OPTIMISING CONVENTIONAL RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS

SYLVIA PRECIOUS MOKUOANE

Dissertation submitted in fulfillment of the requirements for the degree

MASTER OF RADIOGRAPHY: DIAGNOSTIC

in the

Department of Clinical Sciences (Radiography programme)

Faculty of Health and Environmental Sciences

at the

Central University of Technology, Free State

Supervisor: Prof. H Friedrich-Nel, PhD

Co-supervisor: Mrs. B Van Der Linde, MTech

BLOEMFONTEIN

August 2020

DEDICATION

I dedicate this dissertation to the younger version of me. If only you understood the potential instilled within you from a younger age, you would have dared to break wider boundaries, climb taller mountains and dive into deeper oceans sooner. But I know all this time that feels lost was a part of the divine process. You did not waste time, you simply rested in the stillness of dreams you thought impossible. Resting for such a time like this, where suddenly wider boundaries feel narrower, taller mountains feel less steep and deeper oceans feel like shallow waters. Now, go on and create the magic you were destined to orchestrate!!!

ACKNOWLEDGEMENTS

"For I know the plans I have for you, declares the Lord. Plans to prosper you and not harm you. Plans to give you hope for a bright future."
(Jeremiah 29:11)

A journey of a thousand miles begins with a single step and is bound to end with reward. I remember my first single step on the journey of acquiring my Master of Radiography like it was yesterday. I remember the moment I knew I had to put my best foot forward and proof to myself that I was worthy and could do it… excellently so. This was when, in a room full of supervisors, when asked whom would wish to be my supervisor, no one responded. There was a sharp silence in the room, which cut through my throat and left me thinking: "Am I really that bad?". That was the golden moment of opportunity, sparked will and ignited tenacity. The will to strive. The opportunity to say "yes" to myself, even when the rest of the world was saying "no".

- I would like to thank God for his grace and his plans of hope, prosperity, and a bright future for me.
- The existence of my mother alone continues to fuel my determination to become the best I can be in the universe.
- My Supervisor, Prof. Friedrich-Nel. Your work ethics and principles motivate me beyond comprehension. I lost my mind countless times along the journey, and all that I had to do, was remind myself of how privileged I was to have you as my Supervisor, and that I could wholeheartedly trust your level of expertise, even when I could not understand the route you were taking me through.
- My Co-supervisor, Mrs, soon to be Dr Van Der Linde, thank you for not declining the role of becoming my Co-supervisor. Thank you for a consistently positive and supportive journey filled with great innovative ideas.
- Mrs Stofile, thank you for being the light at the end of the tunnel when I had lost sight of any light. Thank you for introducing me to the PCXMC20 Monte Carlo programme, which came to shape my research study in a remarkable way.

- Dr Van Der Merwe, thank you for your prayers, emotional support and for constantly cheering me on. You remain the salt of the earth. A true inspiration to the face of mankind.
- My family, friends and Radiography students who helped me through this journey - whether through proofreading, feedback, or moral support. May God bless you. Special shout out to Taahirah Mookrey and Mohlalifi Mosia
- Mrs Viljoen, you remain my all-time number one statistician.
- Dr Van Straaten, Dr Struwig and Dr Daniels Ofori Kusi for their language and technical editing expertise.
- The Central University of Technology, Free State; Department of Higher Education, Science and Technology (DHEST); and the Health and Welfare Sector Education and Training Authority (HWSETA) for funding.
- Drs Van Dyk & Partners and Drs Spies & Partners for granting me permission to perform the research study at their practice, and for the colleagues who helped to make the process easier. Special thanks to Mrs Sinden from Drs Spies & Partners.
- My fellow colleagues from the Radiography programme for their support and encouragement. The Emergency Medical Care colleagues, Ms Dlamini and Ms Geduld for allowing me to invade their office space to work on my writing.

DECLARATION OF OWN WORK

I, Sylvia Precious Mokuoane, hereby declare that ***"Optimising conventional radiographic imaging of the odontoid process"***, submitted for the degree Master of Radiography (Diagnostic) in the Department of Clinical Sciences, Central University of Technology, Free State, is my own work, and that it has not been submitted before to any institution by me or anyone else as part of my qualification.

August 2020

Signature of student Date

ABSTRACT

Optimising conventional radiographic imaging of the odontoid process

Introduction

Plain conventional radiography of the cervical spine involves special attention to the upper most portion of the cervical spine. The attention is directed towards an anatomical feature found in this specific upper most region of the cervical spine, the odontoid process. The reason for the odontoid process being the centre of attention for radiographers and reporting radiologists when it comes to radiographic imaging of the cervical spine is due to its known susceptibility to injury.

Background

The open-mouth view is used as the first preferential method for demonstrating the odontoid process optimally and free of superimposition where specialised modalities are unavailable. This comment is based on the observed practice from several radiology departments in South Africa. When optimal radiographic images of the open-mouth view cannot be achieved after multiple attempts, a conventional tomogram of the odontoid process is performed as an alternative imaging technique of preference; thus, resulting in a questionable radiation dose to the patient.

Aim of study

This research study intended to optimise conventional radiographic imaging of the odontoid process with reference to two specific conventional radiographic imaging methods: the open-mouth view and the conventional radiographic tomogram of the odontoid process. The research study focuses on improving conventional radiography as one of the most homogeneously available radiological imaging modalities in South Africa and the African continent.

Objectives

The objectives that had to be met included respectively evaluating each one of the methods for image quality, repeat rate, reasons for repeat rates and the radiation dose (effective dose) associated with the repeat rates. Establishing a checklist that would help capture all the date during the evaluations.

The last objective was to use the results from each of the conventional radiographic methods that were assessed to compare their eligibility in the overall goal for optimising the conventional radiographic imaging of the odontoid process.

Methodology

The research study was conducted in the Free State, Bloemfontein, at two radiology departments. Data was retrospectively collected from three X-ray machines for X-ray images of patients between the ages of 15 to 75 years. The patients included in the study had both the open-mouth view and the conventional tomogram of the odontoid process, or either one of the two methods as part of the neck examination. 385 examinations, adding up to 421 X-ray images, were evaluated for image quality, repeat rate and radiation dose (effective dose).

Data was collected from the computer systems and the radiology information systems to successfully complete a checklist for each examination. The checklist was specifically designed for capturing data on image quality evaluation, repeat rates and technical exposure factors used on a dedicated software programme called PCMXC20 Monte Carlo software$^{©}$ for effective dose calculations.

Findings

The open-mouth view had the highest repeat rate of 71.7% between the two methods with tilt being the most common error observed throughout. There was a significant difference for tilt (p=0.0019) and motion (p= 0.0001) between the two conventional radiographic methods. The upper spine received the highest effective dose mean (0.875797 mSv) for imaging of the open-mouth view, while the thyroid received the lowest effective dose mean (0.248419 mSv) for conventional tomography imaging.

Limitations

Limitations to the study included the availability of patients adhering to the inclusion criteria and accessing the PCMXC20 Monte Carlo software© for the effective dose calculations.

There were no previous studies precisely associated with the current research study, including any effective dose baselines that could be referenced when reporting back

on the effective dose for the research study, nor studies investigating the radiation dose associated with the high repeat rates from the open-mouth view. The age of the participants was not reported on. This addition could have added more depth to the results. The checklist did not capture gender, which places a limitation for it to be used for studies aiming to report back on gender. Lastly, the data collection process was only performed by the researcher.

Conclusions

Conventional tomography can be recommended as the first method of preference for optimised conventional radiographic imaging of the odontoid process in the absence of special modalities. This approach aligns with literature findings.

Recommendations

A study comparing the effective dose to existing standard effective dose references for the listed tissues reflected on in the current study, can also be conducted. Furthermore, studies investigating the positioning lines that can be used for different patients to overcome tilt as a common positioning error for the open-mouth view, can be conducted. Lastly, a similar study can be done, but with a higher conventional tomography examination sample size.

Although outside the context of this research study, a future study dedicated to investigating the conversion efficiency (as a contributing factor to varying exposure factors) for similar examinations, for different X-ray units with similar specifications can be explored.

Key terms: Odontoid process, open-mouth view, conventional tomography, upper cervical spine, image evaluation, radiation protection, effective dose

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LIST OF ABBREVIATIONS AND ACRONYMS

A

ALARA : As low as reasonably achievable

AP : Anteroposterior

ACR : American College of Radiology

B

BEIR : Biological Effects of Ionizing Radiation

C

CDS : Crowned dens syndrome

CUT : Central University of Technology, Free State

CEO : Chief Executive Officer

CER : Comparative effective research

CT : Computed tomography

CR : Computer radiography

D

DR : Digital radiography

DRL : Diagnostic reference level

E

ED : Effective dose

EC : European Commission

EI : Exposure index

F

FOV	: Field of view
FOD	: Focus to object distance

I

IOML	: Infraorbitomeatal line
IAEA	: International Atomic Energy Agency
IR	: Image receptor
ICU	: Intensive Care Unit
ICRP	: International Commission on Radiological Protection

K

kVp	: Kilovoltage peak

M

mAs	: Milliamperage-seconds
MDCT	: Helical Multidetector-computed Tomography
MRI	: Magnetic resonance imaging
MVA	: Motor vehicle accidents
ms	: Milliseconds
mSv	: Milisievert

N

NEXUS	: National Emergency X-radiography Utilisation Study
NICE	: National Institute for Health Care Excellence

O

OID	: Object to imaging plate distances
OM	: Open-mouth view
OECD	: Organisation for Economic Co-operation and Development

P

PA	: Posteroanterior

Q

QA	: Quality assurance
QC	: Quality control

R

RADPASS	: Radiological patient safety system
ROC	: Receiver operating characteristic
RIS	: Radiology information system
RSD	: Private practice 1: room D
RSE	: Private practice 1: room E
RSSA	: Radiological Society of South Africa

S

SAS	: Statistical analysis system
SID	: Source-to-image distance
SMPTE	: Society of Motion Picture and Television Engineers
Sv	: Sievert
SURPASS	: Structure of the Surgical Patient Safety System

T

TM : Conventional tomogram

U

UFS : University of the Free State

V

VD : Private practice 2

VGA : Visual grading analysis

W

WHO : World Health Organization

CHAPTER ONE

INTRODUCTION TO THE RESEARCH STUDY

1.1 INTRODUCTION

Imagine how less diverse conventional radiographic imaging would be if the human body was not as complex as it is. The thought of such a pleasing reality unfortunately remains a fantasy when considering anatomical structures such as the odontoid process, as seen in Figure 1.1. below.

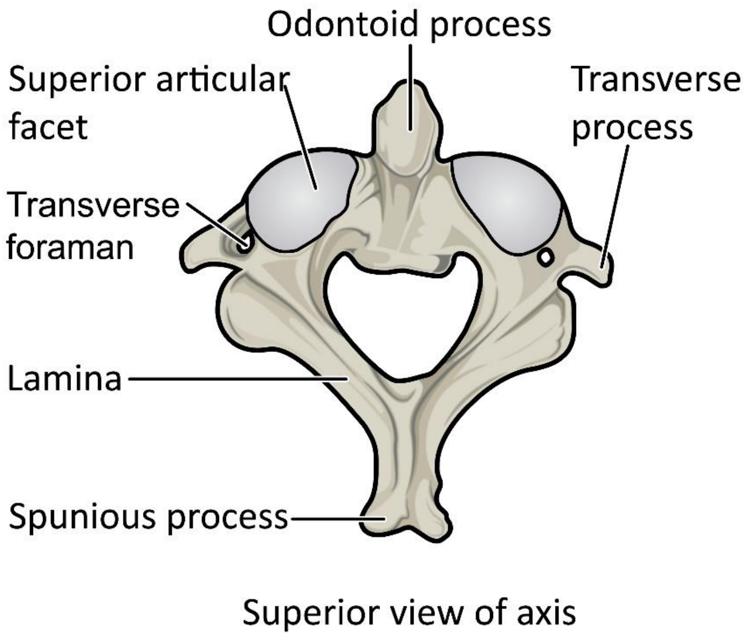


Figure 1.1: Superior view of the axis (Mosia 2020, permission granted)

The odontoid process, also referred to as the ‘dens’, is a unique protrusion of the axis (Schwartz 2008). Together with delicate ligaments and muscles surrounding it, the odontoid process is the pivot for the rotation of the head and the atlas (Bontrager & Lampignano 2011; Saladin 2011). The anatomical structure is not only known for its unique form, but also for being susceptible to morphologic abnormalities and trauma, and therefore needing superior diagnostic imaging methods (Schwartz 2008). Advanced imaging modalities such as Computed Tomography (CT) are recommended for optimal diagnostic imaging of this rather delicate bony structure. However, the availability of advanced imaging modalities is often limited to well-resourced healthcare facilities (Kafibadi & Rangi 2017). In some emerging countries, there are radiology departments that are reliant on conventional radiographic imaging as the sole diagnostic imaging modality (Tenny & Varacallo 2018). The open-mouth view is preferentially used for radiographic imaging of the upper cervical spine and for consequently demonstrating the odontoid process, in the absence of specialised modalities (Jo, Wilseck, Manganaro & Ibrahim 2018).

The goal of achieving the open-mouth view demonstrating the odontoid process optimally and free of superimposition often involves multiple attempts (Josephs 2016). When optimal open-mouth view radiographic images cannot be achieved after multiple attempts, a conventional tomogram of the odontoid process is performed as an alternative imaging technique of preference to the open-mouth view. This sequential routine of resorting to a conventional tomogram for radiographically achieving optimal visualisation of the odontoid process is implemented by several radiology private practices around South Africa that cannot be mentioned to preserve anonymity.

The reason why conventional tomography is regarded as an alternative technique to the open-mouth view, is due to the fact that it was previously suggested that the estimated radiation dose quantity for a conventional tomogram was greater than that of a plain conventional radiographic image (Carlton & Adler 2006). Nonetheless, based on the principle of justification, the benefits associated with conventional tomography of the odontoid process becomes important once the open-mouth view is evidently inadequate on multiple radiographic images. Since conventional tomography has the potential to achieve an optimal radiographic representation of the odontoid process (ICRP 2007).

The present research study thus intended to optimise conventional radiographic imaging of the odontoid process, with reference to the open-mouth view and conventional tomography of the odontoid process.

The optimisation goal was achieved through respectively evaluating each of the methods for image quality, repeat rate, reasons for repeat rates, and the radiation dose (effective dose) associated with the repeat rates. The results from each one of the conventional radiographic methods was assessed for eligibility on the overall goal of optimising conventional radiographic imaging of the odontoid process.

1.2 BACKGROUND TO THE STUDY

Medical exposures make up to thirteen per cent of the total overall sources of ionising radiation (Graham, Cloke & Vosper 2012). According to Bushong (2013), medical exposures increased from 0.5mSv in 1990 to 3.2mSv in 2006. These exposures are divided into two radiology categories, namely therapeutic and diagnostic exposures (Graham *et al.* 2012). Therapeutic exposures are greater when compared to diagnostic exposures.

However, since most people undergo diagnostic examinations more frequently as opposed to therapeutic examinations, diagnostic exposures make a major contribution to the overall medical radiation exposure (Ball, Moore & Turner 2008). Since radiology uses medical exposures as an indispensable resource (Goodman 2010; Graham *et al.* 2012; IAEA 2004a), the importance of assessing and keeping radiation exposures as low as reasonably achievable (ALARA) is ineluctable (ICRP 2007).

However, the holistic optimisation of radiographic examinations for visualisation of the odontoid process is sometimes overshadowed by the access of information advocating the importance of optimal imaging of the upper cervical spine for trauma patients and suspected prevalence of pathology. Radiologists are critical about the standard of the radiographic images they receive from radiographers for diagnostic reporting (Rabie 2017). Subsequently, radiographers strive to produce quality radiographic images of the odontoid process. These quality radiographic images are often achieved through multiple attempts, without considering the total radiation exposure of the patient (Josephs 2016).

While trauma is the main known indication for radiographic imaging of the odontoid process, section 2.3.2 from chapter two (Pathology affecting the odontoid process) unpacks the prevalence of pathology in the upper cervical spine and why radiographic imaging of the odontoid process as part of routine has taken root.

Based on observation and experience, when striving to optimally capture the odontoid process, as a radiographer, the attention is often focused on radiographic image quality, and not on the total radiation dose administered to the patient. After several unsuccessful attempts of the open-mouth view, radiographers' resort to acquiring a conventional tomogram of the odontoid process as a second technique of preference for optimally demonstrating the odontoid process free of superimposition (Hoffman & Hancock 2017). Unfortunately, there are sensitive organs situated near or in the field of interest for radiographic images of the odontoid process, such as the skin, eyes, oesophagus and thyroid (Ball *et al.* 2008).

According to Ball *et al.* (2008), the oesophagus and thyroid have a tissue weighting factor of 0.05, while the skin has a tissue weighting factor of 0.01. Although the tissue weighting factor for these tissues may be recognised as being relatively small, the need to protect these tissues from unnecessary unjustified ionising radiation remains crucial (Ball *et al.* 2008).

Therefore, it would be both clinically valuable to establish information relating to both radiation exposure and radiographic image quality for imaging of the odontoid process for patients referred to the radiology departments for routine cervical spine X-ray examinations. This is especially true when considering the fact that there is a scarcity of literature dedicated to investigating both positioning errors associated with the noticeably high repeat rates, and the radiation dose to the patient as a repercussion for the high repeat rates of the odontoid process.

While it remains valid to question the place of research studies focused on conventional radiographic methods in the constantly advancing radiology world. The scarcity of specialised radiology resources around some parts of the country, South Africa and the African continent remains a problem.

Hence this research study strives to serve counties, provinces, towns within the African continent that are only dependent on conventional radiography. The literature section below, last part of (2.6 Specialised modalities) reflects the reality of the availability of specialised radiology modalities in Africa.

1.3 RESEARCH STATEMENT

The radiation dose to the patient must be optimised in order to comply with radiation doses that are as low as reasonably achievable during radiographic imaging of the odontoid process.

1.4 RESEARCH QUESTIONS

Research question one: Are patients being unnecessarily irradiated during X-ray examinations of the cervical spine for conventional radiographic imaging of the odontoid process?

Research question two: Which conventional radiographic technique between the open-mouth view and conventional tomography of the odontoid process achieves optimisation of imaging of the odontoid process?

1.5. AIM AND OBJECTIVES

1.5.1 Aim of the study

The aim of the research study was to achieve optimisation of conventional radiographic imaging of the odontoid process through retrospectively evaluating radiographic image quality, repeat rates and the radiation dose to the patient for the open-mouth view and conventional tomography.

1.5.2 Objectives of the study

The following objectives were set to achieve the aim of the research study:

I. Compiling a literature review that orientated the literature perspective on optimising radiation exposures during radiographic imaging of the odontoid process for examinations of the cervical spine.

II. Compiling and completing a checklist to retrospectively capture data that were used to evaluate and thoroughly analyse the two specific radiographic imaging methods of the odontoid process.
III. Recording the number of repeated radiographic images and reasons for the repeated radiographic images.
IV. Calculating and evaluating the total effective dose to the patients for either one of the two conventional radiographic imaging methods for the odontoid process.
V. Weighing the total repeat rates, radiographic image quality and effective dose between the two conventional radiographic methods of imaging of the odontoid process.
VI. Establishing recommendations and guidelines to optimise conventional radiographic imaging of the odontoid process to help achieve a balance between radiographic image quality and radiation dose during conclusive examinations of the cervical spine.

1.6 RESEARCH METHODS AND RESEARCH DESIGN

The research methods were focused on the research process, tools and procedures implemented for the research study. These included individual steps in the research process, from creating a research instrument and further using it for the data collection process (Williams & Williams 2011). The research study was conducted using a cross-sectional quantitative study design (Polit & Beck 2012). The research falls in the category of a non-experimental research study, as there was no manipulation of variables (Krishna, Maithreyi & Surapaneni 2010).

Since the research study takes on the retrospective analytical and observatory technique of investigation (Denscombe 2007), a checklist was used as the main research instrument. The data captured in the checklist (Appendix A) were further entered on a Microsoft Excel spreadsheet (Appendix B). The instruments eliminated any variations that would arise from data based on human perception and memory capture (Denscombe 2007).

One of the principal tasks was to evaluate “satisfaction” which coincides with having to conclude on the best sequence of events, or the best conventional radiographic imaging of the odontoid process (Polit & Beck 2012). The task can be compared with the principles of comparative effective research (CER). CER is used by researchers to contrast the benefits and drawbacks of different interventions and strategies to diagnose, prevent, treat and monitor health conditions in the real world (Klenske 2019).

1.6.1 Study location

The research study was conducted at two radiology departments in Bloemfontein, Free State. The first radiology department is in the south of Bloemfontein. The department offers the following services:

Theater screening, fluoroscopy, plain conventional radiography (whole skeletal imaging including special radiographic views), trauma radiography, mammography, bone densitometry and mobile radiography (Drs Spies & Partners 2017). The radiology department has four X-ray rooms, of which three offer Digital Radiography (DR) and one Computer Radiography (CR). Two of the four rooms were used for data collection purposes (Drs Spies & Partners 2017).

The second radiology department is in the central part of Bloemfontein. The radiology private practice offers the following services: Theater screening, fluoroscopy, plain conventional radiography (whole skeletal imaging including special radiographic views), trauma radiography, mammography, bone densitometry and mobile radiography (Drs Van Dyk & Partners 2017). The radiology department has six X-ray rooms, of which five offers DR and one CR. One of the six X-ray rooms was used for data collection purposes (Drs Van Dyk & Partners 2017).

1.6.2 Study population

The study population was restricted to patients between the ages of 15 and 75 that had cervical spine examinations that included the open-mouth view and the conventional tomogram of the odontoid processor either one of the two. The patients were from the two radiology departments of interest and the three X-ray units. Data were collected from July 2018 to October 2018 (Appendix C). The age restriction considered both the anatomy and physiology of bone development (skeletal maturity) and aging (osteoporosis) (Long, Rollias & Smith 2015).

1.6.3 Sampling

As the number of examinations were scarce, all examinations from the population were considered, and an all-population sampling technique was implemented (Viljoen 2018). The researcher aimed to include at least fifty to a hundred examinations in order to achieve statistical conclusion validity and to generalise the results (Pilot & Beck 2012). The selection of examinations was governed by the inclusion and exclusion criteria given in the section below.

The cervical spine examinations that were considered for the research study from the population had to have the following particulars: a referral letter stating the clinical history, raw radiographic images to offer knowledge on the number of repeated radiographic images and allow for radiographic image evaluation of repeated radiographic images.

1.6.4 Research instrument

A checklist that was specifically created for the purpose of collecting data for the research study and Microsoft Excel spreadsheet were used for data collection purposes. The listed data collection instruments ensured that data could be collected by different external researchers whilst still being alert to the same activities, and being able to record the data systematically, thoroughly and consistently (Denscombe 2007).

1.6.4.1 The checklist

During the compilation of the checklist, the researcher carefully investigated the aspects that were needed for the purpose of successfully completing the data collection process as guided by literature. The primary essentials needed were the referral letters, raw and processed radiographic images, and their technical exposure factors from the CR system within the X-ray rooms. Raw radiographic images are those that have not been processed after acquisition; radiographic images that are a true reflection of the positioning technique and technical factors as implemented by the radiographer before initiating the exposure. The processed radiographic images are those that have been altered after making the exposure, for instance; applying collimation, placement of a digital lead marker and windowing the exposure to enhance the radiograph (Carroll 2011).

Information from the above-listed entities would go onto the checklist. The referral letters allowed for identification of the clinical history for every examination, and for recording it on the checklist for classification of the examinations according to the various pathological conditions. The raw radiographic images made it possible for the researcher to assess and critically evaluate the two conventional imaging methods based on the various reasons of repeating. The researcher used the imaging criteria list implemented by McQuillen Martenson (2011) as a standard baseline for the checklist and overall radiographic image evaluation.

The technical exposure factors were used for determining the effective dose through the PCMXC20 Monte Carlo software© (Appendix D). The PCMXC20 Monte Carlo software© is a computer-based Monte Carlo method (Tapiovaara, Lakkisto & Servomaa 1997). Basic information relating to the examination, age and file number were also recorded. The age was recorded to support the inclusion criteria, and the file number was recorded was used on RIS to identify and locate the patient to gain access to their referral letter. All the information served in reporting back on the results of the study to ensure validation.

1.6.4.2 Microsoft Excel spreadsheet

A Microsoft Excel spreadsheet was used to record the information from the checklists into one document. There were four sheets for the following data: number of radiographic images per examination, radiographic image evaluation (reason for repeat), patient history and the effective dose from the PCMXC20 Monte Carlo software©. The Microsoft Excel spreadsheet was structured as per instruction from the statistician who was responsible for statistical analyses.

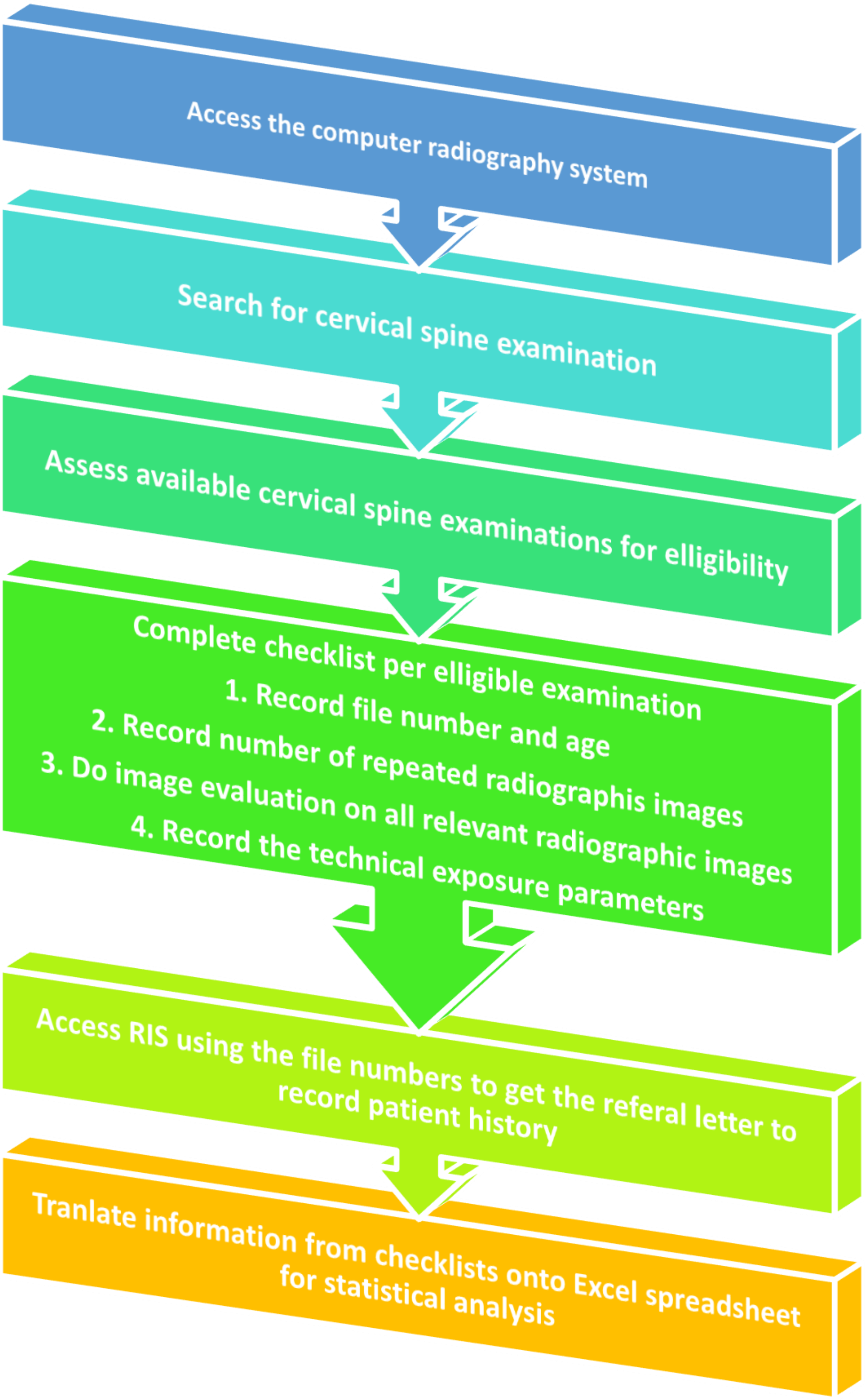
1.6.5 The pilot study

Once ethical approval was obtained, a pilot study was conducted to test the checklist (Appendix E) and the intended data collection process. The researcher randomly selected five cervical spine examinations from the study population that adhered to the inclusion criteria specified in the inclusion and exclusion section above (see 1.6.3). The pilot study assisted the researcher to establish a concrete checklist, and to be able to conclude on what other data could be added onto the checklist for achieving the aim and overcoming the objectives of the research study.

The data collected from the pilot study were included in the data collected for the main research study, considering the scarcity of the radiographic images for the period dedicated to the data collection process, and as the information collected from the pilot study could still be used after having applied small changes to the checklist adapted from the pilot study. The pilot study guided the main data collection technique and the time frame for data collection.

1.6.6 Data collection process

Figure 1.2 below is a summary flowchart with all the steps that were attended to during the data collection process. The figure outlines the process followed for data collection, from accessing the CR system, to translating the data from the checklists onto the Microsoft Excel spreadsheet.



RIS: Radiology Information System

Figure 1.2: Summary flowchart for data collection (created by the researcher)

1.6.7 Analysis of data

Data from the checklists were captured electronically on a Microsoft Excel spreadsheet. The conclusive Microsoft Excel spreadsheet was forwarded to the statistician for analysis (Appendix F). Before forwarding the Microsoft Excel spreadsheet to the statistician, the researcher, together with a second party, verified the data for correctness and to observe trends in the data. The statistician used the SAS Version 9.2. Descriptive Statistics. Frequencies and percentages were calculated for categorical data, means and standard deviations or medians, and percentiles were calculated for numerical data. To compare the data of the two radiographic imaging methods (open-mouth view and conventional tomogram), the following analytical statistics were used: The Chi-Square Test, to test for differences between proportions; the T-test, to compare mean values, or the Mann-Whitney U-test, to compare median values. A significance level (α) of 0.05 was also used.

The data analysis process involved the PCMXC20 Monte Carlo software© used to produce effective doses for various tissues that receive radiation during conventional radiographic imaging of the odontoid process. The effective doses for the following eight tissues were recorded per open-mouth view and conventional tomogram: skin, thyroid, brain, skull, upper spine, oral mucosa, salivary glands and the oesophagus.

1.7 RELIABILITY AND VALIDITY OF THE STUDY

A high level of reliability comes with a research instrument that produces the same data time after time without arising variations from the aspect that is being measured (Denscombe 2007). Validity is the extent to which a research study captures the meaning of the concepts it was intended to (Abbott & McKinney 2013). The reliability and validity of the research study are addressed in Chapter two, section 2.10. Conclusively, the entire research study was guided by literature to ensure that the content of the research is relevant, relatable and reliable within diagnostic radiography. The research study focused precisely on the context of principles of diagnostic radiography. Keywords were used to seek out resources that were significant to the radiographic optimisation of conventional radiographic imaging of the odontoid process.

1.8 ETHICAL CONSIDERATIONS

1.8.1 Approval

The research proposal was approved by the Health Sciences Research Ethics Committee of the Faculty of Health Sciences, University of the Free State (see Appendix G), with the following ethics number: UFS-HSD2018/0257/2905. Approval was granted by the Chief Executive Officers (CEO) of the radiology departments in Bloemfontein (see Appendix H and I) to conduct the study at the specific radiology private practice.

1.8.2 Right to privacy and confidentiality

The assessed patient examinations were marked as ‘patient 1’ and so forth. Under no circumstances were the patients’ information compromised.

1.8.3 Project and patient safety

The main data collection process for the research study was conducted retrospectively. Therefore, patients were not directly involved in the research study. The research study did not under any circumstance disclose patient information. The research study did not pose any risk to neither the patient nor the radiology private practice at which the study was conducted. There were no financial costs involving the radiology department or the patients.

1.8.4 Good clinical practice

The researcher maintained good clinical practice throughout the process of the research study. Adhering to the three basic principles of good clinical practice, respect for the dignity of people involved in the study, not to cause intended harm and to aim for justice as guided by the recently revised Declaration of Helsinki (WMA 2013) (a set of ethical principles providing guidance for physicians performing clinical research that is centred around the researchers role and responsibilities in relation to protecting human subjects (Krishna, Maithreyi & Surapaneni 2010).

1.9 POTENTIAL VALUE OF THE STUDY

The research study was aimed at achieving minimised radiation exposures and maximising radiographic image quality during conventional imaging of the odontoid process, and to achieve a balance between radiographic radiation dose to the patients and image quality during cervical spine examinations. The research study would therefore promote optimisation, justification and limitation of radiation doses to patients at the radiology department of interest, as well as at various radiology departments implementing the same practice for conventional imaging of the odontoid process.

The results of the research study would influence decision making for setting protocols for cervical spine examinations that are dedicated to radiographic imaging of the odontoid process. These decisions would be influenced by the effective dose comparison between the two different conventional radiographic methods. Furthermore, radiology department could use the results of the research study to implement restrictive measurements for the acceptable number of repeated radiographic images per examination in order to keep within the lower effective dose range.

1.10 LAYOUT OF DISSERTATION

The dissertation consists of seven chapters. Four of the seven chapters are structured in article format; chapter three to chapter six. Chapter three has been submitted to the Radiography journal and is added to the dissertation in the format based on the journal guidelines (Appendix J). Chapters four to six are currently being refined by a medical writer in preparation for publication submission (Appendix K). For this reason, each of the four chapters that are in article format will have their own reference list. Due to the format of the dissertation, it is further worth mentioning that the dissertation does not have a dedicated chapter for methodology. The methodology follows in a similar pattern throughout the various chapters and may include some repetition.

Chapter one: Introduction to the research study

This chapter provides an overview of the research study. The chapter includes an outline of the research background, problem statement and the main research questions, and the aim and objectives stemming from the identified problem. This chapter furthermore offers an insight on the methods and design of the research study.

Chapter two: Learning more about radiological imaging of the odontoid process

Chapter two is dedicated to contextualising and providing a theoretical framework for the research study, allowing the reader to have a broader perspective on medical imaging of the odontoid process.

The chapter goes from anatomy and pathology of the odontoid process to a broader view of available imaging modalities and protocols. Radiation optimisation and protection are also addressed. Lastly, a reflection on existing gaps in literature that may be hindering the process of successfully achieving optimisation of radiographic imaging of the odontoid process is provided.

Chapter three (article 1): Checklist for evaluating image quality and radiation dose during radiographic imaging of the odontoid process

Chapter three consists of a literature review article which describes the development of the checklist based on relevant literature that was used for the data collection of the research study (see abstract in Appendix L1). The objective of the article is to report on the development of a checklist that can efficiently capture data to enable the researcher to evaluate radiographic image quality, and to calculate effective dose using the PCMXC20 Monte Carlo software© for the odontoid process. The checklist was designed based on a review of various radiographic textbooks, guidelines and articles. The article was submitted for publication in the Radiography journal.

Chapter four (article 2): Evaluation of the open-mouth view for optimised radiographic imaging of the odontoid process

Chapter four is in article format. The article explores the open-mouth view for radiographic representation of the odontoid process (see abstract in Appendix L2).

The chapter discusses the optimisation of radiographic imaging of the open-mouth view for the radiographic representation of the odontoid process through the evaluation of image quality, repeat rate, reasons for repeat rates, and the effective dose associated with the repeat rates. The findings described in this article were recorded with the checklist outlined in chapter three.

Chapter five (article 3): Evaluation of conventional tomography for optimisation of radiographic imaging of the odontoid process

Chapter five is in article format. The article is based on assessing radiographic imaging of the odontoid process when using conventional tomography as an alternative radiographic technique (see abstract in Appendix L3). The article involves the evaluation of image quality, repeat rate, reasons for repeat rates, as well as the effective dose associated with the repeat rates.

Chapter six (article 4): Optimisation of conventional radiographic imaging of the odontoid process

Chapter six is in article format. The article in this chapter is intended to contrast and narrow down the overall results from the two radiographic imaging methods (see abstract in Appendix L4). The aim of the article is to put the open-mouth view directly next to the conventional tomogram of the odontoid process. Consequently, permitting the opportunity to conclude on the radiographic circumstances for which either one of the two radiographic projections can be utilised for optimised radiographic imaging of the odontoid process.

Chapter seven: Conclusion, recommendations and limitations

Chapter seven contains the concluding remarks and was intended to answer the research questions. It further addresses how each of the main research study objectives were attained. The limitations that were encountered in the process of successfully completing the research study are described, and recommendations that can be applied in striving to optimise conventional radiographic imaging of the odontoid process are made.

1.11 SUMMARY

Chapter one introduced the research study. The chapter outlined aspects of the research study that will help the reader to follow through the various chapters of the dissertation with understanding. Chapter two titled “Learning more about radiological imaging of the odontoid process” is a chapter on literature perspectives dedicated to giving the reader a broader perspective on medical imaging of the odontoid process, as mentioned in the layout section above.

CHAPTER TWO
LEARNING MORE ABOUT RADIOLOGICAL IMAGING OF THE ODONTOID PROCESS

2.1 INTRODUCTION

Cottrell and McKenzie (2010) state that a literature review involves an intensive search of informative justified resources that are based on a specific topic. In the context of this research study, resources that were obtained were linked to "optimising conventional radiographic imaging of the odontoid process". The second part of the process is to attentively engage with the obtained resources to narrow down all the acquired information into a more precise summary report (Cottrell & McKenzie 2010). A literature review forms an important part of a research study, as it provides a clear understanding of the research problem and the background thereof (Cottrell & McKenzie 2010). The literature review must be a junction between the introductory chapter and the rest of the research study.

For instance, while the previous chapter (Introduction to the research study) outlined the background of the research, and the objectives that must be met in order to successfully answer the research questions and achieve the purpose of the research study, the purpose of the literature review chapter is to put the matter into context, and to provide a theoretical framework for the research study. The chapter first offers an outline of the literature search. Thereafter details of the anatomy and pathology of the odontoid process will be provided. The focus then changes to the views expressed in literature available on the preferred imaging protocols of the odontoid process, and an overview of the effects of ionising radiation and optimisation of radiographic procedures. The last section in this chapter summarises the gaps identified in the literature to illustrate the relevance of this specific research study.

2.2 LITERATURE SEARCH

Ebscohost, Science Direct, PubMed and HubMed databases were used to identify resources for the research study based on their significant relevance in medical science and technology. The following key terms were used: odontoid process, open-mouth view, tomosynthesis, upper cervical spine, tomography, radiation optimisation, image evaluation, radiation protection, effective dose, Magnetic Resonance Imaging, and computed tomography. The timeframe for the search was January 2000 to April 2020. The topic presented in the research study proved not to be saturated. Hence, relevant, and significant materials outside of the time frame had to be included to support and strengthen the research study.

Textbooks from the research institution's library were also used in addition to the literature resources derived from the database. The textbooks used were chosen based on their frequent citation in the field of radiology. They were based on the principles of radiation physics pertaining to technical exposure factors, radiographic image critique and evaluation. The textbooks were authored by Ball *et al.* (2008), Bontrager and Lampignano (2014), Carter, Hyatt, Patersob, Pirrie and Thornton (1991), Graham, Cloke and Vosper (2012), and McQuillen Martensen (2011).

2.3 THE ODONTOID PROCESS

The human body is generally a complicated structure. The process of achieving radiographic representations of the various anatomical parts often comes with errors in both positioning and diagnosis (Whitley, Sloane, Hoedley, Moore & Alsop 2005). The statement can well be supported by evidence outlined in chapter four (Evaluation of the open-mouth view for optimised radiographic imaging of the odontoid process) on the technical difficulty associated with the open-mouth view. However, the problem can be overcome once radiographers understand how the anatomical structure of interest and its associated structures are related, how they move, and what their articulation entails (Whitley *et al.* 2005).

The atlantoaxial joint is considered the most movable joint of the body, with the odontoid process forming the axis on which the movement occurs (Goel, Jain, Shah, Patil, Vutha, Ranjan & More 2017). The odontoid process acts as a conductor of movements without participating in the actual stability of the joint. The wide range of movement makes the joint susceptible to instability (Goel *et al.* 2017).

When considering the occiput-atlas-axis anatomical articulation, 40% of all cervical flexion-extension movements, and 60% of global rotation are accounted for in this region (Izzo, Popolizio, Balzano, Simeone, Roberto, Scarabino & Muto 2020). Studying the integral role of this anatomical region, it is disheartening that injuries in this region occur in approximately 30% of patients that have experienced blunt cervical spine trauma, with 17% to 20% of cervical spine fractures involving the axis, while up to 59% of the axis fractures involve the odontoid process (Izzo *et al.* 2020). Accurate evaluation of the odontoid process is important, since the odontoid process is regarded as the central pillar of the craniovertebral junction (Jain, Verma, Garga, Baruah, Jain & Bhaskar 2016).

2.3.1 Anatomy of the odontoid process

In exploring the anatomy of the odontoid process, the theoretical insight is outlined through the perspective of the coronal plane. The coronal plane is the plane dividing the anatomical structure into the anterior and posteriors part (Whitley *et al.* 2005). The vertebrae are divided into five groups: the first group being the seven cervical vertebrae (Saladin 2011). The cervical vertebra supports the head and allow for its movement through the first two distinctive cervical vertebrae as mentioned in section 2.3 above (Saladin 2011).

The first cervical vertebrae, called the atlas, has no body and is a ring surrounding a large opening (vertebral foramen). On each of the sides of the atlas are lateral masses. The superior surface of these masses is called the superior articular facets, and it articulates with the occipital condyle of the skull, allowing mammals that are habitually bipedal the nodding movement (Akobo, Rizk, Loukas, Chapman, Oskouian & Tubbs 2015; Lisle 2012; Saladin 2011; Schwartz 2008; Tenny & Varacallo 2018).

The inferior surfaces of the lateral masses of the atlas introduce the existing distinctive articulation relationship between the first cervical vertebrae and the second vertebrae. The second cervical vertebral (axis) gives way to the rotational movement of the head. The axis is recognised by a unique prominent anterior knob called the odontoid process (Saladin 2011; Schwartz 2008). The knob projects into the vertebral foramen of the atlas, sheltered in a facet and held in a place by a transverse ligament (Akobo *et al.* 2015; Lisle 2012; Saladin 2011; Schwartz 2008; Tenny & Varacallo

2018). Refer to Figure 2.1 below for the anatomical representation of the relationship between the atlas and the odontoid process.

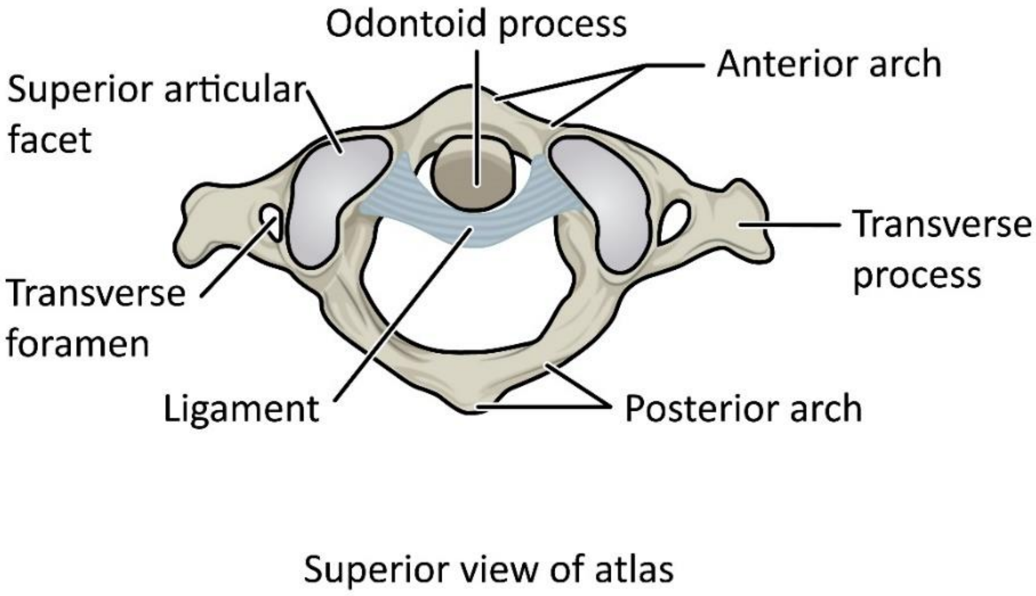


Figure 2.1: Superior view of the atlas (Mosia 2020, permission granted)

When it comes to imaging of the atlas and axis, special anatomical landmarks are used to locate the position of these two cervical vertebrae, since they are not easily identifiable from an anteroposterior (AP) position due to their distinctive location (Whitley *et al.* 2005). The atlas is connected to the occipital condyle of the skull as mentioned above, while both the two vertebral bodies are positioned posterior to the mandible (Saladin 2011). The atlas can therefore be located by identifying the level of the mastoid bone and the axis, by identifying the level of the mandibular angle (Whitley *et al.* 2005).

Conclusively, the cervical spine region does not only serve the purpose of supporting the head and allowing the head movement. The cervical spine serves as shelter and protection for the spinal cord. Any form of harm to the vertebral column may cause even greater harm to the spinal cord. The spinal cord is essential for the pathway of neurological messages conveyed from the brain to the rest of the body (Saladin 2011).

2.3.2 Pathology affecting the odontoid process

Pathologies of the odontoid process can be congenital or acquired. Congenital abnormalities include odontoid dysgenesis such as os odontoideum, condyles tertius, persistent os-terminale and odontoid aplasia. Acquired abnormalities include traumatic, degenerative, inflammatory and neoplastic conditions (Jain *et al.* 2016). Based on the complexity of the odontoid process, radiographic imaging to identify the pathology remains a challenge for radiologists (Jain *et al.* 2016). The table below summarises all that Jain *et al.* (2016) outlined about the abnormalities of the odontoid process and the radiographic imaging modality of preference.

Table 2.1: Pathology of the odontoid process (Jain et al. 2016)

Acquired abnormalities of the odontoid process		
Abnormality	**Definition**	**Modality of preference**
Traumatic	Disruption in the normal bone orientation.	Conventional radiography, CT and MRI
Degenerative	The wearing down of bone and/ vertebral disc space.	Conventional radiography
Inflammatory	Inflammation due to the body’s attack on the tissue.	MRI
Neoplastic	Accumulation of somatic mutations attributing to tumour cells.	CT
Os odontoideum	An ossicle with smooth circumferential cortical margins representing the odontoid process that has no osseous continuity with the body of the axis.	CT
Condyles tertius	Failure of fusion of proatlas with occipital sclerotomes that form clivus.	CT
Os-terminale	Failure of fusion of the terminal ossicle to the remainder of the odontoid process.	CT
Odontoid aplasia	Complete agenesis of the odontoid process.	CT

CT: Computed tomography, MRI: Magnetic Resonance Imaging

Chapter four (*Evaluation of the open-mouth view for optimised radiographic imaging of the odontoid process*) and chapter five (*Evaluation of conventional tomography for optimisation of radiographic imaging of the odontoid process*) report back on the abnormalities and pathological conditions and symptoms that were referred for radiographic imaging.

The chapters offer an insight on the commonly observed conditions for the open-mouth view and conventional tomography as two separate conventional radiographic imaging methods for the odontoid process. Matching the pathology to a radiographic imaging method is one of the steps implemented in optimising radiographic procedures (IAEA 2004a).

2.4 IMAGING PROTOCOLS

Imaging protocols strive to guide radiographers on the routine of radiographic imaging methods to implement based on the pursued diagnosis. Second to the radiographic imaging method of preference is the radiographic views that must be acquired for the chosen method of preference (IAEA 2004a). Imaging protocols may vary from conventional radiography to specialised modalities, depending on the investigated abnormality or pathological condition, and the sensitivity and specification of the radiographic imaging method to the pathology (Kafibadi & Rangi 2017).

Table 2.2 below accounts for information gathered from various resources on the protocols for conventional radiographic imaging in both trauma and non-trauma settings.

Table 2.2: Protocols for conventional radiographic imaging of the cervical spine (compiled by researcher from various resources)

Source	Trauma	Non trauma	AP	Open-mouth view	Lateral	Oblique	Conventional tomography added as a complementary method
Jo, Wilseck, Manganaro & Ibrahim 2018	✓		✓	✓	✓		No
Tenny & Varacallo 2018	✓		✓	✓	✓	✓	No
Markatos, Efstathopoulos, Kaseta, Lazaretos, Chytas & Nikolaou 2018	✓			✓	✓		Yes
Kafibadi & Rangi 2017	✓		✓	✓	✓		No
Jain, Verma, Garga, Baruah, Jain & Bhaskar 2016	✓	✓	✓	✓	✓	✓	No
Georgen, Varma, Ackland, Michaleff, Rosenfeld, Malham, Johnson & Rahman 2015	✓		✓	✓	✓	✓	Yes
Bontrager & Lampignano 2014	✓	✓	✓	✓	✓	✓	Yes
Lisle 2012	✓		✓	✓	✓		No
McQuillen Martensen 2011	✓	✓	✓	✓	✓	✓	Yes
Schwartz 2008	✓		✓	✓	✓		Yes

AP: Anteroposterior

Table 2.3: Protocols for conventional radiographic imaging of the cervical spine continues

Source	Trauma	Non trauma	AP	Open-mouth view	Lateral	Oblique	Conventional tomography added as a complementary method
Whitley, Sloane, Hoedley, Moore & Alsop 2005		✓	✓	✓	✓	✓	Yes
Davies & Pettersson 2002	✓		✓	✓	✓		No

AP: Anteroposterior

A total of twelve resources were found outlining conventional radiography protocols. All twelve protocols included the open-mouth view as an integral view for visualising the odontoid process, since they were mainly linked to trauma. Out of the twelve resources, conventional tomography is considered a complementary conventional radiographic method in six resources.

Section 2.3 below outlines the open-mouth view and conventional tomography as two of the conventional radiographic imaging methods considered for the context of the research study, while section 2.5 outlines CT and MRI as medical imaging modalities outside the context of the research study, and on a larger international scale as supported by Table 2.3 below. The table is based on medical imaging of the cervical spine for trauma considering various modalities. The table accounts for information gathered from various resources on radiographic imaging methods of preference in trauma settings.

Table 2.4: Medical imaging of the cervical spine for trauma considering various modalities (compiled by researcher from various resources)

Resource	Main study focus	Initial preferred modality for trauma cases	Note	Continent
Izzo, Popolizio, Balzano, Simeone, Roberto, Scarabino & Muto 2020	Imaging of cranio-cervical junction trauma	CT	MRI used as a complementary modality	Europe
Eiichiro, Takeshi, Takuya, Yoshiyuki, Hiroshi & Yasuhito 2019	Comparing plain conventional radiographic images with tomographic radiographic series for vertebral fractures	Conventional tomography	Plain conventional radiographic images less sensitive to fractures	Asia
Markatos, Efstathopoulos, Kaseta, Lazaretos, Chytas & Nikolaou 2018	Managing of odontoid fracture	Multimodality approach	Sequence of conventional radiography, CT and MRI	Europe
Jo, Wilseck, Manganaro & Ibrahim 2018	Injury of the cervical spine	CT	The three-radiograph series must be implemented where CT is not available	North America
Tenny & Varacallo 2018	Fractures of the odontoid process	CT	In countries without specialised modalities plain conventional radiographic images are critical	North America

CT: Computed tomography, MRI: Magnetic Resonance Imaging

Table 2.5: Medical imaging of the cervical spine for trauma considering various modalities continues

Resource	Main study focus	Initial preferred modality for trauma cases	Note	Continent
Kafibadi & Rangi 2017	Cervical spine radiology on cervical spine injury	Conventional radiography	CT and MRI used for further investigations	Europe
Siddiqui, Grover, Makalanda, Campion, Bull & Adams 2017	Trauma of the craniocervical junction	CT	MRI used as a complementary modality	Europe
Jain, Verma, Garga, Baruah, Jain & Bhaskar 2016	Pathology of the odontoid process through the prospect of CT	CT	CT as preferred in injuries	Asia
Pena & Wray 2016	Odontoid fractures	CT	MRI suggested for ligament tear	North America
Georgen, Varma, Ackland, Michaleff, Rosenfeld, Malham, Johnson & Rahman 2015	Adult cervical trauma management guidelines	CT	When it comes to cervical spine injuries, CT is the first method of consideration	Australia
Bontrager & Lampignano 2014	Protocol for trauma	Conventional radiography	Editorial mainly focused on conventional radiography	North America
Lisle 2012	Spine trauma	Conventional radiography	CT and MRI as complementary modalities	Europe
Weissleder, Wittenberg, Chen & Harisinghan 2011	Radiographically managing the cervical spine	Conventional radiography and CT interchangeably	Either one of the methods may be used	North America

CT: Computed tomography, MRI: Magnetic Resonance Imaging

Table 2.6: Medical imaging of the cervical spine for trauma considering various modalities continues

Resource	Main study focus	Initial preferred modality for trauma cases	Note	Continent
McQuillen Martensen 2011	Protocol for trauma	Conventional radiography	Editorial mainly focused on conventional radiography	North America
Schwartz 2008	Emergency radiology case studies	CT	Advocates for use of conventional radiographic images in the case of low-risk patients	North America
Davies & Pettersson 2002	Cervical spine trauma	CT	The three-radiograph series must be implemented where CT is not available	Europe
WeiBkop, Reindl, Schroder, Hopfenmuller & Mittlmeier 2001	Comparison of conventional tomography, plain conventional radiographic images and two CT methods for acute fractures	CT	Although conventional tomography showed great potential, CT takes due to technical advancements	Europe

CT: Computed tomography, MRI: Magnetic Resonance Imaging

There are seventeen resources listed in Table 2.3. Ten of the resources refer to CT as the sole imaging method of preference for trauma of the cervical spine, while two extra resources mention CT as part of a preferred multimodality approach, adding up to an inclusive total of twelve out of seventeen resources. Conventional radiography was accounted for in seven resources, for which two resources are a part of a multimodality approach, while one resource explicitly separates plain conventional radiographic images from tomography and highlights conventional tomography as a method of preference between the two conventional radiography methods. It is worth noting that all found resources were international resources (and thus studies), and that they are not accounting for practices on the African continent.

2.5 CONVENTIONAL RADIOGRAPHY

Conventional radiography is often referred to as plain conventional radiography and the production of diagnostic images using a source (X-ray tube) and an image receptor (IR) that can either be film, film screen or recently advanced various IR arrays observed in digital radiography (Lisle 2012). Conventional radiography plays an essential role in the assessment of the cervical spine, even with the increasing popularity of cross-sectional medical imaging (Kafibadi & Rangi 2017). Conventional radiography is widely available, comes at a relatively low cost, is associated with low radiation dosage, and is widely used for the assessment of cervical spine injuries in trauma settings due to its readily available access in all health care levels (Kafibadi & Rangi 2017). Furthermore, conventional radiography offers vital insight on the dynamic stability for patients with degenerative pathologies, more especially rheumatoid arthritis (Georgen *et al.* 2015; Kafibadi & Rangi 2017).

Schwartz (2008) considers the two-step process for critically reviewing conventional radiographic images. First, the overall appearance and secondly the individual vertebra examination. The overall review includes the ABCS (adequacy, bones, cartilage and soft tissue) mnemonic device of assessing the adequacy of the radiograph, vertebral alignment, the bones, the cartilage and the soft tissue.

The individual detailed examination involves identification of important radiographic landmarks (Schwartz 2008). Second to the systematic approach is the target approach, which identifies the injury pattern and anatomical variants that could mimic injury. A systematic approach must be used in analysing cervical spine radiographic images as the initial stage in patient management (Kafibadi & Rangi 2017).

2.5.1 Open-mouth view

According to Hart (2004), the origin of the open-mouth view goes as far as the 1900s, as a radiographic view used in medical imaging for the assessment of the atlas and axis, and in chiropractic for the assessment of the occiput-atlanto articulation, and for determining contra-indications in the adjustment of the cervical spine. As evident from the name, the view is obtained with the mouth opened to rid the incisors from blocking the view of the upper cervical spine. There was a time when the origin of the open-mouth view was credited to the chiropractic profession, as they were the first to produce a photograph of the view.

However, the study of Hart (2004) shows that credit is due to a gynaecologist and radiologist from Germany, Dr Heinrich Ernst Albers-Schonberg (1865, 1921). Dr Albers-Schonberg first provided a description of the procedure for the open-mouth view in 1906. Around the 1930s the open-mouth view was used for the atlas-occiput biomechanical assessment, primarily as a chiropractic procedure. However, there is no official mention of the open mouth being dedicated to radiographic visualisation of the condyles.

The common problems identifiable with the open-mouth view includes the superimposition of the odontoid process (Georgen, Varma, Ackland, Michaleff, Rosenfeld, Malham, Johnson & Rahman, 2015). Positioning of the open-mouth view can either be erect or supine, based on the condition of the patient. The midsagittal plane (the plane separating the left and right side of the human body) coincides with the midline of the IR and precisely at right angles (Georgen *et al.* 2015).

The head of the patient is adjusted so that the line from the lower margin of the upper incisors to the base of the skull is perpendicular to the image receptor; with the patient's mouth wide open (Bontrager & Lampignano 2014). When the circumstances do not allow for the patient's head to be tilted, the central ray may be altered accordingly instead. The radiographer must ensure that there is no rotation of the head and the thorax, and that the mouth is sufficiently opened (Bontrager & Lampignano 2014).

The open-mouth view is prone to what is called the Mach lines, a projection of black lines across the odontoid process that superimpose soft tissue and mimic fracture lines. Hence, great attention must be applied in the analysis and assessment of the open-mouth view (Kafibadi & Rangi 2017). When narrowing down the assessment of conventional radiography images to the open-mouth view, the atlantoaxial and atlanto-occipital joints, the atlas' lateral masses and transverse processes, and the axis' odontoid process and body must be included within the collimated region. The odontoid must be centred to the exposure field (Bontrager & Lampignano 2014).

The upper incisors and the base of the skull must not be superimposing the odontoid process and the facet joint (Bontrager & Lampignano 2014; Kafibadi & Rangi 2017). The fracture of the odontoid process normally occurs across the base and below the suspensory ligament supporting the atlas; hence the base of the odontoid process must not be superimposed (Kafibadi & Rangi 2017).

There are considerable corrective measures that can be implemented: constant reminder for patient to open mouth, checking for rotation during positioning, rising of chin or cephalad angulation in case of superimposition of front teeth over odontoid process, and caudal angulation when the occipital bone is superimposing. However, for patients with prominent maxillae, it might not be possible to rid superimposition completely, and alternative radiographic views (Fuchs (AP) demonstrating the odontoid process projected over the occipital bone) or modalities can be considered (Whitley *et al.*, 2005).

Failure to obtain good initial radiographic images of the odontoid process is a call for complex imaging or long-term monitored immobilisation (Whitley *et al.* 2005). According to Bontrager and Lampignano (2014), failure to visualise the odontoid process using the open-mouth view can be followed by the Fuchs (AP) or the Judd (posteroanterior- PA) and the Ottonello (wagging jaw) method. The three are special radiographic views for radiography of the cervical spine for non-cervical spine injury patients. The radiographic views may not be performed without the permission of the radiologist, and may only be done once the lateral cervical spine has been cleared for possible fractures (Bontrager & Lampignano 2014). The radiographic views will therefore not be outlined to avoid going outside the borders of the context of the current research study.

For the context of this research study, attention will be focused on conventional tomography as an alternative conventional radiographic technique to the open-mouth view at the radiology departments in question, and for a broader international spectrum based on Table 2.3 above, the focus will be on CT and MRI. More literature on the open-mouth view is captured in chapter four.

2.5.2 Conventional tomography of the odontoid process

Plain conventional radiographic images make it difficult to sometimes evaluate the morphological fine details due to the shadows projected over, and the superimposition of the two-dimensional domain, while conventional tomography allows for multiple slices free of superimposition (Ryo, Keiji, Mitsuru, Daisuke & Ken 2017). Conventional tomography has been used to demonstrate the odontoid process when obscured by cranial and facial bones (Whitley *et al.* 2005), and to support the open-mouth view for detailed visualisation of fractures of the odontoid process (Weisskopf *et al.* 2001).

While plain conventional radiography is being replaced by specialised modalities, conventional tomography is being bypassed as part of conventional radiography (Littleton 1985). Despite the trend of specialised modalities (CT), Littleton (1985) believes that conventional tomography may be on the threshold of being rediscovered.

Littleton (1985) could in fact be right. While conventional tomography is generally identified on the basis of older X-ray units, tomosynthesis is an advancement to conventional tomography that provides multiple slices and the filtered back projection (FBP) feature (Kuzuwa, Izumi, Yoshimitsu & Ichihara 2013).

Tomosynthesis is a contraction of two words: tomography and synthesis, defined as an X-ray tomographic imaging method (Yuya, Mitsutoshi, Wataru, Masayuki, Kensuka, Takayuki, Gen, Katsufumi, Kenji & Masashi 2017). Conventional film-based tomography disappeared with the widespread trend of CT (Yuya *et al.* 2017). To date, interest in tomosynthesis has re-emerged from the use of flat panel X-ray detectors (FPD's) and digital image processing technologies, with about the same radiation dose levels as those of plain conventional radiography and 1\10 of the dose of CT (Ryo *et al.* 2017; Yuya *et al.* 2017).

Uchida (2014) reported that the introduction of tomosynthesis as an added advanced and superior feature to recent modern X-ray fluoroscopy units did not receive much attention from doctors at Mitsubushi Kyoto Hospital, as they showed no interest in requesting studies using conventional tomography (Uchida 2014). Over time the orthopaedic department was first to pick up interest and explore the advantages, including the T-smart function. The T-smart function allows for reconstruction that reduces metal artefacts in post-operative patients (Uchida 2014). Furthermore, in the past, conventional tomography images were coronal with the patient positioned parallel to the IR. Currently oblique views are a possibility, helping to achieve more accurate diagnosis over a shorter acquisition time (Uchida 2014).

Takatosh (2010) compared tomosynthesis to plain conventional radiographic images and CT based on exposure dose. Tomosynthesis showed a 1.1 times exposure dose to that of plain conventional radiographic images for frontal images of the head, while in comparison to CT, tomosynthesis offered the advantage of a much lower dose exposure. Furthermore, tomosynthesis permitted imaging in supine, standing and tilted positions, and limited artefacts from mental as opposed to CT (Takatosh 2010).

In a study conducted by Eiichiro *et al.* (2019), which focused on comparing plain conventional radiographic images with conventional tomography images for vertebral fractures, plain conventional radiographic images showed a 30% sensitivity and a 100% specificity, while the conventional tomogram images showed an 80% sensitivity and 75 % selectivity. To identify vertebral fractures, plain conventional radiographic images were able to pick up fractures from three of the ten total cases, while the conventional tomogram images picked up eight of the ten cases (Eiichiro *et al.* 2019).

Hence, Eiichiro *et al.* (2019) concluded that plain conventional radiographic images had a low positive diagnostic rate for fresh fractures and might therefore miss fractures. Further adding that diagnosis by conventional tomography as an initial examination is useful for patients with fresh fractures in conventional radiography

(Eiichiro *et al.* 2019). More literature and insight on conventional tomography is outlined in Chapter five, which is dedicated to investigating conventional tomography as a considerable essential method of preference for the odontoid process.

2.6 SPECIALISED MODALITIES

Five to ten per cent of fractures of the odontoid process require further diagnostic investigations for definitive diagnosis (Weisskopf *et al.* 2001). When considering the craniometrical junction, the important anatomical structures with unique biomechanical properties in this region are prone to injury, and these injuries are sometimes subtle (Siddiqui *et al.* 2017). The National Institute for Health Care Excellence (NICE) guidelines show that CT should be acquired when patients have sustained a head injury, since conventional radiographic images can be inadequate, or in cases where conventional radiographic images demonstrated no abnormality. Furthermore, the guidelines suggest that MRI should be considered in patients with neurological abnormality and concern with spinal cord injury (Kafibadi & Rangi 2017).

Based on a case report and review of the literature by Inoue, Kohno, Ninomiya, Tomita, Iwata, Phue, Kamogawa, Okamoto, Fukumoto, Ichikawa, Onoue, Ozaki and Okuda (2016), CT and MRI show high sensitivity and specificity when it comes to the rapid diagnosis of crowned dens syndrome (CDS). CDS is a rare disease which shows calcification of the cruciform ligament around the odontoid process on radiographic images (Inoue *et al.* 2016).

2.6.1 Computed tomography

CT is a medical imaging modality that produces cross-sectional radiographic images (Lisle 2012). CT offers the advantage of high sensitivity for fracture detection and in some instances, ligamentous disruptions, while unfortunately having the disadvantage of not being able to demonstrate spinal cord injuries and disc herniations, and administrating a much higher radiation dose to the patient than with conventional radiographic images (Georgen *et al.* 2015).

Helical Multidetector-Computed Tomography (MDCT) offers high sensitivity and specificity for bone lesions and displacements in cervical spine traumas as a replacement to conventional radiographic images, while MRI is used to evaluate soft tissues and ligaments and identify spinal cord injury (Izzo *et al.* 2020). Over time CT has taken priority as the standard diagnostic method for looking at bony pathologies of the cervical spine (Weisskopf *et al.* 2001).

While CT continues to evolve over the years with reference to taking lead in the diagnosis of cervical spine trauma, a recent study shows that there are rare instances of misdiagnosis from CT artefacts mimicking type two odontoid fractures (Zhang, Marques, Serafim and Cabral 2020). Zhang *et al.* (2020) found 16 total false-positives in spinal trauma due to CT-generated artefacts. The cases were accounted for in a total of ten resources with their current study counting as the eleventh report. The conclusion was to always pursue thorough clinical examinations to avoid over-reliance on a single CT scan, and to rather add a repeat requisition of the CT or include alternative imaging methods (Zhang *et al.* 2020).

MDCT has the capability to show the thinnest bone fracture or dislocations. Hence, it has rapidly climbed the ladder as the primary modality in cervical spine injuries (Izzo *et al.* 2020).

The list of aspects supporting CT as the primary imaging modality of choice includes its wide availability, quick accessibility and high speed which allows for accelerated patient management. On the contrary, based on the National Emergency X-radiography Utilization Study (NEXUS) guidelines for limiting radiation exposure and costs to patients, the referral of patients to MDCT must be limited to high and moderate risk patients (Izzo *et al.* 2020).

Most trauma centres use CT as the initial imaging modality in high risk trauma patients. Earlier, CT was obtained after conventional radiography to fully define the anatomy after the injury and in cases of high-risk patients (Schwartz 2008). Tables 2.4 and 2.5 below outline a summary of the results from Weisskopf *et al.* (2001) from a study that was dedicated to investigating the sensitivity of various diagnostic methods for acute fractures of the odontoid process.

Table 2.7: Sensitivity of various diagnostic methods for acute diagnosis of odontoid process fractures (Weisskopf et al. 2001).

Sensitivity of various diagnostic methods for acute diagnosis of odontoid process fractures				
Modality	**Conventional tomography**	**Plain conventional radiographic images**	**CT reconstruction**	**Axial CT**
Investigator 1	87.1%	64.5%	96.8%	71.0%
Investigator 2	83.9%	64.5%	100%	67.7%
Investigator 3	83.9%	58.1%	100%	61.3%
Investigator 4	80.6%	67.7%	80.6%	90.3%
Investigator 5	90.3%	64.5%	100%	64.5%
Average	85.2%	63.8%	95.5%	71.0%

CT: Computed Tomography

Table 2.8: Specificity of various diagnostic methods for the diagnosis of acute fractures of the odontoid process (Weisskopf et al. 2001)

Specificity of various diagnostic methods for the diagnosis of acute fractures of the odontoid process				
Modality	**Conventional tomography**	**Plain conventional radiographic images**	**CT reconstruction**	**Axial CT**
Investigator 1	100%	61.5%	100%	100%
Investigator 2	100%	46.2%	100%	100%
Investigator 3	92.3%	30.8%	92.3%	92.3%
Investigator 4	92.3%	38.5%	76.9%	76.9%
Investigator 5	92%	53.8%	100%	100%
Average	95.4%	46.2%	93.8%	93.8%

CT: Computed Tomography

According to Weisskopf *et al.* (2001), conventional tomography was considered the standard investigation modality of choice for injuries for a more detailed visual and understanding of the fracture pattern. However, based on the conventional tomogram equipment used from the time of conducting the study, the acquisition time was 20 to 30 minutes, counting as a great disadvantage. When comparing conventional tomography to plain conventional radiographic images, 6% of the fractures could only be seen on the conventional tomogram, offering important information for the selection of the best therapeutic intervention for patients (Weisskopf *et al.* 2001).

During the time of the study by Weisskopf *et al.* (2001), CT had already emerged as a modality that offered excellent definition of osseous structures, allowing for shorter acquisition times and the opportunity for reconstruction with a scan time of two minutes. Due to the technical advantages of CT, CT and conventional tomography could only be compared based on the final visualisation of the anatomic structure of interest, because the rest of the other technical and technological aspects already put CT above conventional tomography. Therefore, the conclusion made by the authors was that when considering radiation exposure and technical feasibility, CT with 2D reconstructions could replace conventional tomography (Weisskopf *et al.* 2001).

2.6.2 Magnetic Resonance Imaging

MRI is a modality that uses magnetic properties of spinning hydrogen atoms to produce diagnostic images (Lisle 2012). MRI has the advantages of high sensitivity for soft tissue and no use of ionising radiation, with unfortunately the disadvantages of not always being able to capture fractures, being expensive, time consuming, not comfortable for obese patients, and not being widely available (Georgen *et al.* 2015; Izzo *et al.* 2020). The principle indication for MRI for imaging of the cervical spine is for neurological deficit (Kafibadi & Rangi 2017; Schwartz 2008).

In a study by WeiBkopt, Naeve, Ruf, Harms and Jeszenszky (2003) on “therapeutic options and results following fixed atlantoaxial rotatory dislocations”, diagnostic imaging was implemented in observing the effectiveness of the implemented methods and the results thereof. As part of the work-up dynamic for the study, MRI, CT scans, axial CT scans and plain conventional radiographic images (open-mouth view and the lateral view) were acquired to define the extent of the fixed dislocation. The authors highlighted that the radiation exposure associated with CT was a major disadvantage and indicated that MRI was a valuable diagnostic tool for follow-up examinations of patients with atlantoaxial rotatory dislocations (WeiBkopt *et al.* 2003).

When comparing MRI to CT as two specialised modalities, CT is superior to MRI for the visualisation of bone complications. However, MRI can still be used in the case of non-union fractures of the odontoid process (Weisskopf *et al.* 2001). Terry and Varacallo (2018) makes mention of how plain conventional radiographic images remain critical in evaluating and ruling out fractures of the odontoid process in institutions that are without readily available specialised imaging modalities. These circumstances can be observed at radiology department situated in rural and less developed areas in South Africa, and in Africa as a whole.

In making mention of the scarcity of specialised modalities in South Africa and the African continent, the following research studies are worth referencing: Bhutta, Monono and Johnson (2020), conducted a research study under the title of "Management of infective complications of otitis media in resource-constrained settings".

Their finding made mention of how suspected possible intracranial extension requires CT imaging referral and that although this might not be a challenge for some locations, that unfortunately studies in Tanzania and Zimbabwe have proven poor availability and access to imaging resources such as CT.

According to Kabongo, Nel and Pitcher (2015), the South African public health care sector has substantially lower radiology resources. The research study, which was focused on the analysis of licensed South African diagnostic imaging equipment shows that general X-ray units are the most homogeneously distributed and accessible resource with 34.8 resources per million, while CT comes fourth place at 5 resources per million and MRI comes last at 2.9 resources per million (Kabongo *et al*. 2015). The authors added that the access to radiological services in South African is lower than that of all Organisation for Economic Co-operation and Development (OECD) countries. While South Africa is doing better than some sub-Saharan African countries, there is a high discrepancy between the least and best resourced provinces within the country itself (Kabongo *et al*. 2015).

Ngoyi, Muhogoa and Pitcher (2016), explored the marked inequality in global access to diagnostic medical imaging in low-income African countries. The study was conducted in Tanzania and proved that although there was a homogeneous distribution of resources throughout the country, the available resources available per million was lower than the recommended twenty units per million suggested by the World Health Organisation (WHO). A similar research study was performed in

Zimbabwe (Maboreke, Banhwa & Pitcher 2019). The study revealed that over half of Zimbabwe's radiology equipment is saturated in two cities, available to only one-fifth of the country's population. While two-thirds of the radiology equipment belongs to the private sector and thus available to an approximate of 10% of the country's population (Maboreke *et al.* 2019).

2.7 IONISING RADIATION

Ionising radiation is energy that is in transit, and it can either be X-rays or gamma radiation, depending on its wavelength and frequency (Sherer, Visconti & Ritenour 2006). Ionising radiation constitutes to the process of ionisation, which entails the interaction of X-rays with the human body (Sherer *et al.* 2006). The discovery of X-rays has translated into a constantly advancing medical imaging world (Yousif & Nesrin 2015). While medical imaging comprises of various modalities, of which some is non-reliant on ionising radiation, conventional radiography uses X-rays in different amounts and strengths, depending on the body part that is being imaged (Yousif & Nesrin 2015).

While X-ray examinations serve as an important diagnostic tool, the fact that ionising radiation comes with the risk of harm is just as important to consider. The expression used to measure the amount of the X-ray energy absorbed by the human body is radiation dose. For the purpose of this study, effective dose (ED) was considered. ED is an indication of how detrimental to the health of a patient the X-ray energy is, and it is expressed in Sievert (Sv). It is often not possible to directly measure organ dose, hence mathematical models of dose distributions from simulated patients for different examinations and exposure conditions are used (Whitley *et al.* 2005).

2.7.1 Radiobiology and radiosensitivity

As mentioned above, ionising radiation constitutes a hazard to the human body (Graham *et al.* 2012). Hence, accurate radiation dose measurements to the patient are important in order to precisely evaluate the hazard.

Radiobiology (the study of how different tissues respond to radiation) and radiosensitivity (the difference in the manner in which different tissues react to radiation) provide insight on the nature of the direct and indirect hazard and biological damage of ionising radiation (Ball *et al.* 2008).

Under the concept of radiobiology and radiosensitivity, somatic, genetic, stochastic and deterministic effects (see section 2.6.3 below) are well outlined in order to alert radiation workers to the importance of radiation protection and safety (Ehrlich & Coakes 2017).

According to Ball *et al.* (2008), the bone marrow is ranked second place, lens of the eyes fourth place, the skin epithelium is number eight, while the thyroid is number eleven on the relative radiosensitivity of tissues. These are a list of tissues that are found within and close to the field of interest during the imaging of the odontoid process according to the PCMXC20 Monte Carlo software©. The rankings are enough motivation for radiation workers to show sensitivity during imaging of the odontoid process. Hence, in chapters four, five and six the research study reflects on the ED various tissues that are irradiated during imaging of the odontoid process.

2.7.2 Effects of ionising radiation

The dose used in diagnostic radiography is relatively lower than the outlined threshold capable of causing immediate harmful radiation effects. However, radiation received in X-ray examinations is known to increase the risk of malignancy and the probability of skin damage and cataracts above a certain dose (Yousif & Nesrin 2015).

When considering the effects of ionising radiation, the amount of the radiation dose and the periods for which it is administrated are important (IAEA 2004a). The higher the radiation dose received over a longer period, the greater the risk that the patient can experience long-term radiation damage.

This does not take away from the fact that lower doses over long periods of time can also be alarming (The Joint Commission 2011). While keeping in mind aspects that contribute to increased risks of ionising radiation, it is also important to consider patients that are mostly susceptible to the risks. The list includes children, pregnant women and patients with certain pathological conditions (diabetes) (The Joint Commission 2011).

Ionising radiation effects are either deterministic and stochastic effects, or somatic and genetic effects. Deterministic effects entail partial loss of function of an organ or tissue. These effects are seen after a threshold dose, and the degree of the effects depends on the level of the dose. Deterministic effects are evident by extensive cell damage or cell death.

Examples of deterministic effects include cataracts, skin erythema, sterility, radiation sickness and foetal death. Stochastic effects are randomly occurring somatic changes that are dependent on the dose of the ionising radiation. Stochastic effects are unlikely to occur from diagnostic radiographic examinations. The occurrence of stochastic effects is based on the age of the patient, the amount of the radiation dose, as well as the anatomical region that is being irradiated (Sherer *et al* 2006).

Somatic effects are the physical effects that appear in individuals that have been irradiated with ionising radiation. The earlier effects observed will affect the person subjected to the ionising radiation, and not the offspring. 90% of the effects are said to be manageable, while the remaining 10% is cumulative over time of repeated exposure to ionising radiation. Genetic effects, on the other hand, are biological effects affecting the dependents, and they imply damage to the deoxyribonucleic acid (DNA) molecule in the sex cells. During mutation, impaired genetic information is carried down to the dependents, manifesting as various malformations. Both somatic and genetic effects can be linked to the measure of the ionising radiation, the anatomical region that is being irradiated, and the size of the anatomy region (Sherer *et al.* 2006).

2.7.3 Radiation protection principles

The goal to reduce patient dose without the loss of image quality has become a priority in medical imaging. The ICRP has also been attentive to the matter through introducing a few principles, for instance diagnostic reference levels (DRLs), applying ALARA (as low as reasonably achievable), and maintaining image quality as good as necessary for diagnosis (Busch & Faulkner 2015; Yousif & Nesrin 2015). There is generally a long list of ionisation radiation regulations for X-ray examination (Busch & Faulkner 2015).

Justification of examinations remain an essential tool in protecting patients from ionising radiation. Justification implies carefully considering whether the examination offers more benefits than risks to the patient for every examination (Ball *et al.* 2008). Optimisation as an integral aspect of the current research study serves in maintaining radiation doses to the patients that are as low as reasonably achievable through radiation dose restrictions and awareness of radiation dose limitations.

Some of the measures that can be implemented includes awareness for radiation workers and the rest of the medical team, protocols that strive to minimise radiation doses to the patient, avoiding repeated radiographic images, matching examination with clinical history, knowledge of radiation dose thresholds, applying collimation, use of lead markers, in-service training and high image quality at adequate radiation exposures (Ball *et al.* 2008).

Furthermore, adding to justification and optimisation is limitation, which entails making sure that there is no exceeding specified dose limit through implementation of DRLs. Conclusively, there is a much higher responsibility for radiographers to ensure that radiation protection is a priority through every examination they undertake. This is obtainable through everyday practical practices such as patient positioning, using radiation protective gears, selection of suitable projections, beam collimation and optimal exposure parameters (Whitley *et al.* 2005).

2.8 OPTIMISATION OF RADIOGRAPHIC PROCEDURES

More than 80% of overexposures adding up to increased radiation dose to the patient has been a result of human error (Herbst & Fick 2012). These human errors range from radiographic exposure errors (exposure factors and additional technical factors that must be taken into consideration during radiographic examinations) to positioning errors (use of important anatomical landmarks and adapting to unusual circumstances) (Herbst & Fick 2012).

2.8.1 Radiographic exposure factors

The Radiological Society of South Africa (RSSA) has put forth a code of conduct that reinforces minimum radiation doses to patients (RSSA 2002). This chapter considers exposure factors as an integral part of the research instrument (checklists) and more importantly, optimisation. Radiation exposure factors are directly linked to image optimisation and image quality. An ideal radiographic system must be configured in such a way that adequate radiographic images can be obtained at the lowest dose (Whitley, Jefferson, Holmes, Sloane, Anderson & Hoadley 2015).

Exposure factors, namely the milliampere seconds (mAs), kilovoltage peak (kVp) and source-to-image distance (SID) are dependent on the anatomical region that is being imaged, its thickness, density and pathology (Whitley *et al.* 2015). The mAs represents the intensity of the X-ray beam, accounts for the amount of X-ray photons that the radiographer is using, and determines the density perceived on the radiographic image (Bushberg, Seibert, Leidholdt & Boone 2012; Whitley *et al.* 2015). mAs is generally the product of the X-ray tube current (mA) and the time (seconds) of the exposure. When considering movement unsharpness, a combination of higher mA and lower time is used to overcome unsharpness from movement (Bushberg *et al*. 2012).

However, this is not always possible with standard conventional tomography equipment that are not advanced with quicker acquisition times. Insufficient mAs selections are seen on the radiographic image as noise, while mAs levels that are higher will reflect as excessive density (Whitley *et al.* 2015). This observation was used as one of the guiding theories for judging exposure on radiographic images in this research study.

The kVp represents the penetrating power of the beam. Diagnostic radiography offers a kVp range that is applicable to the conventional radiography modality of 50kVp to 120kVp. Although kVp has a considerable influence on density, it mainly controls image contrast. The SID (distance from the source to the image detector) affects both mAs and kVp. This means for every radiographic exposure all three entities must be carefully considered.

There are a few aspects to consider when reflecting on SID: the X-ray tube should not be too close to the patient, as this might result in radiation damage, excessive SID requires higher increases in mAs, and therefore higher X-ray tube loading and lastly, shorter SIDs may result in geometric unsharpness (Bushberg *et al.* 2012; Whitley *et al.* 2015).

The above-mentioned exposure factors can influence the perception of the final radiographic image. The first one can be density. Density is the degree of blackening within the radiograph (Whitley *et al.* 2005). Higher densities often result from the selection of higher exposures of radiation (mAs). On digital systems, low density is observed as areas of the radiographic image that are too bright, while dark areas are related to high densities and higher radiation exposures (Whitley *et al.* 2015).

If we consider the exposure index (EI) used in the checklist in chapter three (*Checklist for evaluating image quality and radiation dose during radiographic imaging of the odontoid process*) to support judgement for the radiographic exposures, radiographic images represented by dark areas would further be represented by an EI that is above range, and vice versa (Bushberg *et al.* 2012; Whitley *et al.* 2015).

As previously mentioned, the human body is a complicated structure that can be difficult to position when obtaining radiographic images, and this may result in radiographic images that may lead to false diagnosis (Whitley *et al.* 2005). In order to successfully be able to detect pathological conditions in the human body, differences in density between the surrounding tissue and the area of pathology must be well captured. These differences in density accounts for contrast (Bushberg *et al.* 2012; Whitley *et al.* 2015).

Contrast is altered through varying kVp. When the kVp selection is low, there is a widened scale of attenuation variance within the radiographic image. There are other factors attributing to contrast, for instance collimation and pathologies. Hence, collimation is identified as one of the radiographic image quality criteria attributes outlined in Chapter three, as supported by multiple resources (Bushberg *et al.* 2012).

When considering density and contrast, it is only fair to further explore radiographic image sharpness. Sharp radiographic images are a prioritised goal in radiography, especially when assessing subtle fractures and changes in the arrangement of a bony structure, as with the assessment of the odontoid process (Whitley *et al.* 2005). For this study, movement and acquisition factors were considered for discussion as two of the aspects leading to unsharpness, and as identifiable common errors in Chapter five.

Movement unsharpness can result from movement of either the patient, the IR or other equipment (Bushberg *et al.* 2012; Whitley *et al.* 2015). While patient movement can be voluntary and restricted through immobilisation, movement can also be involuntary and unavoidable. The use of a lower mAs with a higher kVp can be effective in overcoming movement unsharpness. Acquisition unsharpness accounts for unsharpness encountered during the acquisition process (Whitley *et al.* 2005).

2.8.2 Radiographic image quality

Proper positioning of the patient with reference to the IR is an integral part for optimisation based on both image quality and radiation dose (Axelsson 2007). According to IAEA (2004a), image quality assessments should be addressed on the same level as patient dose.

The IAEA (2004a) released a publication titled “European Guidelines on Quality Criteria for Diagnostic Radiographic Images”. These Europeans guidelines are dedicated to promoting adequate image quality and a reasonably low radiation dose that is comparable throughout Europe (IAEA 2004a). The guidelines address the diagnostic quality of radiographic image quality, the radiation dose to the patient and the choice of radiographic technique (IAEA 2004a).

The guidelines advise on diagnostic requirements, criteria for radiation dose to the patient and examples of good radiographic technique. These guidelines help radiographers to assess a diagnostic imaging method in order to see if it will be able to produce a diagnostic image of standard quality, and to further evaluate if the important image details and image criteria for the anatomical structure of interest are captured to assist in the diagnostic process (IAEA 2004a).

According to the European guidelines, an essential tool to critiquing the radiation dose to the patient is knowing the reference dose values for various radiographic views (European Commission 1996). The reference levels are a guide to being attentive to not exceeding dose limits, and in cases where the dose limits are exceeded, to take the responsibility to investigate the reasons and find relevant solutions. The European guidelines were able to achieve optimal radiographic technique through promoting compliance with the image quality and patient dose recommended criteria. The application of the guidelines led to a reduction of 20% to 69% in patient dose at low cost and acceptable image quality (IAEA 2004a).

2.8.3 Best practice for radiographic imaging

Optimisation must begin with referrals and the motivation for diagnostic requirements in order to reduce the number of referrals, and therefore reduce radiation exposure (Busch & Faulkner 2015). The choice of imaging methods must meet the requirements of the referring doctor and the reporting radiologist (Busch & Faulkner 2015).

Therefore, the radiographer must make good judgement on the method to implement and apply adjustments to the technique when necessary, at the lowest possible risk to the patient (Busch & Faulkner 2015). Second to successfully deciding on the right method and technique, the image quality must be determined. The image quality must match the goal of the procedure, for instance in the context of the current research study, deciding whether the method and technique will be able to optimally observe the odontoid process so that diagnosis is achieved. The assessment may be in two ways, non-obvious pathologies for high image quality, and known pathologies for medium image quality (Busch & Faulkner 2015).

Dose creep has been a matter of concern when it comes to conventional radiography as an indication of the use of high radiation exposures. Radiographers must monitor dose creep consistently and strive to eliminate it through the effective use of validated radiographic exposure charts for all examinations, with reference to patient sizes (Ball *et al.* 2008).

Developed conventional radiography X-ray systems also depend on the initial set up of exposure factors when being installed (Williams, Krupinski, Strauss, Breeden, Rzeszotarski, Applegate, Wyatt & Seibert 2007). Exposure charts are regarded as an essential quality assurance (QA) component of X-ray departments world-wide, since modern conventional radiography systems have a wide exposure latitude which tends to either result in suboptimum radiographic images and/or high patient doses (Williams *et al.* 2007). Furthermore, being able to achieve quality images for accurate diagnosis without any repeats, the implementation of maintained equipment, training and experience of radiographers and robust protocols and procedure outlines are essential (Osma, Sulieman, Suliman & Sam 2010).

2.9 IDENTIFIABLE GAPS

Throughout the process of the literature review, the following were observed:

- Effective dose reference levels for the odontoid process could not be identified.
- Although there are research studies that make mention of the superimposition of the odontoid process from the open-mouth view, no research studies reporting on the repeat rate associated with the superimposition were identified (excluding a non-published research study for the compliance of obtaining a Bachelor of Technology qualification) (Josephs, 2016).
- Adding to the point above, although avoiding repeated radiographic images is listed as one of the radiation protection measures, research studies reporting on the relationship between repeat rates and the radiation dose to the patient were not identified.
- While conventional tomography is capable of imaging the odontoid process, literature published on this topic was limited (see tables 2.2 and 2.3).
- CT was repeatedly confirmed as the best modality for imaging of the odontoid process. However, when considering the economic status and technological advancements of the African continent as seen in section 2.6 (Specialised modalities), one may question whether CT is as readily available for all radiology departments, and thus for all patients in Africa.

- According to the Department of Health of South Africa director-general Matsoso (2019), long waiting times for patients are common in health facilities in South Africa and are recognised as a challenge, with an average score of 68% from the 2012 audit and 73% from the recent 2017/2018 audit. This challenge can be observed in radiology departments particularly when it comes to specialised modalities.
- Literature on the upper cervical spine radiographic imaging protocols from Africa could not be found.
- Due to the fact that the medical imaging field is advancing at such a fast pace, there is a gap in literature when it comes to comparing and exploring conventional radiography methods for the consideration of parts of the world that have not yet advanced into using specialised modalities. This means that, while there is much literature sensitising the medical world on alternative comparable specialised modalities, the same courtesy is not available for plain conventional radiography.
- Research on the odontoid process for trauma is very popular. This creates a question whether imaging of the odontoid process is only essential in cases of trauma.

2.10 VALIDITY AND RELIABILITY

Validity is the extent to which a research study captures the meaning of the concepts it was intended for (Abbott & McKinney 2013). The research study was guided by literature to ensure that the content of the research was relevant, relatable, and reliable within diagnostic radiography. The research study was focused on the context of principles of diagnostic medical imaging. Keywords were used to seek out sources that were significant to the research study. There were two checklists completed per examination for the validity of captured data.

The extent to which a research measure evaluates a concept with consistency is referred to as reliability (Abbott & McKinney 2013). A high level of reliability comes with a research instrument that produces the same data time after time, with arising variations being from the aspect that is being measured (Denscombe 2007).

The integral technical factor values that were inserted onto the PCMXC20 Monte Carlo software© for effective dose calculations were consistent. Hence, the effective dose value can be trusted to be consistent. The use of the Microsoft Excel spreadsheet (used to capture a summary of all data that were collected for the research study) remain standard globally, the captured information can be revaluated, and the inserted formulae can be assessed to rule out any discrepancies.

The checklist used strived to minimise and eliminate variations that could arise from data based on individual perception. The checklist was piloted in order to rule out gaps that could hinder the data collection process. An extensive literature review was used as a guide for all the aspects that were included in the checklist. The checklists were reviewed by the researcher's supervisors. There was a pre- and post-pilot study checklist to ensure validity (Hofstee 2009). All the data captured on the checklist could not be fabricated, since the data was retrieved directly from the RIS and the CR systems. The use of a checklist for capturing data allowed for consistency in evaluating the radiographic images. All radiographic images were evaluated on the scale of the checklist. The checklist consisted of items that were free of errors, for instance grammatical and spelling errors.

Radiology Information System (RIS) is known for containing details of the patient and examinations that the patient went through. The system is trusted for achieving efficiency with workflow, reporting, storage and retrieval (Bushberg *et al.* 2012; Whitley *et al.* 2005). All patient demographic and examination information for the research study was derived from the RIS.

The acquisition workstation and the computer radiography (CR) system are generally placed where the pre-processing task takes place. This processing is dependent on the calibration of the system (Bushberg *et al.* 2012; Whitley *et al.* 2005). The process of radiographic image quality evaluation for this study took place at the acquisition workstations for which all QA tests were performed, and within acceptable limits. The performance of the monitors was also tested through the Society of Motion Picture and Television Engineers' (SMPTE) quality control (QC) test.

The literature on the QA and QC guidelines expressed in the research study were deduced from the American College of Radiology (ACR) modality guidelines and the standards that govern the process of the transfer of radiographic examination information within a radiology department (Williams *et al.* 2007).

2.11 SUMMARY

The purpose of the current chapter was to put context to and provide a theoretical framework for the present research study, namely to optimise conventional radiographic imaging of the odontoid process and contrasting the open-mouth view and conventional tomography. The chapter fulfilled the first objective of the research study, which was focused on conducting a literature review to create a concrete foundation for the research study.

Based on the available literature on this topic, it is evident that specialised imaging modalities for visualisation of the odontoid process have taken the forefront around the world. Yet, in developing countries with limited resources, hospitals and practices that are without readily available specialised imaging modalities, plain conventional radiographic images remain critical in evaluating and ruling out fractures of the odontoid process (Tenny & Varacallo 2018).

The next chapter will describe the development of the checklist that was used as the research instrument for the research study. The chapter serves to address the second objective of the research study, which is centred around creating a checklist that would be used to retrospectively capture data that were used to evaluate and thoroughly analyse the two specific radiographic imaging methods of the odontoid process. The layout and referencing in this chapter follow the layout in which the article was submitted.

CHAPTER THREE

A CHECKLIST FOR EVALUATING IMAGE QUALITY, REPEAT RATES AND EFFECTIVE DOSE DURING RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS

3.1 INTRODUCTION

A checklist is a useful multipurpose tool known to make provision for various activities. It can be used to collect facts, record behaviour, analyse and evaluate objects, and rate personalities[1]. These examples qualify the use of checklists in various professional fields, from engineering, where analysis and evaluation of objects are conducted, to humanities, with the rating of personalities. Christman *et al*.[2] highlighted the emergence of checklists as useful tools in reducing errors pertaining to organised activities in various professional fields.

In the healthcare sector, authors who investigated errors encountered during medical procedures believe that these errors could have been avoided through the implementation of checklists[3]. Hence, over time, the conclusive importance of checklists has become evidently dominant in the healthcare sector. The healthcare sector values validated checklists for the role they have in ascertaining that medical procedures are performed at a high standard, and to promote patient safety.[4] A validated checklist is central to teaching and assessing procedural skills[5]. While one checklist may be dedicated to recording quantities, validated checklists are used for guiding its user through a series of steps to ensure that a task is completed successfully, and for testing the user's knowledge on a specified procedure[5].

In 2016, Rafiei *et al.*[6] developed a validated checklist for a radiological patient safety system (RADPASS) for interventional radiology. The 27-item checklist was based on the structure of the surgical patient safety system (SURPASS) checklist for patients undergoing image-guided interventions. Through the implementation of the validated checklist, the department was able to achieve improved patient safety awareness and efficiency among the healthcare workers carrying out image-guided interventions.

The validated checklist decreased optimal process deviation rates from 24% to 5%, and postponement rates from 10% to 0%.[6] According to Norsok Standard,[7] process deviation comprises activities or events showing inconsistency from accepted performance standards, which may result in loss of life and damage to health.

Gawande [8] also advocated for the use of checklists in the healthcare sector. In the book "*The Checklist Manifesto: How to Get Things Right*", Gawande thoroughly outlines the successful use of a checklist designed for surgical patients by the World Health Organization (WHO),[9] and adopted it for years as a baseline for optimal patient care.[9] The proven success of the checklist was recorded in the United States for central lines in an intensive care unit (ICU), where a decrease of 66% in infections was observed within a period of three months, saving an estimated number of 1 500 patients.[10]

Numerous reasons have been asserted for the application of checklists in general, in various professional fields and in the healthcare sector. However, the purpose of a checklist must compliment the task for which it has been designed. In the field of quantitative research, checklists are one of the reliable tools that can be used to collect data and record information for analyses and evaluation.[8] Research is centred on answering a unique underlying research question with a view to successfully achieve a list of objectives associated with the research study. Consequently, researchers develop or adjust checklists that ideally complement the objectives to answer their research question.[8]

In 2019, Sebelego[11] assessed radiographers' use of radiographic critique of routine shoulder projections, through which a checklist was established. The checklist consisted of radiographic image criteria that allowed the author to retrospectively determine the adequacy of shoulder images. Sebelego was able to conclusively report back on the radiographic positioning shortcomings as evaluated. The results of the application of the checklists were based on an evaluation of 578 radiographic images of the shoulder.

The list of criteria that were assessed, was divided into categories that included exposure factors, lead markers, positioning and anatomy. The data collected from the checklists revealed that the criteria of the shoulder imaging were met 60% of the time. The list of criteria proposed by Sebelego created a directional foundation with the goal to develop a checklist to capture data for the purpose of image quality evaluation.[11]

In 2018, Kotzé *et al.*[12] also designed a checklist that investigated neonatal chest image quality. The checklist was based on radiographic image quality criteria for neonatal chest derived from literature published by the European Commission (EC)[13] and other authors in the field of radiology. The checklist evaluated aspects such as centring of the field of view, angulation of the main radiation beam, rotation of the chest cavity, anatomy included in the field of view, shielding provided to the neonate, and collimation of the main radiation beam. Although the study focused on criteria for neonatal chest radiographic images, directional information applicable to developing a checklist for plain conventional radiographic image critique was derived from the study.[13]

Like the checklists compiled previously,[11,12] the aim of the research presented here was to develop a checklist that could determine efficiency in recording radiographic image quality evaluation and achieve ED calculations. The checklist was developed based on radiographic imaging criteria derived from different supporting sources, including journal articles, radiographic textbooks and guidelines proposed by experts in the radiology field. The supporting sources were used to address the following research question: "What elements should be considered when developing a checklist for radiographic image quality evaluation, repeat rates and achieving ED calculations using the PCMXC20 Monte Carlo software©. Therefore, the purpose of this article is to translate the design of a standardised checklist for optimising conventional imaging of the odontoid process.

The reason for the odontoid process being a crucial centre of attention for radiographers and reporting radiologists when it comes to radiographic imaging of the cervical spine is due to its known susceptibility to injury. The consciousness often comes with a strive to achieve optimal radiographic images that are achieved through the implementation of various methods in one examination.

This often results in a questionable radiation dose to the patient. The checklist served as a research instrument in a research study intended for the optimisation of conventional radiographic imaging of the odontoid process, with reference to two specific conventional radiographic imaging methods: the open-mouth view and the conventional radiographic tomogram of the odontoid process.

3.2 METHODS

The checklist was developed as part of a descriptive, quantitative research study.[14] However, it was specifically developed in a qualitative realm, where the main goal was to achieve understanding through description, observation and evaluation.[14] During the process of developing the checklist, thorough evaluation and observation were used to review, study and carefully identify factors that contributed to image quality and the total ED to the patient during radiographic imaging of the odontoid process.[15]

Available materials and resources, on the significance of possible criteria that could be used for the checklist were identified through available literature to aid with the initial step of developing a draft checklist; for example, the Delphi process, often used[16] to compile validated checklists was studied as a guideline although it was not implemented in the research process of this research study. The development of the checklist in this research study did not require ethical approval, special permission, informed consent or statistical analysis.

3.2.1 Sampling

Academic databases and search engines were used to locate sources in the literature to develop the draft checklist. These databases and search engines included Ebscohost, Science Direct, PubMed and HubMed. The motivation behind the choice of databases and search engines was because they cater for science and medical journals and guidelines.

Key words that were used during the literature search included: 'checklists in radiology', 'checklists in radiography', 'checklists in healthcare', 'creating a checklist', 'radiographic evaluation forms', 'radiographic image quality', 'radiographic image evaluation' and 'radiographic image critique'. The timeframe for published sources was from January 2000 to December 2018, although some adjustments were allowed to include useful literature published outside the specific timeframe.

The qualitative sampling technique of purposeful sampling was implemented for the research study.[17] The inclusion criteria focused on information-rich articles, guidelines and textbooks with a theoretical focus on developing a basic checklist, radiographic image evaluation research and ED evaluation.

A list of textbooks on the principles of radiation physics, with sections pertaining to technical exposure factors, radiographic image critique and evaluation, from the perspective of patient positioning and consideration of radiographic technical factors, were obtained from the research institute's library. The textbooks selected for inclusion in the study were authored by Ball *et al.*,[18] Bontrager and Lampignano,[19] Carter,[20] Graham[21,22] and McQuillen Martensen.[23] After an intensive literature review was conducted, a draft checklist was developed.

3.2.2 Trustworthiness

On the basis of a qualitative research study, outlining the quality of the findings for trustworthiness needs to be emphasised.[24] A checklist must be simple yet reliable in its capability to collect and record data, as noted by Dean *et al*.[25] The credibility of the final checklist is centred around section A of the checklist.[26] Section A required the demographics of the patients for the examination for which the checklist was completed, which allowed for re-evaluation of the data captured for the specific examination. The checklist could be regarded as dependable because it was stable and could be applied over time and under different conditions. Table 2.1 and 2.2 reflect the number of sources from various parts of the world that were used to support each one of the image quality parameters and the exposure factors included in the checklist.

The checklist could be used by various researchers and radiographers and would remain congruent between different individuals. The checklists could be transferred between a research setting and the workplace,[36] and is therefore not only valid for image evaluation, but also for use by researchers aiming to collect technical factors for obtaining effective doses through the PCMXC20 Monte Carlo software©. Finally, the checklist has been used to successfully capture data relating to the radiographic imaging of the odontoid process using two methods: the open-mouth view and the tomogram. Two hundred and sixteen checklists were completed successfully, assessing a total of 421 radiographic images for the main research study.

3.2.3 Pilot study

In addition to the reliability of the checklist, a draft checklist was adapted based on observations from the pilot study to deliver a final checklist. It is important to pilot a checklist and make changes based on observations to help improve the checklist and close any existing gaps, such as the checklist not addressing the research question and not achieving the research objectives.[25] The checklist was piloted on fifteen patient examinations. Five patient examinations meeting the inclusion criteria were selected from each one of the three X-ray units from which data was collected for the main research study. The findings from the pilot study indicated that to an extent, the checklist was difficult to complete and therefore had to be divided into separate sections. Minor changes were necessary to ensure clarity and completeness of information. The findings of the pilot study were considered in the analysis of the data.

3.3 RESULTS

3.3.1 Build-up of information

The outline of the initially developed checklist was inspired by criteria from different existing checklists, both field-specific and general checklists. Various articles, guidelines and textbooks published during the timeframe January 2000 to December 2018 were located. Inclusion and exclusion criteria were applied to identify articles that were relevant to the design of the checklist for imaging of the odontoid process.

Because of the limited information on the topic, two articles and one textbook published outside the specified timeframe were included in the data. The two articles were critically and directly linked to radiographic image criteria. Figure 3.1 represents the process of applying the inclusion criteria for the material used to develop the draft checklist.

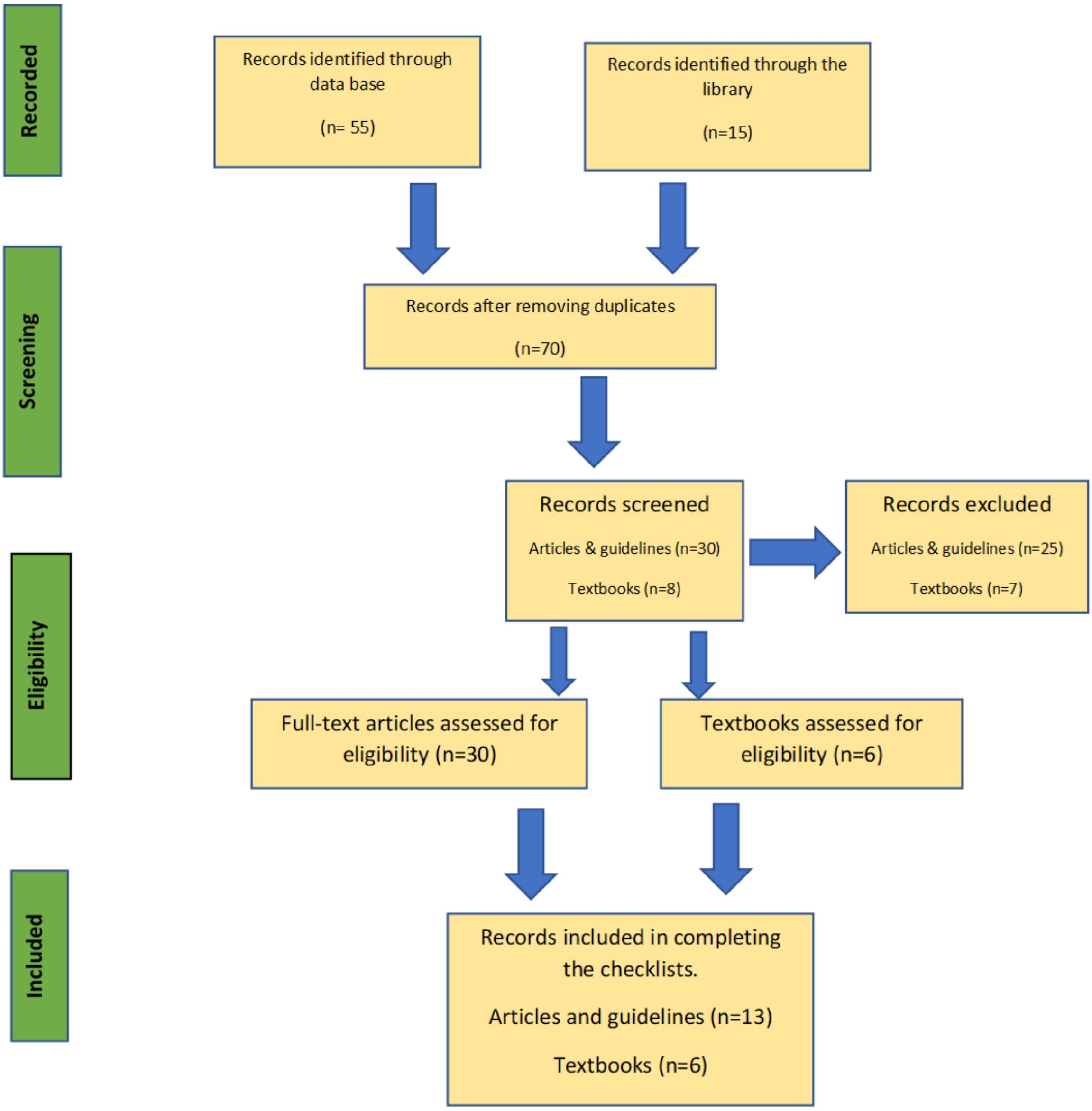


Figure 3.1: Flow diagram for selection of resources (compiled by researcher)

The textbooks used were from the research institution's library based on their frequent citation in the field of radiology. A total of fifteen textbooks were identified, eight were screened for eligibility, and six were selected for use.

During the process of reviewing the articles, the abstracts were used as a guide on whether to consider or disregard the article. Fifty-five articles were identified. Thirty articles were screened for suitability, of which 13 articles were selected for inclusion in the study.

Once the selection of material was concluded, three objectives had to be met. The first objective was to discover guidelines and methods used to establish a checklist for both research and industry use. The routine was divided into two sections, with the first aiming to obtain guidance on how to develop a general checklist. After standard guidelines for a general checklist were acquired, the second objective was to narrow the perspective towards identifying guidelines for image evaluation and dose parameters. The third objective was to combine the literature to develop an inclusive checklist dedicated to the evaluation of radiographic image quality and dose calculations for different radiographic methods.

The textbooks and articles were randomly number-coded (one to six) as they were being located. The numbers were then placed in a hierarchy: the textbooks at the bottom of the hierarchy were disregarded because they were not relevant to the given three categories outlined in Table 3.1, and a purposeful sampling method was implemented. The disregarded textbooks were not precisely focused on image critique and exposure factors for imaging of the cervical spine, nor did they provide insight on guidelines to develop a basic checklist.

The tables (3.1 and 3.2) below capture how each one of the six textbooks and 13 articles were categorised to assist in shaping different sections of the final checklist. The textbooks (Table 3.1) and articles (Table 3.2) were arranged in ascending order based on the year of publication.

Table 3.1: Categories of textbooks reviewed (created by the researcher)

			Category one	**Category two**	**Category three**
Section of checklist	**Author/s, date (reference number)**	**Title of textbook**	**The theoretical aspect of creating a checklist**	**Radiographic image evaluation**	**Estimated dose (ED) evaluation and technical factors**
Sections C and E	Carter, Hyatt, Patersob, Pirrie and Thornton, 1991 (20)	*Chesney's Equipment for Student Radiographers*		Guidelines are available for critically viewing radiographic images.	The textbook gives insight on technical factors including exposures.
Sections D and F	Graham, 1996 (21)	*Principles of Radiological Physics*			Textbook on radiation physics that covers exposure factors.
Sections D and F	Ball, Moore & Turner, 2008 (18)	*Essential Physics for Radiographers*			Textbook on radiation physics that covers exposure factors.
Sections C to F	Bontrager and Lampignano, 2011 (19)	*Textbook of Radiographic Positioning and Related Anatomy*		Radiographic image positioning, criteria and technical factors.	Aspects of radiographic exposures.

Table 3.1 continued.

Section of checklist	**Author/s, date (reference number)**	**Title of textbook**	**Category one**	**Category two**	**Category three**
			The theoretical aspect of creating a checklist	**Radiographic image evaluation**	**Estimated dose (ED) evaluation and technical factors**
Sections D and F	Graham, Cloke and Vosper, 2012 (22)	*Principles and Applications of Radiological Physics*			Textbook on radiation physics that covers exposure factors.
Sections C to F	McQuillen Martensen, 2011 (23)	*Radiographic Image Analysis*		Radiographic critique	Guidelines on exposure factors.

Textbooks in one category were placed on the second level of the hierarchy (n=3), textbooks that fell under two categories were placed on the third level of the hierarchy (n=3), while articles falling in all three categories were placed in the top and final level (n=0).

Table 3.2: Categories of articles reviewed (created by the researcher)

Section of checklist	Author/s, date (reference number)	Title of article	Category one	Category two	Category three
			The theoretical aspect of creating a checklist	**Radiographic image evaluation**	**Estimated dose (ED) evaluation and technical factors**
Sections C and E	Rossmann, 1966 (27)	Comparison of several methods for evaluating image quality of radiographic screen-film systems.		The article compares several methods often used for image quality evaluation. The methods were studied as an insight on image quality evaluation.	
Sections C and E	[No authors listed], 1996 (13)	European guidelines on quality criteria for diagnostic radiographic images in paediatrics.		The article focuses on the comparison between two methods used for radiographic image evaluation: visual grading analysis (VGA) and the receiver-operating characteristic (ROC) method.	

Table 3.2. (continued)

Section of checklist	**Author/s, date (reference number)**	**Title of article**	**Category one**	**Category two**	**Category three**
			The theoretical aspect of creating a checklist	**Radiographic image evaluation**	**Estimated dose (ED) evaluation and technical factors**
Sections C and E	Burnside, Andriole, & Dillon 2000 (28)	Double-exposure artefact mimicking a cervical spine fracture on computed radiography.		The article was based on artefacts as an important part of image quality. The article supported the list of criteria.	
Entire checklist outline	Delport & Roestenburg, 2011 (29)	Quantitative data-collection methods: questionnaire, checklists, structured observation and structured interview schedules.	The article explores various qualitative methods of data collection, among other checklists.		
Entire checklist outline	Koetser, De Vries, Van Delden, Smorenburg, Boermeester & Van Lienden 2012 (30)	A checklist to improve patient safety in interventional radiology.	The article outlines the benefit of using a checklist in interventional radiology.		

Table 3.2. (continued)

Section of checklist	**Author/s, date (reference number)**	**Title of article**	**Category one**	**Category two**	**Category three**
			The theoretical aspect of creating a checklist	**Radiographic image evaluation**	**Estimated dose (ED) evaluation and technical factors**
Sections D and F	Ofori, Gordon, Akrobortu, Ampene & Darko 2014 (31)	Estimation of adult patient doses for selected X-ray diagnostic examinations.			The article makes use of the Caldose x 5.0 software to assess the entrance skin doses and effective dose. The checklists will aid to collect the exposure factor for doses estimated using software.
Sections C and E	De Crop, 2015 (32)	Image quality evaluation in X-ray medical imaging based on Thiel embalmed human cadavers.		Image evaluation as a component of patient dose optimisation in medicine.	

Table 3.2. (continued)

Section of checklist	**Author/s, date (reference number)**	**Title of article**	**Category one**	**Category two**	**Category three**
			The theoretical aspect of creating a checklist	**Radiographic image evaluation**	**Estimated dose (ED) evaluation and technical factors**
Sections D and F	Ladia, Skiadopoulos, Kalogeropoulou, Zampakis, Dimitriou & Panayiotakis 2016 (33)	ED and image quality evaluation in paediatric radiography.		Image quality evaluation by radiologists	The use of PCXMC to estimate the dose and the risk thereof during imaging of the chest and abdomen.
Entire checklist outline	Rafiei, Walser, Silberzweig & Nikolic 2016 (6)	Checklists for image-guided interventions.	The benefits and implementation of a checklist in healthcare. Exploring the importance of checklists.		
Sections D and F	Yacoob & Mahammed, 2017 (34)	Assessment of patients' X-ray doses at three government hospitals in Duhok city.			The relationship between quality control and the ED to patients, and using this in relation to technical factors.

Table 3.2. (continued)

Section of checklist	**Author/s, date (reference number)**	**Title of article**	**Category one** **The theoretical aspect of creating a checklist**	**Category two** **Radiographic image evaluation**	**Category three** **Estimated dose (ED) evaluation and technical factors**
Sections D and F	Woodward, 2011 (35)	Digital radiography: exposure factor selection and ALARA.			Listing of exposure data based on simulation performed in the laboratory, using anthropomorphic phantom.
Sections C and E	Kotzé, Friedrich-Nel & Van der Merwe 2018 (12)	An instrument to assess neonatal chest image quality.		A checklist for assessing chest images in aid of image quality evaluation.	
Sections C and E	Sebelego, 2019 (11)	Radiographers' utilisation of radiographic critique of routine shoulder projections.		Radiographic image critique checklist of the shoulder in aid of image quality evaluation.	

The same process used for the textbooks was applied to the articles. Eventually, no articles fell into all three categories - 12 articles fell into one category, two articles fell into one category, and 17 articles were discarded.

3.3.2 Checklist design

The radiographic image analyses textbook by McQuillen Martensen[23] was the basis for the lists of aspects that were considered for the image quality evaluation part of the checklist. McQuillen Martensen[23] based the authorship of the textbook on his ten-year experience in radiology, research on every procedure, a review of existing textbooks, the cadaver laboratory and film archives. The textbook has been designed to provide education to facilitators, students and radiographers on the information needed to analyse and evaluate radiographic images for positioning and exposure accuracy.[23] The leading question behind the textbook was: "Which way is the correct way?" Hence, the textbook served as an ideal foundation for the list of aspects to consider for developing the checklist.

McQuillen Martensen[23] developed an image analysis form, with sections outlined on the form that included correct anatomical lead marker, maximum recorded detail and sharpness, radiographic density, radiographic contrast, accurate placement of histogram, no artefacts and anatomy placed correctly on the image receptor. During the review of the form by McQuillen Martensen,[23] eight of the sections were used for the development of the intended checklist. Table 3.3 outlines the sections that were used, and a list of aspects that were considered from each section.

Table 3.3 was used as a reference point for navigating and reviewing various radiographic textbooks, online software and study guides. The main goal was to find common terminology used to refer to all the various aspects of radiographic image evaluation that McQuillen Martensen compiled. Much technical consideration goes into a final radiographic image, with each entity being diverse that could be evaluated independently. Developing a checklist for evaluating image quality therefore becomes a challenging task, especially where different X-ray units are involved.

Table 3.3: Image quality evaluation criteria from McQuillen Martensen's image analysis form (McQuillen Martensen 2006)

IMAGE QUALITY CRITERIA	Correct anatomical lead marker	Marker visualised within collimation area	Does R and L marker correspond with correct side of the patient?	
	Relationship between the anatomical structure accurate	Anatomy at centre of image	Joints of interest open	Collimation
	Maximum recorded detail and sharpness	Are there signs of double exposure?	Signs of undesirable motion	
	Radiographic density	Is the radiographic image too light or too dark?	Is there enough demonstration to show cortical outlines	Does image show quantum mottle
	Radiographic contrast	Enough subject contrast to record soft tissue		
	Image histogram accurately produced	Exposure indicator within acceptable limits	Correct body part visible on image	Collimation
	No preventable artefacts	Any artefacts	Repeating necessary because of artefact	
	Anatomy present and placed correctly on image	Required anatomy on image	Collimation	

Table 3.4 (*Image quality critique parameters*) and Table 3.5 (*Exposure factors*) reflect on a benchmark for the commonly used terminology for radiographic image evaluation and exposure factors used in the literature with the various radiographic image evaluation aspects reported by McQuillen Martensen.[23] The information is arranged in ascending order based on the year of publication.

Table 3.4: Image quality critique parameters (created by the researcher)

Image quality critique parameters	**Kogon Lumsden, 1993 (38)**	**McQuillen Martensen, 2011 (23)**	**Bontrager & Lampignano, 2011 (19)**	**Bontrager & Lampignano. 2014**	**Van der Merwe, 2014 (40)**	**Radcrit [online application], 2018 (41)**	**Siemens Healthiness, 2018**	**GE Healthcare, 2019 (43)**	**Siemens Healthiness, 2019 (44)**
Tilt: The upper incisors and the base of the skull are not superimposing the dens and the atlantoaxial joint.	✓	✓	✓	✓	✓	✓	✓	✓	✓
Alignment: The spinous process of the axis aligned with the midline of the axis's body. The long axis of the cervical vertebrae aligned with the IR.	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rotation: The spinous processes are in profile and not visualised towards either one of the sides of the cervical spine.	✓	✓	✓	✓	✓	✓	✓	✓	✓
Asymmetry: The atlas is situated symmetrically on the axis. The lateral masses of the atlas are at equal distances from the dens.	✓	✓	✓	✓	✓	✓	✓	✓	✓
Collimation: Four-sided collimation which includes atlantoaxial and atlanto-occipital joints, the atlas' lateral masses and transverse processes, and the axis' dens and body.	✓	✓	✓	✓	✓	✓		✓	
Centering: The dens is centred to the exposure field.	✓	✓	✓	✓	✓	✓	✓	✓	
Exposure: Quantum mottle supported by the EI value that is below range for underexposure, and high density supported by an EI value that is over the range for overexposure.	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 3.4. (continued)

Image quality critique parameters	**Kogon Lumsden, 1993 (38)**	**McQuillen Martensen, 2011 (23)**	**Bontrager & Lampignano, 2011 (19)**	**Bontrager & Lampignano, 2014 (39)**	**Van der Merwe, 2014 (40)**	**Radcrit [online application], 2018 (41)**	**Siemens Healthiness 2018 (42)**	**GE Healthcare, 2019 (43)**	**Siemens Healthiness, 2019 (44)**
Patient motion: The bony margins and trabecular markings of the cervical vertebra clearly demonstrated.		✓	✓	✓	✓	✓		✓	✓
Double exposure: One radiographic image demonstrated over another radiographic image.							✓		
Lead marker: The presence of a visible anatomical marker on the correct anatomical side of interest without cut off.	✓	✓	✓	✓	✓	✓		✓	
Artefacts: The presence of grids and detector faults, foreign body objects on the processed radiographic image.	✓	✓	✓	✓	✓	✓		✓	
No anatomy: There is no anatomical structure of interest on the final produced radiographic image.		✓	✓		✓			✓	

The radiographic evaluation criteria terms that were used for the checklist as derived from McQuillen Martensen,[23] and the various other sources from which the information was obtained. A list of 14 factors were used for image quality criteria from nine different supporting literature sources. Among the list of criteria, five were supported by all nine literature sources. The rest of the criteria were supported by not less than three literature sources, apart from double exposure source (a film in computed radiography being irradiated twice), which was supported by only one source.

A possible reason for double exposure no longer being a common error in radiography is because diagnostic radiography has shifted towards digital radiography, where double exposure is not possible due to the absence of film screens[35]. Also, in cases where double exposure has been addressed, it has often been listed as an artefact[37]. However, the fact that the criteria were derived from Table 3.3 above, and that one service provider noted the parameter on their list of reasons for image reject, qualify the criterion as significant. In addition, some radiology departments are still using analogue technology, and the intended checklist would therefore be applicable to and not discriminate against analogue radiology departments.

Table 3.5 represents the list of criteria referring to exposure factors. The exposure factors set on the control panel prior the acquisition of the radiographic images will determine the density and contrast of the final radiograph. These are the parameters that promote ideal contrast, density, and histogram, as represented in Table 3.4[9].

Table 3.5: Exposure factors (created by the researcher)

Exposure factors	**Carter, Paterson, Hyatt, Milne & Pirrie 1991 (20)**	**Graham, 1996 (21))**	**Ball, Moore & Turner 2008 (18)**	**McQuillen Martensen, 2011 (23)**	**Graham, Cloke & Vosper 2012 (22)**	**Van der Merwe, 2014 (40)**	**Bontrager & Lampignano, 2014 (39)**	**Ofori, Gordon, Akrobortu, Ampene, A.A. & Darko *et***	**Yacoob & Mahammed, 2017 (34)**	**Radcrit [online application], 2018 (41)**
kVp: The energy of the electrons from the filament across the X-ray tube to the anode.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
mAs: The unit to describe the product of tube current & exposure time.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SID: The distance from the source of X-rays to the image receptor.		✓	✓	✓	✓	✓	✓	✓	✓	✓
Field dimension: Area to which the X-ray beam was directed to.	✓	✓	✓		✓	✓	✓			✓

kVP = kilovoltage peak; mAs = milliamperage-seconds; SID = Source-to-Image Distance.

The section below narrows down the discussion from the broad perspective of developing a checklist to the process of finalising the intended checklist for the research study. The discussion is divided into short sections from the final checklist, as shown in Figure 3.2 below.

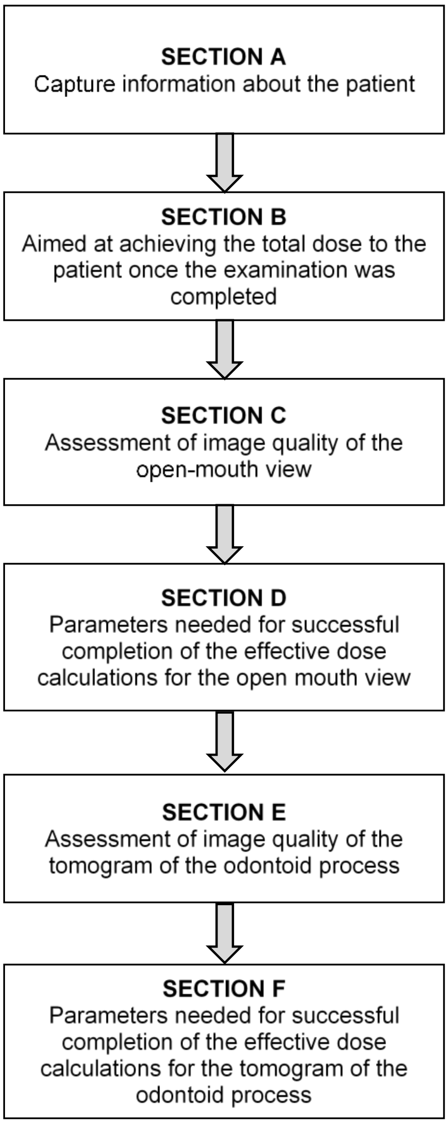


Figure 3.2: The checklist sections (created by the researcher)

Section A: Demographics

This section of the checklist is dedicated to capturing information about the patient. The list of aspects included in section A initially comprised the patient file number, age and gender. The file number had to be recorded to ensure confidentiality and avoid the use of the patient's name and surname.

The age of the patient was necessary to support the inclusion and exclusion criteria and for grouping of data for analyses. However, the patients’ gender was removed from the checklist, since it did not add any significant value to the research.[4]

Section B: radiographic image count

The section aims at recording the total dose to the patient once the examination was completed by recording the total number of radiographic images obtained at the end of each examination, including both the number of images that were accepted and those that were rejected. This section of the developed checklist made it difficult to separate the number of repeated radiographic images for the open mouth from those of the conventional tomogram of the odontoid process. The section had to be revised for distinctive differentiation between the total number of open-mouth views per examination, and the total number of tomograms of the odontoid process per examination.

Sections C and E: radiographic image evaluation

Sections C and E were directly linked to section B. The focus of section C was on the assessment of image quality and identifying why the recorded number of radiographic images in section B were rejected. Sections C and E were based on guidance material from the literature summarised in Tables 3.1, 3.3 and 3.4.

Sections D and F: exposure factors

During the compilation of sections D and F, parameters (radiographic exposure factors) that were needed for successfully completing the effective dose calculations were identified, as seen in Table 3.5. In these two sections of the checklist, the computer system for all three X-ray units record time in milliseconds and not in seconds, as noted on the checklist prior to the pilot study (Appendix E). These two sections had to be revised so that seconds (s) could be converted to milliseconds (ms).

3.4 DISCUSSION

3.4.1 General outlook

The basic principles of developing a general checklist prove that a checklist must be simple and remain reliable in its capability to collect and record data.[25] What makes a checklist difficult to complete, is its degree of diversity, which causes the people responsible for completing it to either complete it incorrectly, or to not complete it at all. Items might be interesting within the scope of practice. However, if these items are not important, they might bring unnecessary complexity to the checklist.[45] Hence, deciding on what to add and exclude from a checklist can be a difficult task, and a thorough review of all the elements that will be included in the checklist is important.

While diverging from making a checklist diverse, it is important to select each piece of information required to be collected on the checklist with a purpose. It has to be known where, how and when the information collected would be used.[45] The purpose of parameters recorded on the checklist should be clear, and information collected should be sufficiently important to put into practice. Once having developed a checklist that is user-friendly yet precise, the next consideration is to exclude calculations from the checklist to avoid errors and prolonging the process of completing the checklist. Calculations might be completed at a later stage. The language used in the checklist should be clear and understandable to people within the scope of practice.[25]

The data collected need to be defined without compromising the confidentiality of patients from whose information data will be collected (identification code, age), where the data will be collected (geographic location), and when the data will be collected (period).[45] These factors are clear in section A of the checklist.

3.4.2 Scope specific outlook

The concept of what a radiographer needs to look for when assessing and analysing a radiographic image can stem from a variety of guidelines that are linked with acquired clinical skills. For some radiographers the evaluation of radiographic images is a skill, which has come with experience.

Other radiographers remain sorely dependent on using established guidelines (set criteria on how to critique a radiograph) for every radiographic image they evaluate.[46] Hence, in developing a checklist that provides for image evaluation, one must also consider all the literature available for guidance and go through a thorough sequential process of choosing the guidelines.

During the compilation of section C and section E, the significance of "double exposure" as one of the radiographic image evaluation parameters had to be thought through carefully, as there were not many resources recognising it as a radiographic image evaluation parameter. The reason for this is that radiography has shifted to a digital platform that does not facilitate for double exposure.

However, Burnside *et al*.[28] published a report titled "Double-exposure artifact mimicking a cervical spine fracture on computed radiography". A lateral cervical spine radiograph was obtained on a 54-year-old female. The radiograph revealed grade 3 spondylolisthesis on cervical vertebrae five and six, and disruption of the anterior cortex of the fifth vertebral body. A second radiograph was obtained and appeared normal. A computed tomography scan was performed to address the discrepancy,[28] and therefore double exposure could not be ignored as a radiographic image evaluation parameter. The inclusion of "double exposure" on the checklist added to the transferability of the checklist, since the parameter applies to non-digital radiographic departments.

3.5 CONCLUSION

The checklist that was developed to capture data for a main research study aimed at optimising radiographic imaging of the odontoid process. The development of the checklist was based on an intensive literature review. Textbooks, articles and guidelines were used to identify each feature of the checklist. The final checklist consisted of six sections, with each one of these sections playing a crucial role in collecting data that serve to fulfil the goal of the main research study.

The process of reviewing and refining a checklist can be continuous until the tool has been developed optimally.[47] Checklists are important for different purposes and can be applied to different circumstances as reflected in the article, provided that the checklist is implemented correctly. The correct use of a checklist is highly dependent on how easy it is to navigate. A confusing checklist only complicates the task of completing the checklist. The language used must include terminology familiar in the field of implementation and not foreign to the population that will be using the checklist.

Furthermore, developing a checklist can be a difficult task when the objective and main aim of the checklist are not outlined thoroughly. However, once clarity on the purpose of the checklist has been accomplished, the task can be narrowed down to a more attainable goal.

A thorough pilot study plays an important role when it comes to developing the final checklist, as it generally adds to the validation of the tool. The checklist developed in this study was an essential research tool in successfully completing the data collection process for optimising radiographing imaging of the odontoid process. Hence it has the potential to serve as a functional tool for similar research studies in the future in the field of medical imaging. The checklist has the capability to identify positioning radiographic gaps within radiology departments, repeat rates in both analogue and digital systems, and serve as a guideline for developing learning programmes for career professional development. Hence, developing a checklist that offers reliability, validity and trustworthiness is a vital initial leading step for the data collection process for a researcher.[15]

3.6 SUMMARY

Chapter three was based on the process of the development of the checklist, which is the backbone of this research study. The next chapter, Chapter four, is written in article format, and aims to explore the open-mouth view for radiographic representation of the odontoid process. The chapter is intended to optimise radiographic imaging of the open-mouth view for the radiographic representation of the odontoid process. The goal is achieved through the evaluation of image quality, repeat rate, reasons for repeat rates, and the effective dose associated with the repeat rates as needed to achieve the third and fourth objectives of the research study.

The two objectives entail recording the number of repeated radiographic images and reasons for the repeated radiographic images, and calculating and evaluating the total effective dose to the patients for conventional radiographic imaging methods for the odontoid process using the open-mouth view. All the findings described in this article are based on data captured with the checklist outlined in the current chapter.

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CHAPTER FOUR

EVALUATION OF THE OPEN-MOUTH VIEW FOR OPTIMISED RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS

4.1 INTRODUCTION

The open-mouth view is one of the radiographic views that are obtained for a series of the cervical spine (Bontrager & Lampignano 2014). The open-mouth view specifically aims to demonstrate anatomy of the first (atlas) and second (axis) cervical vertebrae. The radiographic view offers radiographic representation of the following specific features of the atlas and axis: odontoid process, the body of the axis, lateral masses and transverse processes of the atlas and the atlantoaxial and zygapophyseal joints (Saladin 2011). This is complementary to the anteroposterior (AP) of the entire cervical spine, which often does not optimally visualise the atlas and axis due to superimposition (Whitley, Sloane, Hoadley, Moore & Alsop 2005).

The open-mouth view is valued in plain conventional radiography for demonstrating fractures and prevalence of pathology in the atlas and axis region (Bontrager & Lampignano 2014). As a special feature to the anatomical relationship of these first two upper cervical spine vertebrae, the odontoid process is given attention for its known susceptibility to injury (Weisskopf, Reindl, Schroder, Hopfenmuller & Mittlmeier 2001). Hence, Whitley *et al.* (2005) consider it important for radiographers to achieve open-mouth view radiographic images that optimally demonstrate the odontoid process.

The challenging aspect to this consideration of Whitley *et al.* (2005) is that demonstrating the odontoid process optimally on an open-mouth view has been proven to be difficult, as seen by a high repeat rate found by Josephs (2016). Josephs (2016) encountered an alarming concern of increased radiation exposure to trauma patients undergoing a cervical spine radiographic routine, which particularly included the open-mouth view. The concern led to an investigation aimed at assessing reasons behind the open-mouth view being repeated at rates which constituted to high radiation exposures to patients at Kuruman Hospital in the John Taolo Gaetsewe district of the Northern Cape.

While Josephs' research study (2016) focused solely on trauma, in 1993, Johnson and Lucas used 1 033 cases of non-traumatic cervical spine series from two large medical centres and a large multispecialty to investigate patients' characteristics, indications and radiographic evaluation. The research study was done to examine the prevalence of disease in the upper cervical spine for non-trauma cervical spine examinations. The results of the research study allowed the researchers to reflect on the significance of the implementation of the radiographic imaging of the upper cervical spine when using a dedicated radiographic view (open-mouth view) (Johnson & Lucas 1993).
While the research studies conducted by Josephs (2016) and Johnson and Lucas (1993) were both centred around the open-mouth view, each of the two studies focused on a different aspect. Josephs (2016) focused on investigating the radiographic errors for which the open-mouth view radiographic images were repeated at a high and alarming rate, while Johnson and Lucas (1993) investigated whether the open-mouth view served as a significant aid in the conclusive diagnoses of the cervical spine.

The gap from both the above research studies is that, although both the investigations were provoked by the need to scrutinise the open-mouth view, none formally explored the associated radiation dose to the patient. The current research study therefore intended to optimise radiographic imaging of the open-mouth view as a method of preference for imaging of the odontoid process. This entails retrospectively evaluating the open-mouth view using a dedicated checklist, for repeat rates, radiographic image quality and further exploring the summative ED to the patient using the PCMXC20 Monte Carlo software©.

4.2 LITERATURE PERSPECTIVES

Ebscohost, Science Direct, PubMed and HubMed were used to identify resources based on their significant relevance in medical science and technology. The following key terms were used: odontoid process, open-mouth view, upper cervical, image evaluation, radiation protection, effective dose. The timeframe for the search was

January 2000 to April 2020. However, relevant and significant materials outside of the time frame were included to support and strengthen the research study.
The literature covers a brief insight on the anatomy and radiography of the open-mouth view, radiographic image quality and radiation dose.

4.2.1 Anatomy and radiography represented by the open-mouth view

The anatomical features of the atlas and axis are addressed as radiographically presented on the open-mouth view. The atlas has no body, and is a ring surrounding a large opening known as the vertebral foramen (Marieb & Hoehn 2014). Lateral masses appear on each of the sides of the atlas. The superior surface of the masses is called the superior articular facets, and it articulates with the occipital condyles of the skull to form atlanto-occipital joints that allow a flexion and extension movement (Hutchinson, Mallatt, Marieb & Wilhelm 2014).

The inferior surfaces of the lateral masses of the atlas introduce the existing distinctive articulation relationship between the atlas and the axis, known as a facet joint, that allows for a gliding movement between the two vertebrae. The axis is recognised by a unique prominent anterior knob called the odontoid process. The odontoid process projects into the vertebral foramen of the atlas, sheltered in a facet against the anterior aspect of the bony ring, and held in a place by a transverse ligament (Saladin 2011).

When it comes to imaging of the atlas and axis, special anatomical landmarks are used to assist in locating the position of these two cervical vertebrae, since they are not easily identifiable from an AP position (Whitley *et al.* 2005). The atlas can therefore be located by identifying the level of the mastoids and the axis, and the level of the mandibular angle (Whitley *et al.* 2005). The two mentioned landmarks apply when the skull is positioned in a radiographic baseline position with the infraorbitomeatal line (IOML) perpendicular to the image receptor (Bontrager & Lampignano 2014.

While the landmarks can be used for positioning an average patient for the open-mouth view to achieve an optimal radiographic representation of the odontoid process, the same might not apply for all patients, consequently resulting in radiographic images that are not optimally demonstrating the odontoid process, and further creating a need to perform alternative radiographic views such as AP Fuchs, PA Judd and the Ottonello (wagging jaw methods) and/ modalities (computed radiography and conventional tomography) (Bontrager & Lampignano 2014; McQuillen Martensen 2010; Whitley *et al.* 2005).

Before we can credit or discredit radiographic images, Busti and Kellogg (2015) refer to a special technique that can be used to sequentially read a radiograph without missing one important aspect of interest while concentrating on another. The special technique can also be considered during positioning to avoid errors on the final radiographic image, repeated radiographic images and need for alternative imaging methods (Busti & Kellogg 2015).

The sequence Busti and Kellogg (2015) share involves the following: firstly, making sure that the lateral masses of the atlas are symmetrically aligned with lateral masses of the axis; secondly, making sure there is no asymmetry of the articular spaces between the odontoid and the lateral masses of the atlas; and thirdly, making sure there is no asymmetry of the articular spaces between the lateral masses of the atlas and the body of the axis (Busti & Kellogg 2015). Figure 4.1 below is a representation of a radiographic image of the open-mouth view.

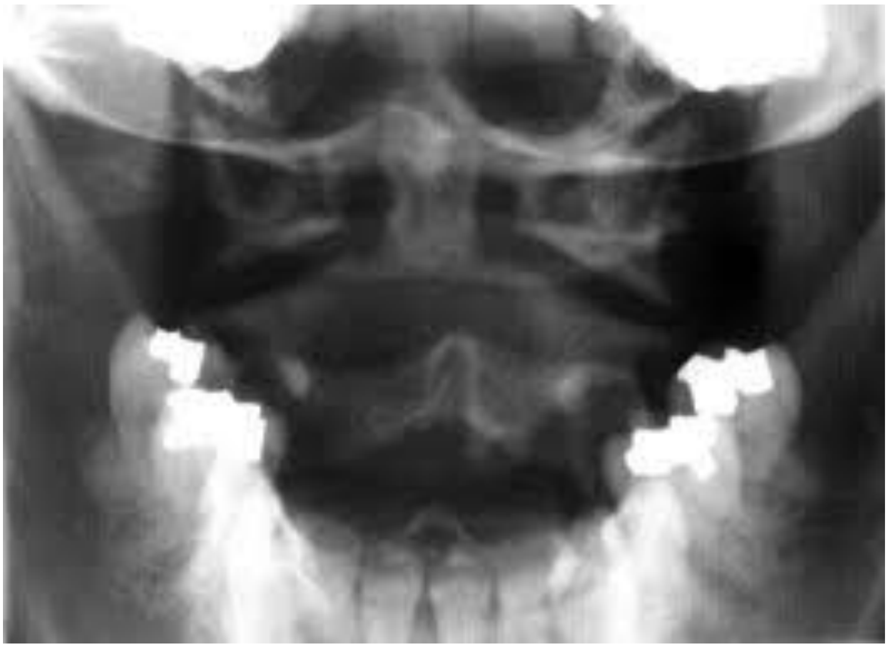


Figure 4.1: Anteroposterior open-mouth view (Central University of Technology, Free State, 2017)

The radiographic image shows partial superimposition of the base of the skull over the superior aspect of the odontoid and the lateral masses. The radiographic image is a typical radiograph which is often obtained in the process of acquiring the open-mouth view. The odontoid process is sometimes superimposed with either the base of the skull and/or the upper incisors (Hubbard, Pickar & Lawrence 2012).

4.2.2 Radiographic image evaluation

During the evaluation of the open-mouth radiographic images, the following list of criteria was used as adapted from a dedicated checklist (refer to chapter two): tilt (the upper incisors and the base of the skull are not superimposing the odontoid process and the atlantoaxial joint); alignment (the spinous process of the axis is aligned with the midline of the axis' body, and the long axis of the cervical vertebrae is aligned with the image receptor); rotation (the spinous processes are in profile and not visualised towards either one of the sides of the cervical spine); symmetry (the atlas is situated symmetrically on the axis, and the lateral masses of the atlas at equal distances from the odontoid process); collimation (four-sided collimation which includes atlantoaxial and atlanto-occipital joints, the atlas's lateral masses and transverse processes, and the axis's odontoid process and body) (Bontrager & Lampignano 2014; Kafibadi & Rangi 2017).

Furthermore, centering (the odontoid process is centred to the exposure field); exposure (quantum mottle supported by the exposure index (EI) value that is below range for under exposure, and high density supported by an EI value that is over the range for over exposure); patient motion (the bony margins and trabecular markings of the cervical vertebra clearly demonstrated); double exposure (one radiographic image demonstrated over another radiographic image); artefacts (the presence of grids and detector faults, foreign body objects on the processed radiographic image); and lastly no anatomy (there is no anatomical structure of interest on the final produced radiographic image) (Bontrager & Lampignano 2014; Kafibadi & Rangi 2017).

The above list of criteria is implemented in a number of radiographic resources such as Kogon and Lumsden (1993), Whitley *et al.* (2005), McQuillen Martensen (2011), Bontrager and Lampignano (2011), Hubbard, Pickar and Lawrence (2012), Bontrager and Lampignano (2014), Van Der Merwe (2014), Busti and Kellogg (2015), Josephs (2016) and Radcrit (2018).

When the open-mouth view fails for any of the above-mentioned criteria, the radiographic view might need to be repeated depending on the judgement of the radiographer. The judgement of repeating a radiographic image takes us back to the motivation behind Josephs' (2016) research study, namely the concern that comes with the radiation exposure to the patient as far as repeating the open-mouth view is concerned.

When reflecting on the basic safety standards and principles of radiation safety for the diagnostic radiography society, Harding (1998) highlights the first key principle of radiation safety as being justification of the exposure. There must always be more benefits than risks for the patient (Harding 1998). Second to that, during diagnostic examinations, the radiation dose must be as low as is reasonably achievable (ALARA) to ensure optimisation (Harding 1998). At the end of every radiographic examination, the three principles of radiation protection (justification, limitation and optimisation) must always be adhered to (Ball, Moore & Turner 2008).

Unfortunately one may conclude based on Josephs (2016) that the known importance of achieving acceptable radiographic images of the open-mouth view, particularly clear radiographic representation of the odontoid process for improved and accurate diagnosis (Rabie 2018; Whitley *et al.* 2005), often surpasses the radiographer's need to optimise the radiation exposure and limit the radiation dose to the patient. Although Josephs (2016) did not statistically account for the repeat rate, the rate observed was enough to encourage the researcher to execute an investigation.

The technical challenge and radiation exposure that comes with the radiographic representation of the odontoid process has led to some protocols excluding the open-mouth view for degenerative diseases, and only for trauma patients (Johnson & Lucas 1993; Whitley *et al.* 2005). This poses a three-part question for the current research study: "what is the repeat rate of the open-mouth view, what contributes to the repeat rate, and what is the ED to the patient associated with the repeat rate?".

Being able to answer these questions would help in optimising the open-mouth view for plain conventional radiographic imaging of the odontoid process.

4.3 METHODOLOGY

The research study was a quantitative retrospective study. The design of the research was an evaluative, descriptive and explanatory research design (Fouche & De Vos 2011). A checklist was developed and used as the main research tool for the study (Chapter three). The research was conducted at two radiology departments in Bloemfontein, Free State.

The data were collected from three X-ray units. The three X-ray units are referred to as: RSD, RSE and VD for anonymity of the manufacturer. Table 4.1 below shows the specification of each X-ray unit.

Table 4.1: X-ray unit specifications

Equipment	RSE	RSD	VD
kV output	150	150	150
Filter	2.87 mmAl	2.55mmAl	1mmCu
Generator	Polydoros 80F©	Polidoris IT©	Unfos Xi ©

Kv: Kilovoltage, RSD: Private practice 1: Room D, RSE: Private practice 1: Room E, VD: Private practice 2

Performing a study which aims to assess radiation dose through calculating the effective dose meant making sure that the three X-ray units were within acceptable limits for both the quality assurance and quality control (Samei 2012). The quality assurance (QA) assessment status of each X-ray unit was as follows: RSE was within acceptable limits for May 2018, RSD was within acceptable limits in July 2018, and VD was within acceptable limits for November 2017 (Appendix N). The QA was performed by the technicians and physicists from the specific manufacturers of the radiography systems in place.

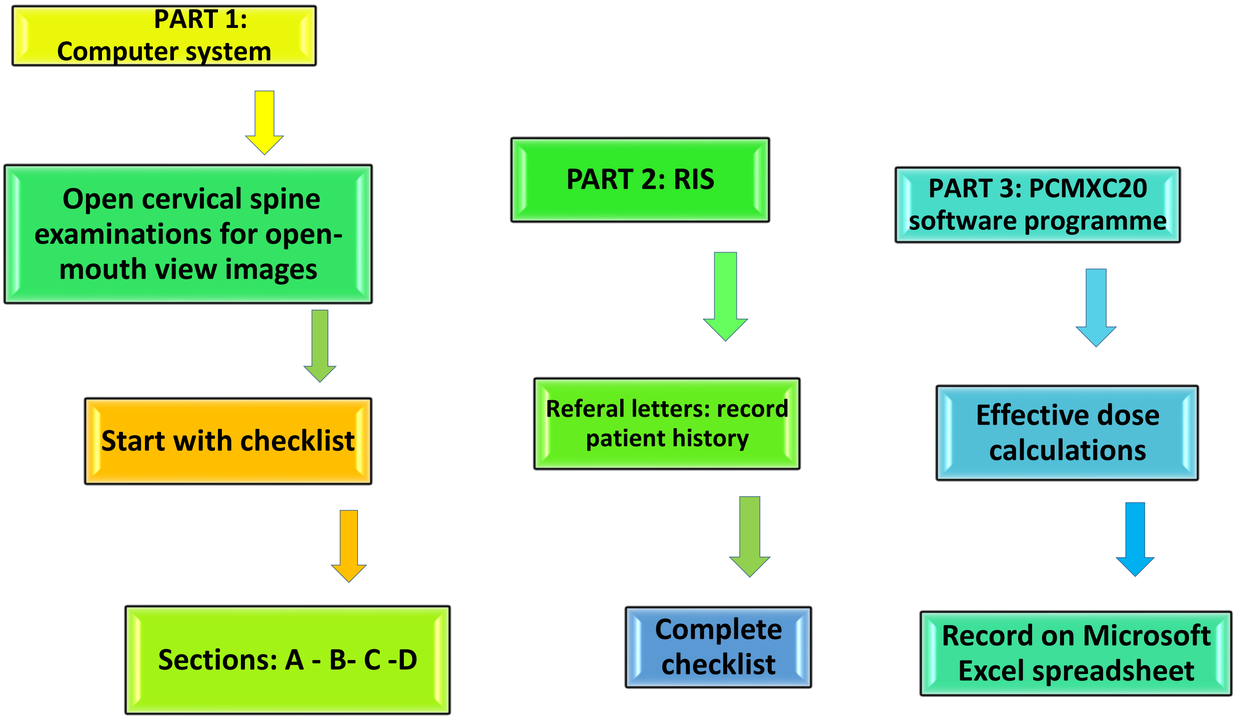
All cervical spine examinations that included the open-mouth view from all the three X-ray units during the period of data collection (July 2018 to October 2018) were considered for the research study population. The cervical spine examinations that were used for the research study had the following particulars: a referral letter stating the clinical history, raw radiographic images to offer knowledge on the number of repeated open-mouth views, and to carry out image evaluation to gain knowledge of the reason for the repeats.

Radiographic images of patients between the ages of fifteen and seventy-five years of age were selected. The age restriction considered both the anatomy and physiology of bone development (skeletal maturity) and aging (osteoporosis) (Long, Rollias & Smith 2015). To ensure anonymity, the assessed patient examinations were marked as ‘patient 1’ and so forth. The data collection process was completed using a checklist and Microsoft Excel spreadsheet (Appendix A and Appendix B). The listed instruments ensured that data could be collected by different researchers whilst still being alert to the same activities, being able to record data systematically and thoroughly, and being able to produce data that were consistent between the researchers (Denscombe 2007).

A pilot study was conducted after ethical approval was obtained, with the following ethics number: UFS-HSD2018/0257/2905 (Appendix G). The purpose was to verify the validity and reliability of the checklist that would be used for collecting data for the research study (English Oxford Living Dictionary 2017). The pilot study assisted with establishing the checklist as a concrete research tool (Hofstee 2009). The data collected in the pilot study were included in the main study. The reason behind this was to account for the scarcity of the open-mouth view examination for the set period for the data collection process.

4.3.1 Data collection process

Figure 4.2. below is a summary flowchart with all the steps that were attended to during the data collection process.



RIS: Radiology Information System

Figure 4.2: Summary flowchart for data collection (created by the researcher)

The first step in retrospectively collecting data was to search from the computer systems (CR) for all the cervical spine radiographic images that would still be available on the system, and not automatically erased as programmed by the manufacturer. The duration for which information could be stored and accessed from the CR systems is manufacturer dependent. Each of the cervical spine examinations had to be opened and observed to see if the examination had the open-mouth view included in the routine that was performed. The CR system offered information that assisted in completing section A (patient information), section B (repeat rate), section C (image evaluation) and section D (technical factors) (Appendix A).

The researcher evaluated each radiographic image to successfully complete each checklist. The researcher had to go through the list of radiographic images to see if there were any rejected images, to determine the number of times the radiographic view was repeated, identify the reason for the repeats, and to determine the exposure parameters that were used. The second part of the process was to log onto the radiology information system (RIS). The RIS gives access to reports and referral letters. Referral letters were retrieved to record and classify the data according to the various referred pathological conditions.

The information from sections A, B and C of the checklist and the effective dose from the PCMXC20 Monte Carlo software© (Appendix D) were translated onto a Microsoft Excel spreadsheet: one spreadsheet for repeat rates, one spreadsheet for image quality evaluation, one sheet for patient history, and one sheet for effective dose capturing. The Microsoft Excel spreadsheet was verified by a second party for verification of the quality of the data. After quality control of the data, the Microsoft Excel spreadsheet was forwarded to the statistician for professional analysis. The quality control process involved going through the process of transferring data from the checklists onto the Microsoft Excel spreadsheet with a second party, and further allowing the second party to assess the data on their own.

4.3.2 Analysis

The PCMXC20 Monte Carlo software© was used for analysing patients' organ EDs (ICRP 2007). The software works on data from the radiographic examination, allowing the user to achieve ED calculations from closed examinations. The user interface has graphic displays to match proper examination conditions. The exposure factors recorded from the CR system per radiograph were the kilovoltage peak (kVp), milliampere-seconds (mAs), source-to-image distance (SID), and field of view (FOV).

First the EDs for a total of eight tissues receiving radiation during imaging of the odontoid process (airway, lymph nodes, oesophagus, oral mucosa, salivary glands, skull, thyroid and the upper spine) were established per open-mouth view. This meant that for five open-mouth views per examination there would be five EDs for each one of the eight tissues. At the end all EDs would be put together for each one of the eight tissues to see what the total ED at the end of the examination per tissue is.

4.3.3 Validation

The four most important tools used for the research study were the checklist for data collection, the PCMXC20 Monte Carlo software© for obtaining the effective dose, the Microsoft Excel spreadsheet, and the statistical software for analysis. The checklist was specifically designed for the purpose of this research study through a thorough article review research. Two checklists were completed respectively (matching and comparing) per examination to eliminate any errors. The PCMXC20 Monte Carlo software© calculates the effective dose with both the present tissue weighting factors of ICRP Publication 103 (2007), and the old tissue weighting factors of ICRP Publication 60 (1991) (Tapiovaara, Lakkisto & Servomaa 1997). The risk estimates are based on the models of the Biological Effects of Ionising Radiation (BEIR) VII Committee (BEIR 2006). The software has been used for numerous research studies that focused on dose calculations and radiation exposure estimations across the globe.

Critical analysis and internalised analysis were implemented to assess any familiar and/ suspicious patterns within the data. Statistical analysis was done by a qualified statistician using SAS Version 9.2. Descriptive statistics, namely frequencies and percentages, were established for categorical data and means, and standard deviations or medians and percentiles were calculated for numerical data.

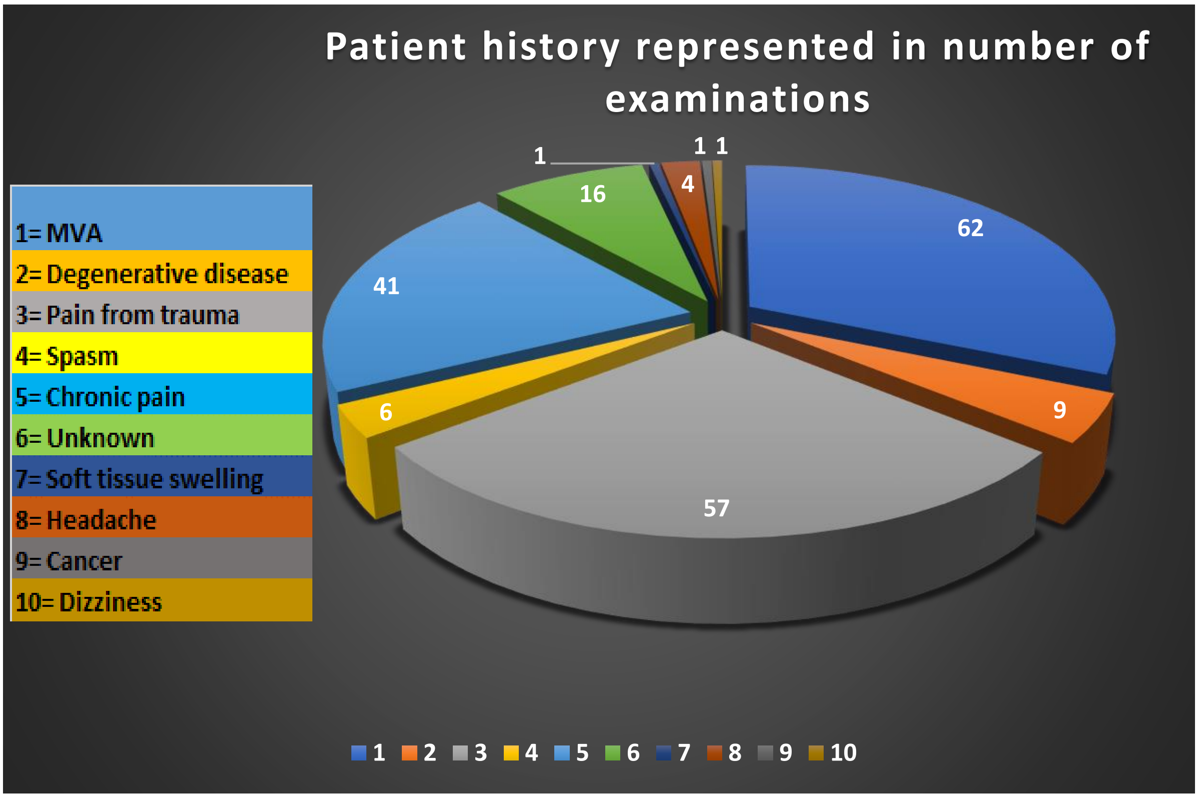
4.4 RESULTS

The results are presented in the following order: number of checklists/radiographic examinations of the open-mouth view evaluated; conclusive list of patient history (pathology); frequency of repeat; image quality evaluation; and the conclusive ED to the patient during imaging of the open-mouth view.

4.4.1 Number of checklists and radiographic images of the open-mouth view evaluated

Once the data collection process was concluded, 198 checklists were completed. The total number of checklists were completed from 198 examinations of the cervical spine that included the open-mouth view. By the end of the data collection process, 385 radiographic images of the open-mouth view were evaluated.

4.4.2 Patient history for cervical spine requisitions series including the open-mouth view



MVA: Motor vehicle accident

Figure 4.3: Patient history (created by the researcher)

Pathology has been used as a reference point when considering the implementation of the open-mouth view as part of the cervical spine routine. Careful consideration of the implementation of the open-mouth view is used as a method of radiation protection to the patient (Johnson & Lucas 1993; Whitley *et al.* 2005).

The figure above shows the pathological indications for which patients were referred. The pathological conditions are accounted for based on the number of examinations completed, and not in percentages, meaning that 160 patients of the 189 patients (84%) were referred for trauma (MVA, pain from trauma and chronic pain).

4.4.3 Repeat rates

Based on the radiographic image evaluation process, 276 radiographic images of the open-mouth view had errors, while 109 radiographic images were free of errors. The radiographic image evaluation made it possible to assess the frequency of repeats for the overall data (see Figure 4.4 below).

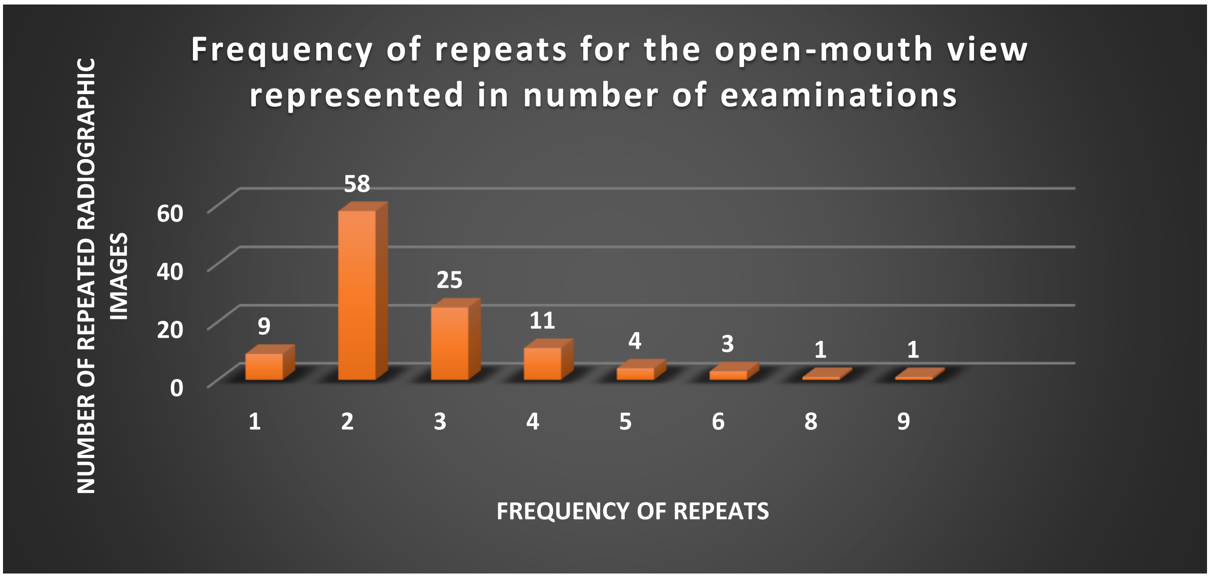


Figure 4.4: Frequency of repeats (created by the researcher)

The average frequency with which the open-mouth view radiograph could be acquired in one examination was twice. This meant that in one examination, there was a high probability for the open-mouth view to be obtained twice due to an error. There were over fifty examinations with the repeat frequency of two. The results also show that at some point the open-mouth view was repeated nine times.

4.4.4 Image evaluation

The image evaluation section accounts for the list of criteria seen in Figure 4.5 and Figure 4.6. below. Figure 4.5 is based on the positioning errors and accounts for seven positioning errors, while Figure 4.6 is based on exposure errors and accounts for three errors.

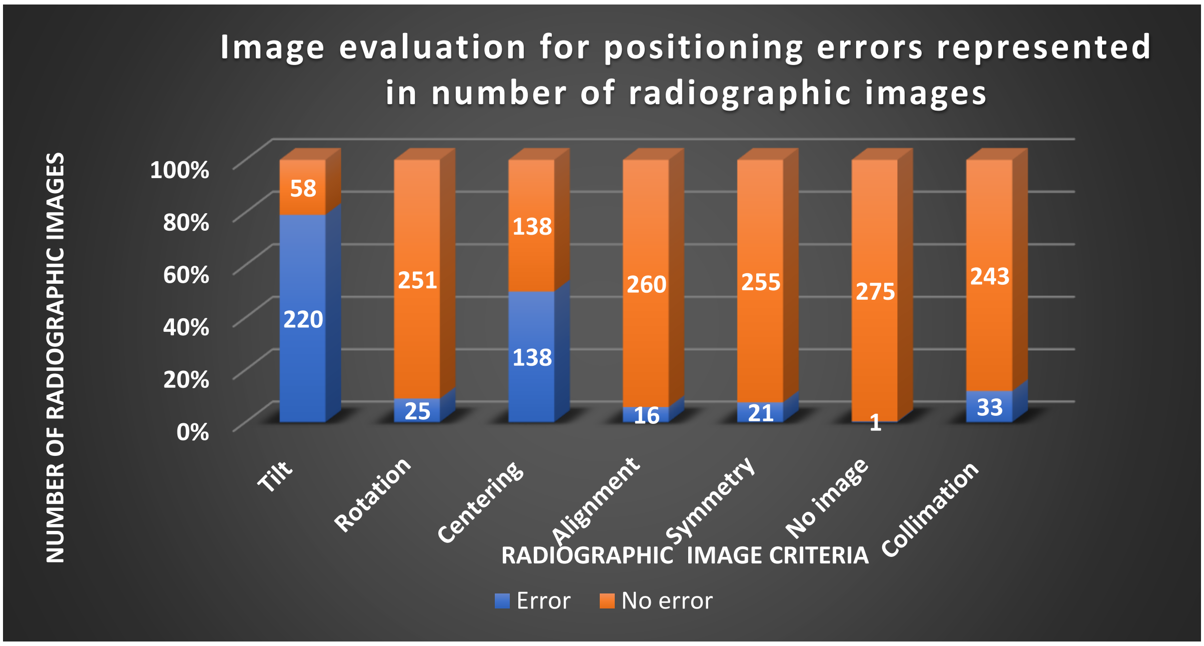


Figure 4.5: Radiographic image evaluation for positioning (created by the researcher)

The list of errors was derived from the extensive literature review which was performed during the development of a checklist. The checklist was used as a dedicated research instrument for this research study. Each one of the positioning errors has been supported by literature from articles, textbooks and guidelines within the radiology field.

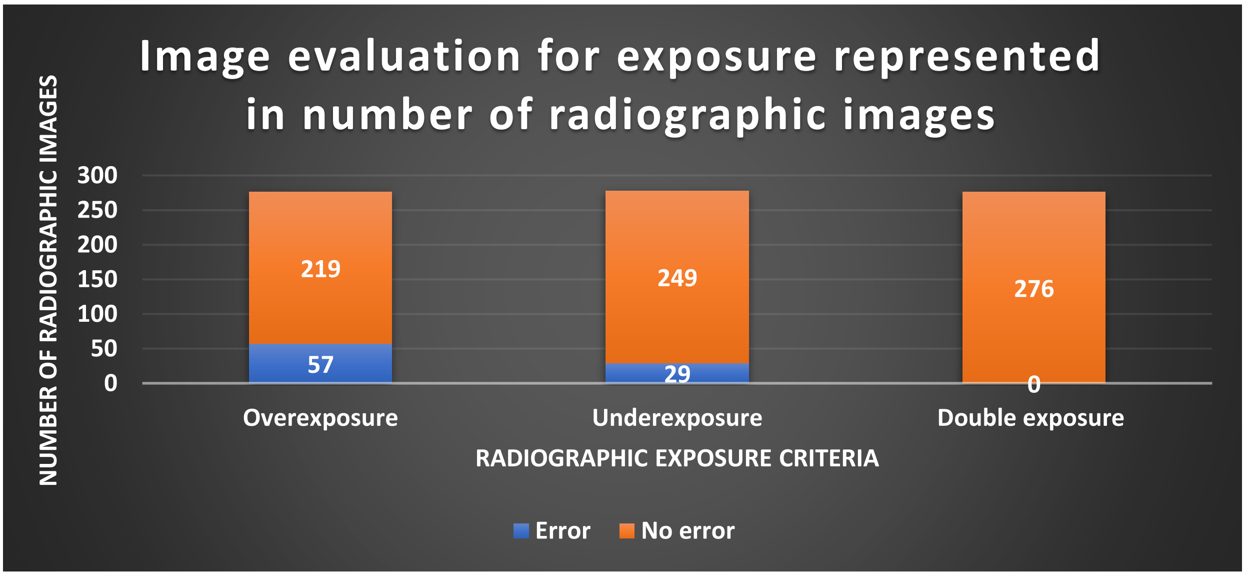


Figure 4.6: Radiographic image evaluation for exposure (created by the researcher)

The radiographic evaluation for exposure was based on the EI and visual assessment of quantum mottle and image density. However, based on the visual evaluation of the radiographic image for assessment of quantum mottle (underexposure) and high density (overexposure), the radiographic images showed optimum exposure.

4.4.5 Dose evaluation

The gathered data on ED were on eight body tissues as previously mentioned (airway, lymph nodes, oesophagus, oral mucosa, salivary glands, skull, thyroid and the upper spine). In order to establish if the variables follow a normal distribution or not, the Shapiro-Wilk test was performed. If the p-value from the test is < 0.05 then the data are skewed. If the p-value from this test is > 0,05 then the data follows a normal distribution. Almost all the variables were skewed, and the results were therefore based on the median and percentiles (Viljoen 2018).

Table 4.2: Effective dose from three X-ray units for eight tissues (created by the researcher)

Tissue	RSD calculations	RSE calculations	VD calculations
Airway	0.345812	0.802355	0.428864
Lymph nodes	0.379471	0.788455	0.462847
Oesophagus	0.492107	0.642815	0.412581
Oral mucosa	0.36695	0.807749	0.506556
Salivary glands	0.444032	0.866106	0.610442
Skull	0.36397	0.799326	0.384417
Thyroid	0.464155	0.754718	0.37587
Upper spine	0.333698	0.875797	0.362013

RSD: Private practice 1: Room D, RSE: Private practice 1: Room E, VD: Private practice 2

The table reflects specifically on the total ED per tissue for all three X-rays units from which data was collected. The colour red is used to represent higher ED values, the green is used to represent the lower ED values, while the yellow is used to represents ED values that fall in-between the higher and lower ED values. As seen in the table, RSE has the most alarming effective dose measurements. RSD is reflecting the lowest effective dose amongst the three X-ray units.

4.5 DISCUSSION

4.5.1 Patient history for imaging of the open-mouth view referrals

The pathological conditions recorded from the 198 checklists were divided into two categories: the trauma category and the non-trauma category. Under the trauma category, motor vehicle accidents (MVA), pain from trauma and chronic pain were included, whilst degenerative disease, spasm, soft tissue swelling, cancer, headaches and dizziness were included in the non-trauma category. Conclusively, based on the results of the research study, trauma was proven to be more dependent on the acquisition of the open-mouth view, with a total of 122 out of 198 patients. This reflection supports Johnson and Lucas' (1993) conclusion that the open-mouth view is not worth the technical difficulty, radiation exposure and expense for non-trauma patients.

4.5.2 Repeat rates

The final appearance of a radiograph is a result of a diverse interaction of multiple factors. These factors can each be interpreted separately to identify each one's unique role in image interpretation and acquisition (Rossman 1966). The same factors that must be considered during radiographic interpretation after the radiographic image was successfully acquired also need to be considered before acquiring the radiographic image. This process helps in ensuring that the final radiographic image matches the optimal radiographic image that the radiographer is supposed to strive to obtain. This creates direction for positioning and selection of technical factors to avoid repeating the radiographic images.

Figure 4.4 shows that the open-mouth view has a high probability of being acquired twice before achieving an acceptable radiograph. Fifty-eight percent of the patients had the open-mouth view taken twice. The practice of achieving an optimal open-mouth view on a second attempt can be ignored, but in one incidence, the procedure was repeated nine times, as seen from one patient's data. The case for which the open-mouth view was repeated nine times provokes an alarming concern and creates a sense of curiosity on the radiographer's judgement and implementation ALARA (Josephs 2016).

4.5.3 Image evaluation

When establishing criteria for image evaluation, the assessment criteria that are being implemented should consider all the important factors that are contributing to optimal image formation (Kogon & Lumsden 1993). Some of the questions that a radiographer may ask themselves is whether the part is well positioned, tilted, rotated or off-centered (Kogon & Lumsden 1993). Figures 4.5 and 4.6 in the result section reflect on aspects which were evaluated under image evaluation.

On an optimal open-mouth view the upper incisors and the base of the skull must not be superimposing the odontoid process and the facet joint. The spinous process of the axis must be aligned with the midline of the axis' body. The long axis of the cervical vertebrae must be aligned with the IR (Bontrager & Lampignano 2014). The atlantoaxial and atlanto-occipital joints, the atlas' lateral masses and transverse processes, and the axis' odontoid process and body must be included within the collimated region.

The odontoid must be centred to the exposure field. The bony margins and trabecular markings of the cervical vertebra must be clearly demonstrated without any motion. Lastly, the atlantoaxial joint must be open as previously mentioned. A total of 276 radiographic images out of 385 radiographic images did not meet the criteria. This accounts for 71.7% of the evaluated radiographic images.

With reference to Figure 4.5, tilt was the main error. Tilt was evident in 220 radiographic images. Tilt for the open-mouth view refers to the superimposition of the odontoid process. It shows whether the odontoid process is demonstrated free from superimposition of the base of the skull and/or the upper incisor, or if there is in fact superimposition. Tilt can be concluded to be the most common error for the open-mouth view, with a total of 92% occurrence in Josephs' (2016) research study. Centring for the open-mouth view is the second most common error on 130 radiographic images. The positioning error has to do with making sure that the odontoid process is centred to the field of interest.

Collimation is third on the list of the most common errors and may be described as unacceptable (absence of collimation), acceptable (visible on two or more sides), or excellent (demonstrated on all four sides) (Kogon & Lumsden 1993). The primary X-ray beam should be conformed within the collimation boundaries, and not extend beyond the area of interest. The irradiated area should cover the tissue of diagnostic interest. The implantation of proper collimation reduces the amount of scattered radiation and improves image contrast. Proper application of collimation results in improved image quality, because it reduces the amount of scatter radiation produced. When judging a radiographic image for exposure, one may look at light diffusion as it affects visibility of detail. Quantum mottle is one of the features identified when assessing exposure, observed as variations of photographic density which relates to the graininess of the radiographic image (Rossman 1966).

Density is controlled by the mAs and is described as the overall “blackness” seen on a radiograph (Carlton & Adler 2006). Excessive density is one of the most frequently experienced technical errors directly proportional to the amount of radiographic exposure the patient receives. Density can therefore be expressed as unacceptable (too dark or too light) or acceptable (proper mAs).

In the modern digital radiography world, overexposed radiographic images are easily accepted due to inherent algorithms, leading to overexposure to the patient. On the contrary, underexposed radiographic images cannot be compensated for, as they have increased noise (quantum mottle) which reduces diagnostic accuracy (Seibert 2004). The radiographic images were conclusively judged on whether they were over- or underexposed based on appearance and the exposure index (EI). 57 radiographic images were overexposed, while 27 radiographic images were underexposed. Most of the underexposed radiographic images did not show any quantum mottle. The EI was below range, hence the conclusion for underexposure.

Double exposure is not a problem in digital radiography where there is no use of film. Hence, there were no radiographic images repeated for double exposure, since all three X-ray units from which data was collected use digital machines. Table five from the list of appendices is a summary of image evaluation. The table shows instances in which a radiograph was repeated for more than one error. The highest number of errors on one radiograph were seven errors, on a single radiograph out of the total number of radiographic images assessed for the open-mouth view. Tilt was the most common error that existed with other errors. Radiographers are aware of the importance of optimal X-ray image quality.

Hence, it is encouraged to critically analyse the process of image formation (Kogon & Lumsden 1993). The approach to image quality evaluations can form a useful tool in the continued quest for radiographic excellence (Kogon & Lumsden 1993).

4.5.4 Dose evaluation

Effective dose is used to measure radiation dose to patients. The phenomena reflects on the exposure to organs and tissues which can induce radiation effects with different probabilities, depending on the specific organ (Bushong 2013). When using mathematical formulae to determine ED, the equivalent dose in each organ and tissue is multiplied with a tissue weighting factor, and then summing the results over the whole body to give the ED (Bushong 2013).

The unit for ED is the sievert (Sv). For purposes of this study, a software programme was used to acquire the EDs as previously mentioned (Shannoun, Blettner, Schmidberger & Zeeb 2008). ED gives a legitimate reflection of potential detriment from ionizing radiation. It is therefore used for evaluation of examinations involving ionizing radiation. It is an inclusion of cancer, severe hereditary disease and length of life lost (Harding 1998).

With reference to Table 4.2, the RSD X-ray unit was giving the lowest ED to the patient (green), following VD (yellow) and then RSE (red). The reason for this is because different X-ray machine manufacturers can have different conversion efficiency and therefore depend on varying exposure factors to produce an adequately exposed radiographic image. For this reason, although this is outside the scope of this research study, it is important for radiography departments to enquire with manufacturers, and to know the science of the X-ray units they intend to purchase as compared to other X-ray units on the market.

4.6 CONCLUSION

The research question for the research study was focused on achieving an insight into the repeat rate of radiographic images, the reasons behind the repeat rate, and the influence of the repeat rate on the radiation dose to the patient. The question was answered, and based on the results of the research study, the repeat rate on average is two open-mouth view radiographic images per patient.

The most encountered error amongst these repeated radiographic images was tilt (superimposition of the odontoid process by either the occipital bone or incisors). Adding to the repeat rates, there is an alarming 1% chance that a patient may have the open-mouth view repeated nine times.

The research study showed that radiation exposure to the patient can unfortunately not be accounted for only based on the number of repeated radiographic images per examination. The X-ray unit used to perform the examination has a great influence on the total radiation dose to the patient. The task of using radiation protection shields as the main form of protection is no longer substantial. Assessing and measuring the radiation dose has become just as important.

The challenge which radiographers are confronted with is the judgement between radiation reduction and maintaining high image quality with no loss of density, as it is not only important to reduce radiation dose, but to also determine the right balance between patient dose and image quality.

The recommendations that can be implemented to optimise the open-mouth view as a method of preference for radiographic imaging of the odontoid process includes implementing a rule that allows for the open-mouth view to not be repeated more than once. Seeing that tilt is the most common error, an experimental research study can be conducted to establish positioning lines that can be used for positioning of the open-mouth view, with reference to the patient’s unique skull anatomy (shape and size). The third and last recommendation is for radiology departments to always get an insight on the manufacturer’s conversion efficiency before purchasing an X-ray unit, in order to protect the patient from relatively higher radiation exposure factors that could have easily been avoided. The limitation of the research study included access to the PCXMC20 Monte Carlo software©. The search for the software delayed the process of obtaining the EDs.

4.7 SUMMARY

Chapter four successfully served the purpose of reflecting on the third and fourth objectives of the entire research study, which are: recording the number of repeated radiographic images and reasons for the repeated radiographic images, and calculating and evaluating the total effective dose to the patients for conventional radiographic imaging methods for the odontoid process using the open-mouth view.

Chapter five below is in article format. The article is based on assessing radiographic imaging of the odontoid process when using conventional tomography as an alternative plain conventional radiographic method. The article involves the evaluation of image quality, repeat rate, reasons for repeat rates, and the effective dose associated with the repeat rates. The chapter serves in optimisation of plain conventional radiographic imaging of the odontoid process when using conventional tomography. All the findings described in the article are based on data captured via the checklist outlined in Chapter three.

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CHAPTER FIVE
EVALUATION OF CONVENTIONAL TOMOGRAPHY FOR RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS

5.1 INTRODUCTION

Radiography is a broad medical field which incorporates various methods for obtaining diagnostic radiographic images of the human body (Bontrager & Lampignano 2014). Conventional tomography is listed as one of the methods used within the diagnostic radiography scope (Bontrager & Lampignano 2014). As opposed to the general basic radiographic image acquisition routine which involves both the X-ray tube and the X-ray bucky being kept in a stationary position during image acquisition, conventional tomography incorporates the movement of the X-ray tube and the image receptor (IR) (Carlton & Adler 2006).

A conventional tomogram generally offers the representation of anatomy that is lying in a plane of tissue while it blurs out and eliminates the detail of anatomy above and below the plane of interest. The technique works on primarily demonstrating coronal sections, unless the patient is positioned in a way that permits sagittal and transverse sections. Even with the inherent radiographic advantages of conventional tomography, the technique often takes a backseat in plain conventional radiography, since it is known for higher exposure settings consequently regarded as a high radiation dose to the patient (Carlton & Adler 2006).

The lack of preference for conventional tomography is witnessed when it comes to conventional radiographic imaging of the upper cervical spine for optimal demonstration of the odontoid process. The open-mouth view remains the first method of preference used for radiographically demonstrating the odontoid process and relative anatomical structures where specialised modalities are not readily available or prioritised (Bontrager & Lampignano 2014; McQuillen Martensen 2011; Whitley *et al.* 2005).

Conventional tomography is introduced into the examination after unsuccessful attempts of achieving an optimal open-mouth view (Whitley *et al.* 2005). While some radiology departments (level three hospitals) opt for specialised modalities (Computed Tomography) as advocated by a fair number of literature resources, the preferential sequence of events at some reviewed private practices in South Africa, including the two where the research study was conducted, use conventional tomography for radiographic representation of the odontoid process. Level three hospitals are defined as academic hospitals with most specialised services (Western Cape Government 2018).

The research study intended to assess imaging of the odontoid process when using conventional tomography as a radiographic technique of preference. Researchers have identified a gap in not investigating alternative methods and in channelling attention into the main radiographic imaging methods without a comparison to alternative methods (Abdallah & Mohamoud 2015). Thus, the intended research study does not only serve to optimise radiographic imaging of the odontoid process when using conventional tomography, but also as a comparative technique for conventional radiographic imaging of the odontoid process.

The research study was completed through retrospectively evaluating repeat rates, image quality and the radiation dose to the patient during acquisition of conventional tomography of the odontoid process. The evaluation was achieved through a checklist established to serve as a dedicated research instrument in a research study focused on optimisation of radiographic imaging of the odontoid process in the absence of specialised modalities. The radiation dose was estimated using effective dose (ED), which is a representation of the relative health risk to which the patient is exposed. The calculations were achieved through the PCMXC20 Monte Carlo software$^{©}$.

5.2 LITERATURE PERSPECTIVES

Literature used to guide the research study was retrieved from Ebscohost, Science Direct, PubMed and HubMed based on their significant relevance in medical science and technology. The main key terms used were as follows: odontoid process, conventional tomography, linier tomography, upper cervical spine, image evaluation, radiation protection and effective dose. The time frame for the search was January 2000 to April 2020. Relevant and significant materials outside of the time frame were included to support and strengthen the research study. This was adding to the scarcity of research and resources available on conventional tomography of the upper cervical spine.

5.2.1 Conventional tomogram of the odontoid process

Plain conventional radiography involves superimposition of complex shadows of anatomy (Schwartz 2008). Hence, the selection of technical exposure factors is aimed at enhancing and highlighting anatomical structures of interest, while the rest of the anatomy is not thoroughly represented (Bushong 2013). The one practical example is in radiographic imaging of the thorax for lung studies versus radiographic imaging of the thorax for rib studies. There is a variation in technical exposure factors to help achieve the distinctive variance (Bontrager & Lampignano 2014; Whitley *et al.* 2005).

The need for conventional tomography was inspired by failure to radiographically demonstrate underlying structures in the human body using basic plain conventional radiography, more especially in instances where there would be tumours involved, and where there was an urgent need for scrutinised and precise radiographic interpretation (Long, Rollias & Smith 2015). Multiple varying radiographic views were implemented as an attempt to overcome the inherent anatomical shadows, yet the goal was still not ideally accomplished. The introduction of conventional tomography initiated the process of achieving slices of the anatomy of interest, with the advantage of using the standard X-ray tube and IR (Bushong 2013). Figure 5.1 below shows how the X-ray tube moves with reference to the anatomy of interest and IR during a conventional tomogram technical setting.

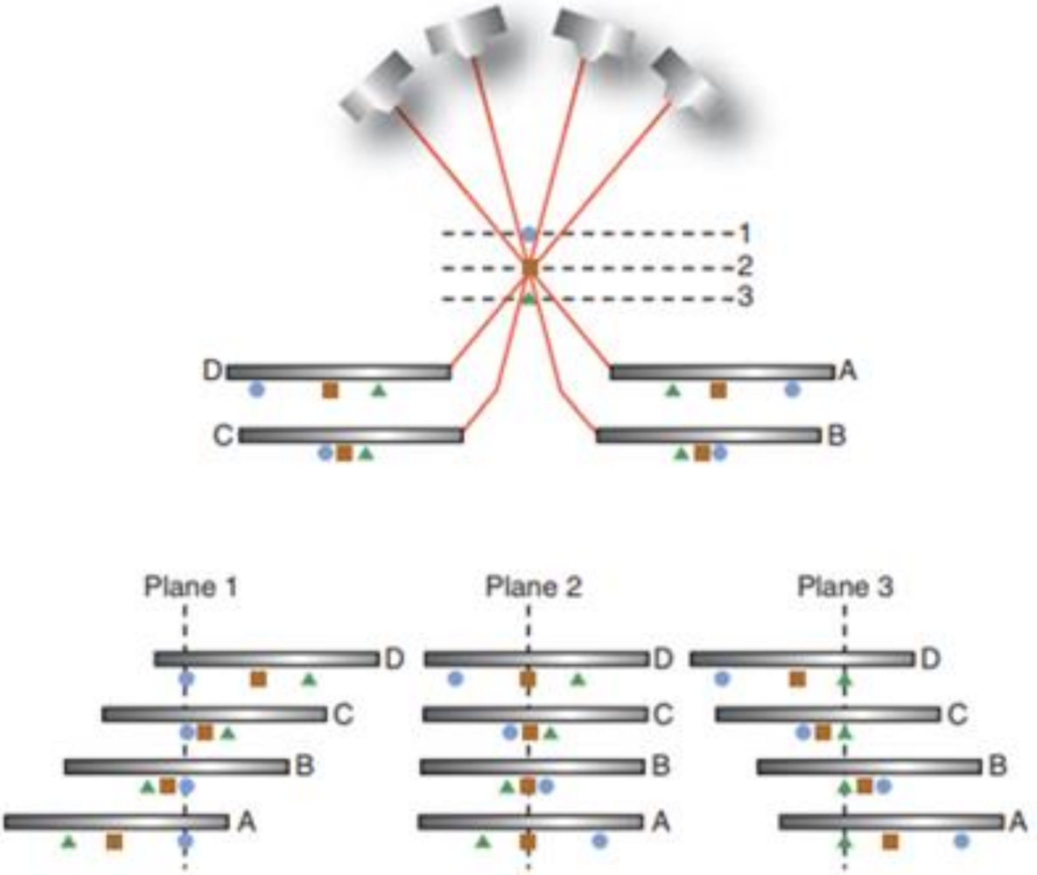


Figure 5.1: Movement of the X-ray tube and imaging plate (Bushong 2013, permission granted)

During acquisition of a conventional tomogram, the anatomy above and below the structure of interest is blurred out. Based on the figure (Figure 5.1), phase one and phase three would be blurred out, while phase two is the sharpest slice of the three. This, at a given point, results in a clear radiographic demonstration of the anatomical part of interest (Bushong 2013).

5.2.2 Technical factors

Figure 5.2 below is a tomographic slice from a conventional tomogram series of the odontoid process. When referring to Figure 5.1, Figure 5.2 would be a representation of phase two, the sharpest and optimal plane.

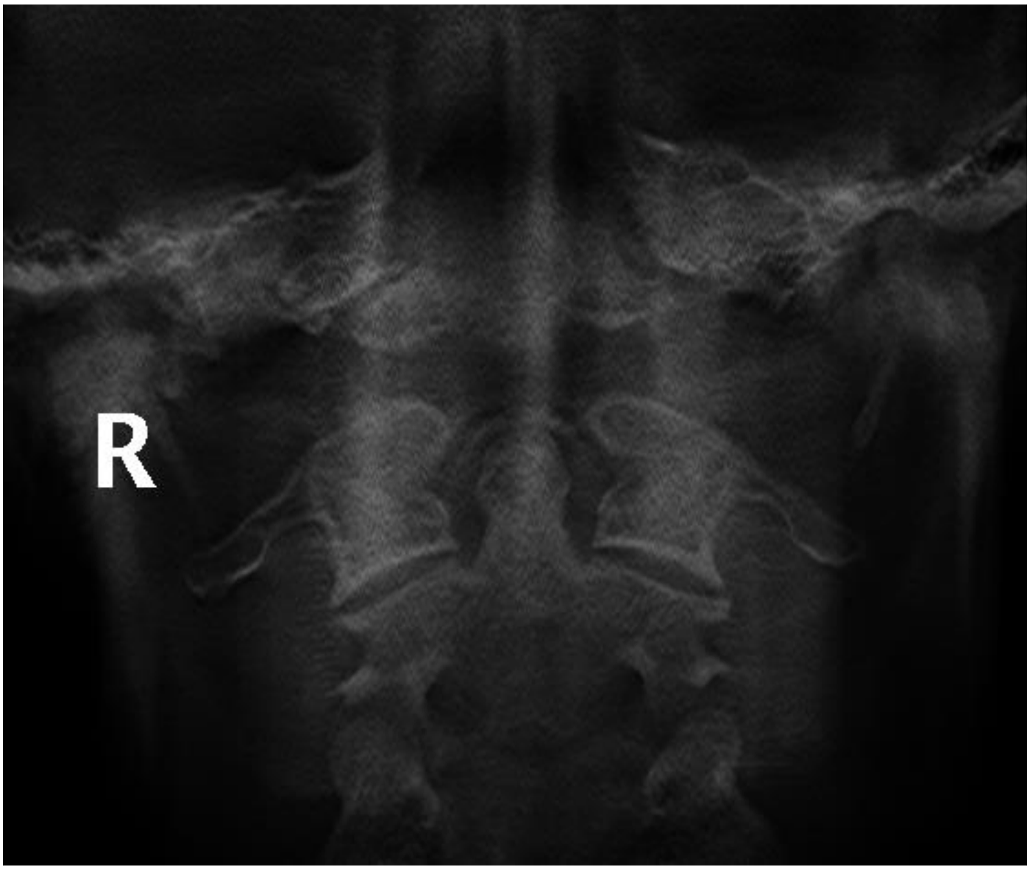


Figure 5.2: Conventional tomogram of the odontoid process (Drs Van Dyk & Partners 2018)

Figure 5.2 is achieved through a list of inherent settings: tomographic amplitude, exposure amplitude, blur, the distance from the fulcrum and the image receptor, focal plane, section thickness, and lastly the orientation of the tube. The selection of correct technical factors and positioning skills remain as important with conventional tomography as it is with acquiring a basic standard radiographic image.

Clark (1981) indicates that the quality of a conventional tomogram is highly dependent on sharpness. Minimum radiographic unsharpness remains a key goal in conventional tomography, even with the inherently known possibility of unsharpness. The sharpness is dependent on the thickness that the radiographer selects, and maximum sharpness is demonstrated by a selection of thin slices (Clark 1981).

The selection of a correct exposure angle, which accounts for the influence of the thickness of the tomogram section, also constitutes to sharpness. The smaller the exposure angle, the thicker the sections produced, and the less the sharpness (Clark 1981).

For accurate tube movement, the tube and IR must move in straight lines and in opposite directions, achieving a constant ratio between the focus to object distance (FOD) and object to IR distances (OID) throughout the movement, evident by the recorded anatomical structure of interest (Clark 1981). The odontoid process (level of the first two cervical spine vertebrae) must be precisely at the level of the tomogram for accurate localisation.

Furthermore, the choice of proper technical exposure factors requires special attention to compensate for the time needed for the exposure amplitude. Radiographers need to be just as attentive as they are with any other conventional radiographic methods - especially considering the radiation dose disclaimer associated with conventional tomography which the research study intended to investigate (Graham, Cloke & Vosper 2012).

5.2.3 Radiographic image evaluation

Once a conventional tomogram is achieved through the considerable number of technical factors, the next stage is to assess the final radiographic image. The following list of criteria was used as adapted from the checklist mentioned above. The list of criteria is implemented in a number of radiographic resources such as Kogon and Lumsden (1993), Whitley *et al.* (2005), McQuillen Martensen (2011), Bontrager and Lampignano (2011), Hubbard, Pickar and Lawrence (2012), Bontrager and Lampignano (2014), Van Der Merwe (2014), Busti and Kellogg (2015), Josephs (2016) and Radcrit (2018) for the evaluation of conventional radiographic examinations.

Tilt was not considered due to the ability of the conventional tomogram to rid superimposition. Alignment (the spinous process of the axis must be aligned with the midline of the axis' body, and the long axis of the cervical vertebrae must be aligned with the image receptor); rotation (the spinous processes are in profile and not visualised towards either one of the sides of the cervical spine); symmetry (the atlas is situated symmetrically on the axis and the lateral masses of the atlas at equal distances from the odontoid process); collimation (four-sided collimation which includes atlantoaxial and atlanto-occipital joints); the atlas' lateral masses and transverse processes; and the axis' odontoid process and body are included.

Centering (the odontoid process is centred to the exposure field); exposure (quantum mottle supported by the exposure index (EI) value that is below range for underexposure, and high density supported by an EI value that is over the range for overexposure); patient motion (the bony margins and trabecular markings of the cervical vertebra clearly demonstrated); double exposure (one radiographic image demonstrated over another radiographic image); artefacts (the presence of grids and detector faults, foreign body objects on the processed radiographic image); and lastly no anatomy (there is no anatomical structure of interest on the final produced radiographic image). The list accounts for what was thoroughly considered during the evaluation.

5.2.4 Radiation considerations

As with any other radiographic procedure, exposures for conventional tomography should be justified as per basic radiation safety standards and principles (Abdallah & Mohamoud 2015). The benefit to the patient must always outweigh the risks (Ball, Moore & Turner 2008). The benefit associated with conventional tomography has thus been highlighted as the ability to produce slices through the anatomy of interest, riding superimposition and overcoming the anatomical shadows encountered in plain conventional radiography, while using the same standard X-ray tube and IR (Ball *et al.* 2008).

For the purpose of radiation dose evaluation for conventional tomography of the odontoid process, the research study intended to explore the ED. ED is the best measure for estimating the risk of the radiation to the patient through accounting for the absorbed dose and the radiosensitivity of the irradiated organs (ICRP 1991).

5.3 METHODOLOGY

The research study was conducted through the principles of a quantitative retrospective study. The design was an evaluative, descriptive and explanatory research design (Fouche & De Vos 2011).

The research was conducted at two radiology private practices in Bloemfontein, Free State. Data was collected from two X-ray units named RSE and VD (for anonymity of the venders when reporting back on the EDs to the patient). The period for the data collection process was from July 2018 to October 2018.

The two X-ray units were assessed for quality assurance (QA) and quality control (QC) testing. The quality assurance was successfully completed, and all results recorded (Samei 2012). RSE was tested in May 2018, and VD was tested in November 2017. Both X-ray units were within acceptable limits for the QA. Performing a research study intended to venture into assessing radiation dose is matched with an expectancy for QA and QC that are within acceptable limits for reliability of results (Samei 2012).The QA tests were performed by the technicians and physicists from the specific manufacturers of the radiography systems in place. Table 5.1 below shows the specification of each X-ray unit.

Table 5.1: X-ray unit specifications

Equipment	**RSE**	**VD**
kV output	150	150
Filter	2.87 mmAl	1mmCu
Generator	Polydoros 80F©	Unfos Xi ©

Al: aluminium, Cu: Copper, RSE: Private practice 1; Room E, VD: Private practice 2

During the data collection process, all cervical spine examinations that included the conventional tomogram of the odontoid process from the two RSE and VD X-ray units were considered for the research study with accordance to the data collection period. The cervical spine examinations had the following list of preferential particulars: a referral letter stating the clinical history, and raw radiographic images to offer knowledge on the number of repeated conventional tomograms of the odontoid process, and to carry out image evaluation to gain knowledge on the reason for the repeat. Radiographic images of patients between the age of fifteen and seventy-five year were selected for skeletal maturity and osteoporosis-related concerns (Long, Rollias & Smith 2015).

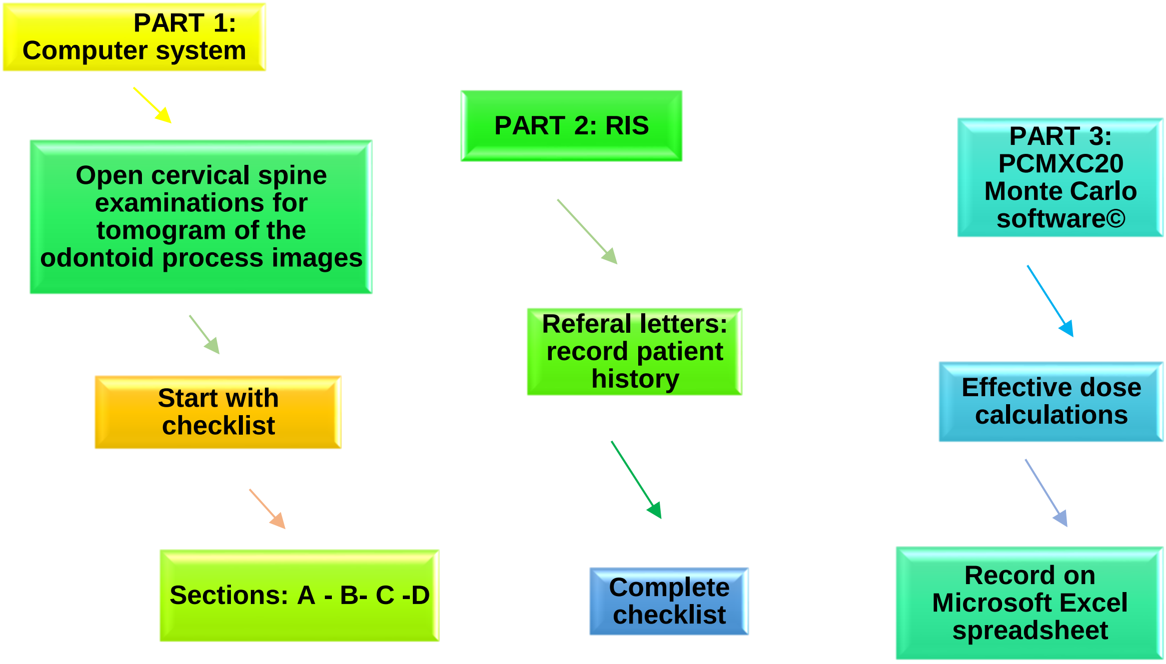
To ensure anonymity, the assessed patient examinations were marked as ‘patient 1’. The data collection process was completed using a checklist for recording data and a Microsoft Excel spreadsheet for summarising data for the statistician from the checklists (Appendix A and Appendix B).

The listed instruments ensured reliability in the sense that different future researchers can use the instruments and still be alert to the same activities and results, be able to record data systematically and thoroughly, and produce data that are consistent with the data captured for the current study (Denscombe 2007).

A pilot study was conducted after ethical approval was obtained, with the following ethics number: UFS-HSD2018/0257/2905. The purpose of the pilot study was to verify the validity and reliability of the checklist for the specific data that had to be collected for the purpose of successfully fulfilling the aim of the research study (English Oxford Living Dictionary 2017). The pilot study assisted with establishing a concrete research instrument (Hofstee 2009). The data collected in the pilot study were included in the main research study to account for the scarcity of the conventional tomography examinations for the period dedicated for the data collection process.

5.3.1 Data collection method

Figure 4.3 below is a summary flowchart with all the steps that were attended to during the process of data collection. The flowchart reflects on the three-part process of data collection, from accessing the computer system, to going onto the RIS for referral letters to record the patient history, as well as establishing the ED and recording all conclusive data onto the Microsoft Excel spreadsheet.



RIS: Radiology Information System

Figure 5.3: Summary flowchart for data collection (compiled by researcher)

The first step in retrospectively collecting data was to search from the computer radiography (CR) systems for all the cervical spine radiographic images that would still be available on the system, and not automatically erased as programmed by the manufacturer. The duration for which information could be stored and accessed from the CR systems is manufacturer dependent. Each of the cervical spine examinations was opened and observed to see if the examination had a conventional tomographic series included in the routine performed. The CR system offered information that assisted in completing section A (patient information), section B (repeat rate), Section E (image evaluation) and section F (technical factors) of the checklist.

The researcher evaluated each tomographic series to successfully complete two checklists per examination. The two checklists allowed for verification of the data captured. When the information from the two checklists was not matching, the researcher would scrutinise the data to observe discrepancies.

The list of tomographic series was evaluated to see if there were any rejected series, the number of times the series was repeated, the reasons for the repeats were identified, and to determine the technical exposure factors used.

The second part of the process was to log onto the radiology information system (RIS). The RIS gives access to radiology reports and referral letters; therefore, referral letters were retrieved to record and classify the data according to the various referred conditions (pathology). Once all the checklists were completed, the researcher moved onto completing the effective dose using the PCMXC20 Monte Carlo software©. The information from all the checklist sections were translated onto a Microsoft Excel spreadsheet with four sheets, one sheet for repeat rates, one sheet for image quality evaluation, one sheet for patient history, and one sheet for effective dose capturing. The conclusive Microsoft Excel spreadsheet was forwarded to the statistician for analysis.

5.3.2 Analysis of data

Data from the checklists and the PCMXC20 Monte Carlo software© were captured electronically by the researcher in the Microsoft Excel file. Any further analysis was done by a statistician using SAS Version 9.2. Descriptive statistics, namely frequencies and percentages, were calculated for categorical data and means, and standard deviations or medians and percentiles were calculated for numerical data. The following analytical statistics were used: the Chi-Square test, to test for differences between proportions; and the T-test to compare mean values, or the Mann-Whitney U-test to compare median values. A significance level (α) of 0.05 was used.

PCMXC20 Monte Carlo software© was used for analysing patients' tissue EDs (ICRP 2007). The software works on data from the radiographic examination, allowing the user to get ED from closed examinations (retrospectively). The user interface has graphic displays to match proper examination conditions.

The exposure factors that had to be recorded from the CR system per radiograph were the kilovoltage peak (kVp), milliAmpere-seconds (mAs), source-to-image distance (SID) and field of view (FOV). First, the ED per conventional tomographic series of the odontoid process for a total of eight tissues receiving radiation during imaging of the odontoid process (airway, lymph nodes, oesophagus, oral mucosa, salivary glands, skull, thyroid and the upper spine), were established.

5.3.3 Validation

The four most important instruments used for the research study were the checklist for data collection, the PCMXC20 Monte Carlo software© for obtaining the effective dose, the Microsoft Excel spreadsheet for summarising the data for the statistician, and the statistical software for statistical analysis. The checklist was specifically designed for the purpose of this research study through a thorough article review research study. Two checklists were completed respectively (matching and comparing) per examination to eliminate any errors. Microsoft is a trusted software nationwide, hence the Microsoft Excel spreadsheet remains reliable.

The PCMXC20 Monte Carlo software© calculates the ED with both the present tissue weighting factors of ICRP Publication 103 (2007), and the old tissue weighting factors of ICRP Publication 60 (1991) (Tapiovaara, Lakkisto & Servomaa 1997). The risk estimates are based on the models of the BEIR VII Committee (BEIR 2006). The software has been used for numerous research studies that focus on dose calculations and radiation exposure estimations across the globe.

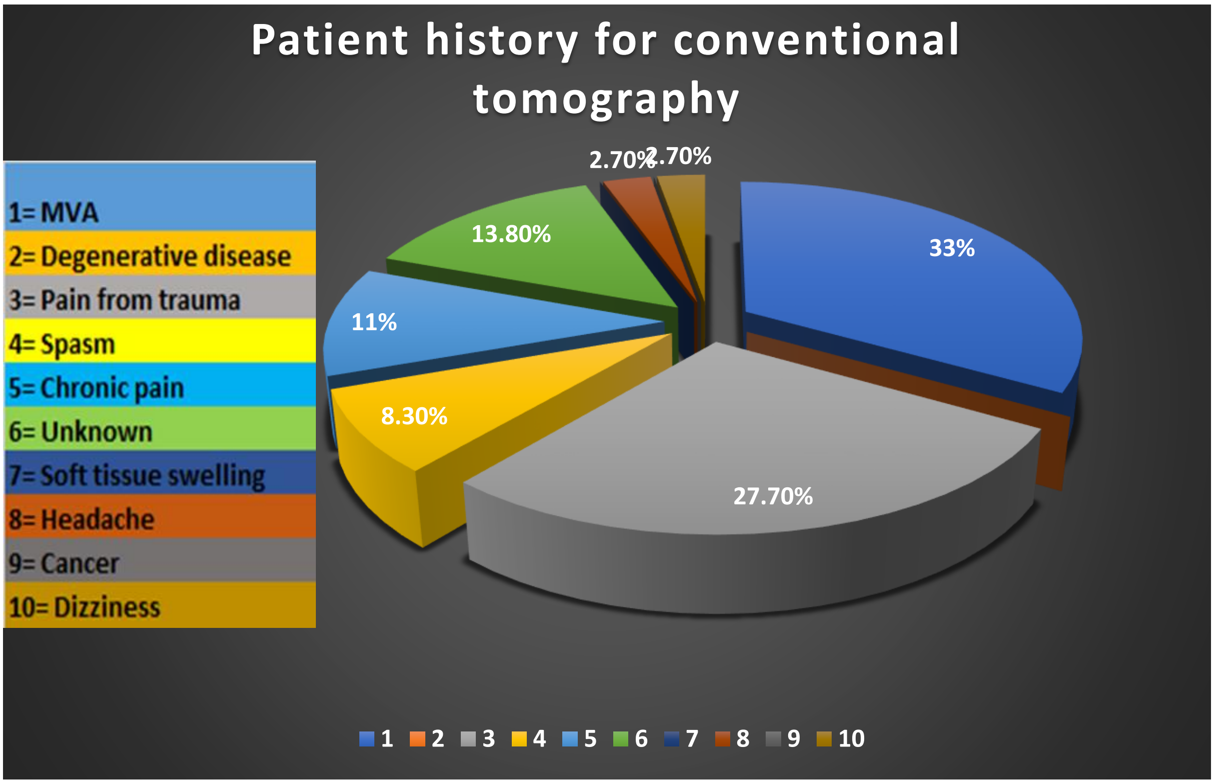
5.4 RESULTS

The results are presented in the following order; number of checklists/radiographic examinations of the conventional tomogram of the odontoid process evaluated, and conclusive list of patient history (pathology); frequency of repeat rate; image quality evaluation; and the conclusive ED to the patient during conventional tomography of the odontoid process

5.4.1 Number of checklists/examinations investigated

A total of 36 checklists were completed for the purpose of the research study, resulting in 36 conventional tomographic series being evaluated. This was a small number which resulted from the scarcity of conventional tomograms. As mentioned previously, conventional tomography is regarded as a second alternative method to the open-mouth view for radiographic visualisation of the odontoid process in plain conventional radiography. Out of the 36 conventional tomographic series, none of the series were repeated. Eighteen of the examinations were performed in conjunction with the open-mouth view during one examination as an alternative conventional radiographic imaging method for the odontoid process, while the rest of the other eighteen conventional tomograms were performed as the first method of preference.

The figure below shows the pathological indications for which patients were referred and had the conventional tomogram acquired. Trauma takes lead, with 22 patients of the 32 patients (68.75%) accounting for motor vehicle accidents (MVA), pain from trauma and chronic pain. When taking a closer look at the pie chart, it is noticeable that although soft tissue swelling is listed on the key patient history, it was automatically not represented on the pie chart since it covers a small percentage. This omission of soft tissue swelling from the pie chart was due to the software Microsoft Excel Algorithm.



MVA: Motor vehicle accident

Figure 5.4: Patient history for cervical spine requisitions series including the conventional tomogram of the odontoid process

Pathology plays a big role in the radiographic imaging of the odontoid process (Johnson & Lucas 1993; Whitley *et al.* 2005. The undeniable need to clearly show the odontoid process is often well guided by the pathology that is being investigated.

5.4.2 Repeat rates

The repeat rate report shows that none of the conventional tomograms of the odontoid process were repeated, and thus the conclusive probability of repeating for the conventional tomogram is zero. Thus, there is a 100% chance that a conventional tomogram of the odontoid process will be performed once per examination.

It is worth noting that, even with a zero-repeat rate, there were noticeable errors in four of the series. The errors were not worth repeating the series based on justification. The section below outlines the subtle errors observed.

5.4.3 Image quality evaluation

According to the data acquired, there were four conventional tomographic series with errors, therefore only the four conventional tomographic series are accounted for when reporting on image quality evaluation. Figure 5.5 below provides a summary of the errors.

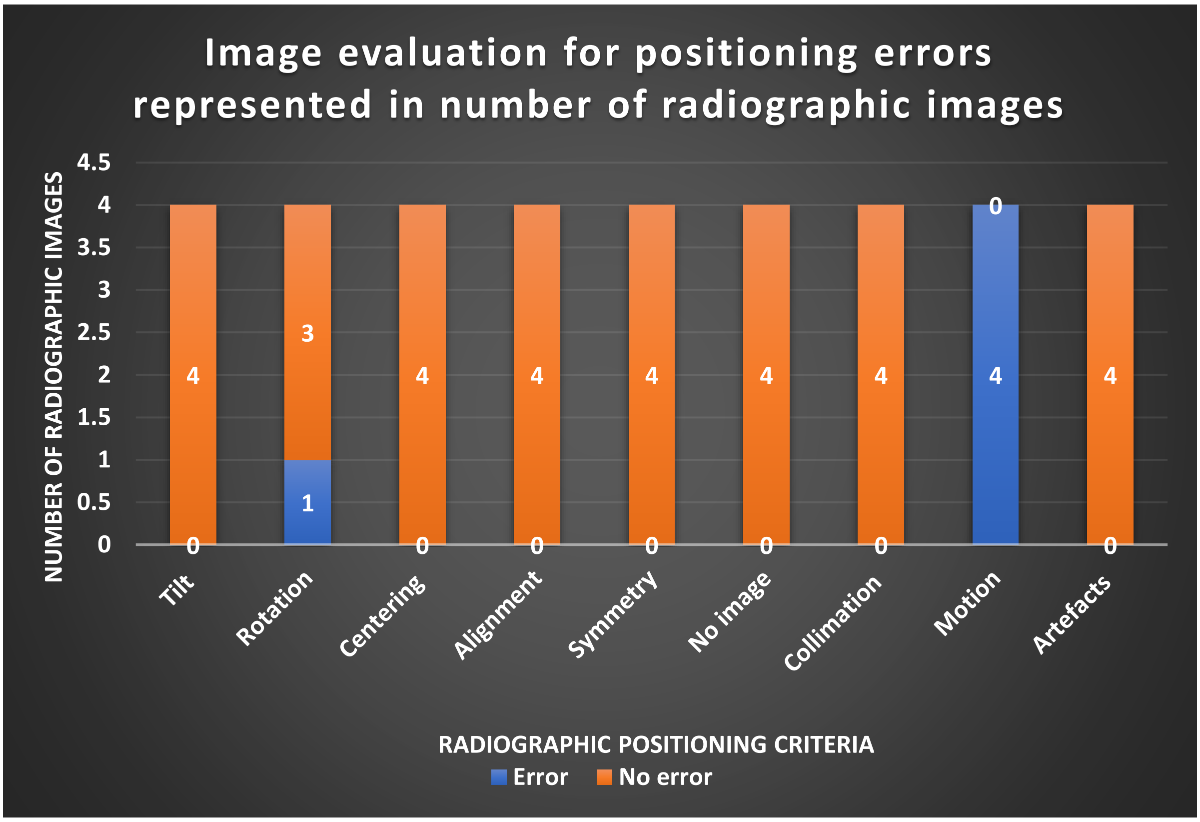


Figure 5.5: Number of errors versus no errors based on the seven radiographic image criteria (created by the researcher)

A conventional tomogram series normally consists of several slices that the radiographer chooses for the examination. From the acquired slices, the radiographer chooses the ones that are most in focus to send to the radiologist for reporting. The ED was established using exposure parameters used for all collective acquired slices in a series.

The errors recorded on four of the series were motion (accounting for a 100% occurrence, thus observed in all four tomographic series) and rotation (accounting for 25% of the errors, thus one tomographic series of the four showing errors).

The results suggest that at some point one of the four conventional tomographic series had both motion and rotation. Second to positioning errors, we consider the evaluation of radiographic images for technical exposure factors. Based on the results of the research study there were no errors associated with technical errors. All series were optimally exposed.

5.4.4 Dose evaluation

Data on ED were analysed for eight body tissues around the area of interest: airway, lymph nodes, oesophagus, oral mucosa, salivary glands, skull, thyroid and the upper spine. Table 5.2 below documents the ED to the listed tissue from the two X-ray units.

Table 5.2: Effective dose from two X-ray units for eight types of tissues (created by the researcher)

Tissue	RSE calculations	VD calculations
Airway	0.80325	0.271126
Lymph nodes	0.803485	0.271148
Oesophagus	0.675841	0.261369
Oral mucosa	0.794978	0.264104
Salivary glands	0.797554	0.272286
Skull	0.803507	0.27095
Thyroid	0.793632	0.248419
Upper spine	0.80326	0.270425

RSE: Room E from the RS radiology private practice. VD: VD radiology private practice

The red column represents the high ED values. Based on the table, RSE gave higher EDs. The green column represents lower ED values. VD therefore represents the lower EDs.

5.5 DISCUSSION

The discussion will follow the order in which the results were presented, focusing solely on aspects that need a thorough discussion for the aim of the research study. Patient history will be discussed, followed by repeat rates, image evaluation and the effective dose.

5.5.1 Patient history for imaging of conventional tomogram referrals

The history was grouped into two categories to narrow down the list, namely trauma and non-trauma. The trauma category consisted of the following: MVA, pain from trauma and chronic pain. 33% of the patients referred for radiographic images of the cervical spine were involved in MVAs, whilst 27.7% of the patients were referred for pain from trauma and chronic pain (11.1%) of the neck.

A total of 72% of the patients therefore were grouped under trauma. Under the non-trauma category was the following: spasms, unknown, headaches and dizziness. The highest number under non-trauma was for unknown referrals.

Trauma remains common for cervical spine referrals that also focus on radiographic representation of the odontoid process. A total of 72% of the patients were referred for pain from trauma (Whitley *et al.* 2005). Based on observation from the workplace, a similar trend is evident. The radiographic representation of the odontoid process cannot be ignored in the case of trauma patients. However, when considering the acquisition time for a conventional tomogram, the 100% occurrence of motion becomes a practical consideration, since it would be difficult for a patient that is in extreme pain to keep still.

Literature indicates that the radiographic representation of the odontoid process is trusted in ruling out fractures from trauma (Weisskopf, Reindl, Schroder, Hopfenmuller & Mittlmeier 2001), whilst degenerative pathological conditions are directed to Magnetic Resonance Imaging (MRI) for a unique opportunity to visualise nerves, connective tissue and bone in all planes without the use of contrast agents (Einig, Higher, Meairs, Faust-Tinnefeldt & Kapp 1990).

5.5.2 Repeat rates

Moving onto the repeat rate, the conventional tomogram of the odontoid process has a high probability of not being repeated. The results inform us that conventional imaging of the odontoid process using tomography guarantees less repeats for the patient. A radiographic method that offers lower repeats is a method that can be prioritised in promoting radiation protection for the patients.

5.5.3 Image evaluation

When considering image evaluation, the radiographer would generally consider basic criteria mentioned earlier such as alignment of the odontoid process, the spinous process with the midline of the axis' body. The long axis of the cervical vertebrae must also be aligned with the IR (Bontrager & Lampignano 2014).

Furthermore, the atlantoaxial and atlanto-occipital joints, the atlas' lateral masses and transverse processes, and the axis' odontoid process and body should be included within the collimated region, to mention a few. These are factors that the radiographer should be alerted to, and attempt to achieve. However, as seen with the results, sometimes the objective of a perfect series of radiographic images is not possible.

While there were no examinations that were repeated, four tomographic series had minor image quality faults. 11.1% conventional tomogram series out of 36 series did not precisely meet the criteria. With reference to Figure 5.5, motion was the main error evident in all the four conventional tomogram series with errors, at a 100% occurrence probability. Motion is often experienced in examinations where long exposure settings are necessary, and conventional tomography marks as one of the radiographic methods which uses a longer requisition time than usual in plain conventional radiography. Hence, four had evidence of motion, adding onto the fact that the conventional tomograms of the odontoid process were mostly performed on trauma patients who were possibly in pain. This points to the need for immobilisation methods for conventional tomograms of the odontoid process.

Furthermore, motion can be encountered from unclear instructions or lack of effective communication from the radiographer to the patient during acquisition. The patient needs to understand that they need to keep still during image acquisition. Careful attention must go into technical factor considerations.

The relationship between the odontoid process and the anatomical structures situated lateral to the odontoid process is recognised as the evidence of absence of rotation. In judging rotation, we consider the distance from the odontoid process to the lateral anatomical structures. The distance must remain equal on both sides as an indication that there is no rotation: one series had rotation, thus a 25% probability.

The occurrence of rotation just as with motion can be linked to the fact that radiographic images on trauma patients must be obtained without manipulation of the patient's head, which generally makes it a difficult task to complete with outmost optimality.

The study reveals that the conventional tomogram of the odontoid process under image quality is achieving optimisation, since the highest number of errors on one radiograph were two errors, on a single series out of the total number (36) of tomographic series assessed for the conventional tomogram of the odontoid process.

5.5.4 Dose evaluation

ED was established using the PCMXC20 Monte Carlo software© as previously mentioned. The conventional tomograms were acquired from two X-ray units. Based on Table 5.2 above, the VD X-ray unit offers the least ED to the patient (green) and the RSE X-ray unit offers the highest ED (red). The reason behind the different ED can be linked with different manufacturers having different conversion efficiency which affects the exposure factors required to achieve an adequately exposed radiographic image. The highest ED observed for VD was 0.272286 mSv for the salivary glands. The highest ED observed for RSE was 0.803507mSv for the skull.

The VD X-ray unit had the lowest ED to the patient for conventional tomography of the odontoid process. Thus, although outside the scope of this research study, it is worth mentioning that critically looking at the manufacturers' specifications when purchasing an X-ray unit remains an important aspect of making informed decisions. While it would be insightful to match the results of the ED observed from the current study, reference studies that were found were not investigating small tissues within an anatomical region, but rather the whole anatomical region. This leaves us with only the opportunity to judge or contrast the one X-ray unit with the other.

5.6 CONCLUSION

Conventional tomography has fallen into place in plain conventional radiographic imaging to close the gaps encountered during plain conventional radiographic imaging (Whitley *et al.* 2005). While the technique is recognised as a high radiation dose technique in plain conventional radiography, the investigated ED in this research study has proven that the suggestion is not always the true.

The research study focused on achieving an insight on the repeat rates, the reasons behind the repeat rate as observed during image evaluation, and the influence of the repeat rate on the ED to the patient. When coming to repeat rates and image quality, conventional tomography offers assurance of no repeats, with a 100% pass rate. Thus, patients going for a cervical spine routine which includes the conventional tomogram of the odontoid process will have the tomogram acquired only once.

There is a possibility of some recognisable errors that are not worth repeating the tomographic series for. The decision to repeat lies with the radiographer's judgement under the application of justification. The most commonly encountered error for conventional tomography of the odontoid process is motion. The error can be overcome through effective communication with the patient, striving to select the shortest acquisition time possible, choosing the correct fulcrum height, and lastly implementing effective immobilisation methods.

The research study showed that radiation exposure to the patient can be directly linked to the X-ray unit used to perform the examination. RSE administrates the highest dose to patients. Radiology departments must get an insight on the different X-ray machine conversion efficiency to protect patients from radiation exposures that could easily have been avoided through informed decision making. The limitations of the research study included the scarcity of conventional tomograms of the odontoid process examination for images within the period dedicated to the data collection process and access to the PCXMC20 Monte Carlo software© .

Based on the outcome of this study, the following recommendations are made in terms of image quality, effective communication during the procedure and immobilisation methods to help rid the motion associated with conventional tomography are of utmost importance. When it comes to the effective dose to the patient, various radiology departments must seek information on the radiation dose output before purchasing a new X-ray unit.

A future study intended to investigate the radiation dose output for different X-ray units with similar specifications is recommended. A future study intended to compare the ED's to existing standard ED's for the listed tissues could also be performed, as well as a high sample size research study.

In conclusion, although this might not apply to all radiology departments, many of them are using conventional tomography for radiographic imaging of the odontoid process, and have to depend on the methods for optimisation when it comes to image quality and radiation dose for X-ray units that offer low radiation outputs.

5.7 SUMMARY

Chapter five successfully served the purpose of reflecting on the third and fourth objectives of the entire research study, which were as follows: recording the number of repeated radiograph series and reasons for the repeated radiographic images, and calculating and evaluating the total effective dose to the patients for conventional radiographic imaging methods for the odontoid process using conventional tomography.

Chapter six is in article format. The chapter is aimed at contrasting and narrowing the overall results from the two conventional radiographic imaging methods. The aim of the article is to put the open-mouth view directly next to the conventional tomography of the odontoid process, and, consequently, permitting the opportunity to conclude on the radiographic circumstances for which either one of the two radiographic views can be utilised for optimised radiographic imaging of the odontoid process. The chapter answers the fifth and sixth objective of the research study related to weighing the total repeat rates, radiographic image quality and effective dose between the two conventional radiographic methods of imaging of the odontoid process, and to advise accordingly.

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CHAPTER SIX

OPTIMISATION OF CONVENTIONAL RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS: CONTRASTING THE OPEN-MOUTH VIEW AND CONVENTIONAL TOMOGRAPHY

6.1 INTRODUCTION

Statistics show that cervical spine fractures are a common diagnosis in emergency medical care (Weisskopf, Reindl, Schroder, Hopfenmuller & Mittlmeier 2001). Fractures in this region account for 1 to 3 per cent of the total injuries encountered in emergency medical care. In the quoted percentage, the upper cervical spine (atlas and axial) accounts for 25% of the cases. Adding to that, the odontoid process is affected in 55% to 80 % of the incidents (Weisskopf *et al.* 2001). The cervical spine is further involved in most patients with rheumatoid arthritis (RA), at a count of 80% (Joaquim, Ghizoni, Tedeschi, Appenzeller & Riew 2015). The main alterations of RA are visualised at the movable region of the cervical spine, which is the atlas and axial region (Casey, Choid & Crockard 2006).

Based on these statistics, medical imaging of the odontoid process can be considered a vital step in responding and managing prevalence of pathology in the upper cervical spine. Imaging for the cervical spine generally varies from conventional radiographic methods (plain conventional radiography and conventional tomography) to specialised radiographic methods such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) (Keller, Bieck, Karul, Schönnagel, Adam, Habermann & Yamamura 2015). Considering the attention that needs to be focused, specifically on radiographic imaging of the cervical spine for the representation of the odontoid process, it makes sense to prioritise optimising radiographic imaging of the anatomical structure.

While this can be done through the consideration of all the various medical imaging methods available, there are radiology departments that do not have the luxury of specialised radiographic imaging methods. However, in striving for a more inclusive resolution, it would be of essence to consider the evaluation of conventional radiographic imaging methods.

The following plain conventional radiography methods are alternatively implemented to achieve a proper representation of the odontoid process and relative anatomical structures of the upper cervical spine: open-mouth view, anteroposterior (AP) Fuchs, wagging jaw, posteroanterior (PA) Judd and a conventional tomogram, to mention a few (Bontrager & Lampignano 2014; Long, Rollias & Smith 2015; McQuillen Martensen 2011; Whitley, Sloane, Hoadley, Moore & Alsop 2005).

The principle of comparing methods that serve the same radiographic imaging purpose has taken lead as a radiation protection measure, and in promoting a technique that offers high sensitivity, low radiation exposure to patients and radiographic images that help with accurate diagnoses (Klenske 2019). Furthermore, studies show that procedures carried out with different methods, deliver different radiation doses and result in variable diagnostic performance (Manning, Bunting & Leach 1999).

In a few observed radiology departments in South Africa, the open-mouth view and the conventional tomogram of the odontoid process are performed as alternative methods of preference for the radiographic representation of the odontoid process. The open-mouth view is generally placed first and the conventional tomogram second due to the apparent high exposure quantity associated with conventional tomography technical settings (Carlton & Adler 2006). Thus, the research study would evaluate the open-mouth view and conventional tomography for optimisation of the radiographic imaging of the odontoid process when accounting for repeat rates, image quality and radiation dose based on effective dose (ED).

6.2 LITERATURE PERSPECTIVES

The academic databases and search engines used for the literature perspectives include Ebscohost, Science Direct, PubMed and HubMed. The key terms used in searching for material for the research study were open-mouth view, odontoid process, conventional tomography, tomography, radiation protection and cervical spine. The literature consulted and reflected on in the following section adds to the proposed research study on the two conventional radiographic imaging methods of the odontoid process.

According to Long *et al.* (2015), upper cervical spine conventional radiographic imaging is being replaced with CT. The decision is based on the technical difficulty and false fractures resulting from superimposition of the odontoid process and lateral masses by surrounding anatomical shadows, when it comes to imaging of the upper cervical spine using the plain conventional cervical spine radiographic routine (open-mouth view, axial AP, lateral and obliques) (Long *et al.* 2015).

In the year 1984, Braunstein, Weissman, Seltzer, Sosman, Wang and Zamani published literature at the American College of Rheumatology, in Georgia on "Computed tomography and conventional radiographic images of the craniocervical region in rheumatoid arthritis". According to their findings, the CT scan images showed a much greater extent of erosion in nine out of twelve patients. The CT scan images revealed attenuation of the transverse ligament and the presence or absence of spinal cord compression, whereas plain radiographic images did not (Braunstein *et al.* 1984).

In October 2012, Seo, Kim, Choi and Nahm published an online report case on a 46-year-old female patient who had complained of progressive posterior neck pain for six months. The open-mouth view showed the possibility of ligament rupture and instability in the first cervical spine vertebra, thus revealing only indirect information about transverse ligamentous disruption (Seo *et al.* 2012).

Johnson and Lucas conducted a study in 1993. The topic of their research was "Cervical spine evaluation: Efficacy of open-mouth view for non-traumatic radiography". The study was done to examine the prevalence of disease in the upper cervical spine in an outpatient setting for non-traumatic cervical spine evaluation. Based on the outcome of the study, the open-mouth view is suggested to be compulsory for patients that are at risk of pathological conditions in the upper cervical spine. However, for a high number of patients coming into various radiology departments, imaging of the odontoid process is not worth the radiation exposure, technical difficulty and expense (Johnson & Lucas 1993).

Furthermore, a study was done by Weisskopf *et al.* (2001) with the tittle “CT scans versus conventional tomography in acute fractures of the odontoid process”. Conventional tomography had a specificity of 95.4 % and a sensitivity of 85.2%, while CT had a specificity of 93.8% and sensitivity of 95.5%.

The authors concluded that CT examinations, with sagittal and coronal reconstructions, were equivalent with respect to diagnostic accuracy, and can therefore replace conventional tomography in the evaluation of odontoid fractures. Although there are multiple research studies in favour of specialised diagnostic modalities due to their multiple advantages, there are unfortunately radiology departments without the luxury of specialised modalities (CT and/ MRI) (Ehrlich & Coakes 2017). Radiology departments without specialised modalities depend on optimisation of plain conventional radiographic methods (Ehrlich & Coakes 2017). Adding to that, specialised modalities come with the setbacks of higher costs (Dr Spies & Partners 2017). CT scans operate on high radiation exposures as opposed to plain conventional radiography (Bontrager & Lampignano 2014).

The other setback worth mentioning is the training required for the operation of specialised machines. Such training requires time and funds to pay for trainers. During instances where the radiation worker has had training, there are circumstances which require the need for a reporting radiologist to be present, and to oversee the examination (Ehrlich & Coakes 2017). Therefore, shifting the attention from optimising radiographic imaging of the odontoid process through contrasting all existing radiographic imaging methods, to rather contrasting conventional radiographic imaging methods, is substantial and beneficial to the entire radiology society.

6.3 METHODS

This research study was conducted through the principles of a quantitative retrospective study. The design for the research was an evaluative, descriptive and explanatory research design (Fouche & De Vos 2011). The setting for the research study was two radiology departments in Bloemfontein, Free State. Data were collected from three X-ray units named RSE, RSD and VD. The X-ray units were kept anonymous to protect the vendors when reporting back on the ED to the patient. During the data collection process, all cervical spine examinations for patients between the ages of 15 to 75, that included the open-mouth view and the conventional tomogram of the odontoid process from the three X-ray units within the data collection period (July 2018 to October 2018) were considered for the research.

The cervical spine examinations had the following preferential particulars: a referral letter stating the clinical history, raw radiographic images from the CR system to offer insight into the number of repeated images, and to carry out image quality evaluation to gain knowledge on the reasons for the repeated radiographic images.

Radiographic examinations of patients between the age of fifteen and seventy-five years were used for the study. The age restriction was set to overcome skeletal maturity and osteoporosis-related concerns (Long *et al.* 2015). All examinations were marked as ‘patient 1’ to avoid using patients’ identity. A total of 216 examinations were evaluated. Table 6.1 below shows a breakdown of the examinations.

Table 6.1: Checklists completed for research study (created by the researcher)

Type of Image	Frequency	Percent	Cumulative frequency	Cumulative percentage
OM and TM	18	8.33	18	8.33
OM only	180	83.33	198	91.67
TM only	18	8.33	216	100

OM: Open-mouth view TM: Conventional Tomogram

There were more open-mouth view examinations than conventional tomograms, as reflected in the table above. The data collection process was initiated using a checklist. The checklist was used for recording data that serves to report back on the repeat rates, image quality evaluation and the technical exposure factors that were to be used for achieving the ED. The PCMXC20 Monte Carlo software© was introduced for the ED calculations derived from the insertion of the technical factors into the software interface. The data from the checklists and PCMXC20 Monte Carlo software© was translated and summarised on a Microsoft Excel spreadsheet for statistical analysis.

A pilot study was conducted after ethical approval was obtained with the following number: UFS-HSD2018/0257/2905. The pilot study served to verify the validity and reliability of the checklist and the PCMXC20 Monte Carlo software© for the purpose of successfully fulfilling the research study (English Oxford Living Dictionary 2017; Hofstee 2009).

The data from the pilot study were included in the main research data. The reason for this was to account for the scarcity of the conventional tomography examinations for the period dedicated for the data collection process.

6.3.1 Analysis

The PCMXC20 Monte Carlo software© was used for analysing patients' organ EDs (ICRP 2007). The software can operate on the insertion of data from completed radiographic examinations, thus allowing for retrospective ED calculations. The user interface has graphic displays to match proper examination conditions. The technical exposure factors needed from the CR system per radiograph are the kilovoltage peak (kVp), milliampere-seconds (mAs), source-to-image distance (SID), and field of view (FOV). ED for eight tissues (airway, lymph nodes, oesophagus, oral mucosa, salivary glands, skull, thyroid and the upper spine) receiving radiation during imaging of the odontoid process was established.

Critical analysis was implemented to assess any familiar and/ suspicious patterns within the data before forwarding the data to the statistician. Statistical analysis was done by a qualified statistician using SAS Version 9.2.

6.3.2 Reliability

The three X-ray units were assessed for quality assurance (QA) and quality control (QC) testing. Performing a research study intended to venture into assessing radiation dose is matched with an expectancy for QA and QC that are within acceptable limits for reliability of results (Samei 2012). The QA assessment status of each X-ray unit was as follows: RSE was within acceptable limits for May 2018, RSD for July 2018, and VD for November 2017. The dates of the QA tests were still valid when the data collection process was undertaken.

Quality control plays a fundamental role in maintaining low doses and adding onto high image quality; hence, data collection on research striving to optimise radiographic imaging should be conducted on X-ray units which have been tested (Yacoob & Mohammed 2017). The QA was performed by the technicians and physicists from the specific manufacturers of the radiography units in place.

6.4 RESULTS

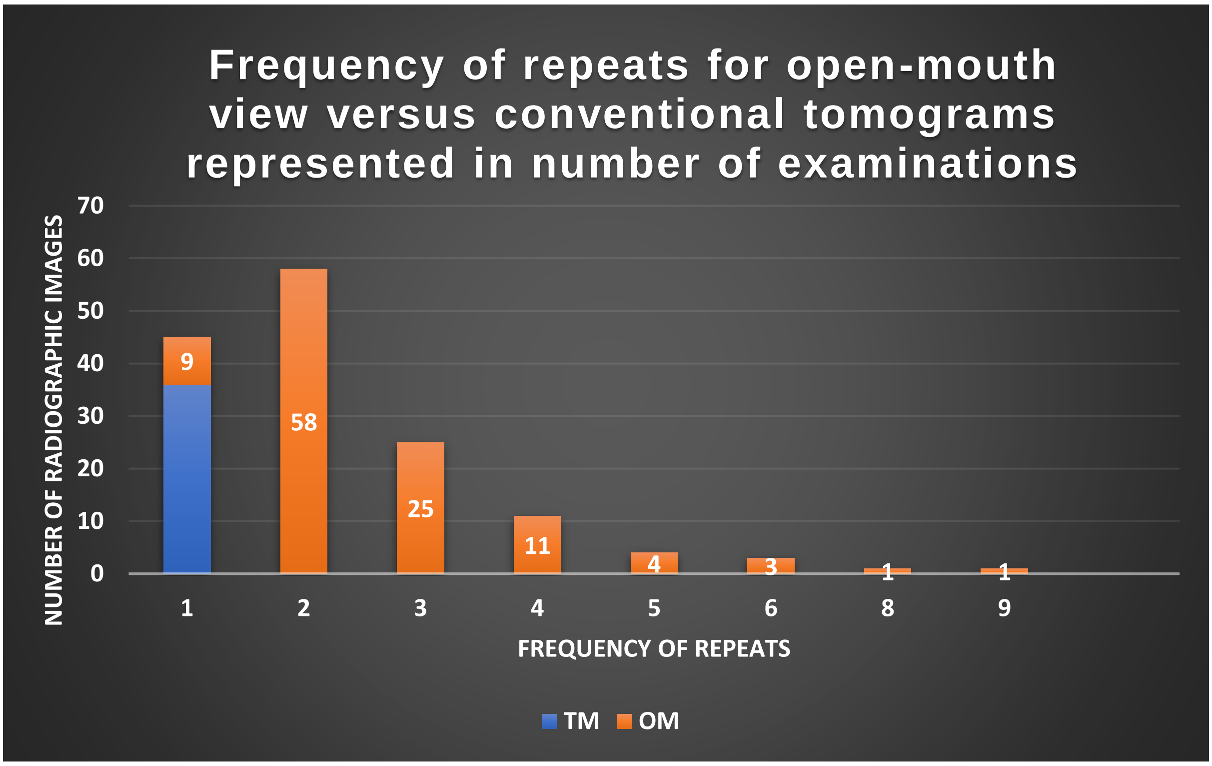
Two hundred and sixteen checklists were completed for the research study. More checklists were completed for the open-mouth view. The conventional tomogram of the odontoid process is less performed due to the scare of higher quantities of radiation (mAs) associated with conventional tomograms (Carlton & Alder 2006).

Due to the known and expetant scarcity of the conventional tomograms of the odontoid process, the goal was to achieve at least thirty conventional tomograms as per the assisting statistician’s advice (Viljoen 2018). Checklists, and capturing the data for thirty-six conventional tomograms of the odontoid process were achieved at the end of the data collection process. Table 6.2 below reflects on the total radiographic images evaluated from the total 216 examinations (patients) used for the overal research study.

Table 6.2: Total number of radiographic images evaluated

Variable	Number of examinations/patients	Sum of radiographic images for all examinations/patients
Number of open-mouth view images	216	385
Number of conventional tomographic images	216	36
Total number of images		421

The total number of radiographic images (421) includes repeated radiographic images per examination. Derived from the total number of radiographic images, Figure 6.1 below reflects on the frequency of attempted images per examination.



OM: Open-mouth view TM: Conventional Tomogram

Figure 6.1: Frequency of repeats (created by the researcher)

The conventional tomogram was attempted once for all of the thirty-six examinations, while the open-mouth view was mostly attempted twice, going up to a maximum of nine attempts. The total number of examinations evaluated accounts for a total of 280 radiographic images with errors (Table 6.3 below).

Statistically speaking, there is a significant difference in the repeat rate between the open-mouth view and the conventional tomogram of the odontoid process (p<0.0001). The section below thoroughly outlines the errors for which the radiographic images were repeated.

Table 6.3: Errors on evaluated radiographic images (created by the researcher)

Method of acquisition	Open-mouth view	Conventional tomogram of the odontoid process	Total radiographic images with errors for entire study
Radiographic images with errors	276 (71.69%)	4 (11.11%)	280
Radiographic images without errors	109 (28.31%)	32 (88.89%)	141
Total radiographic images	385	36	421

p < 0.0001 (Fisher's Exact Test)

6.4.1 Radiographic image evaluation

Table 6.4 gives an insight on each radiographic image evaluation criteria as a separate entity from the checklists. The evaluation of each of the radiographic images reflecting radiographic errors is presented.

A significant difference exists for tilt and motion (p=0.0001 and p=0,0019 respectively). Tilt was evident in the open-mouth view examinations, while there were no images with tilt for conventional tomography of the odontoid process. Motion was seen in all the conventional tomograms with errors, with a very low occurrence in the open-mouth view examinations.

Table 6.4: Errors per conventional radiographic technique (created by the researcher)

Critique	Open mouth without error	Open mouth with error	Tomogram without error	Tomogram with error	Total images without errors	Total images with errors	(Fisher's Exact Test) P value
Asymmetry	255 92.39%	21 7.61%	4 100%	0 0	259	21	p=1.0000 no significant difference
Motion	275 99.64%	1 0.36%	0 0%	4 100%	275	5	p=0.0001 significant difference

Table 6.5: Errors per conventional radiographic technique continued

Critique	Open mouth without error	Open mouth with error	Tomogram without error	Tomogram with error	Total images without errors	Total images with errors	(Fisher's Exact Test) P value
Collimation	243 88.04%	33 11.96%	4 100%	0 0%	247	33	p=1.0000 no significant difference
Centering	138 50%	138 50%	4 100%	0 0%	142	138	p=0.1225 no significant difference
Under exposure	249 90.22%	27 9.78%	4 100%	0 0%	253	27	p=1.0000 no significant difference
Over exposure	219 79.35%	57 20.65%	4 100%	0 0%	223	57	p=0.5853 no significant difference
Double exposure	276 100%	0 0%	4 100%	0 0%	280	0	N/A
No image	275 100%	1 0.36%	4 100%	0 0%	279	1	p=1.0000 No significant difference
Artefacts	271 98.19%	5 1.81%	4 100%	0 0%	275	5	p=1.0000 No significant difference
Tilt	56 20.29%	220 79.71%	4 100%	0 0%	60	220	p=0.0019 Significant difference
Rotation	251 90.94%	25 9.06%	4 100%	0 0%	255	25	p=1.0000 no significant difference
Alignment	260 94.2%	16 5.8%	3 75%	1 25%	263	17	p=0.2227 no significant difference

6.4.2 Radiation dose evaluation

Table 6.5 reflects on all the ED per irradiated tissue from all three X-ray units and both the radiographic methods. Table 6.5 puts each X-ray unit's results next to each other for the two conventional radiographic methods.

Table 6.6: Effective dose from three X-ray units for eight tissues (created by the researcher)

Tissue	RSE conventional tomogram	RSE open-mouth view	VD conventional tomogram	VD open-mouth view	RSD open-mouth view
Airway	**0.80325**	*0.802355*	0.271126	0.428864	0.345812
Lymph nodes	**0.803485**	*0.788455*	0.271148	0.462847	0.379471
Oesophagus	**0.675841**	*0.642815*	0.261369	0.412581	0.492107
Oral mucosa	*0.794978*	**0.807749**	0.264104	0.506556	0.36695
Salivary glands	*0.797554*	**0.866106**	0.272286	0.610442	0.444032
Skull	**0.803507**	*0.799326*	0.27095	0.384417	0.36397
Thyroid	**0.793632**	*0.754718*	0.248419	0.37587	0.464155
Upper spine	0.80326	**0.875797**	0.270425	0.362013	0.333698

RSE: Private practice 1: Room E, RSD: Private practice 1: Room D, VD: Private practice 2

The table is colour coded as follows: the two lighter grey columns represent the conventional tomogram examination mean ED, whilst the three darker grey columns represent the open-mouth view examination ED. Furthermore, the green font ED is the lowest, and the yellow font ED is between the lowest and the highest ED. The red font, is categorised into three groups: the plain red font ED represent the high ranking, the red italics font and underlined represent the higher ranking, and the red bold font represent the highest ranking calculations. The highest-ranking ED mean (highest bold red font value) for the entire study was for the open-mouth view performed at RSE for the upper spine at 0.875797, while the lowest ranking ED mean (lowest green font value) was from the conventional tomogram for the thyroid at 0.248419.

6.5 DISCUSSION

The results of the research study revealed the following for the open-mouth view: the open-mouth view is commonly requested for trauma for 84% of the requests. The average number of times for which the open-mouth view can be acquired per examination is two times (58%). The highest number of repeated open-mouth views per examination is nine times.

The most common error for which the view is repeated is for tilt (71.7%). The research study by Josephs (2016) also revealed that tilt was the reason behind 92% of the radiographic open-mouth view images being repeated.

The research study was intended to investigate the reasons for a high number of repeated open-mouth view radiographic images for trauma patients at the Radiology Department of Kuruman Hospital in the John Taolo Gaetsewe district of the Northern Cape.

The effective dose to the patient at the end of the examination is proven to not only be based on the repeat rate, but perhaps also on the manufacturer's conversion efficiency since it determines the varying exposure factors needed to produce an adequately exposed radiographic image. With advancements in the world of diagnostic radiography, it is crucial to strike a balance between image quality and radiation dose (Uffmann & Schaefer-Prokop 2009). While modern radiography X-ray units (DR and CR) strive to reduce radiation doses to patients, there is a substantial opposing increase in patient dose that goes unnoticed (Uffmann & Schaefer-Prokop 2009).

The RSE X-ray unit gave the highest ED for the open-mouth view. The upper spine received the highest effective dose at a total mean value of 0.875798 mSv from the RSE X-ray unit. The highest effective dose as observed for RSD was 0.492107 mSv for the oesophagus. The highest ED observed for VD was 0.610442 mSv for the salivary glands. The RSD X-ray unit was the manufacturer with the lowest ED to the patient for imaging of the open-mouth view. The difference in ED between the different X-ray units is the reason why there are a fair number of research studies dedicated to contrasting the performance of systems to define the amount of possible dose reduction, while still achieving good image quality (Uffmann & Schaefer-Prokop 2009).

The following was revealed for the conventional tomogram of the odontoid process: the conventional tomogram of the odontoid process was mostly performed for trauma patients (72.22%). The repeat rate for a conventional tomogram of the odontoid process is zero. However, there were images that revealed subtle motion (11.11%). Time is an important exposure factor in conventional tomography. The time set for the series needs to match the time that is necessary to match the time needed for the tube to complete the tomographic amplitude (Carlton & Adler 2006). The time frame can result in patient motion.

Secondly, the anatomical structure of interest must also be positioned precisely on the correct level of the fulcrum. The fulcrum, together with the focal plane, also play an important role in whether the anatomical structure of interest shows motion or desired sharpness (Carlton & Adler 2006).

The ED between the two X-ray units for conventional tomography of the odontoid process was significantly different. The RSE X-ray unit had the highest ED calculations, while VD had the lowest calculations. The highest ED recorded for RSE was at 0.803507 mSv for the skull and 0.272286 mSv for the salivary glands for VD.

The same sentiments about the open-mouth view can be expressed with the conventional tomogram. The dose that the X-ray unit issues determines whether the ED to the patient will be high or low. When contrasting the two methods, it is conclusive that in the present study the conventional tomogram of the odontoid process offers fewer repeat rates. When unpacking the evaluation of image quality, a significant difference was found for tilt (p= 0.0019) and motion (p= 0.0001) when using the fisher's exact test.

This meant that while the open-mouth view can be frowned upon for the technical challenge of overcoming tilt, the conventional tomogram of the odontoid process would be frowned upon for motion. However, while motion can be found in 11.11% of conventional tomograms of the odontoid process, tilt was found in 71.7% of the open-mouth view examinations. When reflecting on tilt, several case studies show that open-mouth view radiographic images often reflect apparent fracture lines which are an illusion of overlapping shadows (Schwartz 2008).

Unlike being able to compare and make conclusions from the image evaluation results, making a conclusive comparison for radiation cannot be made without considering a number of aspects. Looking at the present research study, the upper spine had the highest effective dose mean value of 0.875797 mSv from the RSE X-ray unit, open-mouth view imaging, while the thyroid had the lowest effective dose from VD X-ray unit, conventional tomogram imaging at 0.248419.

According to these values, the conventional tomogram of the odontoid process resulted in lower ED than the open-mouth view. Yet, if we look at the conventional tomogram of the odontoid process from the RSE X-ray unit, the statement would be proven false. Hence, the first point of reference would be the manufacturer from which a radiology department buys an X-ray unit, its conversion efficiency, radiation dose output, and whether it is a screening unit or non-screening unit.

It is important to keep in mind that radiation dose optimisation is achieved when radiographic imaging is performed with the least quantity of radiation that provides adequate image quality and imaging diagnostic guidance (Alzimami, Sulieman, Paroutoglou, Potamianos, Vlychou & Theodorou 2013).

Based on this standard, it is evident that the conventional tomogram of the odontoid process takes preference based on image quality. However, when it comes to radiation dose, each X-ray unit must first be evaluated for radiation dose output. Radiology departments can therefore rather opt for the open-mouth view if the X-ray unit they are in possession of gives high ED.

6.6 CONCLUSION

The results showed that the probability of repeating a conventional tomogram of the odontoid process is unlikely, while there is a definite chance that the open-mouth view might need more than one attempt. Therefore, judging from the perspective of repeat rates, the conventional tomogram takes preference in imaging of the odontoid process. Repeated radiographic images do not only come with added radiation exposure to the patient, but are also time consuming and restrict effective patient flow and the provision of high customer service.

Under radiographic image evaluation, tilt (open-mouth view) and motion (conventional tomogram) are the most common positioning errors. The results reflect a gap on the radiographer’s positioning skills for overcoming tilt (manipulation of the central ray and the patient’s head). Thus, experimental positioning studies can be undertaken to resolve the dominant error. Based on motion, effective communication and immobilisation methods can be implemented and attention given to technical factors affecting sharpness.

The RSE X-ray unit gives higher ED for both open-mouth view and conventional tomogram images. This could suggest that radiographers screen for positioning when using the RSE X-ray unit, since it is a screening X-ray unit, and by doing so, they subject the patient to a higher radiation dose. While it is unsettling to suggest which method in particular will have higher ED calculations, it is evident that some X-ray units give higher radiation exposures than others, and that the choice of the X-ray unit manufacturer will determine the ED, irrespective of the method of choice.

While the place for plain conventional radiographic imaging of the odontoid process can be regarded as insignificant based on the availability of CT, the radiology field have rankings that go from level one hospitals to level three hospitals. Depending on where a radiographer is positioned, there might not be access to CT. A level one hospital is a district hospital where there are limited specialised services, while a level three hospital is an academic hospital with speciality services (Western Cape Government 2020).

Based on the application of justification of radiographic procedures, it would be unjust to disregard plain conventional imaging methods that have been proven to be effective and choose a specialised imaging method that not only comes with a higher radiation dose, but added expenses for the patient. That places a huge compromise on patient care.

The challenges encountered with the research study included a smaller sample size for conventional tomography. A study with a higher sample size is therefore suggested. Further studies can be intended for investigating the radiation dose output for different X-ray units with similar specifications, comparing the EDs to existing standard EDs for the listed tissues, and lastly investigating ways to overcome the tilt encountered with the open-mouth view.

6.7 SUMMARY

Chapter six weighed the total repeat rates, radiographic image quality and effective dose between the two conventional radiographic methods of imaging of the odontoid process. This helped to conclude on the radiographic circumstances for which either one of the two radiographic views can be utilised for optimised radiographic imaging of the odontoid process. Chapter seven will address the conclusion that were highlighted in chapter six through making concluding remarks and answering the research questions, and indicating how each of the main research study objectives were attained.

The limitations that were encountered in the process of successfully completing the research study will be described, and the recommendations that can be applied in striving to optimise conventional radiographic imaging of the odontoid process, will be highlighted.

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CHAPTER SEVEN
CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

7.1 INTRODUCTION

The concept of the current research study can be compared to comparative effective research (CER). The reason why it would be possible to compare the concept is because CER is used by researchers to contrast the benefits and drawbacks of different interventions and strategies to diagnose, prevent, treat and monitor health conditions in the real world (Klenske 2019). The system entails comparison for better outcomes of interest for patients. In the field of radiology CER is said to help with guiding practice, policy, and future research. The current research study was in a similar fashion.

The research study was intended to evaluate two methods for plain conventional radiographic imaging of the odontoid process, and to further contrast the two methods in order to achieve radiographic optimisation for plain conventional radiographic imaging of the odontoid process. Quality radiographic images that ideally demonstrate the odontoid process, free of superimposition, are important considering the susceptibility of the odontoid process to injury (Weisskopf *et al.* 2001). These quality radiographic images can be a challenge and involve the application of different methods at multiple attempts (Josephs 2016).

The research study was achieved through retrospectively evaluating the open-mouth view and conventional tomography of the odontoid process for the number of repeated radiographic images, image quality and effective dose (ED). There were two research questions to be answered. The first research question was: “Are patients being unnecessarily irradiated during X-ray examinations of the cervical spine for radiographic representation of the odontoid process?” The second research question was: “Which conventional radiographic technique between the open-mouth view and conventional tomography of the odontoid process achieves optimisation of imaging of the odontoid process?”

The following research statement was presented: “The radiation dose to the patient must be optimised in order to comply with radiation doses that are as low as reasonably achievable during radiographic imaging of the odontoid process”. Six objectives were established and used to guide the research study. The current chapter is centred around concluding on the events of the research study by answering the research questions and reporting back on how the objectives of the research study were accomplished. Furthermore, the chapter considers the limitations that were encountered and recommendations to be implemented in order to optimise radiographic imaging of the odontoid process.

7.2 RESEARCH QUESTIONS

Are patients being unnecessarily irradiated during X-ray examinations of the cervical spine for conventional radiographic imaging of the odontoid process? Due to the repeat rates associated with the open-mouth view, and further considering the acquisition of a conventional tomogram as a second method of preference, patients are indeed being subjected to unnecessary radiation doses.

In relation to the question: “Which conventional radiographic technique between the open-mouth view and conventional tomography of the odontoid process achieves optimisation of imaging of the odontoid process?”, it became evident that the conventional tomogram of the odontoid process offers a greater degree of optimisation than the open-mouth view.

7.3 RESEARCH STATEMENT

The research statement: “The radiation dose to the patient must be optimised in order to comply with radiation doses that are as low as reasonably achievable during radiographic imaging of the odontoid process”, has been the foundation for various research studies. The ability to consider the benefits of either one of the two methods is an essential step in conforming to the research statement.

7.4 ADDRESSING THE OBJECTIVES

The following objectives were established to assist in achieving the aim and goal of the research study:

I. Compile a literature review that would orientate the literature perspectives on optimising radiation exposures during radiographic imaging of the odontoid process for examinations of the cervical spine.

The entire research study was guided by literature perspectives, from Chapter one to Chapter six. Chapter one was an introduction to the research and had to be grounded by literature in order to deem the research study both significant, valuable and relevant to the professional field. Chapter two was focused on literature perspectives, with every section of the chapter derived from literature resources. Chapter three involved creating the checklist as an important research data collection instrument for the entire research study. Chapter three is in article format, and the article is in the form of a review article, while chapters four to six focused on detailing information on the two conventional radiographic imaging methods.

Academic databases and search engines were used to find literature sources to successfully guide the research study. These databases and search engines included Ebscohost, Science Direct, PubMed and HubMed. The motivation behind the choice of databases and search engines as constantly highlighted throughout the study, was because they cater for science and medical journals and guidelines. The timeframe for the search was from January 2000 to 2020 April. However, the timeframes were adjusted to include more useful literature resources that were causally linked to the context of the research study.

II. Compile and complete a checklist that would be used to retrospectively evaluate and analyse two conventional radiographic imaging methods of the odontoid process.

Chapter three of the research study was based on creating a checklist that could achieve efficiency in recording and allowing reliable reporting on radiographic image quality evaluation and effective dose calculations.

The checklist was created based on a radiographic imaging criterion derived from different supporting sources: journal articles, radiographic textbooks, and guidelines from the expertise of radiology (Appendix A).

The resources mentioned in Chapter three were used to assist in answering the following research question: “What elements must be considered when creating a checklist for radiographic image quality evaluation and achieving effective dose calculations using the PCMXC20 Monte Carlo software©?” The list of resources included articles, textbooks, study guides, online software, and guidelines.

The question was successfully answered, and a checklist was created. This checklist was used as an instrument to collect data for this study after it was tested with a pilot study.

III. Calculate and evaluate the total ED to the patients for the two conventional radiographic imaging methods of the odontoid process.

The PCMXC20 Monte Carlo software© programme was used for analysing patients’ organ ED (ICRP 2007). The software can work on data from a completed radiographic examination, allowing the user to get ED retrospectively. The user interface has graphic displays to match proper examination conditions, using the technical exposure factors (kVp, mAs, SID and FOV dimensions) recorded from the CR system per radiograph. The software helped to get a total of eight tissues receiving radiation during imaging of the odontoid process, namely the thyroid, brain, upper spine, oral mucosa, salivary glands, extrathoracic airways, and the oesophagus. The ED is reflected on in Chapter four to Chapter six (sections 4.4.5, 5.4.4 and 6.4.2).

IV. To compare the total repeat rate, radiographic image quality and ED between the two conventional methods of imaging of the odontoid process.

The objective was achieved using the checklist. The checklists captured information that served to cater for all three aspects mentioned in the objective. Section B of the checklist was aimed at achieving the total dose to the patient once the examination was completed, by recording the total number of radiographic images obtained at the end of each examination; the number of radiographic images that were accepted; those that were rejected; and the total number of radiographic images at the end of the examination. Section C and Section E of the checklist were a direct link to section B. The focus of section C was on the assessment of image quality, and identifying why the recorded number of radiographic images in section B were rejected. During the compilation of sections D and F of the checklist, parameters (radiographic exposure factors) that were needed for successfully completing the ED calculations as mentioned above, were identified. The checklist further captured the EI to help qualify the radiographic images as either under- or overexposed, adding to their appearance evaluation for exposure.

V. Weighing the total repeat rates, radiographic image quality and effective dose between the two conventional radiographic methods of imaging of the odontoid process.

The objective was based on the results for the research study as outlined in Chapter six. Chapter six compares the open-mouth view and the conventional tomogram of the odontoid process in order to identify which of the two methods takes preference, and in which aspect of radiographic imaging of the odontoid process. Based on the results, the open-mouth view is indeed associated with higher repeat rates. The reason for the repeat rates can be linked to the positioning errors identified in Chapter four. The conventional tomography comes with less to no repeated radiographic images. Therefore, it can be concluded that radiology departments can prioritise the conventional tomogram of the odontoid process to lower examination time and repeat rates, and to ease patients' concerns related to witnessing one radiographic image being acquired multiple times.

While we conclude that conventional tomography of the odontoid process is the ideal technique, radiology departments must always pay attention to the radiation dose output of the X-ray units they purchase. Although conventional tomography offered less ED to the patient, when focusing solely on the technique, it became evident that one X-ray unit may result in a higher radiation output than another X-ray unit. The question related to radiation doses cannot be directly answered without referring to a few aspects.

Tilt was the main leading reason for repeated open-mouth view radiographic images, while subtle motion was observed on some of the conventional tomography images. The observed repeats from tilt are disturbing and reflect a true sense of urgency for remedial interventions to assist radiographers with overcoming the radiographic positioning error.

The motion observed with the conventional tomogram of the odontoid process is not alarming, as motion can be restricted through several applicable methods, for instance, immobilisation. Furthermore, adding to the conclusion of the results, it remains important to consider the fact that the sample for conventional tomography was lower than that of the open-mouth view.

VI. Establishing recommendations and guidelines to optimise conventional radiographic imaging of the odontoid process to help achieve a balance between radiographic image quality and radiation dose during conclusive examinations of the cervical spine.

Objectives five and six can be linked, as they are addressed in Chapter six. For the purpose of fulfilling objective six, Chapter six will be summarised into a short report and delivered to the radiology departments at which the data collection process was carried out. The information from the research study will further be distributed to radiology departments that are using both the open-mouth view and conventional tomography as alternative methods of reference, as listed in Chapter one. The researcher aims to have all articles (Chapter three to Chapter six) published in accredited journals. Furthermore, the researcher will be presenting the work at conferences where the abstract from the dissertation is accepted. One abstract was accepted for the International Society of Radiographers & Radiological Technologists (Appendix L5). More recommendations and guidelines can be found in Chapter two, section 2.8.3.

7.5 LIMITATIONS

Limitations regarding the literature search, research design and data collection were identified, and are presented in the section below.

7.5.1 Literature research

The literature review process was challenging, since research on the topic of the current research study is limited. The current research study serves in closing the gap through adding to literature resources on the topic of optimisation of conventional radiographic imaging of the odontoid process.

During the literature research there were no baseline ED values to compare the ED of study with. Moving forward, the research study can serve as a baseline for future research studies.

7.5.2 Data collection

The main limitation of the research study included the small number of conventional tomograms of the odontoid process examinations for images within the period dedicated to the data collection process. The scarcity of conventional tomograms can be linked with the fact that conventional tomography is used as a second alternative method of preference to the open-mouth view. Adding to that, radiographers tend to repeat the open-mouth view several times before they move onto the conventional tomogram. One may also assume that, since radiographers do not use conventional tomography often, they are not confident with using it.

Difficulty to access to the PCXMC20 Monte Carlo software© put a hold on the research process, although there are other methods available that could have been used to achieve calculations of the ED, for instance, first achieving the entrance skin dose using a calibrated dosimeter and inserting the value into various formulas (Yacoob & Mohammed 2017). The second method used by Ofori, Gordon, Akrobortu, Ampene & Darko (2014) involved the caldose_x 5.0 (a software instrument that makes it possible to calculate the incident air kerma and entrance surface air kerma), which also involved special formulae (Kramer, Khoury & Vieira 2008).

Both methods required a certain level of expertise and a qualified physicist to assist with the formulae. Hence, the PCXMC20 Monte Carlo software© remained the best option to use for this study. The PCXMC20 Monte Carlo software© allowed for a retrospective research study, avoiding subjecting the patients to radiation for the purpose of completing the study.

The research study was conducted at two private radiology departments offering three different X-ray units. Adding more clinical sites and X-ray units would add more value and validity to the results of the research study.

7.5.3 Research instrument

Another limitation of the research study was the absence of a report on the age of the patients whose examination data was used. Since the study was not directly focused on aspects involving age, no statistical analysis was done on age. The same data can be used in the future to account for the relationship of age on plain conventional radiographic imaging of the odontoid process preferences.

Data for the study were only collected by the main researcher. The opinion of the same person to verify the images and capture the information on the checklist assured consistency in the research process, means that there is also the possibility of bias. This aspect was partly addressed, since the researcher completed two checklists per examination on validity and reliability, as mentioned in Chapter two, section 2.10. In addition, the data translated from the checklists onto the Microsoft Excel spreadsheet were verified by a second party. However, it would have been an advantage for more than one person to partake in the research process and evaluate the images during the data collection process.

The checklist that was established did not capture information about the patients' gender, since the study did not intend to focus on biographic information. However, for a checklist that can be used throughout the scope of plain conventional radiography, it would have been beneficial to include space for capturing the gender of the patients.

7.5.4 Applicability of research study

The comparable context of the research study as seen in chapter six, between the open mouth view and the conventional tomogram of the odontoid process is applicable to radiology departments that are have X-ray units capable of performing conventional tomography. However, radiology departments without conventional tomography compatible X-ray units do not have the benefit of being able to weigh their options between the two methods.

When considering each one of the two conventional radiographic methods as a unique stand-alone radiographic image acquisition routine, the research study becomes significantly applicable to a wider radiology society that is sorely dependent on conventional radiography. This means that the research study is off substantial value to most radiology departments in rural and less developed areas around the world, particularly in the African continent.

7.6 RECOMMENDATIONS

7.6.1 Clinical practice

The research study has created a platform for radiology departments to implement a remedial plan of action centred around the principles of radiation safety and achieving optimal radiographic images of the odontoid process. It also creates awareness for radiology departments to assess and control radiation doses and radiographic image quality on a scale that protects the patient, and to justify and optimise radiation exposures for conventional radiographic imaging of the odontoid process (ICRP 2007).

Although according to the results of this study it is evident and thus concluded that conventional tomography has advantages, there are recommendations that can be implemented to optimise the open-mouth view as a method of preference for radiographic imaging of the odontoid process. For instance, a rule could be implemented that allows for the open-mouth view to not be repeated more than once, meaning that only two open-mouth view images may be obtained per examination. The rule would help lower the repeat rates and optimise the radiation dose to the patient.

Based on the results of the research study, radiology departments that are using X-ray units that offer low radiation doses may use conventional tomography as their first method of preference for radiographic imaging of the odontoid process.

Reflecting on radiation dose, it is important for radiology departments to ensure that QA and QC tests are performed as outlined by the Department of Health. When carrying out QA and QC tests as prescribed, radiology departments would be able to keep track of repeat rates through the reject analysis test, and to address any pressing issues relating to high repeat rates (Osma *et al.* 2010).

Radiographers must practice one of the most important patient care attributes, namely effective communication. Effective communication, together with applying immobilisation methods, can help rid motion as a contributing factor to repeated radiographic images (IAEA 2004b).

Adding to the context of patient-centred care, specialised modalities come with a higher cost as opposed to plain conventional radiography. Furthermore, specialised modalities come with equipment that is not comfortable for all body types. There are often weight limits. Some patients are claustrophobic and unable to go through CT or MRI. The time needed to contrast media CT examination is long as opposed to that of acquiring plain conventional radiography methods outlined in this research study. Furthermore, the dose from CT cannot be compared to either one of the two conventional radiographic methods.

The results of the research study can be used for continued professional development to alert radiographers of the existing gaps found in conventional radiography of the odontoid process. New protocols can be established to match the X-ray units that each radiology department is using, and based on how the X-ray unit affects the radiation dose to the patient.

7.6.2 Research

A research study with a larger sample size is suggested, more especially when it comes to the conventional tomogram examinations. With regard to image quality and repeat rates, tilt was the most common error. This limitation shows that there is a gap between theory and the application of theory in practice.

Thus, an experimental research study can be conducted to establish positioning lines that can be used for positioning of the open-mouth view with reference to the patient's unique skull anatomy (shape and size).

Future research can be intended on investigating the radiation dose output for different X-ray units with similar specifications and comparing the EDs to existing standard EDs for the listed tissues, in order to establish acceptable limits. Lastly, articles can be written and presentations made to share the information obtained through the current research study.

7.7 VALIDITY AND RELIABILITY

The research study was guided by literature to ensure that the content of the research was relevant, relatable, and reliable within diagnostic radiography. The research study was focused on the context of principles of diagnostic medical imaging. Keywords were used to seek out sources that were significant to the research study.

Two checklists were completed per examination for the validity of captured data. Validity and reliability were thoroughly outlined in Chapter two, section 2.10. Adding to the information from section 2.10, the research study was verified for plagiarism (Appendix M) and edited for language by a qualified language editor (Appendix O). Thus, the research study has proven to be both validated and reliable.

7.8 CONCLUDING REMARKS

Optimisation of radiographic examinations remains a critical principle in radiology. While there were research studies that focused on assessing the alarming repeat rates associated with the open-mouth view, and further studies focused on comparing plain conventional radiographic methods (open-mouth view and conventional tomography) with specialised modalities (CT and MRI) for radiographic representation of the odontoid process, no studies that focused on assessing the radiation dose involved in the repeat rates were identified in the literature searches. Furthermore, there was no identified literature comparing plain conventional radiographic methods for radiology communities that do not have the luxury of specialised modalities.

The current research study aimed to evaluate the repeat rates and radiographic image quality for positioning errors accounting for the repeat rates. The study also pointed out the association between the repeat rates and the radiation dose, while contrasting two plain conventional radiographic methods that were compared and seen in literature. While there is the assumption that conventional tomography gives high exposure quantities when compared to plain conventional radiographic image acquisition, there are no research studies dedicated to testing the theory based on the newly manufactured X-ray equipment that offers conventional tomography.

The results of the study thus show that conventional tomography does not automatically imply higher radiation doses to the patient. While there are no ED calculations for the list of tissues addressed in the study, the study has closed this gap as indicated in Chapter two. This study can thus aid as a foundation for future research dedicated to establishing acceptable ED limits for plain conventional radiographic imaging of not only the odontoid process, but the cervical spine as a whole organ.

In a constantly technologically advancing era, with multiple fascinating specialised modalities, one may find the current study to be insignificant. However, it is worth noting that not all radiology departments have the luxury to make use of specialised modalities. Furthermore, some circumstances do not allow for the use of specialised modalities (Izumi, Sakamoto, Kawamata, Yamane, Yonede, Okamoto, Oshima & Nakanishi 2018; Hirakawa, Manaka, Ito, Minoda, Ichikawa & Nakamura 2018).

The advancements that most radiology departments are able to achieve, involve the transition from CR to DR. While conventional tomography can be regarded as outdated, modern DR X-ray units are versatile and have adapted tomosynthesis as an advancement to conventional tomography as one of the multiple features (Takeuchi 2018; Uchida 2014).

The study does not only serve radiology departments that are moving into the future with new DR X-ray units (Shimadzu: SONIALVISION G4) that have the conventional tomosynthesis advancement adaptations from around the globe, but also caters for small departments (level 1 hospitals with small radiology departments and small private radiology practices) that are without specialised modalities and newly advanced DR X-ray units that offer conventional tomography.

This is achieved by thoroughly exploring both the open-mouth view and conventional tomogram of the odontoid process as separate entities before weighing them up against each other.

Moving forward, one may ask if timeous research studies must still be invested in conventional radiography of the upper cervical spine. If the answer is yes, all the suggestive research studies can be undertaken to continue to enhance conventional radiographic imaging of the upper cervical spine. If the answer is no, the strive should be invested in advancing and equipping all radiology departments with specialised modalities.

When considering South Africa and the lack of speciality services and resources as seen with level one hospitals (Western Cape Government 2020), the answer to the question would be yes. Yes, there is a need to pursue research in plain conventional radiography, as there are radiology departments that are dependent on plain conventional radiography. Adding to that, the cost associated with specialised modalities automatically excludes financially disadvantaged patients from utilising it – thus, compromising their right to quality healthcare.

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APPENDICES

Appendix A: Final checklist

DATA COLLECTION FOR COMPLYING WITH THE REQUIREMENTS FOR MTECH RADIOGRAPHY (DIAGNOSTIC)					
"OPTIMIZING CONVENTIONAL RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS"					
TICK ON THE CONVENTIONAL RADIOGRAPHIC IMAGE (S) OBTAINED					
SECTION A					
Practice code		Date			
Room number		EI for cervical spine			
Open mouth only	Tomogram only			Both open mouth and tomogram	
PATIENT INFORMATION					
Patient number					
Year of birth					
REFERRAL LETTER					
Clinical indication					
SECTION B					
TOTAL NUMBER OF OPEN MOUTH IMAGES					
Number of accepted					
Number of rejected					
Total number per projection					
TOTAL NUMBER OF TOMOGRAM SERIES					
Number of accepted					
Number of rejected					
Total number per projection					
SECTION C					
REASONS FOR REJECTED IMAGES FOR THE OPEN MOUTH VIEW					
LIST					
	IMAGE 1	**IMAGE 2**	**IMAGE 3**	**IMAGE 4**	**IMAGE 5**
Tilt: Superimposition of the odontoid upper incisors and base of skull					
Alignment: Lateral masses of C1 and C2 not aligned with the long axis of the cervical spine					
Rotation: The lateral masses do not measure the same cross-sectional distance. The spinous process of C2 not centered.					
Asymmetry: The zygapophyseal joints not symmetric					

Motion: The image is not sharp and is blurry					
Collimation: The odontoid, body of C2, lateral masses of C1 cut off					
Centering: The odontoid not centered to the middle of the cervical spine					
DEI / EI value					
Under exposure: The EI value is below the minimum value, and the radiograph shows quantum mottle					

Overexposure: The EI value is over the maximum level and the image is dark					
No image					
Artefacts					
Double exposure					
SECTION D					
Technical factors					
kVp					
mAs					
mA					
ms					
SID					
Collimation breadth					
Collimation width					
SECTION E					
REASONS FOR REJECTED IMAGES OF THE TOMOGRAM					
LIST					
	SERIES 1	**SERIES 2**	**SERIES 3**	**SERIES 4**	**SERIES 5**
Alignment: Lateral masses of C1 and C2 not aligned with the long axis of the cervical spine					
Rotation: The lateral masses do not measure the same cross-sectional distance. The spinous process of C2 not centered.					
Asymmetry: The zygapophyseal joints not symmetric					
Motion: The image is not sharp and is blurry					
Accurate localisation: The odontoid, body of C2, lateral masses of C1 cut off					

Accurate tube movement: The odontoid process not visible on the series due to incorrect tube movement					
Centering: The odontoid not centered to the middle of the cervical spine					
DEI / EI value					
Overexposure: The EI value is over the maximum level and the image is dark					
Under exposure: The EI value is below the minimum value, and the radiograph shows quantum mottle					
No image					
Artefacts					
Double exposure					
SECTION F					
Technical factors					
kVp					
mAs					
S					
mA					
SID					
Collimation breadth					
Collimation width					

Appendix B: Microsoft Excel spreadsheet

Reject Analysis

Patient	**Number of OM images**	**Number of TM images**	**Total number of images per patient**	**Screening room**	**Non-screening room**	**Pt history**
1	2	0	2		X	C
2	2	0	2		X	A
3	2	0	2		X	E
4	2	0	2		X	E
5	1	0	1		X	E
6	1	0	1		X	D
7	2	0	2		X	B
8	9	0	9		X	F
9	1	0	1		X	B
10	3	0	3		X	E
11	1	0	1		X	E
12	2	0	2		X	A
13	1	0	1		X	B
14	2	0	2		X	A
15	2	0	2		X	A
16	2	0	2		X	C
17	5	0	5		X	A
18	3	0	3		X	F
19	2	0	2		X	B
20	2	0	2		X	B
21	3	0	3		X	C
22	1	0	1		x	E
23	1	0	1		X	A
24	3	0	3		X	E
25	1	0	1		X	E

Image evaluation

Reject analyses	Type of image	Tilt	Alignment	Rotation	Asymmetry	Motion	Collimation	Centering	Under-exposed	Over-exposed	Double exposure	No image	Artefacts	No error
pt 1														
Image one	OM	X						X					X	
Image two	OM	X						X						
pt 2														
Image one	OM	X												
Image two	OM													X
pt 3														
Image one	OM	X						X		X				
Image two	OM							X						
pt 4														
Image one	OM	X						X		X				
Image two	OM													X
pt 5														
Image one	OM													X

pt 6														
Image one	OM							X						

Appendix C: Register for data collection

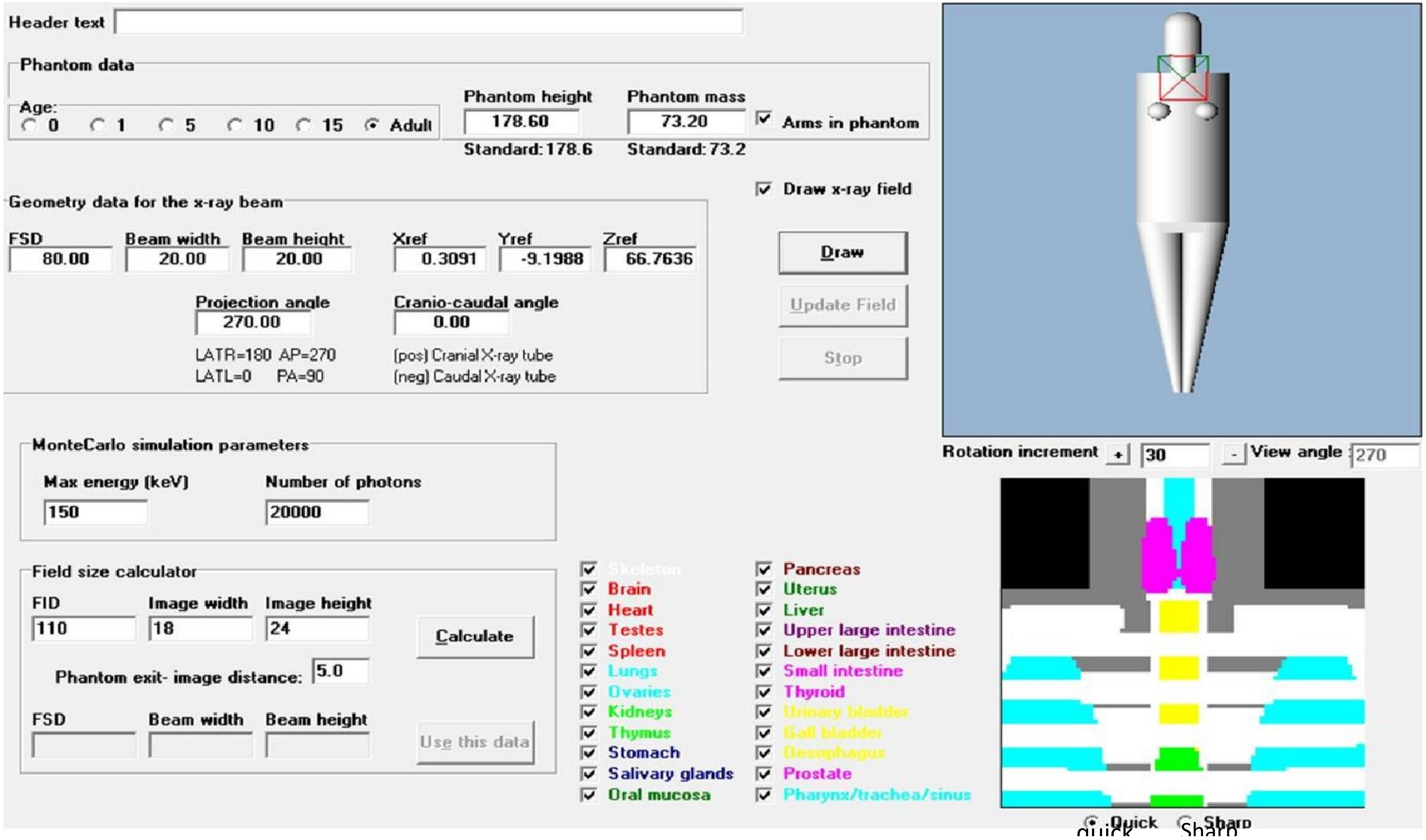
Date	Day	Time in	X-ray Department	Room	Number of OM	OM images evaluated	Number of Tomo	Tomo images evaluated	Both OM and Tomo	OM and Tomo images evaluated
JULY										
29-Jul	Sunday	20H00	Dr Van Dyk & Partners	2	8	21	0	0	0	0
29-Jul	Sunday	19H00	Dr Spies & Partners	E & f	7	19	0	0	0	0
AUGUST										
05-Aug	Sunday	21H00	Dr Van Dyk & Partners	2	4	11	4	4	0	0
05-Aug	Sunday	20H00	Dr Spies & Partners	D & E	4	9	0	0	2	4
12-Aug	Sunday	21H00	Dr Van Dyk & Partners	2	5	6	0	0	3	13
12-Aug	Sunday	20H00	Dr Spies & Partners	D & E	4	4	2	2	2	6

19-Aug	Sunday	21H00	Dr Van Dyk & Partners	2	6	12	0	0	0	0
19-Aug	Sunday	20H00	Dr Spies & Partners	D & E	4	5	4	4	3	7
26-Aug	Sunday	21H00	Dr Van Dyk & Partners	2	0	0	0	0	0	0
26-Aug	Sunday	20H00	Dr Spies & Partners	D & E	12	24	0	0	2	4
SEPTEMBER										
09-Sep	Sunday	20H00	Dr Spies & Partners	D & E	13	23	1	1	4	8
09-Sep	Sunday	21H00	Dr Van Dyk & Partners	2	15	29	0	0	0	0
16-Sep	Sunday	20H00	Dr Spies & Partners	D & E	8	17	0	0	0	0
16-Sep	Sunday	21H00	Dr Van Dyk & Partners	2	6	15	0	0	0	0
23-Sep	Sunday	20H00	Dr Spies & Partners	D & E	0	0	0	0	0	0

23-Sep	Sunday	21H30	Dr Van Dyk & Partners	2	14	32	0	0	0	0
30-Sep	Sunday	20H00	Dr Spies & Partners	D & E	13	15	3	3	0	0
30-Sep	Sunday	21H00	Dr Van Dyk & Partners	2	9		22	1	1	0
OCTOBER										
07-Oct	Sunday	20H00	Dr Spies & Partners	D & E	4		11	0	0	0
07-Oct	Sunday	14H00	Dr Van Dyk & Partners	2	4		7	0	0	0
14-Oct	Sunday	20H00	Dr Spies & Partners	D & E	2		8	1	1	1
14-Oct	Sunday	14H00	Dr Van Dyk & Partners	2	14		30	0	0	0
21-Oct	Sunday	20H00	Dr Spies & Partners	D & E	5		6	0	0	1
21-Oct	Sunday	14H00	Dr Van Dyk & Partners	2	10		21	0	0	0

28-Oct	Sunday	20H00	Dr Spies & Partners	D & E	8	0	0	0	0
28-Oct	Sunday	14H00	Dr Van Dyk & Partners	2	8	12	0	0	0
					187	342	19	19	16

Appendix D: Software interface



Header text

Phantom data

Age: ○ 0 ○ 1 ○ 5 ○ 10 ○ 15 ● Adult

Phantom height	Phantom mass
178.60	73.20
Standard: 178.6	Standard: 73.2

☑ Arms in phantom

☑ Draw x-ray field

Geometry data for the x-ray beam

FSD	Beam width	Beam height	Xref	Yref	Zref
80.00	20.00	20.00	0.3091	-9.1988	66.7636

Projection angle	Cranio-caudal angle
270.00	0.00
LATR=180 AP=270 LATL=0 PA=90	(pos) Cranial X-ray tube (neg) Caudal X-ray tube

Rotation increment + 30 - View angle 270

MonteCarlo simulation parameters

Max energy (keV)	Number of photons
150	20000

Field size calculator

FID	Image width	Image height
110	18	24

Phantom exit- image distance: 5.0

FSD	Beam width	Beam height

☑ Skeleton
☑ Brain
☑ Heart
☑ Testes
☑ Spleen
☑ Lungs
☑ Ovaries
☑ Kidneys
☑ Thymus
☑ Stomach
☑ Salivary glands
☑ Oral mucosa
☑ Pancreas
☑ Uterus
☑ Liver
☑ Upper large intestine
☑ Lower large intestine
☑ Small intestine
☑ Thyroid
☑ Urinary bladder
☑ Gall bladder
☑ Oesophagus
☑ Prostate
☑ Pharynx/trachea/sinus

● Quick ○ Sharp

Appendix E: Pilot checklist

PATIENT NUMBER					
DATA COLLECTION FOR COMPLYING WITH THE REQUIREMENTS FOR MTECH RADIOGRAPHY (DIAGNOSTIC)					
"OPTIMIZING CONVENTIONAL RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS"					
TICK ON THE CONVENTIONAL RADIOGRAPHIC IMAGE (S) OBTAINED					
Open mouth only	Tomogram only			Both open mouth and tomogram	
BIOGRAPHIC INFORMATION					
Gender					
Age					
REFERRAL LETTER					
Clinical indication					
REJECTED IMAGES FOR THE OPEN MOUTH VIEW					
LIST					
	IMAGE 1	**IMAGE 2**	**IMAGE 3**	**IMAGE 4**	**IMAGE 5**
Tilt: Superimposition of the odontoid upper incisors and base of skull					
Alignment: Lateral masses of C1 and C2 not aligned with the long axis of the cervical spine					
Rotation: The lateral masses do not measure the same cross-sectional distance. The spinous process of C2 not centered.					
Asymmetry: The zygopophyseal joints not symmetric					
Motion: The image is not sharp and is blurry					
Anatomy: The odontoid, body of C2, lateral masses of C1 cut off					
Centering: The odontoid not centered to the middle of the cervical spine					
Underexposure: The EI value is below the minimum value, and the radiograph shows quantum mottle					
Overexposure: The EI value is over the maximum level and the image is dark					
kVp					
mAs					
mAs					
SID					
Collimation breadth					
Collimation width					

EI value					
REJECTED IMAGES OF THE TOMOGRAM					
LIST					
	SERIES 1	**SERIES 2**	**SERIES 3**	**SERIES 4**	**SERIES 5**
Alignment: Lateral masses of C1 and C2 not aligned with the long axis of the cervical spine					
Rotation: The lateral masses do not measure the same cross-sectional distance. The spinous process of C2 not centered.					
Asymmetry: The zygopophyseal joints not symmetric					
Motion: The image is not sharp and is blurry					
Accurate localization: The odontoid, body of C2, lateral masses of C1 cut off					
Accurate tube movement: The odontoid process not visible on the series due to incorrect tube movement					
Centering: The odontoid not centered to the middle of the cervical spine					
Underexposure: The EI value is below the minimum value					
Overexposure: The EI value is over the maximum level					
kVp					
mAs					
mAs					
SID					
Collimation breadth					
Collimation width					
EI value					

Appendix F: Statistician certificate

The Chairperson: Health Sciences Research Ethics Committee (HSREC)
For Attention: Mrs. M.G.E. Marais

Block D, Room 104

Francois Retief Building

Faculty of Health Sciences

University of the Free State

Maryn ViljoΣn
Statistics Consulting Services
maryn.viljoen@vodamail.co.za
082 823 5731

Protocol and research methodology consultation • Ethical consultation • Database construction and capturing of data
Analyzing data using statistical software packages (SAS Version 9.1.3) • Statistics consultation services to analyze and interpret data
Conveys results with statistical tables and figures where needed

26 February 2018

Title: "OPTIMIZING CONVENTIONAL RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS."

Researcher: S.P. Mokuoane (Student number: 211099945)

M. Tech Radiography (Diagnostic)
Department of Clinical Sciences: Programme Radiography
Faculty of Health and Environmental Sciences Central University of Technology, Free State

I have seen and read through this protocol. I gave input and recommendations and will be the biostatistician responsible for the analysis of the data.

Maryn Viljoen

M.Sc. Risk Analysis (UFS) maryn.viljoen@vodamail.co.za
082 82 35 731

Appendix G: Approval from Ethics

UNIVERSITY OF THE
FREE STATE
UNIVERSITEIT VAN DIE
VRYSTAAT
YUNIVESITHI YA
FREISTATA

UFS·UV
HEALTH SCIENCES
GESONDHEIDSWETENSKAPPE

Health Sciences Research Ethics Committee

29-May-2018

Dear **Miss Sylvia Mokuoane**

Ethics Clearance: **OPTIMIZING CONVENTIONAL RADIOGRAPHIC IMAGING OF THE ODONTOID PROCESS**
Principal Investigator: **Miss Sylvia Mokuoane**
Department: **Radiography - CUT**

APPLICATION APPROVED

Please ensure that you read the whole document

With reference to your application for ethical clearance with the Faculty of Health Sciences, I am pleased to inform you on behalf of the Health Sciences Research Ethics Committee that you have been granted ethical clearance for your project.

Your ethical clearance number, to be used in all correspondence is:**UFS-HSD2018/0257/2905**

The ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the HSREC for approval to ensure we are kept up to date with your progress and any ethical implications that may arise. This includes any serious adverse events and/or termination of the study.

A progress report should be submitted within one year of approval, and annually for long term studies. A final report should be submitted at the completion of the study.

The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

For any questions or concerns, please feel free to contact HSREC Administration: 051-4017794/5 or email EthicsFHS@ufs.ac.za.

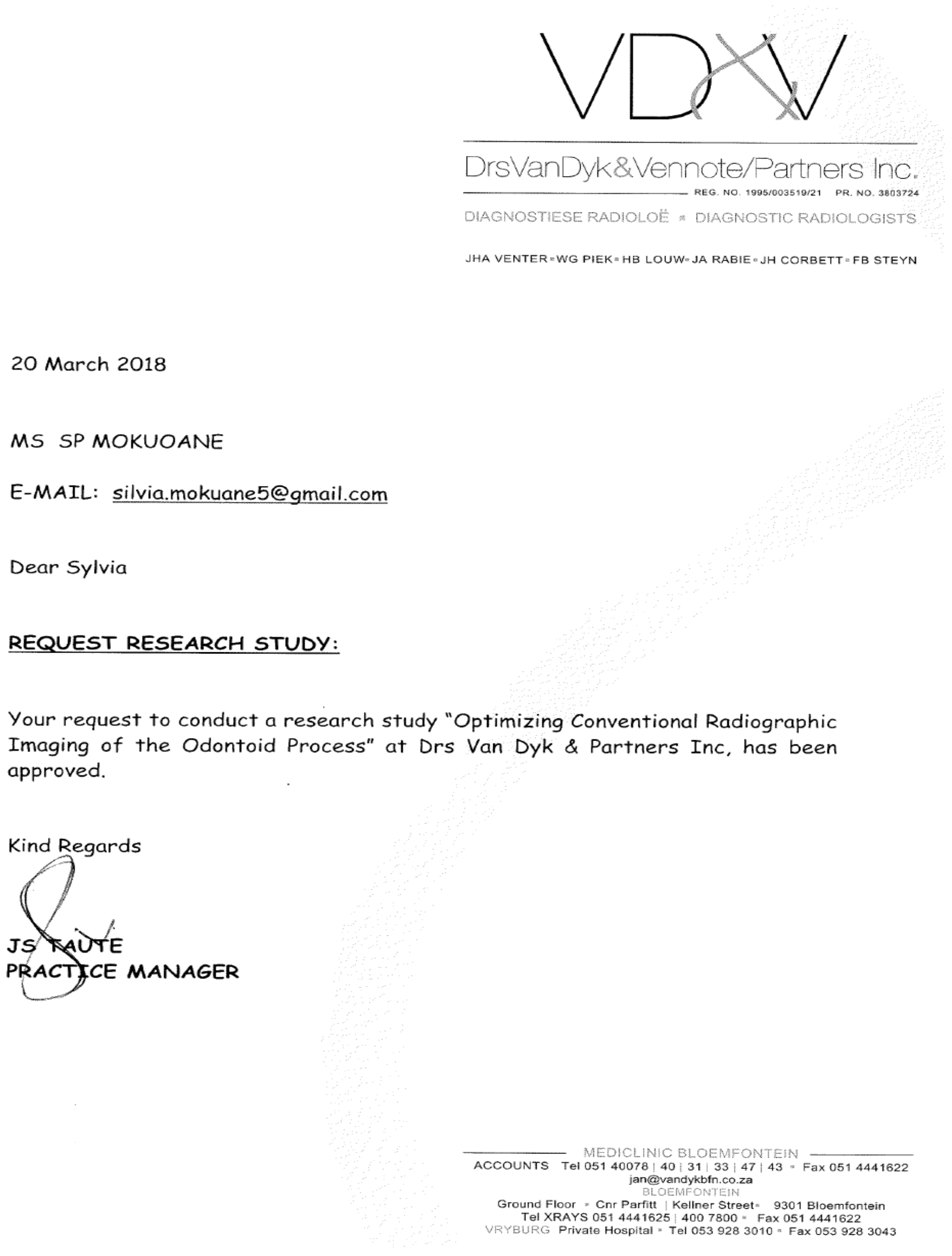
Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours Sincerely

Dr. SM Le Grange
Chair : Health Sciences Research Ethics Committee

Health Sciences Research Ethics Committee
Office of the Dean: Health Sciences
T: +27 (0)51 401 7795/7794 | E: ethicsfhs@ufs.ac.za
IRB 00006240; REC 230408-011; IORG0005187; FWA00012784
Block D, Dean's Division, Room D104 | P.O. Box/Posbus 339 (Internal Post Box G40) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

Appendix H: Approval from Drs Van Dyk & Partners



VDV
DrsVanDyk&Vennote/Partners Inc.
REG. NO. 1995/003519/21 PR. NO. 3803724
DIAGNOSTIESE RADIOLOË ▪ DIAGNOSTIC RADIOLOGISTS
JHA VENTER ▪ WG PIEK ▪ HB LOUW ▪ JA RABIE ▪ JH CORBETT ▪ FB STEYN

20 March 2018

MS SP MOKUOANE

E-MAIL: silvia.mokuane5@gmail.com

Dear Sylvia

REQUEST RESEARCH STUDY:

Your request to conduct a research study "Optimizing Conventional Radiographic Imaging of the Odontoid Process" at Drs Van Dyk & Partners Inc, has been approved.

Kind Regards

JS TAUTE
PRACTICE MANAGER

MEDICLINIC BLOEMFONTEIN
ACCOUNTS Tel 051 40078 | 40 | 31 | 33 | 47 | 43 ▪ Fax 051 4441622
jan@vandykbfn.co.za
BLOEMFONTEIN
Ground Floor ▪ Cnr Parfitt | Kellner Street ▪ 9301 Bloemfontein
Tel XRAYS 051 4441625 | 400 7800 ▪ Fax 051 4441622
VRYBURG Private Hospital ▪ Tel 053 928 3010 ▪ Fax 053 928 3043

Appendix I: Approval from Drs Spies & Partners

RADIOLOË/RADIOLOGISTS
DRS. SPIES en VENNOTE INGELYF
Drs. SPIES and PARTNERS INC.
(REG. NO. 1995/004632/21)
Dir: F.T.S. Böhme, J.I. Basson, W.H. Pieterse, M.N. van der Ness, D.J. Kotzé, A. Cilliers
Praktyk Nr./Practice No. **3801624**
e-pos/e-mail: accounts@spiesinc.co.za

Posbus / P.O. Box 1873
Bloemfontein 9300

Fichmed Sentrum / Centre 9
Gustav Singel 53 Gustav Crescent
FICHARDT PARK
Tel: (051) 522-1963, 522-1966
Faks/Fax: (051)522-8192
Tel: (051) 522-1997 - RT/CT
Tel: (051) 522-1111 - MR

SENTRAMED
3 de Vloer / 3rd Floor
Kerkstraat 56 Church Street
BLOEMFONTEIN
Tel: (051) 447-9878
Tel: (051) 447-3610
Faks/Fax: (051) 447-3621

13 March 2018

To whom it may concern

Herewith permission to Sylvia Mokuoane to perform her research study at our practise, Drs Spies and Partners. Rosepark Hospital.

Regards

Tanya Hoffman

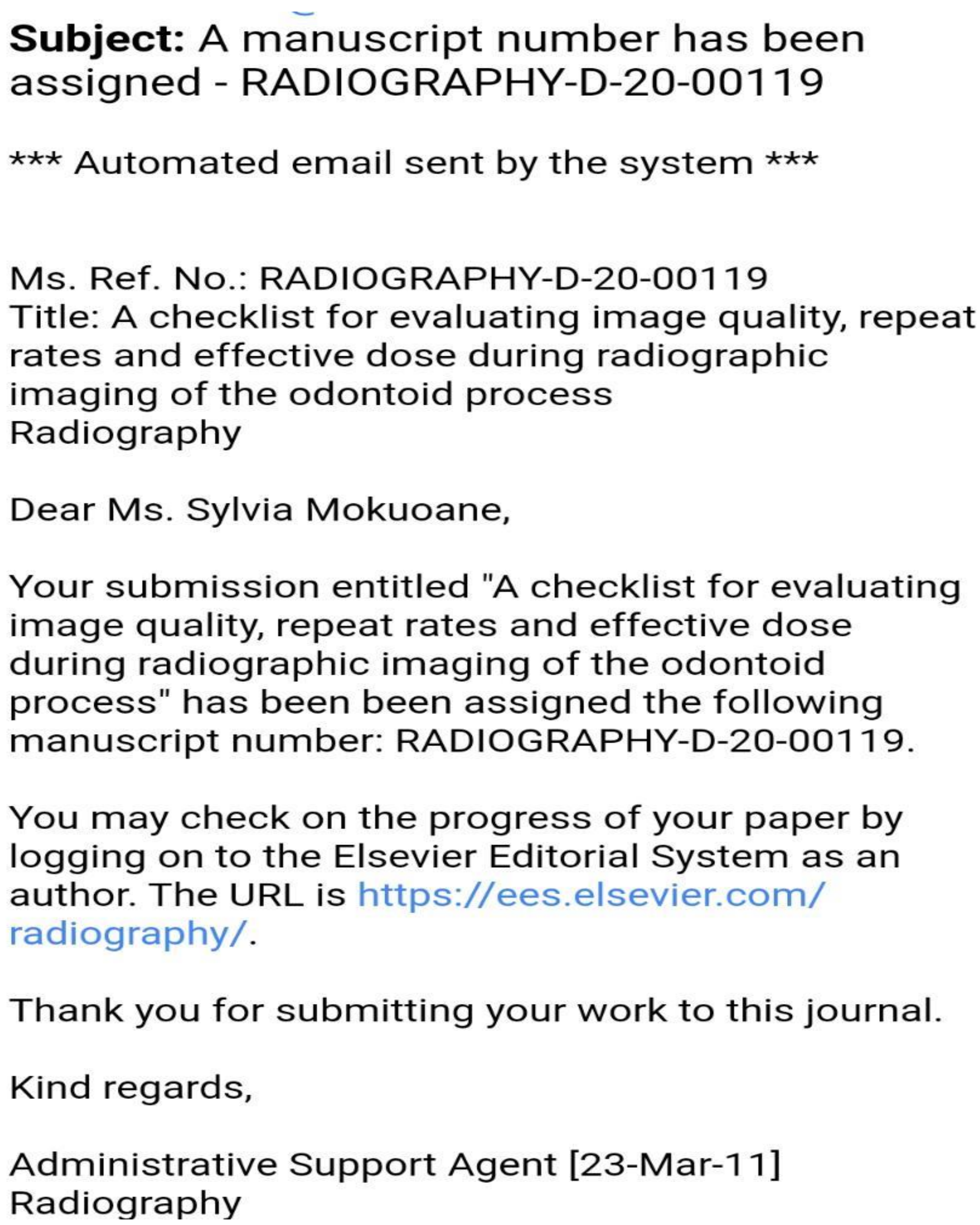
Head Radiographer

Drs Spies and Partners

051 5221963

Hoffman

Appendix J: Proof of submission of an article to a Journal



Subject: A manuscript number has been assigned - RADIOGRAPHY-D-20-00119

*** Automated email sent by the system ***

Ms. Ref. No.: RADIOGRAPHY-D-20-00119
Title: A checklist for evaluating image quality, repeat rates and effective dose during radiographic imaging of the odontoid process
Radiography

Dear Ms. Sylvia Mokuoane,

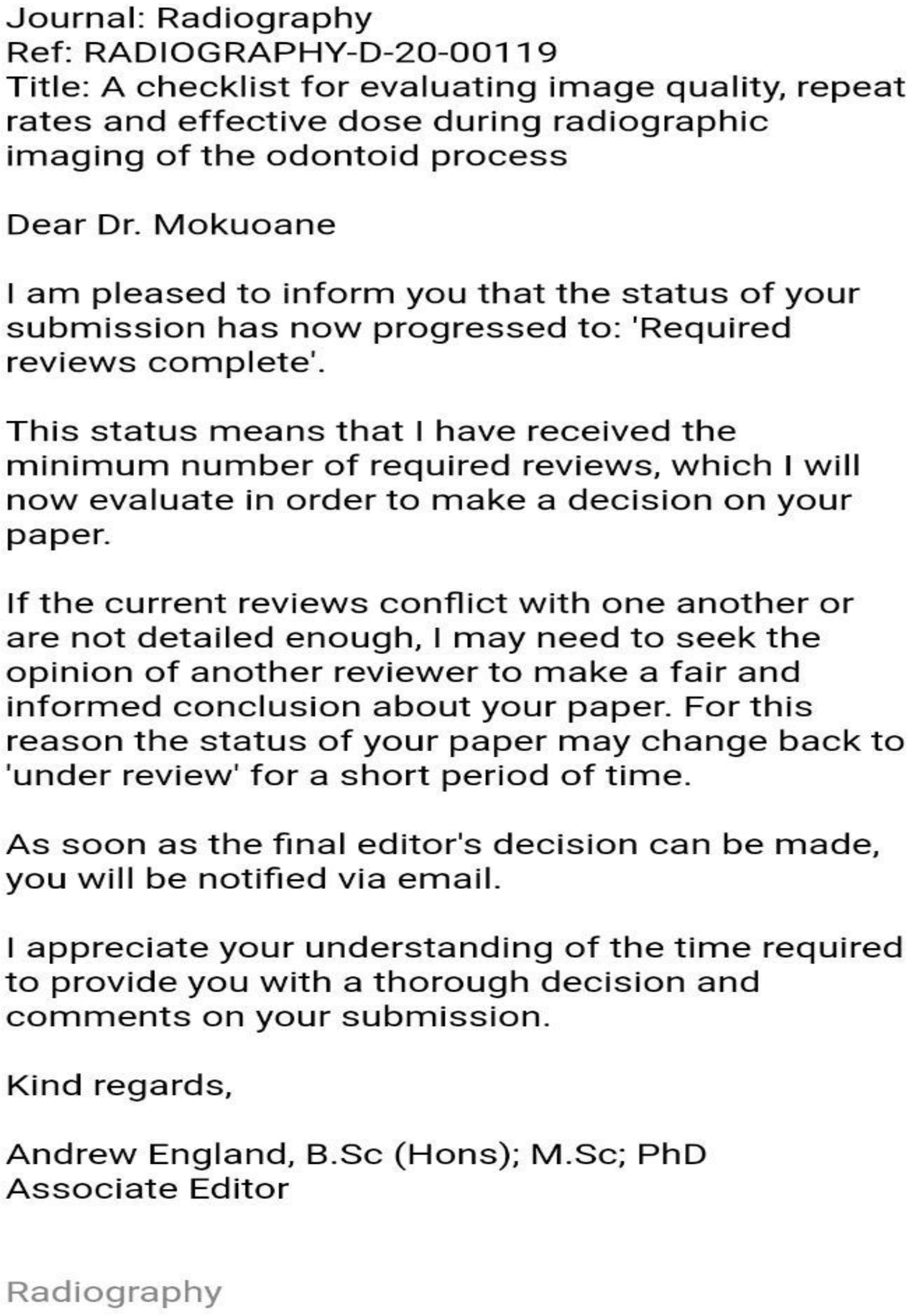
Your submission entitled "A checklist for evaluating image quality, repeat rates and effective dose during radiographic imaging of the odontoid process" has been been assigned the following manuscript number: RADIOGRAPHY-D-20-00119.

You may check on the progress of your paper by logging on to the Elsevier Editorial System as an author. The URL is https://ees.elsevier.com/radiography/.

Thank you for submitting your work to this journal.

Kind regards,

Administrative Support Agent [23-Mar-11]
Radiography



Journal: Radiography
Ref: RADIOGRAPHY-D-20-00119
Title: A checklist for evaluating image quality, repeat rates and effective dose during radiographic imaging of the odontoid process

Dear Dr. Mokuoane

I am pleased to inform you that the status of your submission has now progressed to: 'Required reviews complete'.

This status means that I have received the minimum number of required reviews, which I will now evaluate in order to make a decision on your paper.

If the current reviews conflict with one another or are not detailed enough, I may need to seek the opinion of another reviewer to make a fair and informed conclusion about your paper. For this reason the status of your paper may change back to 'under review' for a short period of time.

As soon as the final editor's decision can be made, you will be notified via email.

I appreciate your understanding of the time required to provide you with a thorough decision and comments on your submission.

Kind regards,

Andrew England, B.Sc (Hons); M.Sc; PhD
Associate Editor

Radiography

Appendix K: Proof of submission of chapters four to six to Medical Writer

3 May 2020

TO WHOM IT MAY CONCERN

CONFORMATION OF ARTICLES RECEIVED FOR LANGUAGE AND TECHNICAL EDITING

I hereby confirm that I have received the three articles listed below from Ms. Sylvia Mokuoane, Master's student in the Department of Clinical Sciences, Central University of Technology, Free State, for language and technical editing.

1. Evaluation of the open-mouth view for optimised radiographic imaging of the odontoid process
2. Evaluation of conventional tomography for radiographic imaging of the odontoid process
3. Optimisation of conventional radiographic imaging of the odontoid process: contrasting the open-mouth view and conventional tomography

For any further enquiries, please contact me at the telephone number or email address provided below.

DR. DALEEN STRUWIG
BSc, BSc Hons (Microbiol), MMedSc (Med Micriobiol), PhD (HPE)

16 Harrismith Street, Dan Pienaar
Telephone: +27 82 562 8461
Email address: struwigmc@ufs.ac.za or daleenstruwig@gmail.com

Appendix L1: Abstract for article for checklist

Abstract: Checklist for evaluating image quality and radiation dose during radiographic imaging of the odontoid process.

Objectives: The research study focused on the development of a checklist that would be used as a research instrument for a study intended to optimise conventional radiographic imaging of the odontoid process. The objective was to develop a checklist efficient in capturing data that would enable the evaluation of radiographic image quality, repeat rates and effective dose (ED) calculations, using the PCMXC20 Monte Carlo software© for various radiographic methods.

Methods: The checklist was developed in a qualitative realm, where the main goal was to gain understanding through observation and evaluation. Purposeful sampling was implemented. The inclusion criteria focused on locating information-rich articles, guidelines and textbooks, with the theoretical intent of developing a checklist for radiographic image quality and ED evaluations.

Results: A total of fifteen textbooks were identified, eight were screened for eligibility and six were selected for use. Fifty-five articles were identified, 30 articles were screened and 13 articles were included as suitable. The review process allowed the researcher to progress gradually throughout the build-up of the checklist. At the end, a checklist with five sections was developed and found to be efficient to capture data from 421 radiographic images.

Conclusions: Developing a checklist can be challenging when the primary aim of the checklist is poorly defined and outlined. However, once a researcher is clear on the purpose of the checklist, the task can be narrowed down into a more attainable goal.

Implications for practice: The checklist that was developed serves as an essential tool in improving radiographers' skills and reducing the ED to patients. The checklist could further be used by facilitators, students and radiographers for research and continued professional education.

Keywords: Checklists in radiology, checklists in radiography, checklists in health care, creating a checklist, radiographic image quality, radiographic image evaluation and radiographic image critique

Appendix L2: Abstract for article on open-mouth view

ABSTRACT: Evaluation of the open-mouth view for optimised radiographic imaging of the odontoid process.

Purpose

The research study intended to optimise radiographic imaging of the open-mouth view for the radiographic representation of the odontoid process through the evaluation of repeat rate, image quality and the effective dose.

Methods

A quantitative retrospective study and an evaluative, descriptive and explanatory research design was performed. 189 checklists from 189 examinations, adding up to 385 radiographic images of the open-mouth view were evaluated from two radiology private practices in the Bloemfontein, the Free State. The radiographic images were evaluated for repeat rates, image quality and effective dose. The effective dose was established using the PCMXC20 Monte Carlo software©.

Results

The average number of times for which the open-mouth view can be acquired per examination was two times (58%). The highest number of repeated open-mouth views per examination was nine times. The repeat rate was 71.7% with tilt being the most common error at 71.7%. The upper spine received the highest effective doses at a total value of 0.875798 mSv from the RSE X-ray unit.

Conclusions

The findings of the study indicate that tilt is the main leading positioning error for repeated radiographic images of the odontoid process, thus further experimental research studies are recommended to determine positioning lines that can be used for different skull anatomical shapes and sizes to overcome the repeat rates associated with tilt.

The maximum number of times for which the open-mouth view stands to be repeated created a need radiology department to incorporate regulations for the number of times that an open-mouth view may be repeated per examination.

Key words: Odontoid process, open-mouth view, upper cervical spine, image evaluation, radiation protection, effective dose.

Appendix L3: Abstract for article on conventional tomogram

ABSTRACT: Evaluation of conventional tomography for optimisation of radiographic imaging of the odontoid process.

Purpose

The study evaluated conventional tomography for optimisation of radiographic imaging of the odontoid process in the absence of specialised imaging procedures (e.g. Computed Tomography and Magnetic Resonance) with reference repeat rates, image quality and the effective dose (ED) to the patient.

Methods

A checklist, compiled through a comprehensive literature review, was used as the research instrument for the research study. After ethical clearance (UFS-HSD2018/0257/2905) 36 conventional tomography series of the odontoid process from two local radiology practices, who consented to participate, were evaluated. The ED was established using the PCMXC20 Monte Carlo software© using the following parameters: source-to-image distance (SID), field of view (FOV), kilovoltage peak (kVp) and milliamperage seconds (mAs).

Results

No images were repeated. However, subtle motion errors were identified on 11.11 % of the total evaluated conventional tomogram series. The effective dose to the patient varied from one X-ray unit to the other. The skull received the highest effective dose (0.803507 mSv) from the RSE X-ray unit. The salivary glands received the highest effective dose (0.272286 mSv) from the VD X-ray unit.

Conclusions

Conventional tomography strikes a safe balance between image quality and radiation dose to the patient, consequently optimising conventional tomographic imaging of the odontoid process in the absence of specialised imaging or in radiology practices with limited resources. Special attention must be given to technical factor settings, patient observation and effective communication to limit the motion observed in the 11.11% of the tomographic series. Future studies intended for comparing the effective dose for various X-ray units are recommended.

Key terms: Conventional tomography, upper cervical spine, image evaluation, radiation protection, effective dose.

Appendix L4: Abstract for article on open-mouth view and conventional tomogram

ABSTRACT: Optimisation of conventional radiographic imaging of the odontoid process.

Objective

The research study intended to optimise conventional radiographic imaging of the odontoid process through contrasting two conventional radiographic methods (open-mouth view and conventional tomography) for repeat rates, radiographic image quality and effective dose (ED).

Methods

216 examinations covering 421 images from two radiology departments (three X-ray units) were retrospectively evaluated using a checklist. The checklist was established through a comprehensive literature review. The ED was established using the PCMXC20 Monte Carlo software©. The parameters used for the software included the source-to-image distance (SID), filed of view (FOV), kVp and mAs which were captured on the checklists.

Results

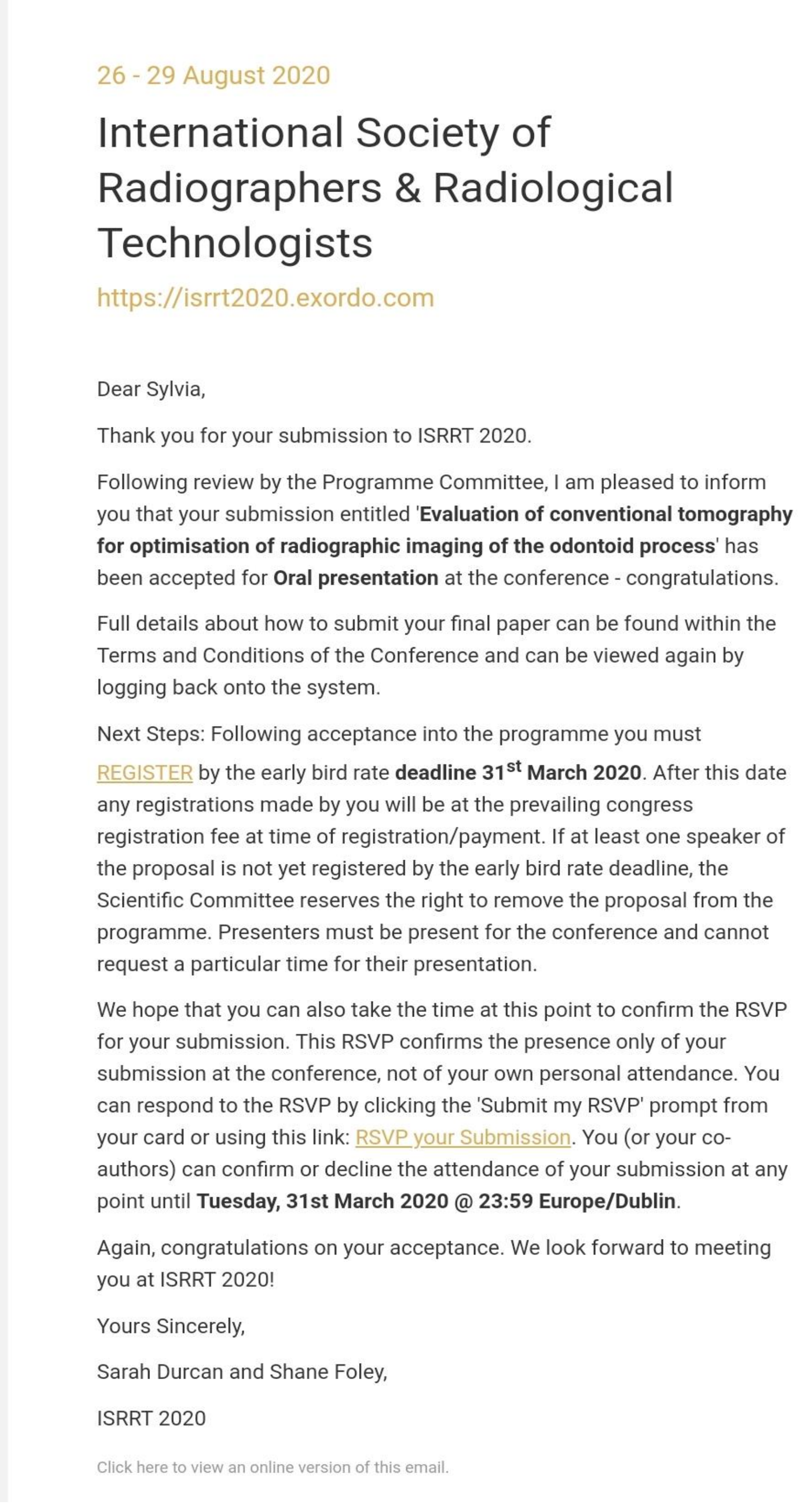
The open-mouth view has the highest repeat rate at 71.7%. Tilt is the most common error, with a 71.7% occurrence for open-mouth view examinations. There is a significant difference for tilt (p= 0.0019) and motion (p= 0.0001) between the two conventional radiographic methods. The upper spine received the highest effective dose mean (0.875797 mSv) for imaging of the open-mouth view, while the thyroid received the lowest effective dose mean (0.248419 mSv) for conventional tomography imaging.

Conclusions

Conventional tomography can be recommended as the first method of preference for optimised conventional radiographic imaging of the odontoid process. The technique achieves a safe balance between image quality and ED to the patient. Future studies can be conducted to address the following: investigating the radiation dose output for different X-ray units with similar specifications, comparing the ED's to existing standard ED's for the listed tissues and lastly a similar study with a higher conventional tomography examination sample size.

Key terms: Conventional tomography, upper cervical spine, image evaluation, radiation protection, effective dose, open-mouth view.

Appendix L5: Acceptance of abstract for conference oral presentation



26 - 29 August 2020

International Society of Radiographers & Radiological Technologists

https://isrrt2020.exordo.com

Dear Sylvia,

Thank you for your submission to ISRRT 2020.

Following review by the Programme Committee, I am pleased to inform you that your submission entitled '**Evaluation of conventional tomography for optimisation of radiographic imaging of the odontoid process**' has been accepted for **Oral presentation** at the conference - congratulations.

Full details about how to submit your final paper can be found within the Terms and Conditions of the Conference and can be viewed again by logging back onto the system.

Next Steps: Following acceptance into the programme you must REGISTER by the early bird rate **deadline 31st March 2020**. After this date any registrations made by you will be at the prevailing congress registration fee at time of registration/payment. If at least one speaker of the proposal is not yet registered by the early bird rate deadline, the Scientific Committee reserves the right to remove the proposal from the programme. Presenters must be present for the conference and cannot request a particular time for their presentation.

We hope that you can also take the time at this point to confirm the RSVP for your submission. This RSVP confirms the presence only of your submission at the conference, not of your own personal attendance. You can respond to the RSVP by clicking the 'Submit my RSVP' prompt from your card or using this link: RSVP your Submission. You (or your co-authors) can confirm or decline the attendance of your submission at any point until **Tuesday, 31st March 2020 @ 23:59 Europe/Dublin**.

Again, congratulations on your acceptance. We look forward to meeting you at ISRRT 2020!

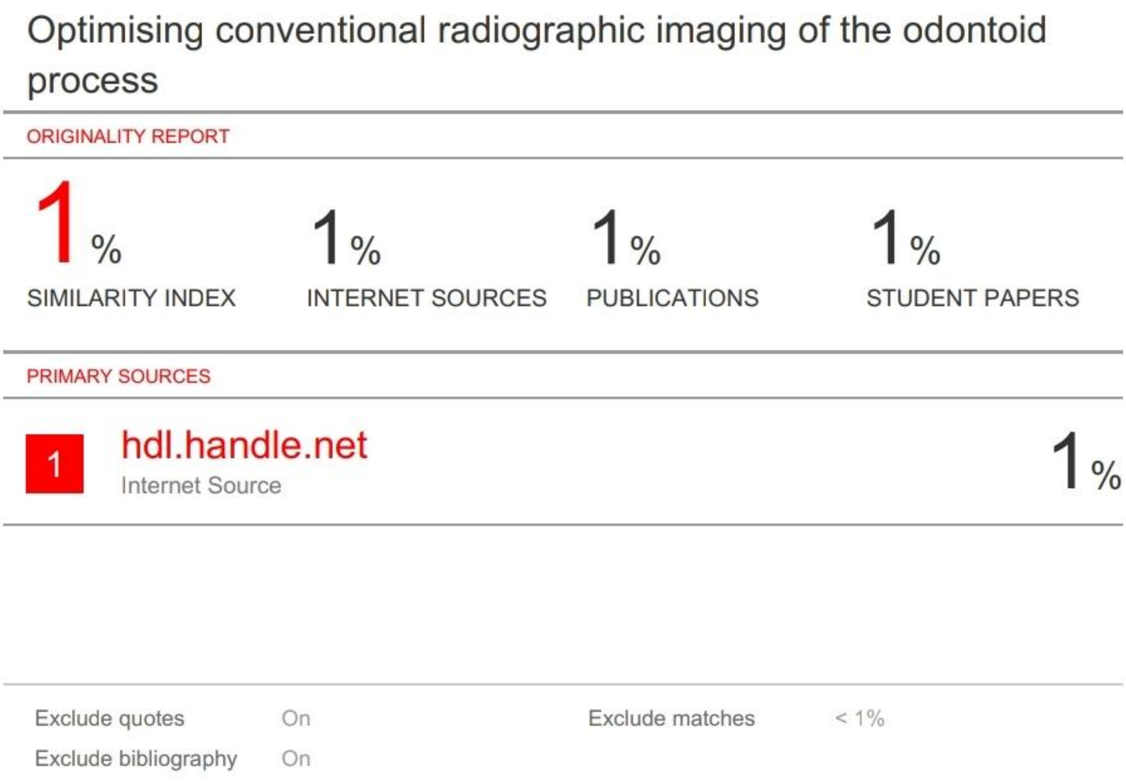
Yours Sincerely,

Sarah Durcan and Shane Foley,

ISRRT 2020

Click here to view an online version of this email.

Appendix M: Plagiarism report



Optimising conventional radiographic imaging of the odontoid process

ORIGINALITY REPORT

1%	1%	1%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

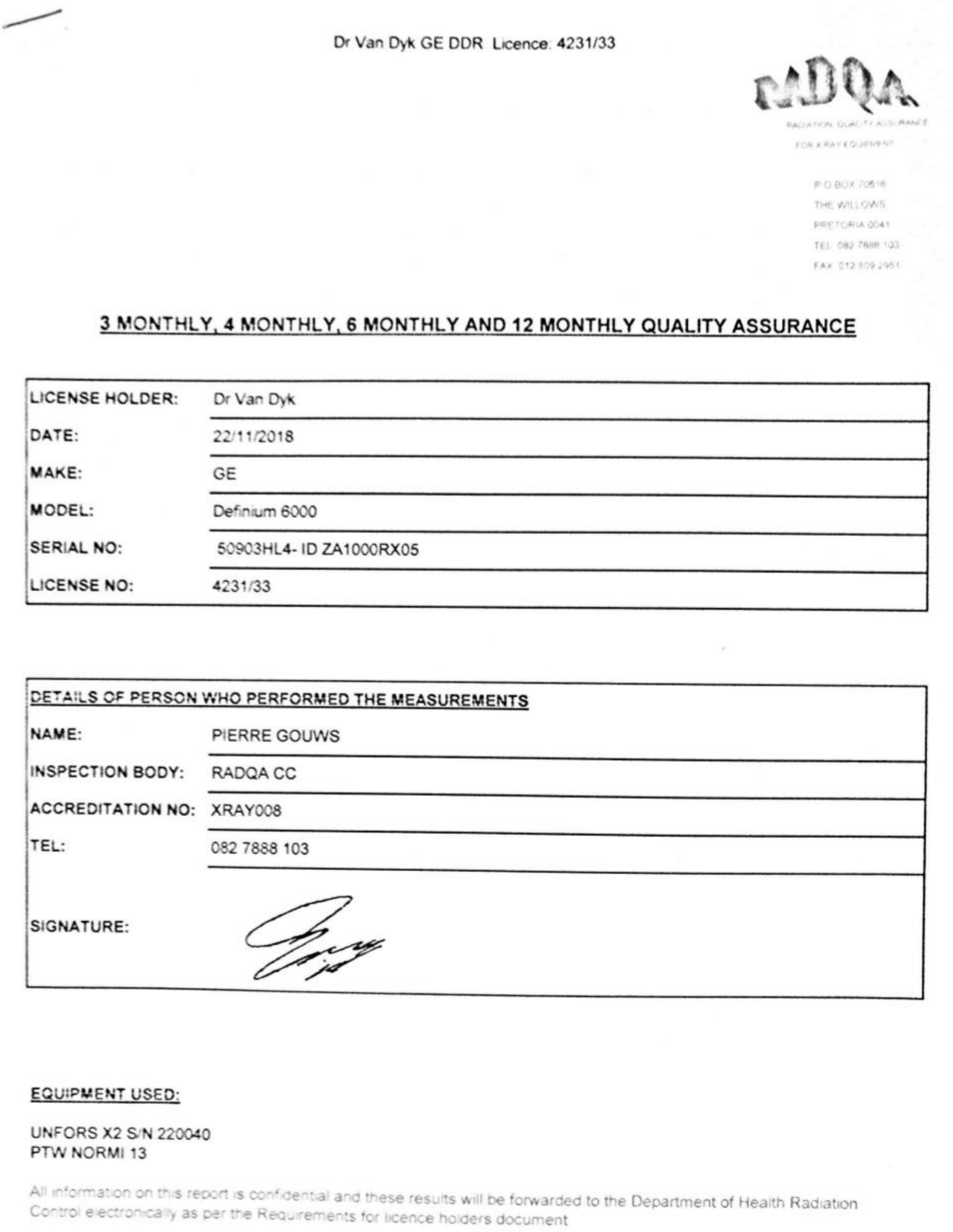
PRIMARY SOURCES

1	hdl.handle.net Internet Source	1%

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		

Please kindly find enclosed a disc with the conclusive plagiarism report outline of the plagiarism report for the dissertation.

Appendix N: QA and QC results



Dr Van Dyk GE DDR Licence: 4231/33

RADQA
RADIATION QUALITY ASSURANCE
FOR X-RAY EQUIPMENT

P O BOX 70616
THE WILLOWS
PRETORIA 0041
TEL 082 7888 103
FAX 012 809 2951

3 MONTHLY, 4 MONTHLY, 6 MONTHLY AND 12 MONTHLY QUALITY ASSURANCE

LICENSE HOLDER:	Dr Van Dyk
DATE:	22/11/2018
MAKE:	GE
MODEL:	Definium 6000
SERIAL NO:	50903HL4- ID ZA1000RX05
LICENSE NO:	4231/33

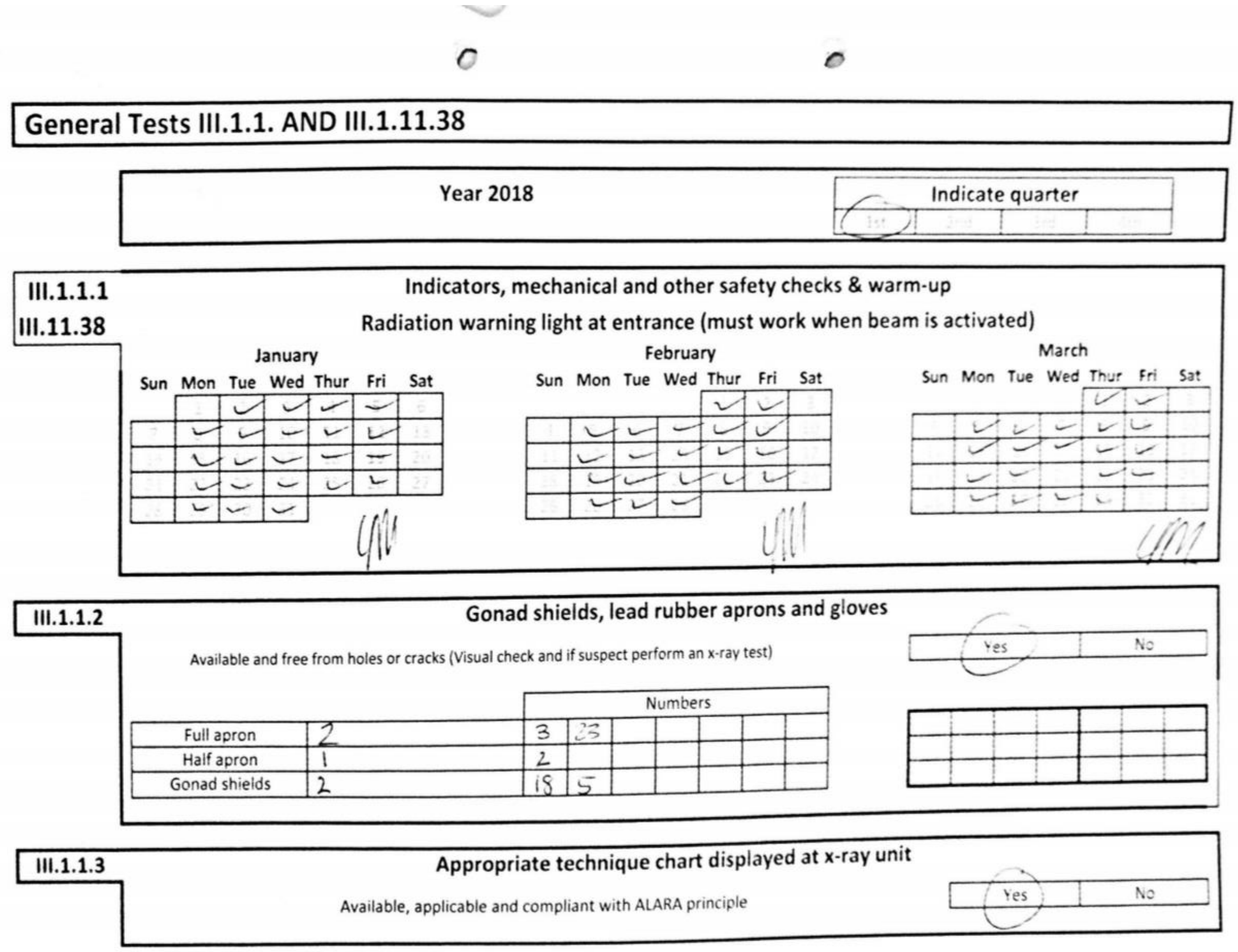
DETAILS OF PERSON WHO PERFORMED THE MEASUREMENTS

NAME:	PIERRE GOUWS
INSPECTION BODY:	RADQA CC
ACCREDITATION NO:	XRAY008
TEL:	082 7888 103
SIGNATURE:	

EQUIPMENT USED:

UNFORS X2 S/N 220040
PTW NORMI 13

All information on this report is confidential and these results will be forwarded to the Department of Health Radiation Control electronically as per the Requirements for licence holders document



General Tests III.1.1. AND III.1.11.38

Year 2018

Indicate quarter			
[✓ 1st]	2nd	3rd	4th

III.1.1.1 Indicators, mechanical and other safety checks & warm-up

III.11.38 Radiation warning light at entrance (must work when beam is activated)

January

Sun	Mon	Tue	Wed	Thur	Fri	Sat
		✓	✓	✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓	✓			

February

Sun	Mon	Tue	Wed	Thur	Fri	Sat
				✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓	✓			

March

Sun	Mon	Tue	Wed	Thur	Fri	Sat
				✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓	✓	✓	✓	
	✓	✓		✓	✓	
	✓	✓	✓	✓		

III.1.1.2 Gonad shields, lead rubber aprons and gloves

Available and free from holes or cracks (Visual check and if suspect perform an x-ray test)

[✓ Yes] No

		Numbers						
Full apron	2	3	23					
Half apron	1	2						
Gonad shields	2	18	5					

III.1.1.3 Appropriate technique chart displayed at x-ray unit

Available, applicable and compliant with ALARA principle

[✓ Yes] No

General Tests III.1.1. AND III.1.11.3

Year 2018

Indicate quarter			
1st	[✓ 2nd]	3rd	4th

III.1.1.1
III.11.38

Indicators, mechanical and other safety checks & warm-up

Radiation warning light at entrance (must work when beam is activated)

April

Sun	Mon	Tue	Wed	Thur	Fri	Sat
1	2	✓	✓	✓	✓	7
8	✓	✓	✓	✓	✓	14
15	✓	✓	✓	✓	✓	21
22	✓	✓	✓	✓	27	28
29	✓					

May

Sun	Mon	Tue	Wed	Thur	Fri	Sat
		1	✓	✓	✓	5
6	✓	✓	✓	✓	✓	12
13	✓	✓	✓	✓	✓	19
20	✓	✓	✓	✓	✓	26
27	✓	✓	✓	✓		

June

Sun	Mon	Tue	Wed	Thur	Fri	Sat
					✓	2
3	✓	✓	✓	✓	✓	9
10	✓	✓	✓	✓	✓	16
17	✓	✓	✓	✓	✓	23
24	✓	✓	✓	✓	✓	30

III.1.1.2

Gonad shields, lead rubber aprons and gloves

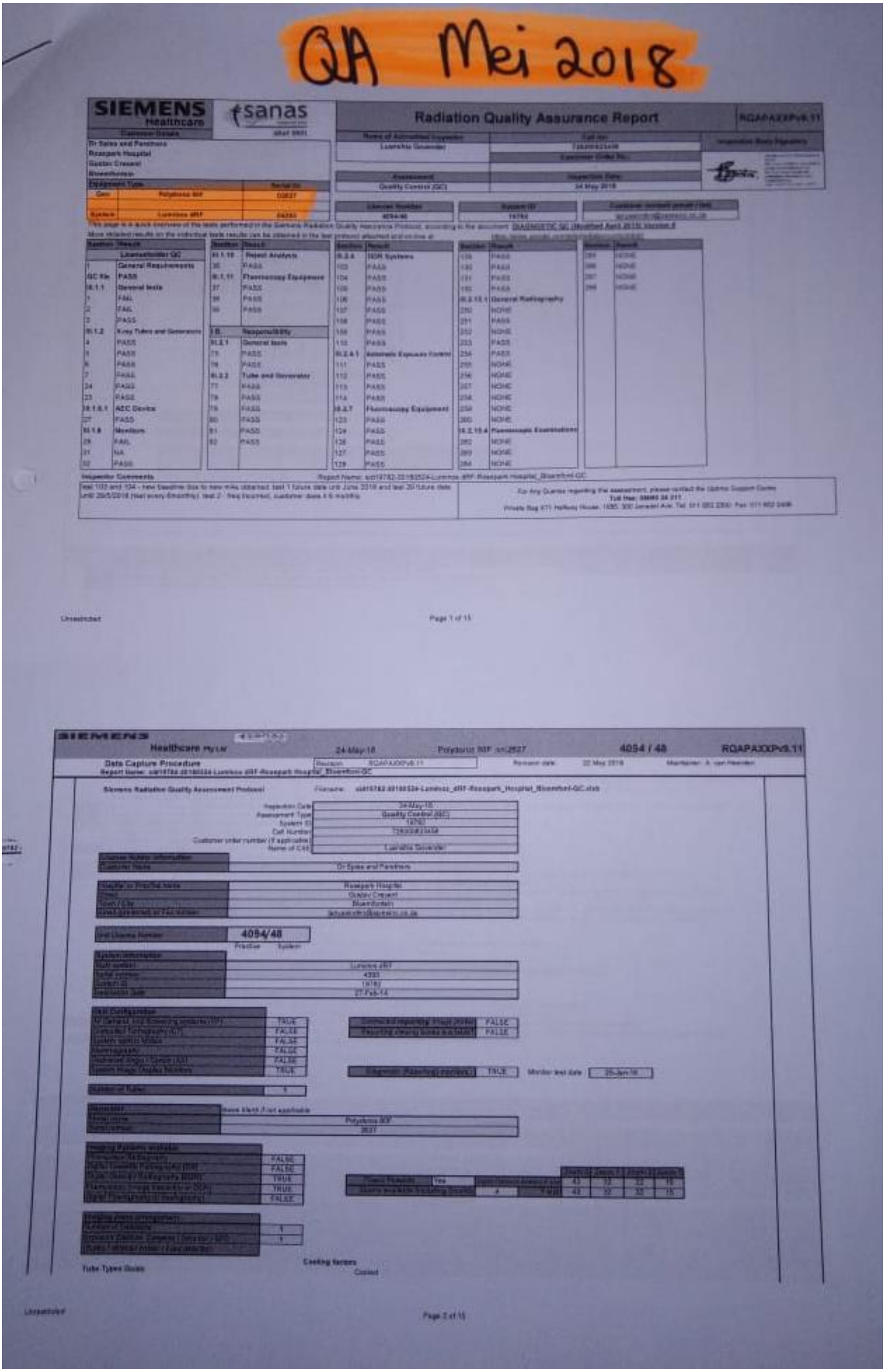
Available and free from holes or cracks (Visual check and if suspect perform an x-ray test) [✓ Yes] No

		Numbers					
Full apron	2	3	23				
Half apron	1	2					
Gonad shields	2	18	5				

III.1.1.3

Appropriate technique chart displayed at x-ray unit

Available, applicable and compliant with ALARA principle [✓ Yes] No



QA Mei 2018

SIEMENS Healthcare

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Radiation Quality Assurance Report

Quality Control (QC)

SIEMENS Healthcare Pty Ltd

24-May-18

4054 / 48

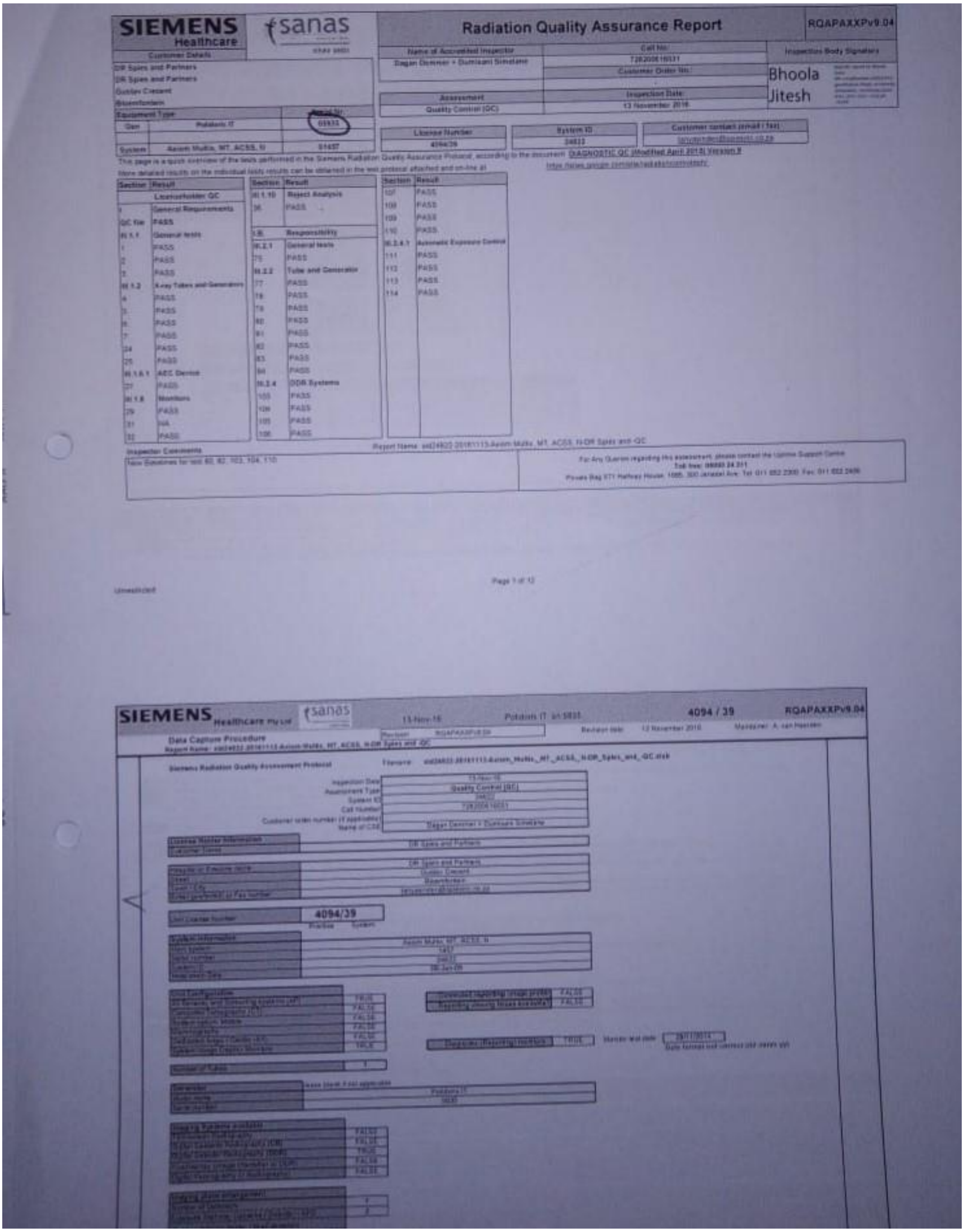
RQAPAXXPv8.11

Data Capture Procedure

Siemens Radiation Quality Assessment Protocol

Quality Control (QC)

4054/48



SIEMENS Healthcare | sanas

Radiation Quality Assurance Report

RQAPAXXPv9.04

Customer Details
DR Spies and Partners
DR Spies and Partners
Gustav Crescent
Bloemfontein

Equipment Type		Serial Nr.
Gen	Polydoros IT	
System	Axiom Multix MT ACSS, N	

Name of Accredited Inspector: Dagan Demmer + Dumisani Simelane

Assessment: Quality Control (QC)

Inspection Date: 13 November 2016

Inspection Body Signatory: Bhoola Jitesh

License Number: 4094/39

Section	Result
	Licenceholder QC
I	General Requirements
QC file	PASS
III.1.1	General tests
1	PASS
2	PASS
3	PASS
III.1.2	X-ray Tubes and Generators
4	PASS
5	PASS
6	PASS
7	PASS
24	PASS
25	PASS
III.1.6.1	AEC Device
27	PASS
III.1.8	Monitors
29	PASS
31	NA
32	PASS

Section	Result
III.1.10	Reject Analysis
36	PASS
I.B	Responsibility
III.2.1	General tests
75	PASS
III.2.2	Tube and Generator
77	PASS
78	PASS
79	PASS
80	PASS
81	PASS
82	PASS
83	PASS
84	PASS
III.2.4	DDR Systems
103	PASS
104	PASS
105	PASS
106	PASS

Section	Result
107	PASS
108	PASS
109	PASS
110	PASS
III.2.4.1	Automatic Exposure Control
111	PASS
112	PASS
113	PASS
114	PASS

Inspector Comments
New Baselines for test 80, 82, 103, 104, 110

Page 1 of 12

Unrestricted

SIEMENS Healthcare Pty Ltd | sanas | 13-Nov-16 | Polydoros IT | 4094 / 39 | RQAPAXXPv9.04

Data Capture Procedure

Siemens Radiation Quality Assessment Protocol

Inspection Date: 13-Nov-16
Assessment Type: Quality Control (QC)

DR Spies and Partners

DR Spies and Partners
Gustav Crescent
Bloemfontein

4094/39
Practice System

Appendix O: Language editing certificate

LINGPRO LINGUISTIC REVISION SERVICES

(Trading as Laurika's Photography)

More than 24 years' relevant experience

10 July 2020

DECLARATION

I, Dr Laurika van Straaten, hereby declare that I am a qualified and professional language practitioner, with more than 24 years' relevant experience in the field of linguistics and linguistic revision.

I have linguistically revised the research dissertation titled *Optimising conventional radiographic imaging of the odontoid process* of Ms Sylvia Precious Mokuoane, Master of Radiography: Diagnostic student at the Central University of Technology, Free State (CUT).

Yours sincerely

Straaten

DR L VAN STRAATEN

LINGUIST

(**BA (Languages)(UNISA)(1995); BA Hons (Translation studies)(UNISA)(1999); MA (HES)(UFS)(2014); PhD (UFS); 2019**