measure. The two groups were then compared using an independent samples t-test. A comparison of the first 9 months and the second 9 months was carried out using a paired samples t-test. For the comparison over-time, false positive rate, false negative rate, and error rate were also calculated.

Insight

You might find it interesting to note that the accuracy data here was compared using parametric statistics. The initial sample of data is in the form of a true positive, false positive, false negative, and true negative. This data might not be normally distributed; however, the data that used sensitivity, specificity, accuracy, and prevalence comes from thousands of cases read by each radiographer. The central limit theorem is a theorem about independent random variables and says that the probability distribution of the average of independent random variables will converge to a normal distribution; thus parametric statistics can be used here.

Choosing independent samples t-tests make sense to compare one group with the other, because the same radiographers were not in Group 1 and Group 2. Choosing a paired sample t-test makes sense to compare the first 9 months with the second 9 months, because it is the same radiographers are in the first and second 9 months.

The paired samples t-test is a more powerful statistical test because the underlying assumption is that there is little variability in the subjects of the test.

8.1.6.3 Results

Overall, the results demonstrated that the radiographers were correct in their interpretation for 97% of the images reviewed. This was comparable or better to the benchmarks in the literature. The results are presented as a combination of descriptive and inferential statistics. The mean specificity, sensitivity, accuracy, and prevalence are presented as a table. The authors found no differences in diagnostic performance between the groups with less than or more than 1200 comments made (sensitivity [$p = 0.69$], specificity [$p = 0.51$], and accuracy [$p = 0.69$]). This indicated that the number of cases commented on did not have a significant impact on the accuracy of the comments.

The comparisons between the first and second 9 months are reported with p -values indicating the difference between the groups. Again, they found no differences in any of the performance metrics assessed between the two nine-month time periods (sensitivity [$p = 0.74$], specificity [$p = 0.38$], accuracy [$p = 0.96$], false positive rate [$p = 0.29$], false negative rate [$p = 0.56$], and overall error rate [$p = 0.588$]). This indicated that the radiographers' accuracy did not decrease or increase overtime.

8.1.6.4 Discussion

The paper then compares the reported accuracy of the Singaporean abnormality detection service to other published work. Comparison with other works was facilitated by international standardization of what is understood by sensitivity, specificity, accuracy, and error rates as well as false positive rates and false negative rates. There are a few other papers that demonstrate the same high level of accuracy from radiographer commenting.

The high level of accuracy in the work was attributed to a combination of the utility of the knowledge gained during training, the experiential self-directed learning and blended learning approaches, the real-life clinical setting possibly mitigating the laboratory effect, and substantial clinical follow-up to assess radiographers ability combined with continued professional development in image interpretation.

Insight

This study does not have a control group; however, comparisons are generated within the group by creating stratifications in the sample. Group 1 had less than 1200 and was compared with group 2 who had more than 1200 comments made. This is an arbitrary line in the sand but facilitates the investigation of causal links

with performance. Likewise, the first 9 months is used to compare the second 9 months. The alternative hypothesis here is that the performance does not change, and the authors accept the alternative hypothesis.

8.1.7 Study 7: Example of a Randomized Trial in Radiography (Andrew England, PhD)

Harding L, Manning-Stanley AS, Evans P, Taylor EM, Charnock P, England A. *Optimum patient orientation for pelvic and hip radiography: A randomized trial. Radiography* 2014; 20:22–32.

This study used a randomized experimental design to evaluate two automatic exposure chamber (AEC) orientations employed during pelvic radiography. Patients were randomized to undergo either computed radiography (CR) or digital radiography (DR) and placed into a group where the two outer AEC chambers would be closest to the patient's head (HT) or where the two outer AEC chambers were closest to the feet (HA). Patients were eligible for inclusion if there were ≥ 18 years old and were referred for pelvic radiography in the absence of acute trauma. Sample size calculations, based on data acquired from anthropomorphic phantoms, indicated that a minimum of 32 patients would need to be randomized into each of the four groups (CR-HT, CR-HA, DR-HT, and DR-HA). Sample size calculations are important when including patients or human volunteers as it would be unethical to over- or under-recruit.

The study authors reported a simple approach to randomization, and although such a method is generally superior to non-randomized methods, alternatives to this "simple" approach could have been advantageous. For example, the numbers of patients examined by CR and DR were different (117 vs 147); this was also the same for the numbers of patients examined in the HT and HA orientations (118 vs 146). Block randomization might have been a more suitable option as it would have ensured equal numbers in the four experimental groups.

The authors stated that baseline parameters, including gender, age, weight, and anteroposterior thickness, were not statistically different between the four groups. This is important as some of these factors could have potentially influenced the dependent variables of radiation dose and image quality. One important consideration is that a lack of statistical significance could, in some instances, be attributed to an insufficient sample size. *P* values are an important indicator of statistical significance, but this must also be considered alongside an appropriate measure of the central tendency (mean/median) and dispersion (standard deviation/interquartile range) of the relevant variable. As can be seen from Table 8.2, there were some slight variations in weight and patient thickness between groups.

The authors commented that post hoc data stratification was undertaken to attempt to correct for two projections being labeled under a generic "pelvis X-ray examination." One option was a full view of the pelvis (Fig. 8.3); superiorly this

Table 8.2 Summary of randomization and baseline variables

Group	DR-HA	DR-HT	CR-HA	CR-HT	P value
No. of patients	83	64	63	54	
Men	46%	34%	33%	40%	>0.05
Age, years	65 ± 13	66 ± 15	65 ± 15	64 ± 17	>0.05
Weight, kg	83.4 ± 17.7	77.9 ± 17.1	76.4 ± 18.3	76.5 ± 20.4	>0.05
Patient thickness, cm	22.5 ± 4.7	22.0 ± 3.6	18.3 ± 7.0	18.3 ± 6.4	>0.05

included the iliac crests and inferiorly the lesser trochanters. A second option was a low centered pelvis; this included more proximal femora and was typically used to evaluate the hip joint either pre- or post-operatively. Post hoc analyses and stratification are valid and well reported options for considering heterogeneous datasets. One further option would have been to use a stratified random sampling approach and include a *true pelvis* and *pelvis for hips* as individual projections within the randomization. This would appear to be logical in that when using an AEC inferior, centering is likely to result in a lower radiation dose and could affect image quality.

Within the study, radiation dose was assessed using the parameters of entrance surface dose and effective dose. Image quality was determined by a pool of observers and rated using an absolute grading scale, which considered eight individual anatomical points. One of the strengths of the study was that the observations between observers (inter-rater) were compared statistically using an intraclass correlation coefficient (ICC). This was a useful determinant of whether all observers were making similar judgments regarding radiographic image quality. Coefficients can be difficult to interpret in isolation and to help Rosner (2005) provided a grading system for interpreting ICC values (Table 8.3).

8.1.8 Study 8: Example of a Non-randomized Trial in Radiography (Andrew England, PhD)

England A, Evans P, Harding L, Taylor EM, Charnock P, Williams G. *Increasing Source-to-Image Distance to Reduce Radiation Dose from Digital Radiography Pelvic Examinations. Radiol Technol* 2015;86(3):246–56.

This study used a non-randomized prospective experimental design to evaluate two source-to-image distances (SID) employed during pelvic radiography. A total of 97 consecutive patients were initially imaged at a standard 115 cm SID, and then a further 99 patients were examined using the same equipment/acquisition parameters but using the maximum achievable SID (135 to 144 cm). For each examination, tube potential, milliamperere seconds, SID, and source-to-skin distances were recorded. This facilitated the calculation of entrance surface dose, including backscatter, and effective dose. The resultant images were independently assessed for image quality by three blinded observers (two radiographers and one radiologist). Image quality was graded using an established scoring system, which assessed

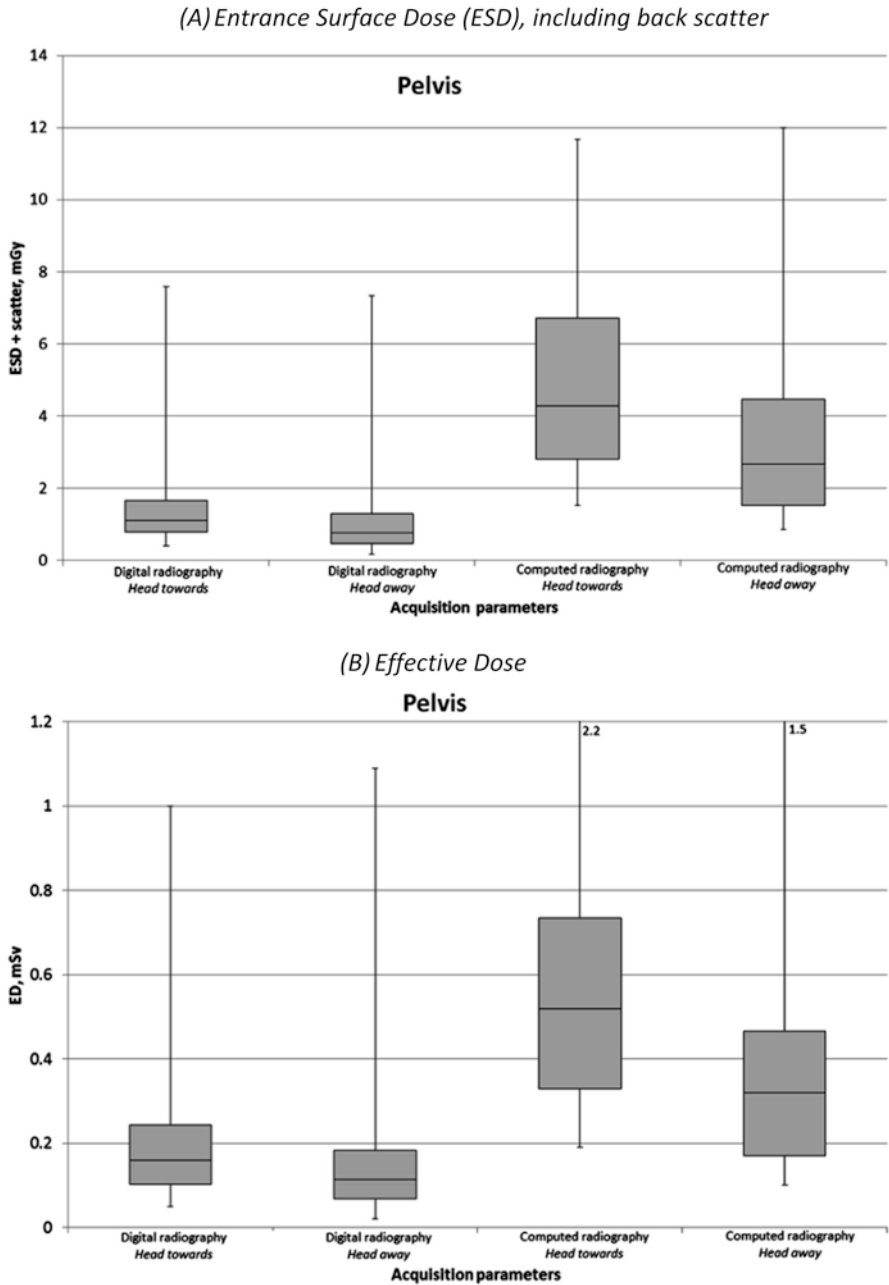


Fig. 8.3 Box and Whisker plot illustration of (a) entrance surface dose and (b) effective dose for “true pelvis, including iliac crest” projections. (a) Entrance surface dose (ESD), including back scatter. (b) Effective dose (from Harding et al., 2013, with permission)

Table 8.3 Interpretation of intraclass correlation (ICC) values according to Rosner (2005)

<0.4	Poor
0.4–0.75	Fair to good
0.76–1.00	Excellent

image quality at multiple anatomical locations. This approach follows the methods for a quasi-experimental study design. This can be a useful technique, especially if the standard SID group data were available retrospectively, as standard clinical practice. If this was the case, then this could speed up data collection in that only the extended SID group data would need to be collected. Due to the nature of the variables required for the analysis, especially radiation dose, a combined retrospective–prospective approach was not feasible. A randomized study design could have been more favorable in that both the standard and extended SID groups could have been recruited simultaneously. This would have also reduced the risk of heterogeneity between the SID groups. Further within the manuscript, the authors did later acknowledge that this was an issue.

For the standard 115 cm SID group, median (interquartile range) entrance surface dose was 1.95 (1.23 mGy–3.10) mGy, which was statistically lower ($P < 0.001$) by 1.15 (0.78 mGy–2.22) mGy for the increased SID group. Effective dose calculations generated a median (IQR) of 0.32 (0.13–0.52) mSv for the standard SID and a lower median of 0.19 (0.13–0.37) mSv for the extended SID group and was statistically significant ($P < 0.001$). No observers (intraclass correlation coefficient = 0.675) found a significant change in image quality by increasing SID (2.0 ± 1.8 vs 1.6 ± 1.4 ; $P > 0.05$)

There were several challenges when interpreting the results of this study. Groups were not homogenous in terms of patient characteristics. Ideally, as stated, the authors would have benefited from using a randomized study design where hopefully equal patient types will have been split between the two randomization groups. With patient weight being a key covariate, the authors could have further considered a stratified randomization process with equal patients across the different BMI ranges between the two groups. With the data already having been collected, the authors were faced with a challenge of managing the differences between the two groups. One option was to take any relevant covariates into account during analysis. This approach relies on several assumptions: (1) data on the relevant covariates were collected during the study and (2) there are accepted statistical methods available. Additionally, for the maximum SID, group 22 patients were imaged at 135 cm and 77 patients at 144 cm. Differences in the maximum SID would have also create a further confounding variable.

Within the study the authors attempted to correct the radiation dose data for differences in patient size and also differences in SID (especially for the extended SID group). Analysis of Covariance is an accepted technique but does require that there are well-established relationships between covariates (patient size, SID) and the dependent variables (radiation dose). Such relationships are likely to hold for radiation dose but would be more challenging for image quality, especially for digital

radiography and the notable wide exposure latitude. Variations between groups are not uncommon and have been reported and dealt with in several leading drug trials. Randomization is a method to potentially avoid these differences between study groups, but would not account for procedural differences, i.e., different SIDs within the extended SID group. For the extended SID period of the study, radiographers were tasked with achieving the maximum permissible SID. This varied according to the height of the radiographer and did provide insight as to whether the theoretical maximum (144 cm) would be achievable in all situations. Study protocols could have insisted that an SID of either 115 or 144 cm was used; any differences would have resulted in exclusion. Such a method would provide a more internally valid dataset; the effect on external validity would not be the same and would not include those situations when an SID of 144 cm would not be achievable. For study findings to be useful, they must attempt to closely reflect real-life situation and be generalizable.

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