



# OPTIMAX 2017

**Radiation dose, image quality optimisation,  
the use of new technology in medical  
imaging.**

*Edited by: A. Meijer, C. Buissink and P. Hogg.*



# OPTIMAX 2017

## Optimising image quality for medical image.

*Oslo, Norway*

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# Foreword

This year OPTIMAX settled in Oslo. After the success of previous years, we are proud to present the fourth Ebook. As in previous years, the group was made up of PhD-, MSc- and BSc students as well as tutors from the seven European partner universities. Professional mix was drawn from medical physics/ physics and radiography. OPTIMAX 2017 was partly funded by the partner universities and partly by the participants. Two students from South Africa and two from Brazil were invited by Hanze UAS (Groningen) and ESTeSL (Lisbon) summer school included lectures and group projects in which experimental research was conducted in four teams.

Four research projects were performed with a focus on radiation dose optimization and image quality, namely: Possible dose reduction for pediatric patients for conventional radiology; Can the tube voltage be lowered with the use of direct-conversion flat panel detector system?; Impact of body size and kV in chest radiography; Quantity assessment on Image quality of CBCT images of head phantom with implants of metal and ceramic objects. The last day of OPTIMAX 2017 there was a poster session and a conference, in which the research teams presented their posters and oral presentations.

This book comprises of two sections, the first two chapters concern generic background information about international teamwork during the OPTIMAX summerschool.

The next chapters with theory on which the research projects were built. The second section contains the research papers of the four research projects. Two research papers, *Can the tube voltage be lowered with the use of direct-conversion flat-panel detector system?* And *Impact of body size and kV in chest radiography: Experimental receiver operating characteristic analysis using a Multipurpose Chest Phantom "Lungman"* have been accepted for the ECR conference, Vienna, 2018 as oral presentations.

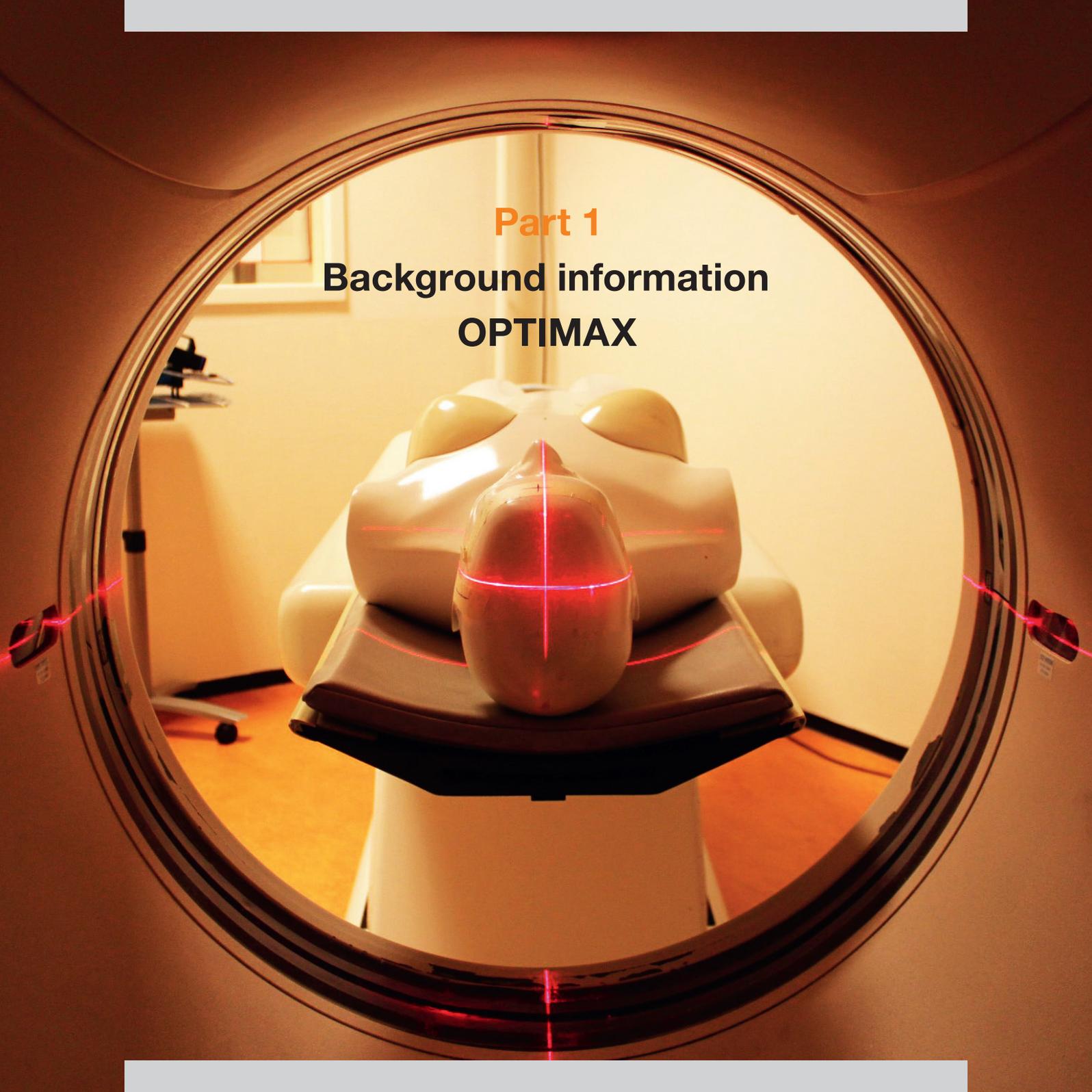
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**Part 1**

**Background information**

**OPTIMAX**





# International team working in medical imaging/radiography research based on experiences from OPTIMAX Project.

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### Keywords:

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International studies and working collaborations are part of the European Commission's agenda to increase mobility within the European context, as a way of facilitating workforce globalisation to respond to the demands of the global market. As a professional in the radiography field with experience in working in international teams, I could not agree more with this agenda. Having such experience, being exposed to other ways of conducting clinical practice, research, thinking, building up knowledge and teaching based on a diverse range of methods and perspectives promotes the opportunity of translating this range of experiences and knowledge into the radiography curriculum that I am associated with. Incorporating this diversity into medical imaging education and practice can also promote the development of students that can work more easily within and contribute to global practice in medical imaging. Furthermore, nowadays the economy in the so-called society of knowledge, research training and clinical practice cannot be effective without international exchange and cooperation. Finally, it is worth noting that the global healthcare economy demands the integration of research into practice and this is a major component of being a profession; the radiography profession is no exception to this philosophical position.

The experience of being integrated within a team composed of members from different countries, with different cultural backgrounds, with a diversity of social values as well different education levels will likely improve crucial skills; such skills include critical thinking and tolerance facilitating the learning and the integration of different perspectives to identify, analyze and solve problems. The diversity in experiences, regarding academic and professional contexts, the interaction with other people and the access to a range of resources can help to identify innovative strategies that would not be even imagined if the routines and practices were always the same. Consequently, working in a team can also be seen as a social process where students and academic staff learn from each other on how to share and respect different ideas and concepts and to integrate them thereby creating international and intercultural perceptions. This is particularly important at Higher Education levels where student radiographer knowledge, attitudes and behaviors can be developed, thereby influencing them as a person and a healthcare professional. Consequently, professional identity, and how we perceive ourselves within our occupational context and how we communicate this to others, will be affected by such developmental interactions. Introducing teamwork and connecting students, radiographers and radiography teaching staff in research at the undergraduate level has the potential to promote a better link between theory and

practice, as well as combining critical thinking and evidence-based practice.

One of my most exciting and fruitful international experiences I have been involved in is OPTIMAX. As a matter of fact, this research summer school allowed me to develop scientific knowledge in radiography field but not exclusively. As an OPTIMAX tutor supervising students and interacting with peers during the research process, I needed to develop skills to be more effective in my role. Skills that I needed to develop were related to language and communication barriers, facilitating the integration of different opinions within team working, the ability to keep the team motivated and engaged, the need to promote social cohesion and interaction - to ensure a healthy team play environment which helps to achieve our research goal. With regard to language and communication, it is worth noting that my first language is Portuguese; this is closely followed by French and Italian. For me, English is final language in this list and English is the international language adopted for communication, both oral and written, in OPTIMAX.

Alongside the personal development opportunities, OPTIMAX also brought several challenges, especially because research is relatively new within professional radiography practice and because the culture of the clinical settings varies amongst OPTIMAX students and tutors. The cultural reality of each OPTIMAX

team member was extremely diverse, making the creative and productive combination of all these differences challenging but paramount. This affected the activities during the research process period until the identification of an integrative approach based on ground rules applicable for all group members after discussion and common agreement. Clarification of responsibilities, concepts, ideas and perspectives in order to reduce assumptions, whilst addressing language and communication barriers, was very important and one of the first steps to be addressed in the team-based OPTIMAX learning environment. I would like to highlight that these important first steps constitute the first milestone that guarantee a successful and effective OPTIMAX summer school. It is worth noting that the first few days of each OPTIMAX summer school involve tasks that help team members understand the personality of their peers, in order to discover their background and knowledge and also the strengths, weaknesses, opportunities and threats to the team. Having done these activities and with the learning points in mind, the team defines ground rules and responsibilities of each member and for the team as a whole. During the research process, regular meetings in the morning and in the afternoon were required as an approach to overcome the challenges identified above. During these meetings, all the information delivered was shared to keep every team member 'on the same page' and to harmonize knowledge and understanding, taking in account that

group members included students and tutors from different academic backgrounds (physics, biomedical sciences, psychology, pharmacy) and education levels (1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> year undergraduate, MSc and PhD). In addition, the discussions during these meetings were implemented to encourage all members to take an active part on exploring current practice using reflexivity and improving critical thinking. For instance, to identify and discuss why the current radiological techniques and procedures are set-up in a certain way or why available techniques and procedures are not applied in a given clinical situation. These group reflective and critical thinking activities were always based on evidence in order to provide an appropriate method and the decisions taken within the group, during the research design. Moreover, following episodes of conflict and debate, meetings to reflect and discuss these episodes were encouraged; these involved all group members (students and tutors) with a view to identifying solutions. These discussions aimed to shed light on and to analyze the positive and the negative aspects of points of disagreement and conflict and consequently to improve and/or develop new rules, protocols and working practices that allowed the team members to move forward and perform the necessary tasks by the establishment of common agreements which can lead to innovate and creative solutions. However, it should be noted that conflict was sporadic and mainly it was generally provoked by the presence of students with

different personalities and learning style; nationality and cultural differences did not cause conflict. For instance, sometimes some of the groups had in their composition students that needed to control all the process to feel confident about the work to be performed. If other students could not tolerate this scenario, another part was affected and resulted in the need for tutor intervention.

Throughout my four years as an OPTIMAX tutor I have noticed a common theme - student get concerned, perhaps due to a lack of experience, about their ability to manage time as well the pressure to finish the research project within the timeframe. On occasion this was also a source of conflict. Taking into account such problems, the approach followed was to enable discussion within the group. It allowed collectively a deep understanding of the problem; this led to a collective solution to be reached. As an example, sometimes, it was necessary to reallocate roles and tasks within the group or the need to share theoretical and methodological knowledge between group members in order to reduce individual and collective anxiety. The allocation of roles and tasks is always made on a voluntary basis to be sure that all students feel comfortable with their roles. That tactic was combined with a level of knowledge of each student, trying to create more balanced subgroups; this could mean that tasks may be allocated to two students where one student has a high level of experience and the other student

has less experience. Also, introvert students were directly instigated to actively participate to be sure they were comfortable, motivated and that they understood the research process, roles and the concepts. When a student expressed doubts or difficulties to the team, debates were created and the members who could help were identified, encouraging cooperation between them despite their diversity of origin, language and education level. Feedback sessions were also promoted always encouraging a constructive approach, reflecting on team work and giving opportunities to identify areas to improve and practices to keep due to the positive outcome.

Social interaction outside the learning and research work was also supported. Indeed, social activities were considered as an opportunity to get to know more about personalities, the cultural range within OPTIMAX as a whole, the preferences and the values of each one and how those aspects might affect the learning and research work. Sometimes exploring the values and understanding of the society surrounding each member was helpful to improve trust and to identify ways of communicating more efficiently. From a tutor's perspective, knowing the preferences and dispositions of each team member was always helpful.

Without any doubt working in a team that is multiprofessional and international has potential to improve ourselves as professionals and also as persons sharing knowledge and experiences. Finally,

the OPTIMAX international collaboration made me more prepared to face diverse work environments and more flexible.



# International team working in research – reflection by a student.

## **Bowdler Matthew**

King's College, London (formerly University of Salford)

For this chapter we invited Bowdler Matthew to write an account of his personal experiences of attending OPTIMAX, with particular emphasis on working in an international research team. Matt is a physics graduate from the University of Salford and he attended OPTIMAX summer schools in Oslo (Norway, 2017) and Manchester (UK, 2016). Presently he is studying medical physics at King's College London. Matt wrote the following:

I believe that OPTIMAX provides a unique opportunity that is quite simply unparalleled in providing such a substantially diverse set of skills and experience beneficial to both academics and students alike. No other summer school provides the opportunity to become involved in cutting edge research as part of a diverse, international team under the tutelage of academics at the forefront of their respective fields. Having now moved into postgraduate studies in order to pursue a career in research, I consider my participation in OPTIMAX to be the most beneficial experience of my academic career so far.

There are a great many additional values in working as part of an international team in comparison to everyday university work. In the two teams I was part of during my experiences at OPTIMAX, each individual member of the team had their own strengths and weaknesses, bringing their own completely unique approach to the various challenges within research, allowing those challenges to be solved from a completely new perspective that I certainly could not have provided on my own merit. These unique and varied approaches meant solutions were found effortlessly and as a result our research moved forward with incredibly rapid progression, the likes of which I haven't seen replicated outside of OPTIMAX.

Having not worked with such a culturally diverse group of people prior to OPTIMAX, the one area I anticipated proving to be a significant barrier was language. However I was in fact staggered at the almost flawless level of English possessed by each and every participant. The level of fluidity was simply

astounding, particularly considering those for which English was one of several spoken languages. I was more than happy to be mistaken in my preconception that the language barrier may create some difficulty when it came to our research. In fact alike most native English speakers who have not been taught a second language, I found this lack of skill to be rather embarrassing.

The most important point I took away from working as part of a multicultural research team was how vital it was that the whole team understood the strengths and weaknesses of each individual member and used this knowledge to help assign them to the task or challenge most suitable based on these strengths. As a physicist, when I came to my first experience at OPTIMAX 2016, I was admittedly nervous about working in a team of radiographers conducting radiographic research. Our research project focused on investigating the impact of the anode heel effect on patient dose and image quality for AP Pelvis X-ray imaging. Having been fortunate enough to work with the anthropomorphic and dosimetry phantoms in my master's project, I flourished in demonstrating the phantoms use for image quality analysis and patient dose measurement explaining the underlying physics and making a significant contribution to the acquisition of the data vital to our research.

Having little previous experience of writing a scientific article from scratch, I personally found it difficult in attempting to generate the original draft of our paper, however it became immediately easier when working as part of a writing team, expanding and improving on the work written by other team members who had considerably more experience in scientific writing. This certainly came in useful the second time I attended Optimax, where I put the writing skills I had developed to good use with most of my time spent drafting and editing our article. Our research for OPTIMAX 2017 also focused on image quality and patient dose through the variation of exposure parameters and the additional use of filtration. This time the research centred on a paediatric phantom with routine clinical fractures.

I also found it pertinent that the current work of each individual team member was understood by the team at all times in order to make sure that the research progressed as efficiently as possible. Without the full cooperation of each group member, it would have become virtually impossible to reach a successful conclusion to the research due to the significant time constraint present. Although the research completed at the first OPTIMAX summer school I attended was in a similar vein to my undergraduate masters albeit completed over a vastly shorter period, I truly feel I gained significantly more experience from the three weeks of my first Optimax than I did over the entirety

of my masters project, mostly due to the wonderfully diverse array of research methods and backgrounds that can only span from working as part of an international research team. The idea of planning, implementing and publishing research within three weeks is certainly no mean feat, however I have never been prouder of the work achieved nor have worked along such hard working people, all sharing the same determination and strive for success.

Following the completion of the research undertaken during my first OPTIMAX experience, our work was successfully approved for oral presentation in the European Congress of Radiology (ECR) 2017 and we were asked to present our work at the congress held in Vienna, Austria. Having not attended an international conference before, I leapt at the opportunity to not only attend, but also present our work at the conference. As someone who struggles tremendously with public speaking, ECR provided me with the opportunity to work on this incredibly important skill and I found the experience to be thoroughly rewarding. I wasn't the only student to present our work at the congress and with this being the first time that either one of us had presented at an international conference, it proved immeasurably useful to have someone to share ideas with and practice in preparation for our talks. For my presentation I was humbled to have the support of not only our research group who came to show their

support in person, but also the OPTIMAX tutors from around the globe, there to offer their support as well as in some cases present their own research.

Away from the on-going research, OPTIMAX also provided some incredible social opportunities, which in retrospect I consider to be as important as the research itself in upholding the positive mindset necessary to meet the demands of the course. The opportunity to relax together outside of the hectic work schedule worked brilliantly in strengthening our bond as a team and motivating us to work harder in our research. Talking to students from such an array of different backgrounds considerably expanded my views on the different cultures around the world. It was particularly interesting to listen to the remarks made by different people about my own country, the similarities and differences shared between their own country and my own which varied considerably depending on whom you spoke to. For example the opinion on our weather seemed to differ rather dramatically depending on if you were speaking to a South African or a Norwegian.

Having OPTIMAX hosted by the University of Salford gave me the opportunity to present my own culture to the visiting participants with an array of nationalities, for some of which this was their first time venturing outside their own country. Although Manchester is not my hometown, showing the participants around the

city was a thoroughly gratifiable experience and I took great pleasure in planning events alongside the other home students in order to create the most enjoyable and memorable experience possible.

In contrast, with the most recent OPTIMAX being held in Oslo, Norway, it was my turn to be the visiting student, presented with the incredible opportunity to fully embrace another culture. I plan to live abroad at some period in my lifetime and the opportunity to study abroad certainly helped me to gauge how difficult it would be to transition into a different culture. It also provided the opportunity to catch up with my Norwegian friends who I had met attending OPTIMAX in Salford, some of whom I had not seen since. Following my first experience with OPTIMAX, to my great surprise I started to develop an interest in language and had been learning Norwegian for just short of a year by the time I arrived in Oslo for my second OPTIMAX. As those who have learnt another language are aware, learning a second language can be extremely time consuming and challenging especially from adulthood, however there is no better way to learn than being immersed in the language and during my time in Norway I improved significantly. That said I do fear I will never be able to roll my R properly.

From both my experiences of OPTIMAX I have met people I consider life long friends who I talk to on a daily basis and will hopefully visit sometime in the future.

I truly consider OPTIMAX to have been my foundation in research, providing me the experience necessary to take the next step in my academic career. I feel the achievement of securing a place on what I can only describe frankly as my dream course weighs heavily on the experience I gained through OPTIMAX, for having not only a publication to my name but also having presented that research at an international conference helped me significantly as an applicant to stand out from the crowd. I also feel this is not the last time that this experience will prove beneficial, particularly when it comes to searching for research positions overseas where prior international experience proves invaluable. I will forever grateful to the tutors of the course for providing me with such an incredible opportunity.

# A philosophical proposition: 'is there such a thing as an objective measure of medical image quality?'

**P Hogg<sup>1</sup>, I.H.R. Hauge<sup>2</sup>, J Jorge<sup>3</sup>**

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It requires very strong minds to  
resist the temptation of superficial  
explanations: *Albert Einstein*

Until relatively recently research in the medical imaging field has tended to be positivist in nature, drawing on traditional research designs from the fundamental sciences, such as physics and engineering, and also human studies in medicine. The general intention is to exert control over the research process in order to minimise error to discover new knowledge thereby identifying truth. Fundamental to this approach is the need to be objective throughout the whole research process. These underlying philosophical research principles apply to the assessment of image quality in medical imaging

and with this in mind we shall explore the notion of subjective and objective measures of image quality.

Medical image quality can be assessed in two different ways. The first method involves the use of a visual approach, in which human observers assess images for quality, by assessing a range features and characteristics within the image. In clinical practice this is normally done with a suggested medical condition in mind. This visual approach is often described as subjective in the literature, perhaps due to the possible variations of opinion that exist between different observers and also within the same observer at different points in time. Using this approach a numeric value might be assigned to the quality of an image quality, alternatively a qualitative description of its quality might be provided. The second method involves physics-based approaches

which provide numeric measurements of image quality; examples include Signal to Noise Ratio (SNR) and Contrast to Noise Ratio (CNR). The physics-based approaches are usually described as objective measures of image quality, probably due to the fact that if the analysis is performed in the same way on successive occasions, then the result is expected to be the same. Consequently much store is placed on the physics-based approaches because at first sight they are said to offer better reproducibility which is perhaps due to their [perceived] higher objectivity.

In this chapter we shall explore the notion of *subjective* and *objective* approaches to the assessment of image quality and we will propose that visual and physics-based methods are both subjective but if done adequately they will both offer valuable and perspectives on medical image quality that would be complementary in nature.

First let us consider definitions of *subjective* and *objective*. A subjective view is said to be influenced by or based on personal beliefs, feelings and prior knowledge and experience. It therefore stands to reason that a subjective view could vary between people and also within the same person as time progresses. By contrast, an objective view is not influenced by personal beliefs, feelings and prior knowledge and experience; it is said to be impartial or natural. The terms subjective and objective are

used in medical imaging literature to reflect these definitions and with these definitions in mind, at a superficial level, it follows that visual measures of medical image quality would appear to be subjective and that physics-based measures would appear to be objective.

It is intuitive that visual appreciation of medical image quality must be affected by beliefs, feelings, prior knowledge and experience. As experience and knowledge increase then the ability to make a better informed judgement about medical image quality would also increase: a student radiographer (novice) would probably reach a less informed and different conclusion to that of a consultant radiologist (expert). Beliefs play a part in decision making too, for instance some people might prefer one particular texture within an image whilst others prefer something else. Feelings play a role too and this can be highly complex. Assessing a medical image for its quality when the observer is 'tired' versus 'not tired' could impact the result; also being 'stressed' versus 'not being stressed' could have an impact on the outcome too. Not surprisingly, appreciation of images using visual means can be highly subjective and this is not disputed; however it does represent how images are appraised routinely in the clinical setting. Similarly, it is intuitive that physics-based measures of a medical image quality must be objective, as they present numeric values that can be analysed using

mathematical formulae to give highly specific and often singular answers about the quality of an image.

However, is the differentiation between visual/subjective and physics-based/objective really that simple? Are the physics-based approaches totally objective in nature or might it be that high levels of subjectivity are inherent and unavoidable within them? Let us consider the process of making physics-based measures of image quality, using SNR as a catalyst to facilitate a discussion into whether physics-based measures are truly objective in nature. SNR involves placing regions of interest (ROIs) onto images, then extracting data from the ROIs and then analysing the data with equations to reach a conclusion about a specific aspect of quality inherent to an image. First we should acknowledge that at various junctures throughout the process of calculating SNR important decisions need to be made which can affect the results and therefore the conclusions. With this in mind let us explore the notion of subjectivity within physical-based measures of image quality.

The first decision surrounds the actual use of SNR as a measure, as alternatives to SNR exist for assessing medical image quality. By definition SNR only assesses noise in an image and it does not take into account other important image attributes, such as *other* physical measures or indeed whether the image is of adequate quality in order to establish

a diagnosis. The decision making process when selecting SNR as an indicator of quality would certainly take into account the research question, however it would be influenced by individual researcher preferences as well as their prior knowledge and experience. Consequently, there is a level of subjectivity inherent in the decision making process when selecting SNR as an indicator of image quality.

When placing an ROI certain decisions need to be made. These include 1. the size of the ROI and 2. the exact location in which it would be placed and 3. the number of ROIs used. Various arguments can be made about ROI size, these might be practical (e.g. the image might be small, so the ROI would also have to be small) and theoretical (e.g. a larger ROI is better than a smaller ROI in order to minimise random variation between pixels). To improve objectivity in decision making the researcher can draw on various theories to minimise, but not eliminate, researcher subjectivity in an attempt to improve objectivity, reliability and validity. The ROI must then be positioned somewhere in the image. If the image is completely uniform then the decision making process would be fairly straight forward, albeit edge effects might need some consideration. However, the scenario of a uniform medical image rarely exists as nearly all medical images, human- or phantom-based, contain a range of structures of differing sizes,

textures and densities/intensities. The placement of the ROI is therefore a complex process, which is informed by the research question, theory and researchers' prior experience in order to minimise, but not eliminate, subjectivity. In some cases computer programmes have been written to automatically position ROIs to help improve ROI positioning; however such software will have been written by human programmers who are equally laden with their own preferences, prior experiences and inherent knowledge. Whilst automated approaches minimise variations in where ROIs could be placed between and within researchers who place them, the computer programmes still impose a subjective bias which has been forced on them by the programmer. Also, several computer programmes might exist to achieve automatic ROI placement and each could position ROIs differently; these differences would again be influenced by the biases and assumptions imposed by the programmer. Also the actual selection of a specific automatic computer-based approach for ROI placement introduces another level of subjectivity, which again could be based upon personal beliefs, feelings and prior knowledge and experience. The final step is the mathematical treatment of the ROI data. For SNR to be calculated at least two methods exist and they produce similar but not the same result. Again the researcher makes a decision on which mathematical method to use and once more the decision making process can be influenced by

personal beliefs, feelings and prior knowledge and experience.

It becomes clear that the process of making physics-based measures of image quality is laden with many decision points that can be heavily influenced by personal beliefs, feelings and prior knowledge and experience. Consequently, it can be argued that physics-based measures of image quality cannot be considered to be truly objective as there are many points within the process that allow for human intervention and subjectivity. With this notion in mind we propose that physics measures (e.g. SNR) of medical image quality should be named *physical measures of image quality* rather than objective measures of image quality. On the same basis *visual measures of image quality* should be named as such, rather than simply calling them subjective measures of image quality.

Points of reflection: It is possible that any measure of image quality, whether physical or visual, has the potential for subjectivity and therefore bias. Rather than considering measurement objectivity, perhaps researchers should have in mind the will and the duty of objectification when producing new knowledge to demonstrate how the experimental measurements are performed to be accurate, precise, valid and reliable. Maybe we would take the view that objectivity is only a shared subjectivity among the scientific community?



## References

1. <http://dictionary.cambridge.org/dictionary/english/subjective>
2. <http://dictionary.cambridge.org/dictionary/english/objective>





# Image Quality: An unanswered problem?

**Dr John D. Thompson**

University of Salford

Radiology has two key foci – producing a diagnostic image, and interpreting it correctly. Knowledge and expertise are critical to the correct interpretation of a radiological image and confounding factors such as search strategy, fatigue and unwanted interruptions in the radiology reading room can all contribute to errors that detract from a correct interpretation. Objective observer studies can help us understand image interpretation and errors, but what about image quality – how do we know that we have produced a good quality image?

Image quality should always be perceived in terms of the task, and indeed whether the correct imaging modality has been used. It would be unfair to judge an image as poor quality if it had no chance of answering the clinical question. This can put some limitation on the traditional methods of assessing image quality, such as contrast-to-noise ratio (CNR), modulation transfer function (MTF), and spatial resolution, since there is no definitive relationship between these quantitative measures and observer performance. Rossman and Wiley<sup>1</sup> were some of the first to recognise this long-standing problem in radiology and it is still difficult to explain changes in these physical attributes of image quality on the diagnostic decision making process. In contrast to physical methods, visual assessment of images takes the entire imaging

chain into account, from image acquisition to the identification of pathology.

Despite the limitations associated with the correlation of physical attributes of image quality with diagnostic performance, they still maintain a critical role in radiology to ensure the correct and consistent operation of equipment. Observer work with contrast detail phantoms can provide a good indication of the overall system performance. However, when using clinical images, it can be advantageous to use objective methods that measure observer performance. Such methods include those that consider the detection of abnormal conditions (i.e. receiver operating characteristic (ROC) analysis), visual grading analysis (VGA) and alternative forced

choice (AFC). All of these can be valuable in image quality assessment but it is imperative that the correct tool is chosen for the task at hand, which depends on the research question.

### **Alternative Forced Choice (AFC)**

Two-alternative forced choice (2-AFC) is one of the most common psychophysical experiments performed. It requires the observer to either detect a signal in an image, or state in which image the signal is stronger or visually more obvious. This type of test is not only used in diagnostic imaging studies, as the stimulus could be audio, as well as anything on the visual spectrum (i.e. brightness, speed). In the simplest radiological task the observer would be asked to say which signal was brighter, and in a 2-AFC study, choose the brighter of the two images. The greater the difference in brightness between the two images, the greater the probability that the observer will make the correct decision. The probability of making the correct choice is a good measure of the sensitivity of the observer in the specified task. This type of study can be useful for determining a threshold for detection of a signal.

### **Visual Grading Analysis (VGA)**

If the research question revolves around a comparison of image quality using different acquisition methods (such as variation in x-ray beam quality/quantity) it can be useful to perform a VGA study. In these

studies, the evaluation of image quality is determined by a grading of the visualisation of clinically relevant structures.<sup>2</sup> many visual grading methods incorrectly use statistical methods that require data belonging to an interval scale. The rating data from the observers in a visual grading study with multiple ratings is ordinal, meaning that non-parametric rank-invariant statistical methods are required. This paper describes such a method for determining the difference in image quality between two modalities called visual grading characteristics (VGC) Once data has been collected, a visual grading characteristic (VGC) analysis can be performed. There are two types of VGA study: (i) relative, and (ii) absolute.

For relative visual grading studies, there is a requirement to produce a reference image to which all other test images are compared based on pre-determined criteria. A scale of 5 points is typically used to indicate whether the observer finds the test image superior (+ve score), inferior (-ve score) or equal (score = zero) compared to the reference image. For absolute visual grading studies, there is no reference image and the test images are scored individually; again a rating scale is used to do this.

VGA studies are generally performed in the absence of any disease/pathology/lesion as these can create non-standard image appearances that are difficult to compare.<sup>3</sup> The assumption is that if normal structures are more visible, then abnormal conditions, when present, would also be more visible.

When planning a VGA study it is important to critically consider the number of criteria that are used to assess the image. VGA studies are generally considered to be of reduced demand on the observer in comparison to those with a search component (such as ROC), but the observer must not be overloaded with a large number of criteria with which they assess the images.

### Detection of Abnormal Conditions

First, it is important to understand how decisions are classified in observer studies. In signal detection studies, it is the number of 'hits' and 'false alarms' that are of interest – the larger the difference between these outcomes, the better the performance. In observer studies using clinical images we tend to refer to these outcomes as true positive (the 'hits'; the observer correctly indicates a pathology) and false positive (the 'false alarms'; the observer indicates a pathology that is not there). Again, the greater the difference between these two classifications, the better the performance. There are four different paradigms used to assess the detection of abnormal conditions in a background of mostly normal conditions:<sup>4</sup>

- Receiver Operating Characteristic (ROC)
- Location ROC (LROC)
- Region-of-Interest (ROI)
- Free-response (FROC)

All of the above paradigms require a search component and are focussed on the correct classification of disease (i.e. the observer correctly identifying cases that are normal and abnormal). When using clinical images, this can require a level of observer expertise greater than that required for AFC and VGA methods. These paradigms take advantage of a rating scale that can indicate observer performance over a range of sensitivity and specificity. In general, a figure-of-merit (FOM) and a graphical representation of it are produced as a measure of performance.

When using the ROC paradigm, the observer is simply required to indicate whether they believe the image to be abnormal or not, where the rating scale would indicate the likelihood of the condition being present. This provides a single rating for this case and is considered a *case-based* analysis. This is perfectly acceptable for global/diffuse conditions, but if localisation is important to the task then the LROC, ROI or FROC paradigm should be employed. In LROC the observer is required to localise and rate the most suspicious area of the image, again producing a single rating per case. For the ROI paradigm, the image is divided into separate regions and a rating is applied to each region, thus fixing the number of ratings. The FROC paradigm allows the observer to make (theoretically) unlimited localisations

of suspicious areas, creating a truly *lesion-based* analysis.

All the paradigms described above require averaging over cases and observers in order to smooth out sampling effects – this requires complex statistical methods<sup>5-7</sup> sensitivity at a false-positive rate  $\leq 0.10$ , or specificity at a false-negative rate  $\leq 0.10$  outside the scope of this summary.

This brief summary introduces validated methods for an assessment of image quality. The suitability and choice of the correct method used depends on the research question.

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# How to identify and minimise systematic and random error in experimental research.

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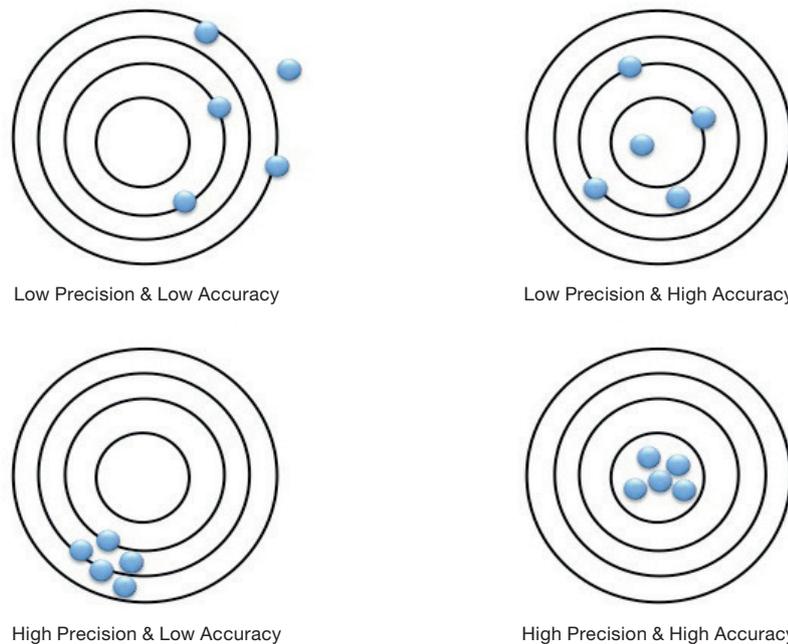
## 1.1 Introduction

Experimental research is pivotal to the development and optimisation of medical imaging. Evidence-based research may be translated into clinical practice to improve the quality of care provided to patients. In radiology, this may be achieved through enhancing the diagnostic efficacy of various medical imaging examinations and reducing the associated risks as much as possible. However, it is important to assess the quality and integrity of such research studies prior to implementing their findings into clinical practice as errors may be introduced during the research process, which may render the findings invalid. Errors are typically classified as systematic (affecting the accuracy of measurements) or random (affecting the precision of measurements).

The International Vocabulary of Basic and General Terms in Metrology (VIM) define accuracy as the “closeness of the agreement between the result of a measurement and a true value.” Since a true or accepted value for a physical quantity may be unknown, it is not always possible to determine the

accuracy of a measurement. Precision refers to how closely two or more measurements agree with other i.e. the reproducibility of the measurement. A graphical representation of precision and accuracy is demonstrated in [figure 1.1](#). In [figure 1.1](#) the ‘dots’ are intended to be located in the centre; if they were then it would have high precision and accuracy.

As scientific researchers, it is our duty to minimise error by suitable sampling, data processing and analysis using rigorous, reproducible methods and appropriate statistical analysis. Precise, accurate data is crucial to inform evidence-based practice. In this chapter, random and systematic errors are explained with reference to medical imaging research and practical solutions proposed for dealing with these errors.



**Figure 1.1** Precision and accuracy

## 1.2 Random error

### 1.2.1 What is random error?

As the name suggests, random errors in experimental research are completely random and unpredictable. These errors are caused by uncontrollable bi-directional fluctuations in variables, which cannot be replicated by repeating the experiment. Random errors affect the precision of measurements during experimental research.

Random error is divided into two main types: Type I, or alpha error, occurs when the researcher rejects the null hypothesis when it is true (also known as a 'false positive' finding) e.g. the researcher concludes that there is a high frequency of a disease in the underlying population when there is not (Hulley and Cummings, 1998). Type II, or beta error, occurs when the researcher accepts a false null hypothesis (also known as a 'false negative' finding) E.g. If the researcher concludes that there is no correlation between a disease and patients' genetic history when there is.

### 1.2.2 How can we minimise random error in medical imaging research?

Although it is not possible to completely eliminate random error, it can be minimised by increasing sample size and using an average measurement from a set of measurements. Prior to conducting research, power analysis should be used to determine a suitable sample size to minimise random error. A well-refined sampling strategy is also recommended. In order to minimise random errors arising from equipment precision limitations during data collection, it is recommended to use rigorous measurement protocols, increase the number of measurements obtained and average the resultant measurements (Jcgm, 2008).

A common example of random error in medical imaging research is that resulting from equipment precision limitations. In radiation dose optimisation research, random error may be introduced when a single dose measurement is used instead of acquiring and averaging multiple dose readings under constant conditions (i.e. same dosimeter, location, imaging exposure parameters etc). It is important to find the mean of multiple repeat dose readings to enhance precision, particularly at low dose exposures where dosimeters are less sensitive. For example, the sensitivity of metal oxide semiconductor field effect transistor (MOSFET) dosimeters, commonly used in dose optimisation research, is too low for single in

vivo measurements for doses below 1.7mGy (Koivisto *et al.*, 2015). Acquiring multiple dose measurements and averaging these reduces random error, thereby improving the precision of measurements obtained in research studies.

The second common source of random error in medical imaging research outlined earlier is that resulting from insufficient sampling. Random error is more likely to occur when the sample size is small due to chance variation which causes a sample to be different from the underlying population (Blackmore *et al.*, 2010). For example, in epidemiologic studies measuring the frequency of disease occurrence in a specified population, chance variation may produce contrasting results for two samples from the same specified population. Statistical power analysis should be performed prior to conducting research to determine a suitable sample size, thereby avoiding a type II error. Statistical power analysis is a measure of the likelihood that statistical significance will be found in a sample if the effect exists in the full population.

### 1.2.3 Quantifying and reporting random error

In the past,  $p$  values have been widely used as a method of quantifying the likelihood of Type I errors. A  $p$  value less than 0.05 indicates that there is a less than 5% chance that the observed difference in a sample would be seen if there was in fact no true difference in the population (Blackmore *et al.*, 2010).

However the  $p$  value is a function of sample size and magnitude of effect, therefore is limited in assessing random error e.g. a large actual difference between cohorts may be determined statistically insignificant ( $p > 0.05$ ) if small sample sizes are used or visa versa. Many scientific journals are now advocating the use of confidence intervals to assess the potential for random error. A confidence interval provides a range of values that is expected to include the true value of the parameter being estimated; the narrower the confidence interval, the more precise the estimate.

### 1.3 Systematic error

#### 1.3.1 What is systematic error?

Systematic error, also known as bias, affects the accuracy of measurements obtained during research studies. Unlike random errors, these errors are reproducible with data distorted in one direction only and are independent of sample size. Because the data is distorted in one direction (either lower or higher than true values), systematic errors can be difficult to detect.

Systematic errors often occur due to a problem that persists throughout the entire experiment causing distortion of all data. There are many different types of systematic error or bias, which should be considered in medical imaging research such as selection bias, equipment bias, observer bias and response bias. Scientific articles published in peer reviewed journals

typically include a synopsis of the study limitations which outlines bias that may have been introduced and the likely direction of that bias e.g. in the case of observers in a paediatric dose optimisation study with limited experience reviewing paediatric scans, it is possible that further dose reduction may be achieved if experienced paediatric radiologists were included in the study as they may tolerate lower image quality than inexperienced observers.

#### 1.3.2 How can we minimise systematic error in medical imaging research?

The risk of systematic error occurring can be reduced through rigorous, well-designed research studies. Practical solutions for dealing with some of the systematic errors commonly encountered in medical imaging research will be discussed in this section.

Selection bias may occur during the sampling process if the researcher selects a sample that would support their research hypothesis e.g. a survey of radiographers' opinions on continued professional development (CPD) distributed to radiographers attending a CPD event may introduce bias as these participants may have a more positive attitude towards CPD than other radiographers not attending this CPD event. This sample is not truly representative of the study population. Randomised controlled trials are optimal to minimise bias. Selection bias may also result from self-selection of individuals to participate

in a study. Phrasing of questions in a survey may influence responses if the respondent responds in a way they think the researcher wants them to respond, rather than what they actually think (Ramlaul, 2010). Researchers should avoid using leading questions such as ‘Don’t you agree that CPD opportunities should be provided by employers free-of-charge for their employees?’.

Systematic error may also be introduced through use of poorly maintained or improperly calibrated equipment in medical imaging research e.g. dosimetry equipment that has not been properly calibrated will produce erroneous dose measurements. Proper calibration and quality assurance testing of all equipment is very important in medical imaging research. A rigorous method should be in place to avoid introduction of bias e.g. for dose optimisation research, quality control tests should be performed on X-ray equipment and dosimeters properly calibrated. Clear, explicit instructions should be provided to observers grading image quality in these studies. Observer bias can be removed by using a double blinded study, where the researcher and observers are blinded from details of the study which may influence their decisions when grading image quality e.g. visibility of clinical indications for performing the study or visibility of the exposure factors used to acquire the image.

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# Attending the European Congress of Radiology.

## The student perspective:

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This chapter comes in two parts. The first part is written jointly by Yohan and Sofia, two former OPTIMAX students. The second part is written by Jonathan McNulty, a committee member of the European Federation of Radiographer Societies (EFRS). The purpose of this chapter is to give tips and insights about attending the European Congress of Radiology (ECR), with a specific emphasis on students. ECR is the second largest radiology conference in the world. It attracts around 26000 people and it provides an enormous opportunity for refreshing knowledge, learning about new research, finding out about new imaging equipment and also networking with colleagues.

Being a student is not easy, especially if you want to attend ECR or other conference and you have a limited budget to do so. In order to help you attend these conferences we will give you some advice that worked for us while managing our trip to ECR in Vienna. In this chapter, we will let you know what you need to think about before, during and after attending ECR always bearing in mind a limited budget.

## **1. Things to think about before you attend ECR**

### **1.1 Talk to your school**

First of all, you should check with your school if you are allowed to attend the ECR Conference, because you might miss some classes. Once you have the school's agreement and you have defined what to do to make up for missing classes, you will have to check if your school can provide you with a budget.

Make sure the school's managers/board is aware of the importance of your participation in ECR; remind them of the benefits of your participation to the school's international image. Of course, not all schools are able to help, but considering ECR is an excellent learning opportunity for students it might be that your school could be in a position to make a small financial contribution. To help you to have the school's approval you can propose to present some of the findings or things you have learned during the congress to the other students or teachers once you are back. If you fail to convince them to support you financially, don't give up going because you still can do it with a smaller budget.

## **1.2 The Flight**

Once you are allowed to go to ECR, you must buy the ECR student registration ticket and plan the flight. The price of the flight depends on the airline, the number of days before the flight departs, the day of the week you want to depart and even the departure time. Don't forget: the sooner you buy your ticket the cheaper it will be. The easiest way to obtain a low price for the flight is to check low cost companies first. Unfortunately, you cannot fly low cost directly to Vienna from all places, which means long term planning can really save you a lot of money. Usually, ECR starts in the middle of the week, which is good because the flight prices tend to be cheaper after the weekend, mostly on Tuesday and Wednesday.

While choosing your flight do not forget to check if the schedule influences the price of your ticket. This is important because most airlines have cheaper prices, for example, in the early morning; more expensive ones tend to be in the afternoon and at night. So, compare schedules and prices before buying the ticket.

The biggest problem that happens when traveling is luggage. In order to get a cheaper fare, a cabin bag is preferable and as ECR lasts for four days you will have enough space for all your stuff. Besides, some airlines allow you to take with you a small backpack or bag besides regular cabin luggage, so make sure you have read all the information related to the airline policy and regulations before buying your ticket.

## **1.3 Accommodation**

When choosing the place to stay, there will be three options: a youth hostel or a bed and breakfast, a house or flat rental or, of course, staying in a hotel. To make a decision about the place, you must bear in mind how many people are going with you. On the one hand, if you are going alone, then the best option for you will probably be a youth hostel or a bed and breakfast. On the other hand, if you are going with a group, it will be way cheaper if you share a house. To share a bedroom or a flat is always cheaper than to stay in a single room in a hotel. Although hotels are more easily available, this option is always more

expensive than house or flat sharing. Nowadays, it is quite easy to look up flats or houses to rent as there are websites where you can find all sorts of advertisements and information on house rental and house sharing. This is also the case for short stays. It is also important to check the online reviews of the place you choose to go to, once it will allow you to have a different perspective about the place and what you should expect from it. Sometimes it is worth spending a little more money in the accommodation if that means making sure you are in a good place.

When finding a place to stay you should look for somewhere which is near the underground *red line* or near the *Opera House* as these are the best references to the ECR conference centre. Of course, the closer you get to the Opera House the more expensive the houses or flats will be, so the best option for someone with a limited budget is to find a house or a flat along the underground red line.

If you rent a house or flat or choose to stay in a hostel that does not offer meals, the best way to eat well and cheap is to find a supermarket so you can buy and cook your own food instead of going to a restaurant. This will make you save a lot of money because restaurants are generally expensive in Vienna.

In order to make it easier to find a house with the characteristics you are looking for, we do advise you

to look for it in specific and trustworthy websites dedicated to the matter. Do not forget that flight rules also apply here: make sure you have all the information about rental policies and regulations and look for lodging as soon as you can because the sooner you do this the cheaper it will be.

## 2 Things to think of while you are there

### 2.1 Travelling

There are two types of travel you need to take while in Vienna: from the airport to the place you are staying and also traveling around the city.

On your way from the airport to your lodging you will have three options: taxi, coach and train. Train can be fairly cheap - you just need to be careful to take the right train as there will be two different trains you can take. On the one hand, there is CAT (green), which is faster and has less stops. On the other hand, there is RailJet (red) which has more stops but it is way cheaper. Coach travel is also cheap; coaches are located straight outside the airport and there is a direct one to the city centre. Do remember to buy a return ticket as this is cheaper than two single tickets.

The best way to travel inside the city is the underground, not only because it is cheaper than other means, but also because it covers all Vienna city center and some touristic areas. In the ECR mobile phone app you can get a discount for public

transport tickets. Also buying a multiday ticket can be cheaper than buying single journey tickets.

A quite important thing about travelling is the time you take to reach your destination, so make sure you know how long it will be to take you from your lodging to the ECR conference centre to avoid missing the start of a lecture. We recommend you to add fifteen minutes to the estimated journey time. This will allow you to be on time even if there is an unforeseen event.

## **2.2 Eating**

The best way to save money in food is to buy it directly from the supermarket. In it you will find a big diversity of food and other supplies you might need. This will allow you to cook at home and save money, especially in what concerns breakfast and dinner. For lunch, there are not many cheap restaurants in the ECR conference centre but if you attend a presentation during lunch time, they will offer you some sandwiches and water. Besides, ECR offers water and apples, all day in a self-service facility. Also you could take your own homemade lunch in a bag and eat it as there are many areas within the conference centre where you can do this.

Although supermarkets are cheap you may want to taste the traditional food in Vienna which means a restaurant is your best shot. Even though going to a restaurant can be expensive, there are

some restaurants near the Vienna Zoo which are affordable. You will find more information about cheap restaurants if you go to a tourist information center or if you buy a tourist guide book of Vienna.

## **2.3 ECR Mobile Phone App**

There are several advantages in downloading the ECR App. One of them is the discount on the underground fare, which allows you to choose from different types of tickets according to the number of days you are staying in Vienna. The other main advantage is that you can easily manage the conference presentations/lectures you want to attend. The app will also let you know when presentations/lectures you want to attend are about to start. When choosing the presentations, you must bear in mind the highlights of the day, which correspond to the most interesting researches and advances in the field of radiology. You should also be careful not to overlap the presentations and still have time to go from a conference to another because, since there are several pavilions and rooms, you can take up to 10 minutes to find the room where the next presentation will be.

Besides the ECR phone app you can also use the online program. By using this you will have even more details about the lecture itself. Using the online program can also be easier than the phone app if you take into account the preparation that some lectures may require, for instant you might be more prepared for a lecture if you have previously read the articles in

which the presentation was based on. This allows you to have more knowledge of the topic and even makes you capable of asking some questions at the end of the presentation, if you have any.

### **3. Things to think about after you have attended ECR**

After you attended the ECR conference, the most important of all is not to forget what you have learned and how to apply that new knowledge on a daily basis. Considering that going to ECR is also an opportunity to travel abroad, to visit a beautiful city and to meet new people. Another thing you can do is to look through the amount of money you spent and what you could have done in order to spend less, if that should be the case. Thus, you will realise that going to ECR has turned into an opportunity to develop functional skills as well. Travelling with a student budget, with a low budget, is not always easy but it does become easier every trip. So, don't let money prevent you from participating in ECR in Vienna!

We hope these tips will help you while you are planning your trip to ECR and we hope you enjoy going there and learn from it as much as we did.

### **4. The European Federation of Radiographer Societies and ECR**

Jonathan McNulty: *Vice-President, European Federation of Radiographer Societies; Associate Dean, School of Medicine, University College Dublin*

The European Federation of Radiographer Societies (EFRS) was founded in 2008 and currently represents over 100,000 radiographers and 8,000 student radiographers across Europe through 37 national societies and 57 educational institutions across 33 countries. According to Article 2 of the EFRS Constitution<sup>1</sup>, the role of the EFRS is to:

*“represent, promote and develop the profession of radiography in Europe, within the whole range of medical imaging, nuclear medicine and radiotherapy and moreover everything that is directly or indirectly related or beneficial to this role, everything in the broadest meaning.”*

The Educational Wing of the EFRS is comprised of 57 educational institutions that are affiliate members of the EFRS and the aim of the Educational Wing is to promote and develop all levels of radiography education and research across Europe. Shared objectives of both the Board of the EFRS and the Educational Wing are to: promote research and dissemination; and to develop evidence-based practice and radiographer-led research. In support

of these objectives, the European Congress of Radiology (ECR) is now the official scientific congress of the EFRS and European Society of Radiology (ESR) for medical imaging radiographers. It is also one of the largest medical meetings in Europe and the second largest radiological meeting in the world with a record 26,000 participants for ECR 2017. An extensive radiographers programme is now fully integrated into ECR with the biggest ever radiographers programme at ECR 2017 which included 23 sessions (five refresher courses covering a range of topics, eight scientific sessions, two professional challenges sessions, a special focus session, a student session and three voice of EPOS (electronic poster online presentation) sessions, and, for the first time ever, an EFRS Pros and Cons session and a radiographer's rising stars session aimed at students and newly qualified radiographers. In addition to the main radiographers programme, the EFRS Educational Wing also hosts its annual meeting and annual student meeting (open to students from educational institutions within the Educational Wing) during ECR and there are many other sessions of interest to radiographers and students across the main congress programme where contributions from radiographers can also be found. As we look ahead to ECR 2018, the radiographers programme continues to grow with three radiographer's rising stars sessions. A tremendous amount of work, by the EFRS appointed Radiographers Scientific Subcommittee, goes into

preparing the radiographers programme each year with planning starting two years in advance of the congress.

There are some fantastic opportunities available to student radiographers and newly qualified radiographers to help them participate in ECR. These include the *Rising Stars* which includes the *Invest in the Youth* programme which, as the name suggests, was introduced to support younger participants in ECR. This programme supports 1,000 young professionals, including radiographers in training under the age of 30, who must be members of the ESR (only €11) and are the presenter of a scientific paper or poster. Free registration to ECR and up to four nights hotel accommodation is provided. Also under the Rising Stars banner is the *Student Abstract Submission*, open to undergraduate students, under the age of 30, submitting abstracts under specified topics. In this case free registration, up to four nights accommodation, and travel is covered. This year the EFRS and ESR also launched the new *Shape your Skills* programme to support 500 early career radiographers through free registration and two nights hotel accommodation. This programme is open to radiographers in their first five years of practice who are ESR members and who submit an abstract to ECR. The EFRS and ESR have also launched a new award scheme for radiographers in the form of: *Scientific Paper Abstract Awards* (three awardees will

receive a printed diploma, free registration to ECR 2019, and free one-year online access to the official journal of the EFRS, *Radiography*); *Poster Awards* (three Magna Cum laude awardees will receive a printed diploma, free registration to ECR 2019, and free one-year online access to *Radiography*, together with one student award of a printed diploma, a Sacher cake, and free one-year online access to *Radiography*); and *Best Scientific Presentation Award* (who will receive an Open Access waiver for *Radiography* for their next publication; this is worth approximately €2,000). All will be formally presented by the EFRS and ESR Presidents during a special event at ECR.

Due to the combined efforts of the EFRS and ESR, radiographer participation continues to grow each year with 1,393 radiographers and 602 radiography students attending ECR 2017 (up 21% on 2016). When live online viewers are included, 2,389 radiographers and radiography students participated with the average age of radiography participants coming

down each year indicating that the sessions aimed specifically at students and young radiographers and opportunities listed above are having an impact. Most of the sessions within the radiographers programme are also simultaneously translated into French, German, Italian, and Spanish. Year on year the number of abstracts submitted by radiographers and radiography students continues to grow which contributed to the always improving programme. Radiographers and radiography students are now at the heart of ECR each year. ECR is recognised internationally as one of the leading congresses in terms of their Social Media activity where radiographers and radiography students are some of the most active contributors.

For more information on the EFRS see [www.efrs.eu](http://www.efrs.eu) and for more information on ECR for radiographers see [www.myesr.org/radiographers](http://www.myesr.org/radiographers). On behalf of the EFRS we look forward to your future participation in EFRS activities and look forward to seeing you at ECR.

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## Part 2

**Empirical research conducted  
during OPTIMAX 2017**





# Radiography: Impact of lower tube voltages on image quality and radiation dose in chest phantom radiography for averaged sized and larger patients.

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## **Keywords:**

Chest radiography, DR, image quality, kVp, tube voltage, obese patients.

## **Abstract**

**Background:** A tube voltage of 120 kVp is the standard in chest radiography. However, three studies have found that a lower kVp (e.g. 80 kVp) may provide better image quality for visualizing lung tissue and the cardiac silhouette. The aim of this study is to investigate the impact of tube voltage reduction on dose and image quality of DR chest phantom radiographs.

**Method:** An anthropomorphic chest phantom, without and with additional chest plates, to simulate a normal and large male chest torso body type, was imaged in posterior-anterior (PA) and lateral projections using stepwise increases of 10 kVp, from 60 to 130 kVp. Subjective image analysis was conducted by doing visual grading analysis (VGA). Six observers rated the image quality score (IQS). In addition, the contrast-to noise ratio for nine regions was obtained. In order to optimize with regards to both image quality and dose, the figure of merit (FOM) (=Contrast-to-Noise-Ratio squared/DAP), was estimated at each selected kVp.

**Results:** Visual grading analysis showed that the best IQS can be obtained at a lower tube voltage than 120 kVp, but only for PA projection when imaging larger persons, does a lower kVp (100 kVp) provide a better FOM than 120 kVp, and this only occurs when imaging the vertebrae, trachea and left ventricle

**Conclusion:** The VGA analysis showed that it is possible to reduce the kVp, and still get good image quality. However, more extensive VGA is needed in order to come to a definite conclusion.

## 1 Introduction

Conventional chest radiography remains one of the most commonly undertaken diagnostic examinations, making up 64.7% of all X-ray examinations performed in European countries (1-2). Posterior-anterior (PA) and lateral projections of the chest have an estimated effective dose of about 0.3 and 1.5 mGy, respectively per examination, which is significantly lower than other modalities (1).

Radiographers should adhere to the ALARA principle which indicates that dose should be kept as low as reasonably achievable while maintaining diagnostic image quality. With the development of technology, digital radiography (DR) systems have widely replaced computed radiography (CR) and film-screen technology. The wide dynamic range and high dose efficiency of DR allows dose reduction (3). Detector sensitivity and digital post-processing functions enable better image quality to be achieved at lower radiation doses (4). Compared to film-screen

technology, DR has a dynamic range which enables image quality to be preserved at lower and higher doses. Therefore there is a reduced probability of overexposure imposing detrimental visual effects due to DR's post-processing capabilities (5). This has led to a phenomenon known as 'dose creep', in which the patient receives additional dose for no additional benefit in image quality (6). Radiographers should therefore maximise the dose efficiency of DR detectors by adjusting exposure parameters accordingly. However, caution should be exercised when doing this because significant underexposure of images may lead to an increase in noise, which may warrant a repeat image thereby incurring a higher dose to the patient (6).

While tube voltage of 120 kVp is the standard in chest radiography (7), some studies have found that a lower kVp (e.g. 80 kVp) may provide better image quality for visualizing lung tissue and the cardiac silhouette (8-9). Lee et al. demonstrated an improvement in image quality noting that signal-to-noise ratio (SNR) increased as tube voltage was lowered (8). Contrary to this, Compagnone et al. demonstrated no improvements in image quality when kVp was lowered from 125 kVp to 95 and 85 kVp. However, they suggest an alternative protocol of 75 kVp for lowering the effective dose by 18% while maintaining image quality at a constant level (10). Bernhardt et al. (9) used 3 kVps (91, 121 and 150), but this study used

a similar approach to Lee et al. (8) who tested more kVps with 10 kVp increments.

The aim of this study was to investigate the impact of tube voltage reduction on dose and image quality of DR chest radiographs, on a phantom without and with different amounts of added fat (referred to as 'plates' in this paper).

## 2 Materials and method

### X-ray equipment

An Arcoma Intuition DR system (Arcoma AB, Växjö, Sweden) X-ray unit, with a Varian A-192 (Varian Medical Systems Incorporated, Palo Alto, USA) tube and Siemens beam collimator (Siemens Healthcare AS, München, Germany) were used to acquire images. The X-ray unit has an inherent total filtration of 2.5 mm Al. The large focal spot was used (1.2 mm). An integrated DAP-meter (last calibrated: 14/06/2017) was used to measure dose. A Canon CXDI-701C Wireless (Canon Inc. Headquarters, Tokyo, Japan) image receptor was used for the acquisition of all images, with an imaging area of 35 cm x 43 cm, matrix size of 2800 x 3408 pixels and a 125 µm pixel size. An anti-scatter grid (JPI Healthcare Solutions, Plainview, NY, USA) of type AAS (aluminum interspacer, aluminum cover, square) with a grid ratio of 10:1, grid frequency of 52 lines per cm and a focal distance suitable for the source-to-image distance (SID) was used.

### **Anthropomorphic phantom and experimental set-up**

An anthropomorphic multipurpose chest phantom N1 “LUNGMAN” (Kyoto Kagaku Co. Ltd, Kyoto, Japan) with and without additional chest plates was used to simulate average and larger patients (Figure 1). The phantom is an accurate life-size anatomical model of a human male chest torso, which contains a soft tissue substitute material and synthetic bones. Posterior anterior position with the phantom against the digital image receptor SID of 180 cm, was applied for all acquired images. The median sagittal plane (MSP) was on the lower border of the scapula. The beam was collimated to include the apices of the lungs superiorly, bases of diaphragm inferiorly and the skin borders laterally. Collimation field (37.6 cm x 34.3 cm) remained constant for all exposures. Both lateral automatic exposure control (AEC) chambers were used.

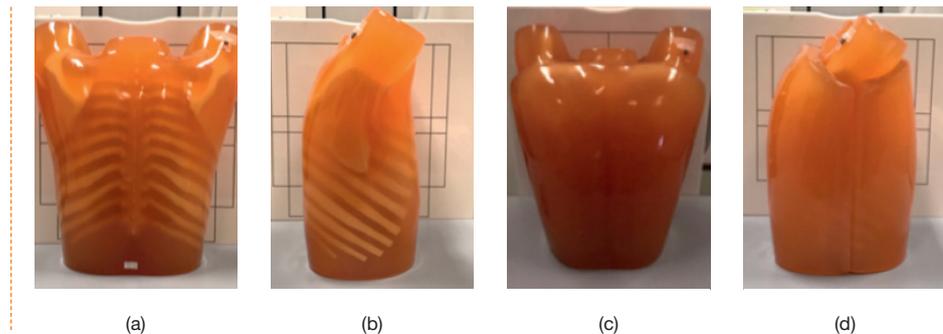
For the lateral projections, placing the phantom with left side of the thorax in contact with the image receptor and centring the mid-coronal plane on the seventh thoracic vertebra. The beam was collimated to include the apices of the lungs superiorly, bases of diaphragm inferiorly and the skin borders laterally. The PA and lateral positioning of the phantom are shown in Figure 1.

The central AEC chamber was selected. The phantom was imaged both with and without chest plates at 130, 120, 110, 100, 91, 81, 71 and 61 kVp. Details of applied exposure parameters (kVp and mAs) are listed in Appendix A.

### **Image quality: visual grading analysis**

The images were reviewed on a 5 MP, 21.3 inch, EIZO Radiforce GS520 class Monochrome LCD Monitor (EIZO Inc., Cypress, CA, USA) using ViewDEX (11) software calibrated according to

**Figure 1:** Lungman phantom without plates positioned for PA (a) and lateral (b) and with plates for PA (c) and lateral (d).



the DICOM Grayscale Standard Display Function (GSDF). Visual grading analysis (VGA) was carried out by three academic radiography staff members and three undergraduate radiography students using ten image quality criteria (Appendix B) (12). A questionnaire with four questions focused on image quality (image noise, contrast resolution and spatial resolution) and diagnostic acceptability. The other six questions determined whether there was visually sharp reproduction of specific anatomical image features as illustrated in European guidelines (13). In total, the observers rated 32 images. A five-point Likert scale was used to assess these criteria, ranging from one, which indicates poor, to five, which indicates excellent image quality. The questionnaire restricted participants to select one answer per row. Images were randomised and observers were blinded to their acquisition conditions. Duplicate images were included to determine intra observer variability. Image quality score (IQS) was determined

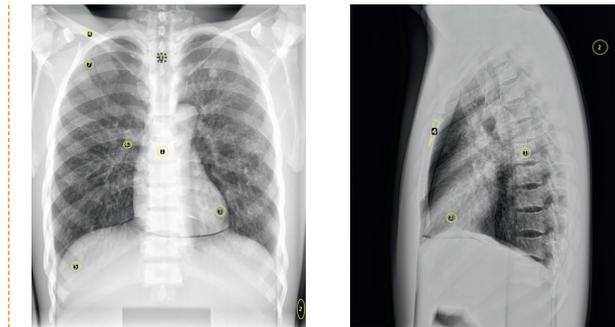
by the estimating the VGA score, which Månsson (14) defines as:

$$VGA = \frac{\sum_{O,I} S_c}{N_i N_o} \quad (\text{eq.1})$$

In equation 1,  $S_c$  represents each criterion score given by the observers,  $O$  represents the observer and  $I$  represents the image.  $N_i$  represents the total number of images and  $N_o$  is the total number of observers. In addition, the standard deviation at each kVp was found.

**Image quality: contrast to noise ratio** The ImageJ software (16) was used to define regions of interest (ROIs) for CNR calculations. For each ROI, the mean signal value and standard deviation (noise) for the signal and the background was determined. Placing the ROIs in different parts of the phantom by following Ferreira's method (15) (Figure 2), the signal for the

**Figure 2:** Regions of Interest in PA (parenchyma, bronchi, left ventricle, diaphragm, trachea and vertebrae) and lateral (left ventricle, upper sternum and the vertebra) views.



PA projection was determined from the clavicle, parenchyma, bronchi, left ventricle, diaphragm, trachea and vertebrae (Figure 2). For the lateral projection, the signal was determined from the left ventricle, upper sternum and the vertebra (Figure 2).

Placement of ROIs was verified by stacking the images and consequently, all ROIs were positioned in the same place on each image. However, for unknown reasons, the 81 kVp image for PA with plates was not aligned with the stack. The positions of the ROIs were reproduced as best as could be, but unfortunately they did not include the exact same pixels.

The contrast-to-noise ratio (CNR) was estimated from Equation 2, where  $S_2$  is the average pixel value for the signal.  $S_{ref}$  is the mean pixel value in the ROI in the background (Figure 2).  $STD DEV_2$  is the noise for the ROI of the signal, while  $STD DEV_{ref}$  is the noise for the background.

$$CNR = \frac{|S_2 - S_{ref}|}{\sqrt{\frac{STD DEV_2^2 + STD DEV_{ref}^2}{2}}} \quad (\text{Equation 2})$$

### Optimization: Figure of merit

Dose area product (DAP), measured in mGy cm<sup>2</sup>, used as an indicator of dose. With CNR and DAP, it was possible to calculate the figure-of-merit (FOM) described by Raaum & Førde (17):

$$\text{Figure of merit (FOM)} = \frac{CNR^2}{DAP} \quad (\text{Equation 3})$$

FOM quantifies the relationship between image quality and dose, and is applied in order to find the optimal kVp when considering both radiation dose and image quality.

### Statistical analysis

Intra-observer variability was evaluated by duplicating three images; these were placed randomly in the image data set. The observers had no knowledge of the duplication. Statistical analysis was carried out using SPSS Software Version 22.00 (IBM, New York, USA). It was used to analyse the results of the evaluation by intra-class correlation (ICC) (18) and to certify the variability of the observers. Duplicate images were inserted to evaluate intra-observer variability. An ICC is a useful estimate of inter rater reliability in this study because it is highly flexible.

### 3 Results

#### Automatic exposure control and exposure index

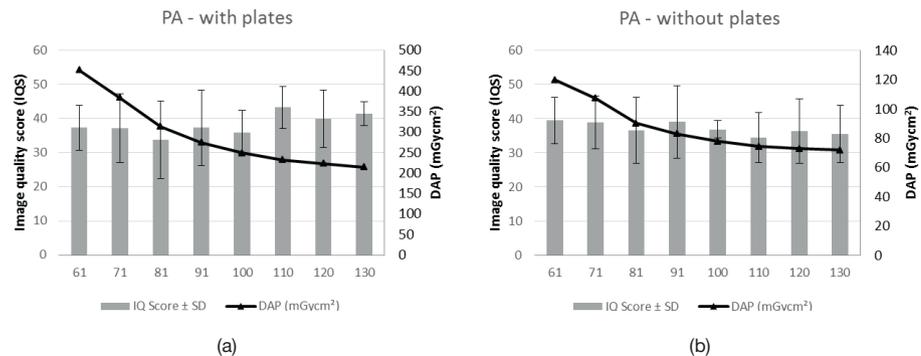
The exposure index increased with increasing kVp (Appendix A). For 120 kVp the exposure index varied from 122 to 167 depending on projection (PA or lateral). The AEC compensated when the kVp increased by increasing the mAs, in order to keep the dose constant (Appendix A). The DAP decreased with increasing kVp (Appendix A).

#### Image quality score and DAP

For the PA projection without plates, the IQS ranged from 34.5 (5% less than for 120 kVp) to 39.5 (9% more than for 120 kVp) and DAP ranged from 71.8 (1% less than for 120 kVp) to 119.8 (65% more than for 120 kVp) mGycm<sup>2</sup> (Figure 3a). The reference image of 120 kVp showed an IQS of 36.3, and a DAP value of 72.8 mGycm<sup>2</sup>. The best IQS was achieved at 61 kVp (39.5 (9% more compared to 120 kVp)), but at a 65% higher DAP value.

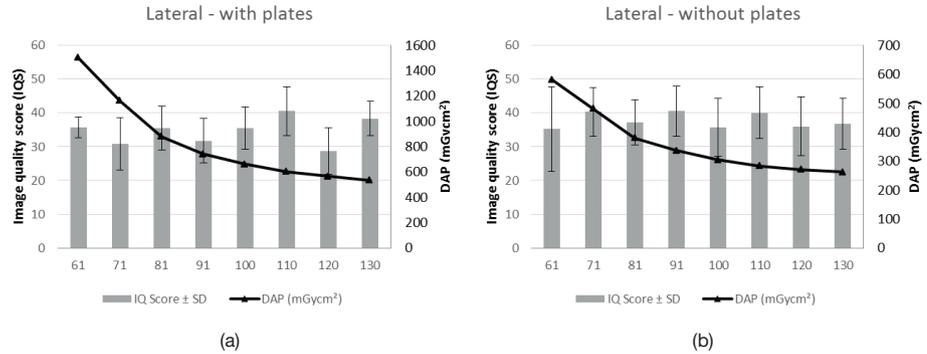
For the PA with plates, the IQS ranged from 33.8 (15% less than for 120 kVp) to 43.3 (8% more than for 120 kVp) and DAP ranged from 215.1 (4% less than for 120 kVp) to 452.3 (102% more than for 120 kVp) mGycm<sup>2</sup> (Figure 3b). The highest IQS (43.3) was obtained for 110 kVp at a DAP value only 4% higher than for 120 kVp.

For the lateral projection without plates the IQS ranged from 35.2 (2% less than for 120 kVp) to 40.5 (13% more than for 120 kVp) and DAP ranged from 262.8 (3% less than for 120 kVp) to 582.3 (115 % more than for 120 kVp) mGycm<sup>2</sup> (Figure 4a). The reference image of 120 kVp showed an IQS of 36.0, and a DAP value of 271.1 mGycm<sup>2</sup>. The best IQS was achieved at 91 kVp (40.5 (13% higher than for 120 kVp)), but with a 24% higher DAP-value than for 120 kVp. At 110 kVp a 11% higher IQS than for 120 kVp was achieved at only a 4% higher DAP.

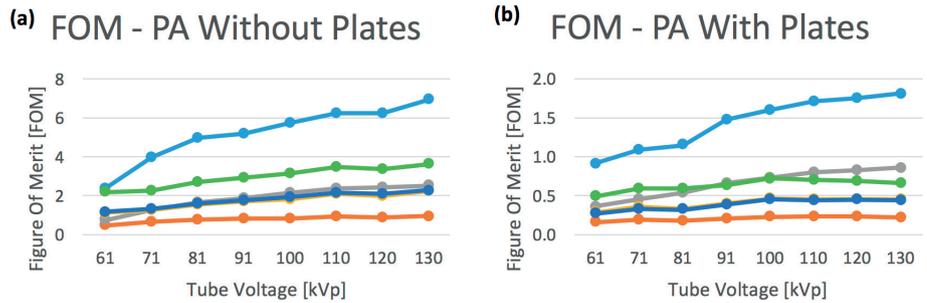


**Figure 3:** IQS and DAP as a function of the kVp for the PA projection a) without plates; b) with plates.

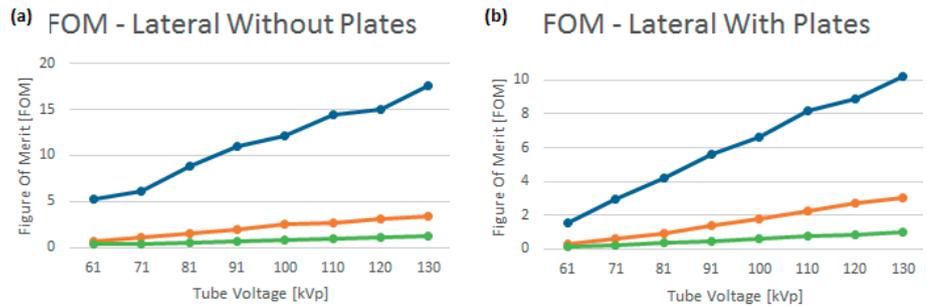
**Figure 4:** IQS and DAP as a function of the kVp for the lateral projection a) without plates; b) with plates.



**Figure 5:** Figure of Merit (FOM) for the PA projection a) without plates; b) with plates. (note: difference in scale)



**Figure 6:** Figure of Merit (FOM) for the lateral projection a) without plates; b) with plates. (note: difference in scale)



For the lateral view with plates, the IQS ranged from 28.7 (for 120 kVp) to 40.5 (41% more than for 120 kVp) and DAP ranged from 534.2 (6% less than for 120 kVp) to 1502.7 (166% more than for 120 kVp) mGycm<sup>2</sup> (Figure 4b). The highest IQS (40.5) was obtained for 110 kVp at a DAP value only 7% higher than for 120 kVp.

According to the European Commission (1), DAP values of both PA and lateral without and with plates were below the dose reference value (DRV) of 160 mGycm<sup>2</sup> (for 120 kVp).

#### Figure of Merit

For the PA projection without plates had the highest FOM (2.53-2.25) at 130 kVp for all tissues (Figure 5a).

For the PA projection with plates 100 kVp provided the highest FOM for imaging the vertebrae (0.72), trachea (0.46) and left ventricle (0.23). For imaging the diaphragm 120 kVp provided the highest FOM (0.45), while 130 kVp provided the highest FOM for bronchi (0.86) and parenchyma (1.81).

In both lateral phantom images, without and with plates (Figure 6), FOM values increased in a linear fashion as kVp increased (Figure 6). 130 kVp had the highest FOM values for the lateral both without and with plates.

#### Statistical analysis

For single and average measures, the values ranged from -0.012 to 0.469. For the single measures (variability of one, single observer) 100% of the measures were below 0.4, while for the average measures (variability of observers averaged together) 93% of the measures were below 0.4. Therefore there was no correlation in the results indicating suboptimal variability results (Appendix B).

## 4 Discussion

In this study, the kVp was lowered in order to study the influence on contrast-to-noise ratio, IQS and the figure of merit, defined as CNR squared divided by the DAP.

For normal sized persons, the best IQS can be achieved at a lower kVp than 120 kVp (AP: 61 kVp, lateral: 91 kVp). For larger patients, the best IQS can also be achieved at a lower kVp than 120 kVp (AP: 110 kVp, lateral: 110 kVp). However, by using 91 kVp for a normal sized person in the lateral projection this came with a 24% increase in dose. By increasing the kVp to 110 the IQS was still better than for 120 kVp, but the dose was only 4% higher.

Only for PA projection when imaging larger persons, does a lower kVp (100 kVp) provide a better FOM than the FOM obtained at 120 kVp, and this only occurs when imaging the vertebrae, trachea and left ventricle.

Bernhardt et al. explored the optimization potential of three different kVp values (90, 121, 150 kVp). However only large steps in tube voltage were tested and not much is known about the kVp values in ranges 90-121 and 121-150. In our study kVp's from 61 to 130 were included, using 10 kVp decrements (9). This results in more accurate findings, since a differentiation between more kVp's is possible.

An anthropomorphic phantom was used because it produces life-like images and has radiation absorption properties close to human tissue (19). Both in our study and that of Bernhardt et al., the visual grading was based on anatomical structures and not on the ability to identify pathology (9). In order to increase the validity and applicability of future studies, visual grading on pathological findings is necessary.

Image analysis with ImageJ was perturbed by wrong alignment of the stack of the 81 kVp PA with plates. The position was however reproduced manually and its results corresponded with the same pattern as the others. It can be argued that the measurements of the ROIs of the image 81 kVp PA with plates could be biased. For future research, it is essential to have the same position for all ROIs.

It is recommended to perform VGA in lighting below 50 lux (20). The light conditions were not kept constant for all observers. This could have an effect on the results.

Duplicate images were inserted to evaluate intra-observer variability; however, the outcome was not satisfactory and indicated suboptimal variability. This is probably due to the fact that the observers were not trained before performing VGA. It showed the importance of training the observers in future or follow-up studies.

Physical calculations and visual grading on image quality were both performed in this study. The IQS suggested that it is possible to reduce the kVp, 130 kVp also gave a good score for all combinations besides the PA without plates. FOM scored high for 130 kVp in all combinations. Based on the results, it was evident that a decrease in kVp is somewhat impossible without a consequent increase to dose. The use of lower kVp is possible, but it compromises the ALARA principle. Hence an alternative protocol of 130 kVp may produce a visually acceptable image with the lowest dose. Because of DR's post-processing abilities it is possible to use a higher kVp (e.g. 130) while maintaining image quality. The IQS and FOM results were contradictory and this could be due to the suboptimal conditions of the VGA.

In this study, automatic exposure control was used for the exposures. This meant that the mAs was adjusted in order to obtain a constant dose level. The DAP increased with decreasing kVpn accordance with Uffmann et al. (21) If the objective of the study was to just see how a change in kVp altered the image quality, one could consider performing exposures at the same mAs as for the 120 kVp exposure.

## 5 Conclusion

Visual grading analysis showed that the best IQS can be obtained at a lower tube voltage than 120 kVp, but only for PA projection when imaging larger persons does a lower kVp (100 kVp) provide a better FOM than 120 kVp, and this only occurs when imaging the

vertebrae, trachea and left ventricle. Therefore, it is not recommended to use kVp lower than 120 kVp other than when imaging a larger person in the lateral projection. More extensive VGA is needed in order to come to a definite conclusion.

## 6 Acknowledgements

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## APPENDIX A

Phantom	Projection	kVp	mAs	Exposure index	Figure of merit (FOM)									
					Parenchyma	Bronchi	Diaphragm	L Ventricle	Trachea	8 T vertebra area	L ventricle	Upper sternum area	8 T vertebra area	
Without plates	PA	61	9.4	38	2,4	0,7	1,2	0,5	1,1					
Without plates	PA	71	6.0	55	4,0	1,3	1,3	0,6	1,3					
Without plates	PA	81	3.9	66	5,0	1,6	1,6	0,8	1,5					
Without plates	PA	91	2.9	80	5,2	1,9	1,8	0,8	1,7					
Without plates	PA	100	2.3	93	5,7	2,1	1,9	0,9	1,8					
Without plates	PA	110	1.9	103	6,2	2,4	2,1	0,9	2,1					
Without plates	PA	120	1.6	122	6,2	2,5	2,1	0,9	2,0					
Without plates	PA	130	1.5	144	6,9	2,5	2,3	0,9	2,2					
With plates	PA	61	36.3	39	0,9	0,4	0,3	0,2	0,3					
With plates	PA	71	21.6	58	1,1	0,4	0,3	0,2	0,4					
With plates	PA	81	13.6	77	1,2	0,5	0,3	0,2	0,3					
With plates	PA	91	9.6	88	1,5	0,7	0,4	0,2	0,4					
With plates	PA	100	7.3	103	1,6	0,7	0,4	0,2	0,5					
With plates	PA	110	5.9	116	1,7	0,8	0,4	0,2	0,5					
With plates	PA	120	5.0	131	1,8	0,8	0,5	0,2	0,5					
With plates	PA	130	4.3	140	1,8	0,9	0,4	0,2	0,4					

**Table 1:** Applied exposure parameters (kVp and mAs) used when imaging the anthropomorphic phantom without and with additional chest plates

Phantom	Projection	kVp	mAs	Exposure index	Figure of merit (FOM)								
					Parenchyma	Bronchi	Diaphragm	L Ventricle	Trachea	8 T vertebra area	L ventricle	Upper sternum area	8 T vertebra area
Without plates	Lateral	61	41.9	109							0,7	5,2	2,2
Without plates	Lateral	71	24.5	111							1,0	6,0	2,3
Without plates	Lateral	81	15.1	121							1,5	8,9	2,7
Without plates	Lateral	91	10.9	121							1,9	10,9	3,0
Without plates	Lateral	100	8.2	136							2,5	12,1	3,1
Without plates	Lateral	110	6.6	152							2,7	14,4	3,5
Without plates	Lateral	120	5.5	167							3,1	15,0	3,3
Without plates	Lateral	130	4.8	179							3,4	17,6	3,6
With plates	Lateral	61	105.0	50							0,3	1,6	0,5
With plates	Lateral	71	58.9	67							0,6	2,9	0,6
With plates	Lateral	81	34.7	75							0,9	4,2	0,6
With plates	Lateral	91	23.6	93							1,4	5,6	0,6
With plates	Lateral	100	17.6	106							1,8	6,6	0,7
With plates	Lateral	110	13.8	121							2,2	8,2	0,7
With plates	Lateral	120	11.3	134							2,7	8,9	0,7
With plates	Lateral	130	9.6	143							3,1	10,2	0,7

**Table 1:** Applied exposure parameters (kVp and mAs) used when imaging the anthropomorphic phantom without and with additional chest plates

## APPENDIX B

**Table 2:** Consent form that the participants in the visual grading analysis study filled out before enrolling in the study.

Consent form  
OPTIMAX 2017 GROUP 2

**Information on the study**

In this study students and teachers were asked to visually grade chest X-ray images on different kVps (PA and lateral view; average and thicker person). They were asked to grade 35 images on image quality and the results will help determine if a lower kVp may be used for chest X-ray examinations using DR-detectors. The image quality criteria were adopted from the Quality Criteria for Diagnostic Radiographic Images. The image reviewing session will take approximately 45 minutes. The participants shall not be harmed in this study.

I have read this information sheet and have had time to consider whether take part in this study. I understand that my participation is voluntary and that I am free to withdraw from the research at any time without disadvantage. I agree to take part in this research. I agree that the data collected here can be used in the publication of higher degrees, scientific publications.

Name of participant (in block letters):

Signature:

Date:

**Table 3:** Questionnaire for the visual grading analysis study. All criteria are evaluated on a five-point Likert scale. Criteria number 1-4 are from and criteria 5-10 are from the European guidelines (22) on quality criteria for diagnostic radiographic images.

Criteria number	Please grade the following image quality criteria:
1	Image noise
2	Contrast resolution
3	Spatial resolution
4	Diagnostic acceptability
	Please indicate whether there is visually sharp reproduction of the listed anatomical criteria:
5	Vascular patterns in the periphery of the lungs
6	Trachea and proximal bronchi
7	Borders of the heart and the aorta
8	Diaphragm and costo-phrenic angles
9	Retrocardiac lung and the mediastinum
10	Spine through the heart shadow

**Table 4:** Results from the interclass correlation. Six viewers were included (numbered from V1 to V6), and the interclass correlation between them was estimated.

Variables		Interclass correlation	
		Single	Average
V1	V2	0,039	0,075
V1	V3	0,057	0,108
V1	V4	0,116	0,208
V1	V5	-0,15	-0,352
V1	V6	-0,012	-0,024
V2	V3	-0,036	-0,074
V2	V4	-0,117	-0,264
V2	V5	0,045	0,085
V2	V6	0,044	0,084
V3	V4	0,306	0,469
V3	V5	0,025	0,049
V3	V6	-0,04	-0,083
V4	V5	-0,07	-0,151
V4	V6	0,123	0,219

# Analysis of image quality and effective dose in adult chest phantom radiography with high BMI.

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## Keywords:

Chest radiography protocol, image quality, overweight patient, effective dose

## Abstract

**Aim:** To investigate the impact of different kVp and mAs values on effective dose and image quality using a chest phantom that simulates a normal sized and an obese patient.

**Methods and materials:** A chest phantom with simulated pathological nodules was imaged at various kVp and mAs values. To determine the image quality, CNR and SNR were calculated. An observer study was carried out using relative visual grading with a 3-point Likert scale to assess image quality and nodule visibility. The VGA-study reference image was of the phantom at standard size

without the chest plates using 125kVp, 2.4mAs by AEC and 24 $\mu$ Sv. Visual grading scores were compared against SNR and CNR values in order to determine the optimal acquisition parameters. Effective dose was calculated using Monte Carlo simulation software, and a Figure of Merit was calculated.

**Results:** The image obtained with 125 kVp and 4.0 mAs had the highest SNR, and the one with 125 kVp and 2.0 mAs had the highest CNR. The observers found that 125 kVp/4.0 mAs was the most optimal image and 125 kVp/6.88 mAs had the least image quality, when compared to the reference image. On calculating the Figure of Merit, 125 kVp/2.0 mAs has the highest score. The effective dose varied from 5.34  $\mu$ Sv to 73.5  $\mu$ Sv for the range of parameters used.

**Conclusion:** It is possible to get higher SNR, CNR and VGA-scores in large sized patient chest radiography at lower mAs than that given by using standard AEC, due to post-processing. Manual mAs better control the image quality than using AEC. Anatomical features are better detected using a higher mAs and a standard kVp. Better image contrast is achieved when a lower kVp and standard mAs is utilised. A protocol for larger patients needs to be tailored accordingly.

## Introduction

The prevalence of obesity in European Union (EU) member states is increasing rapidly. In 2014, it was estimated that 51.6% of the EU's population was overweight.<sup>1</sup> The World Health Organization (WHO) regards obesity as a global epidemic.<sup>2</sup> Obesity also increases the risk of developing diseases and results in an increased need for medical procedures, including x-ray examinations, compared with normal weight individuals.<sup>3</sup>

Overweight people have a greater body volume than those with normal weight. Consequently, for a good quality diagnostic image, the x-ray beam requires more energy and intensity to pass through obese patients as the image receptor has to receive adequate radiation.<sup>4</sup> Therefore, using a standard postero-anterior (PA) chest protocol for a high body mass index (BMI) patient will give an inadequate exposure resulting in suboptimal image quality, thus impacting on pathology identification and its

characterisation. A suboptimal image will likely require an additional image, thereby exposing the patient to an unnecessary second radiation dose.

The European Guidelines only state the diagnostic requirements and criteria for a standard sized adult patient at 70 kg and 170 cm height.<sup>(1)</sup> A *one size fits all* approach will not work in terms of producing acceptable image quality together with the directive 'As Low As Reasonably Practicable' (ALARP).<sup>6</sup> Therefore, it is important that imaging departments are prepared to manage larger patients.

Using an anthropomorphic phantom, our study aims to investigate the impact of different kVp and mAs values on dose and image quality for PA chest radiography with a view to evaluate a new protocol.

## Materials and methods

### Equipment

A multipurpose anthropomorphic adult male chest phantom (Lungman)<sup>7</sup> was imaged. This phantom is commonly used in medical imaging research<sup>8</sup> and Lungman has a chest girth of 94 cm, with dimensions of 43 cm (w) x 40 cm (d) x 48 cm (h). The approximate weight of the phantom is 18 kg; which is representative of a standard patient of 65.4 kg. The approximate BMI of Lungman is 23.1 kg/m<sup>2</sup>, which is considered normal weight. Chest plates, representing human adipose tissue,<sup>7</sup> measuring 30 mm in thickness were added to the anterior and posterior aspects of the Lungman to simulate a larger body type (See Fig. 1). The weight of the larger Lungman is 36 kg; which is representative of a larger, non-standard patient weight of approximately 82 kg (figure 1).<sup>7</sup> The approximate BMI of the larger Lungman is 29 kg/m<sup>2</sup>, which is considered overweight.

**Figure 1:** The Lungman multipurpose anthropomorphic adult male chest phantom and 30 mm chest plates.



Three spherical nodules in sizes 8 mm, 10 mm, 12 mm with a soft tissue density of +100 Hounsfield Units were inserted within the pulmonary vasculature of the Lungman at three different left lung locations to mimic real pathology.<sup>7</sup>

A Siemens Multix Top X-ray Tube and a Siemens Vertex Top Bucky wall stand were used. A 35 cm x 43 cm Canon CXDI-701C wireless CsI digital detector was used with an anti scatter grid (grid ratio of 1:17 and 70 grid lines/cm). A broad focal spot of 1.0 mm was selected, which also complies with the European Guidelines and the manufacturer's recommendations. The Tungsten anode had an angle of 12°. Total filtration of the beam was 3.0 mm Aluminium.<sup>5</sup>

The Lungman was placed in a fixed PA position, to eliminate re-positioning errors, against the vertical bucky (see Fig. 2)<sup>9</sup> with a constant 180 cm source to image distance (SID).<sup>5</sup> The primary x-ray beam was collimated to the lateral margins of the phantom.<sup>10</sup>

The acquisition parameters for the initial exposure were based on the European Guidelines for PA chest radiography of a standard sized patient.<sup>5</sup> The kVp was set to 125 with the automatic exposure control (AEC). Both lateral AEC chambers were selected<sup>11</sup> and a resultant 2.4 mAs was measured.

To test other parameters used in the clinical setting images were acquired by altering kVp to 133, 117 and 90 whilst keeping the mAs constant at 2.5 mAs.<sup>12</sup> This constant value of 2.5 mAs was based on the AEC result in the first exposure.

As the Signal-to-Noise Ratio (SNR) changes with the number of photons detected, different mAs values from 0.5 to 4.5 mAs were used with a fixed voltage.

Eleven images of Lungman without the plates were acquired using the parameters in Tab. 1.

The chest plates were placed on Lungman (referred to as 'non-standard Lungman') and the experimental procedure was repeated as indicated above.

### **Dose Calculation**

The mAs values were used to calculate the effective dose (ICRP 103)<sup>13</sup> using Monte Carlo simulation software (PCXMC 2.0).<sup>14</sup> The focus to skin distance for the standard Lungman was 160 cm and for the non-standard, 154.0 cm.

The collimation size for the images was 33.7 cm width and 34.6 cm height. The maximum energy of the tube was 150 keV and the number of photons produced 900 000.

**Figure 2:** Lungman in PA position against the vertical bucky.



**Table 1:** Acquisition parameters for standard Lungman exposure and effective dose.

kVp	mAs	Effective dose ( $\mu\text{Sv}$ )
90	2.5	9.857
117	2.5	20.817
125	0.5	4.961
	1.0	9.922
	1.6	15.876
	2.0	19.844
	2.4 (AEC)	22.522
	3.2	31.751
	4.0	39.689
133	4.5	44.65
	2.5	29.121

### SNR/CNR

SNR and Contrast-to-Noise Ratio (CNR) were calculated using Eq. 1 and  $2.15 \bar{x}$  stands for average pixel value (signal) and  $\sigma$  for the standard deviation (noise).  $\bar{x}_1$  and  $\sigma_1$  represent the background values,  $\bar{x}_2$  and  $\sigma_2$  represent the object values.

$$\text{SNR} = \frac{\bar{x}}{\sigma} \quad \text{Equation 1}$$

$$\text{CNR} = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}}} \quad \text{Equation 2}$$

ImageJ software<sup>16</sup> were used to define Regions of Interest (ROIs) for calculating CNR and SNR. Eight ROIs (1-8) were placed on various anatomical regions.<sup>17</sup> A further three ROIs (9-11) were placed on the nodules (see Fig. 3). The ROI's were placed in the same position and had the same diameter. SNR of an image is the average of the eight SNR values that were calculated.<sup>3</sup> CNR from the ROI of the nodules against the lung parenchyma were calculated and averaged to obtain the image CNR.



**Figure 3:** Image of Lungman to demonstrate ROI positions used in the SNR and CNR calculations.

A reference image for relative visual grading was selected based the SNR/CNR measurements, group consensus and the effective dose.

### Observer Study

An observer study was performed using relative visual grading.<sup>18</sup> The reference image was compared with 6 images; ‘itself’ and 5 images of the non-standard Lungman. The images were viewed on dual screen EIZO 5 Megapixels monitors, which were calibrated to DICOM Grey Scale Standard. Twenty observers

aged 20 - 64 years old with upto 40 years experience in assessing radiographs reviewed the images. The observer room had no windows and the lights were switched off. A 3-point Likert scale (worse/equal/better) was used to grade the images. The 8 image quality questions used to compare the images (Tab. 2) were adapted from the EU guidelines<sup>5</sup>. The observer could select only one answer for each of the questions.

IBM SPSS Statistics 22<sup>20</sup> was used to calculate the inter class correlation of the observers answers.

**Table 2:** Questions for the relative visual grading study<sup>5, 19</sup>

#	Questions
Q1	Compare the sharpness of the heart between the image and the reference image
Q2	Compare the sharpness of the aorta between the image and the reference image
Q3	Compare the sharpness of the left diaphragm between the image and the reference image
Q4	Compare the sharpness of the right diaphragm between the image and the reference image
Q5	Compare the sharpness of the edges of these 3 nodules between the image and the reference image
Q6	Compare the contrast with the background for all of the nodules between the image and the reference image
Q7	Less noise means a better image quality. Knowing this, what do you think of the image quality of this image
Q8	Compare the differentiation between soft tissue, air and bone on this image and the reference image

### Figure of Merit

A figure of Merit was calculated to correlate the findings of the observer study with the effective dose. The images that scored better than the reference had a value of 2, the images that scored equal had a value of 1 and the images that scored worse than the reference image had a score of 0. The sum of the image quality of the visual grading study was divided by the effective dose to give a figure of Merit.

### Results

#### SNR and CNR

To determine the standard protocol, SNR and CNR were calculated for all of the images of the standard Lungman (see Fig. 4). The image with the acquisition parameters 125 kVp and 2.4 mAs had the highest SNR (24.88). The image with the acquisition parameters 125 kVp and 1.6 mAs had the highest CNR (7.95). Based on SNR, CNR, the effective dose and their appearance, five images of the non-standard Lungman were selected to compare against the reference image of the Lungman.

Fig. 5 shows the SNR and CNR of the images of the non-standard Lungman that were selected for the observer study. 125 kVp and 4.0 mAs resulted in the highest SNR (20.41). 125 kVp and 2.0 mAs resulted in the highest CNR (8.77). Furthermore, 125 kVp and 6.88 mAs both SNR/CNR are reduced.

### Observer Study

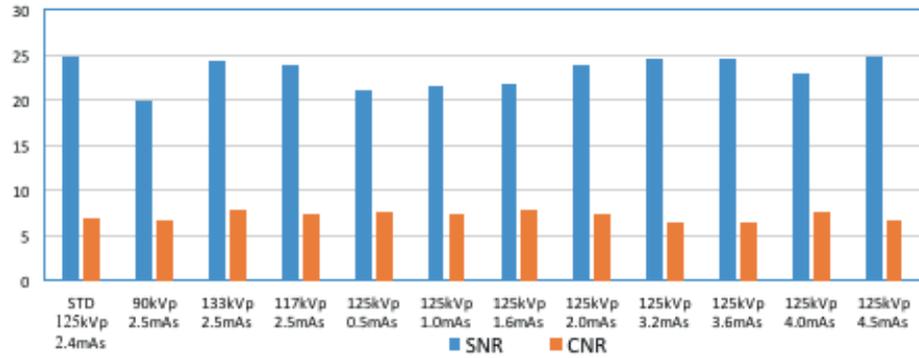
The consistency of the observers, in terms of image analysis was tested, using the IBM SPSS software. The test scored 0.778 ( $p < 0.0005$ ), highlighting although ages and experience of the observers varied, their results were consistent.

Tab. 3 illustrates the relative visual grading results. It lists the observers answers highlighting which images were equal/better to the reference image for each question. The total value is the sum of all observer scores for each image. The values highlighted represent the highest score for each question and total.

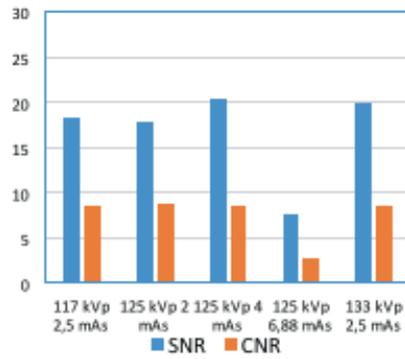
The visual grading study indicates that 125 kVp/4.0 mAs for the non-standard Lungman is the best in terms of image quality. 51% of the answers from the visual grading study deemed this image to be of equal/better image quality compared with the reference image. According to the observers this image better differentiates between the soft tissue, air and bone than the other images.

The image acquired with 125 kVp and 4.0 mAs received the highest proportion of equal/better responses, totalling 82, (green box Tab. 3) highlighting that it had either an equal or better image quality than the reference image. The blue boxes illustrate which of the images scored the highest response for

**Figure 4:** SNR and CNR in Lungman x-ray images with different parameters

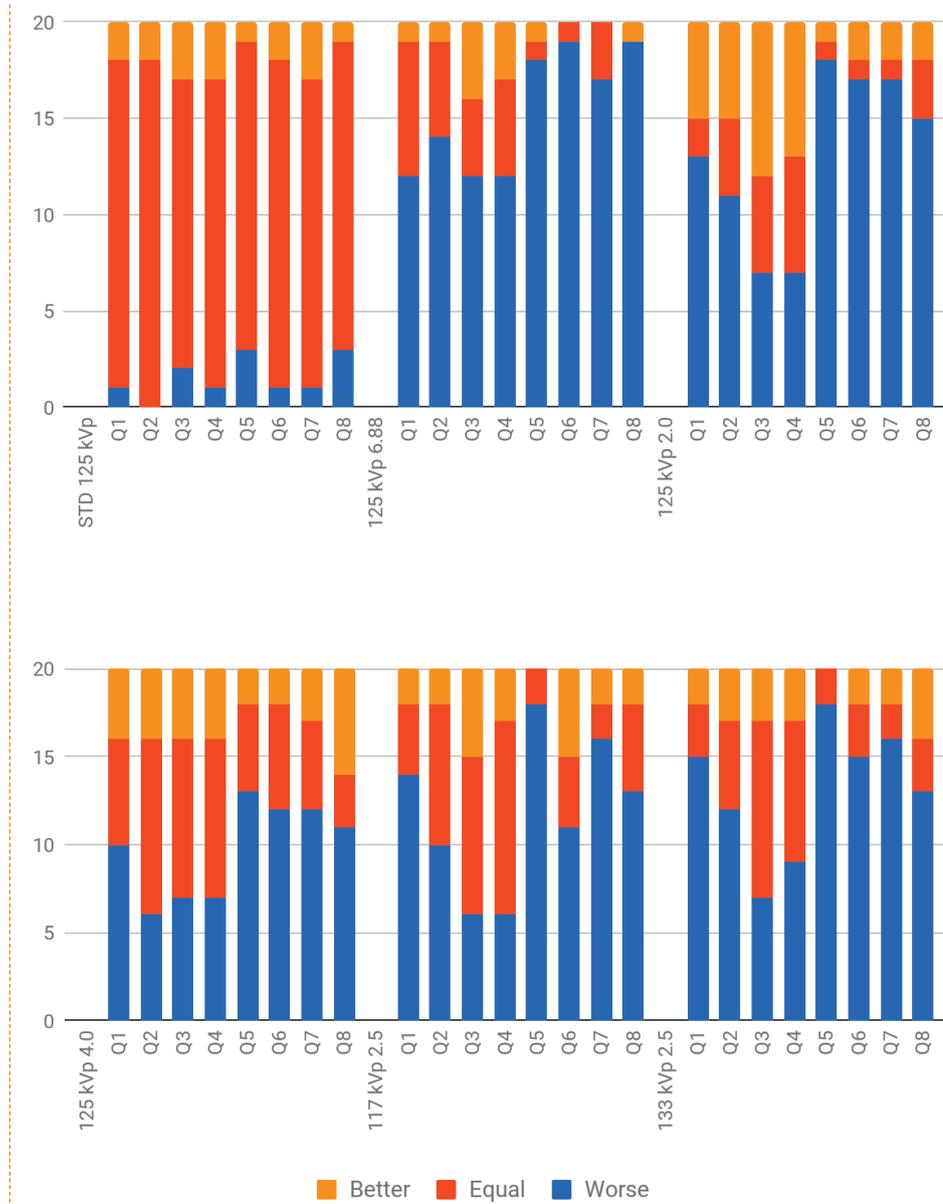


**Figure 5:** SNR and CNR in non-standard Lungman x-ray images with different parameters



**Table 3:** Results of relative visual grading performed by 20 observers with eight quotations as listed in Tab. 2.

Image	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Total
STD 125 kVp 2.4mAs	19	20	18	19	17	19	19	17	148
117 kVp 2.5mAs	6	10	14	14	2	9	4	7	66
125 kVp 2.0mAs	7	9	13	13	2	3	3	5	55
125 kVp 4.0mAs	10	14	13	13	7	8	8	9	82
125 kVp 6.88mAs	8	6	8	8	2	1	3	1	37
133 kVp 2.5mAs	5	8	13	11	2	5	4	7	55



**Figure 6:** Representation of visual grading study results

particular questions. The observers found that image 4 was of equal/better image quality in terms of the sharpness of the aorta and heart, sharpness of the nodules and the noise and contrast of the overall image. Hence, this table highlights that 125 kVp and 4.0 mAs produced the best results in terms of image quality for the non-standard Lungman. 117 kVp/2.5 mAs scored the highest response rate for the other three questions. The lower kVp and mAs resulted in an equal/better sharpness of the diaphragms and contrast of the nodules relative to both the reference image and image with 125 kVp/4.0 mAs, according to the observers.

Fig. 6 represents the results from the visual grading study. The answers to each of the questions are displayed for each image.

The estimated effective dose varied from 21.4  $\mu\text{Sv}$  to 73.6  $\mu\text{Sv}$  for the non-standard Lungman (see Fig.7) with a calculation error of  $\leq 0.1\%$ .

The result of the Figure of Merit (Tab. 4) calculation doesn't necessarily mean that the image is better than the others, but that the image has the most optimal image quality at the lowest dose. On calculating the figure of Merit it was found that 125 kVp/2.0 mAs has the highest score.

### Discussion

The aim of this study was to investigate the effect of different kVp and mAs values in PA chest radiography for Lungman, with and without chest plates. To date, the European Guidelines (1996) only have a standard protocol for standard sized patients.<sup>5</sup> These guidelines are outdated and not reflective of recent patient trends in terms of size.<sup>2</sup> Technical parameters should be

Figure 7. Effective dose for the STD image and the five non-standard Lungman images estimated with PCSMC 2.0.

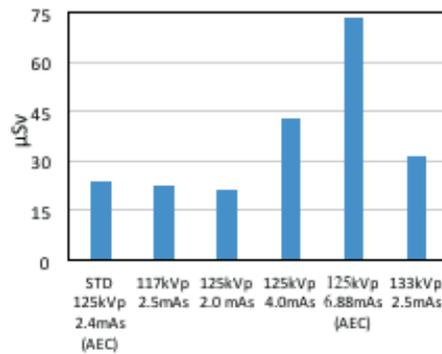


Image	Visual Grading Score	Effective Dose ( $\mu$ Sv)	Figure of Merit
STD 125kVp 2.4mAs (AEC)	165	23.8	6.93
117kVp 2.5mAs	87	22.4	3.88
12 kVp 2.0mAs	87	21.4	4.07
125kVp 4.0mAs	111	42.8	2.60
125kVp 6.88mAs	48	73.6	0.65
133kVp 2.5mAs	74	31.4	2.36

**Table 4:** Figure of Merit

adjusted to different patient types, not only in terms of collimation, but also in terms of kVp and mAs values.

Our study found that based on both SNR/CNR calculations and the observer study that 125 kVp and 4.0 mAs produce the image of highest quality for non-standard Lungman. However, the Figure of Merit found that 125 kVp and 2.0 mAs were the optimal acquisition parameters for diagnostic image quality and low effective dose.

### SNR/CNR

Carcuri<sup>26</sup> states that utilisation of the AEC helps overcome reduced image receptor signal. However, utilisation of the AEC (6.88 mAs) for the non-standard Lungman resulted in an image of very poor image quality as is reflected in the SNR/CNR values. In contrast, the 125 kVp/4.0 mAs image of the non-standard Lungman has an SNR of 20.20, this was the highest value.

The image obtained with 125 kVp/6.88 mAs has the lowest CNR; 2.72. The CNR value of the 125 kVp/4.0 mAs image is 8.76. Thus, imaging the non-standard Lungman with a higher kVp and a lower mAs results in a lower dose and an higher SNR and CNR values.

### Observer study

An optimal exposure technique gives good anatomical detail. It was found that the observers matched the SNR/CNR findings and graded the image obtained using 125 kVp/4.0 mAs to be of equal/better image quality to the reference image. The observers found that the overall sharpness of this image was of equal/better quality compared to reference image. This is to be expected as a higher mAs value was selected which improves the sharpness of anatomical features.

Interestingly the image that was acquired with 125 kVp/ 6.88 mAs was found to be of worse image quality across all criteria when compared to the

reference image. Thus, the observers subjective analysis is therefore reflective of the low SNR value that was observed in the physical measurements.

The observer study found that the image produced using 117 kVp/2.5 mAs was the second most optimal, according to observer, in terms of image quality. It has the best contrast differentiation for the nodules.

### **Figure of Merit**

The parameters 125 kVp/4.0 mAs produce the best quality image according to the physical and subjective datasets. However, this image is not optimal in terms of dose. Whilst the dose increases due to non-standard Lungman size it is still important that the dose remains ALARP. The figure of Merit found that 125 kVp/2.0 mAs produced the most optimal image in terms of image quality and effective dose. However, the findings of the visual grading study state that 125 kVp/ 2.0 mAs lacked clarity for nodule identification, mainly as a result of the lack of contrast that could be visually detected.

The lower value of 2.0 mAs is reflective of the post processing that occurs within the imaging system. It seems that post processing of images on the system can result in a diagnostic image at a lower effective dose.<sup>21</sup> This further reinforces the fact that the current guidelines are outdated and not

representative of current imaging practices and imaging systems.

### **Conclusion**

The physical measures and the observer study concluded that 125 kVp/4.0 mAs were the optimal acquisition parameters for high image quality. However, the figure of Merit determines the image quality in terms of the effective dose and concluded that 125 kVp/2.0 mAs were the optimal parameters. This highlights that diagnostic images can be obtained using lower doses when both the image quality and the effective dose are taken into consideration.

Furthermore, our study found that AEC does not always result in optimal image quality or a lower effective dose. Hence, a protocol for larger patients' needs to be tailored accordingly. Manual exposure parameters better control the image quality. Anatomical features are better detected using a higher mAs and a standard kVp. Better image contrast is achieved when a lower kVp and standard mAs is utilised.

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# Paediatric Phantom Dose Optimisation Using Digital Radiography with Variation of Exposure Parameters and Filtration whilst minimising Image Quality Impairment.

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## Abstract

**Objective:** To induce a reduction in dose, using a paediatric phantom, through the variation of exposure parameters and filtration, without adversely affecting image quality.

**Methods:** All images were acquired using a Kyoto Kagaku paediatric phantom and a Canon DR detector. The phantom was positioned supine for all projections: wrist (DP, lateral) and ribs (AP, oblique). Three dose protocols were established using different mAs values (high, medium and low) and copper (Cu) filtration was added to each protocol. DAP was used to calculate the ESD for each exposure.

Using ImageJ, CNR was calculated for the physical measurement of image quality. Image quality was assessed by fifteen observers (visual grading analysis (VGA)).

**Results:** The highest doses were recorded with the high dose protocol, ranging from 5.60-39.22 $\mu$ Gy for the wrist and 5.33-129.67 $\mu$ Gy for the ribs. When increasing the Cu filtration a decrease in ESD was observed. A difference of 0.1 in VGA score was noted between high and low dose protocols without the use of filtration, while a difference of 0.3 was noted when using filtration. As mAs increased, VGA scores increased. Fracture visibility was minimally affected by Cu filtration or projection variation.

**Conclusion:** The variation of exposure parameters in digital radiography can achieve a dose reduction without impairing image quality in bone fractures. Superior image quality can be achieved for DP and lateral wrist projections without Cu filtration. However, the addition of Cu filtration for the rib projections has almost no impact on overall image quality.

## Introduction

Due to the detrimental effects of radiation, it is imperative that the dose received by the patient be as low as reasonably achievable (ALARA), whilst still obtaining images of a clinically acceptable standard (1). This is of particular importance when considering paediatric patients who, due to their additional life expectancy and increased tissue radio-sensitivity, are considerably more sensitive to the detrimental effects of ionising radiation (2). Although the radiation dose received for diagnostic purposes is low, it is pertinent that each exposure be

minimised due to the cumulative nature of radiation. This is because the cumulative dose received through multiple exposures can substantially increase the lifetime risk of certain cancers (3). Our work follows on from previous research (4–6) and further evaluates the plausibility of ascertaining decreased patient dose through modified exposure parameters, whilst assuring that the acquired images are clinically acceptable.

Several fundamental differences exist between conventional film-screen radiography and digital radiography. Hence, new protocols and strategies are required for effective optimisation in digital imaging (7). Various optimisation studies identify methods of dose reduction, by providing a systematic approach to recognising the factors that could be manipulated easily in a clinical setting (8). Our study assessed the impact of mAs and additional beam filtration on paediatric phantom dose and image quality. Copper (Cu) filtration is currently recommended for both adult and paediatric exposures, particularly if highly radiosensitive organs are directly exposed (9), and added filtration has been shown to reduce the overall effective dose for each individual paediatric exposure by up to 38% (8).

Paediatric digital radiography remains a challenge for many radiographers (10). The subsequent need for focused paediatric care is outlined by 'The Image Gently Campaign' (11), which reports a lack of both expertise and educational resources surrounding this area. This requirement is reinforced by The International Commission on Radiological Protection (ICRP), which identifies a need for both optimisation and consistence in digital paediatric imaging (12). Although a considerable proportion of recent research surrounds paediatric diagnostic imaging, Jones et. al highlights an absence of literature regarding optimisation in paediatric extremity imaging (6).

The question to be addressed through our study is as follows; using a paediatric phantom with multiple bone fractures, could the variation of exposure parameters and filtration in Digital Radiography achieve a reduction in dose without substantially affecting image quality?

The aim of our study was to induce a dose reduction for a paediatric phantom with bone fractures through the variation of exposure parameters and filtration without adversely affecting image quality.

## Methods and Materials

### Study Phantom

A Kyoto Kagaku 5-year-old (105cm/20kg) paediatric anthropomorphic phantom (PBU-70B) (Figure 1), was imaged. Fractures were present on the left side of the phantom (13)(14). Two regions were selected for this study, namely wrist and rib. Wrist fractures are one of the most commonly occurring fractures in paediatric patients and rib fractures have a considerable risk of misdiagnosis (15).

### Imaging Systems and Positioning

All images were acquired using an Arcoma X-ray imaging system with DAP integration. The X-ray tube has the option to add 0.1, 0.2 or 0.3mm Cu filtration (16). All images were acquired on the same indirect Canon DR detector (CXDI-701C Wireless General Purpose) with a caesium iodide scintillator with a



**Figure 1:** Picture of the phantom used for this study (14)

detective quantum efficiency (DQE) of  $>70\%$ . This detector has a pixel size of  $125 \times 125 \mu\text{m}$  and an image matrix size of  $2800 \times 3408$  pixels, with an effective imaging area of  $35 \times 43 \text{cm}$ . The resolution of the detector is  $4.0 \text{lp/mm}$  with 4096 gradations (17)(18). No anti-scatter grid was used during this study, as this would increase patient dose (19).

The phantom was imaged in the supine position for both antero-posterior (AP) and oblique rib projections. For the oblique projection, a radiolucent pad was

placed beneath the phantom, positioning the phantom at 20-degree obliquity. The collimated field remained constant at  $15 \times 26 \text{cm}$ , with a source-to-image-distance (SID) of 110cm. Dorso-palmar (DP) and lateral standard wrist projections were also acquired, with the collimated field fixed at  $14.5 \times 8 \text{cm}$  and an SID of 110cm (20). A fine focal spot was used for both wrist projections, while a broad focal spot was used for both rib projections.

### Protocol

A total of thirty-six images were acquired, nine for each projection. Three separate image acquisition dose protocols were used; low, medium and high. The high dose protocol employed standard exposure parameters, with tube potentials of 48kV and 52kV for the DP and lateral wrist projections, respectively. A tube intensity time product of 2mAs was applied for both DP and lateral wrist projections, when this was used (20). The high dose protocol employed 60kV and 0.63mAs for the AP rib projection and 68kV and 3.2mAs for the oblique rib projection (2). For each projection, the mAs was then lowered in two separate steps and low and medium protocols were constructed (Tables 1 and 2). For each protocol, the effect of Cu filtration was assessed using no filtration as well as 0.1mm and 0.2mm added Cu filtration.

### Dose Measurement

Dose Area Product (DAP) values were derived using a calibrated integrated ionization chamber. DAP was then used to calculate the Entrance Skin Dose (ESD) for each exposure, using equation 1.

$$ESD = \left( \frac{DAB}{A} \right) * BSF \quad (\text{eq. 1})$$

The size of the collimated field is represented by A and the backscatter factor is represented by BSF. The

backscatter factor used throughout this study was 1.3, as recommended by Toivonen *et al* (21).

### Image Quality

Contrast-to-noise ratio (CNR) was used to determine a physical measurement of image quality. CNR assesses the effect of changes in beam quality on image quality. ImageJ (22) was used to define regions of interest (ROIs) for CNR calculations. Four ROIs were placed on homogenous regions within each of the thirty-six total images, two on soft tissue and two on bone (Figure 2). For the two ROIs placed on soft tissue and the two placed on bone, a mean value was calculated to get more reliable measurements. CNR was then calculated using equation 2, where  $S_1$  represents the mean pixel value within the ROIs placed on bone, and  $S_2$  represents the mean pixel value within the ROIs placed on soft tissue. The  $\sigma_1$  represents the standard deviation of bone (6)(23).

$$CNR = \frac{(S_1 - S_2)}{\sigma_1} \quad (\text{eq. 2})$$

Fifteen observers assessed visual image quality for each image through visual grading analysis (VGA). The observer group consisted of thirteen Radiography students of varying levels (years 1-4), as well as two experienced radiographers. ViewDEX was used to display the images, illustrate visual

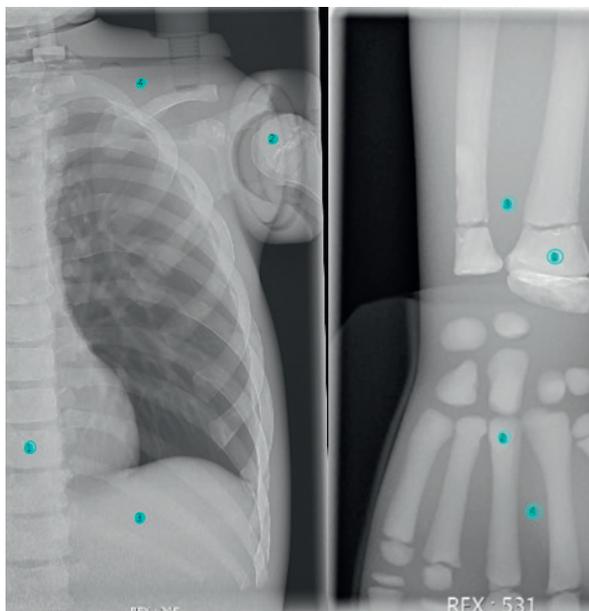
**Table 1:** Wrist protocol with dose and image quality measurements

Wrist	Projections	Kv	mAs	Cu Filter	CNR	DAP (mGy/cm <sup>2</sup> )	ESD (μGy)	VGA <sub>r</sub>
Low	Dorso-palmar	48	0.5	none	10.4	0.7	7.84	3.5
				0,1mm	5.5	0.3	3.36	2.5
				0,2mm	3.7	0.1	1.12	1.7
	Lateral	52		none	13.3	0.9	10.09	3.1
				0,1mm	10	0.3	3.36	2.4
				0,2mm	6.9	0.2	2.24	1.8
Medium	Dorso-palmar	48	1	none	14.4	1.4	15.69	3.8
				0,1mm	8.3	0.5	5.6	3.1
				0,2mm	5.5	0.3	3.36	2.3
	Lateral	52		none	15.1	1.7	19.05	3.8
				0,1mm	12	0.8	8.97	3.1
				0,2mm	10	0.3	3.36	2.4
High	Dorso-palmar	48	2	none	16.2	2.8	31.38	4.2
				0,1mm	11.4	1.1	12.33	3.3
				0,2mm	7.6	0.5	5.6	3.1
	Lateral	52		none	16.3	3.5	39.22	4.1
				0,1mm	15.6	1.4	15.69	3.7
				0,2mm	11.4	0.8	8.97	3.1

**Table 2:** Ribs protocol with dose and image quality measurements

Ribs	Projections	Kv	mAs	Cu Filter	CNR	DAP (mGy/cm <sup>2</sup> )	ESD (μGy)	VGA <sub>r</sub>
Low	AP	60	0.4	none	4.7	3.9	13	3
				0,1mm	3.9	1.8	6	2.6
				0,2mm	2.9	1	3.33	2.2
	Oblique	68	2	none	2.3	24.6	82	3.5
				0,1mm	1.8	12.5	41.67	3.4
				0,2mm	1.5	7.7	25.67	3.1
Medium	AP	60	0.5	none	5	4.9	16.33	3.1
				0,1mm	4.1	2.3	7.67	2.9
				0,2mm	3.5	1.3	4.33	2.5
	Oblique	68	2.5	none	2.2	30.6	102	3.7
				0,1mm	1.9	15.6	52	3.4
				0,2mm	1.5	9.7	32.33	3.1
High	AP	60	0.63	none	5.9	6.1	20.33	3.5
				0,1mm	4.6	2.8	9.33	2.8
				0,2mm	3.6	1.6	5.33	2.7
	Oblique	68	3.2	none	2.3	38.9	129.67	3.7
				0,1mm	1.8	19.9	66.33	3.3
				0,2mm	1.6	12.4	41.33	3.4

**Figure 2:** ROIs for the wrist DP and rib AP views, with ROI 1 and 2 on bone and ROI 3 and 4 on soft tissue



scoring criteria and also collect observer scores (24). Prior to image-viewing, the observers were trained in the visual assessment task in order to maximise validity and reliability. The observers could pan and zoom, but the use of windowing was prohibited. They were made aware of the fracture location prior to rating the images. The observers first scored the eighteen wrist images, followed by a short break, before scoring the eighteen rib images. All images were randomized and observers were blinded to acquisition conditions and exposure factor information. A five-point Likert scale was used to assess five criteria: overall image quality,

contrast, sharpness, noise and fracture visibility. With this scale, a score of 1 indicates Poor, while that of 5 indicates Excellent. Numerical scales as such are often used to simplify information and to improve inter-observer agreement (24). Ambient lighting conditions in the observation room remained constant throughout the image-viewing process at less than 10 lux (25)(26). The monitor used for observer analysis was also fixed throughout the study, with an area of 32.4x43.2cm.

Images were displayed on a 21.3-inch Monochrome LCD monitor MS25i2 (ML21025), manufactured by

Totoku™ (27), calibrated to the DICOM greyscale standard (28). All observer information was anonymised. The total VGA ( $VGA_T$ ) was calculated using equation 3.

$$VGA_T = \frac{\sum_{O,I} S_c}{N_I N_O} \quad (\text{eq.3})$$

In equation 3,  $S_c$  represents each criterion score given by the observers, O represents the observer and I represents the image.  $N_I$  represents the total number of images and  $N_O$  is the total number of observers (29). A separate VGA score was calculated using the three primary visual image quality parameters; contrast, sharpness and noise ( $VGA_{CSN}$ ) (30). This score was calculated by adding the observer scores from these three criteria and generating a mean value. The  $VGA_{CSN}$  was then correlated with fracture visibility for each projection.

### Statistics

Descriptive statistics were used to analyse the data. This data was imported to Statistical Package for the Social Sciences (SPSS). Mean VGA, CNR and  $R^2$  correlations were calculated using Excel. A very high correlation is noted between 0.90 and 1, while a high correlation is between 0.70 and 0.90. A moderate correlation is seen between 0.50 and 0.70 (31). An independent samples Kruskal-Wallis non-parametric

test was used to analyse statistically significant differences at 95% confidence level between the 15 observers regarding VGA.

### Ethics

As this study involved the use of an anthropomorphic phantom and no human subjects, ethical review was not necessary. All observers gave their informed consent prior to this study, through their participation in the OPTIMAX 2017 summer school.

## Results

### Dose Protocols

**Table 1** highlights the protocols for wrist with dose and image quality measures: kV, mAs, ESD and VGAT. As expected, dose measurements and CNR decreased with added filtration. The average reduction for all three filters was identical for DP and lateral wrist projections, at 76%. The most substantial reduction in image quality occurred with 0.2mm added Cu filtration. Overall, the addition of filtration reduced dose for all projections, however this results in an overall reduction in image quality. VGAT is lower with the addition of filtration.

**Table 2** demonstrates the relationship between dose measurements (DAP and ESD), CNR, and  $VGA_T$  for each of the three dose protocols for both rib projections. The primary focus of this table is on AP and oblique rib projections and again, both dose

and CNR values decreased with added filtration. For the AP rib projection, with no added filtration, there was a 36% dose decrease from high to low dose protocols, with an equal decrease between both high and medium, and medium and low dose protocols. However, the  $VGA_T$  differed by merely 0.1 between high and low dose protocols with no added filtration. When 0.1mm Cu filtration was added, there was a comparable dose decrease of 36% between high and low dose protocols, with an 18% decrease between high and medium dose protocols, and a 22% decrease between medium and low dose protocols. However, the  $VGA_T$  differed by just 0.3 between high and low dose protocols with 0.1mm added filtration. With 0.2mm added Cu filtration, there was a similar dose decrease of 38% from high to low dose protocols, with a 19% decrease between high and medium protocols and a 23% decrease between medium and low dose protocols. Again, the

$VGA_T$  differed by just 0.3 between high and low dose protocols, with 0.2mm added filtration.

For the oblique rib projection, with no added filtration, there was a 37% dose decrease from high to low dose protocols, with a reduction of just 0.2 in  $VGA_T$ . When 0.1mm Cu filtration was added, there was a similar 37% reduction in dose, with an increase of 0.1 in  $VGA_T$ . With 0.2mm added filtration, there was a dose decrease of 38% and a reduction of just 0.3 in  $VGA_T$ . A dose variation of 20-22% was found between high and medium, and medium and low dose protocols, for all three filtration settings for all three dose protocols.

### Dose Measurements

Figure 3 demonstrates the combined mean ESD for the high, medium and low dose protocols for wrist and ribs. As expected, the highest doses were recorded using the high dose protocol. The dose

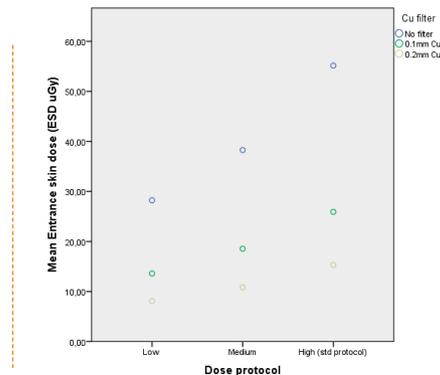


Figure 3: Mean ESD for each protocol and Cu filtration level

levels ranged from 8.09-28.23 $\mu$ Gy, from 10.85-38.27 $\mu$ Gy and from 15.31-55.15 $\mu$ Gy for the low, medium and high dose protocols, respectively. There was an overall decrease in ESD with added Cu filtration, as seen in Figure 3. There was a 51.8% reduction in ESD when 0.1mm Cu filtration was added, with the low dose protocol. The entrance surface dose was reduced by 47.7% and by 53.0% for the medium and high dose protocols, respectively. A greater dose reduction was achieved with 0.2mm added Cu filtration, at 71.4%, 71.6% and 72.2% for the low, medium and high dose protocols.

### Contrast-Noise-Ratio Measurements

Figure 4 displays the mean CNR for each projection and for each of the three dose protocols. A wide range is seen in CNR values for both wrist projections, with that of the DP wrist varying between 3.7 and 16.2

and that of the lateral wrist varying between 6.9 and 16.3. The difference between CNR values for both rib projections, however, is much less varied, ranging between 2.9 and 5.9 for the AP projection, and 1.5 and 2.3 for the oblique projection. As expected, the CNR for all exposures decreased with increased filtration, for all three dose protocols.

### Quality of Phantom Images

As seen in Tables 3 and 4,  $VGA_{CSN}$  scores increase as mAs increases. However, with added filtration, a notable reduction is seen in image quality scores for all projections. This reduction is marked in the DP wrist projection, with a reduction of 2.07 for the low dose protocol, 1.53 for the medium dose protocol, and 1.27 for the high dose protocol. A similar reduction in image quality is seen in the lateral wrist projection, with a decrease of 1.2 for the low dose

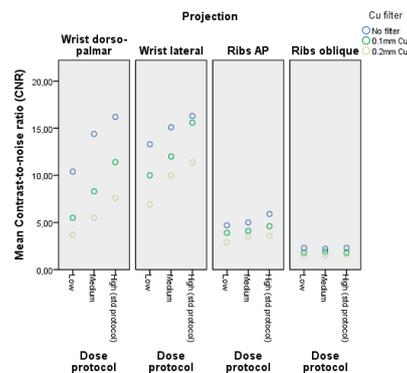


Figure 4: Mean CNR for each protocol and Cu filtration level

**Table 3:** Wrist image quality visual grading scores and CNR

Ribs	Projection	Kv	mAs	Cu Filter	Overall Image quality score (SD)	VGA <sub>CSN</sub> (SD)	Fracture visibility (SD)	CNR
Low	AP	60	0.4	none	3.07(0.64)	2.98(0.31)	3.20(1.15)	4.7
				0.1mm	2.73(0.76)	2.60(0.27)	2.67(0.96)	3.9
				0.2mm	2.20(0.92)	2.09(0.17)	2.47(1.13)	2.9
	Oblique	68	2	none	3.53(0.64)	3.71(0.37)	2.73(1.16)	2.3
				0.1mm	3.47(0.74)	3.58(0.42)	2.60(1.03)	1.8
				0.2mm	3.20(1.00)	3.24(0.29)	2.60(1.13)	1.5
Medium	AP	60	0.5	none	3.13(0.59)	3.07(0.24)	3.20(0.52)	5
				0.1mm	3.00(0.74)	2.87(0.00)	3.07(0.70)	4.1
				0.2mm	2.53(0.65)	2.42(0.14)	2.47(0.94)	3.5
	Oblique	68	2.5	none	3.87(0.74)	3.93(0.12)	3.07(0.74)	2.2
				0.1mm	3.47(0.74)	3.53(0.18)	2.93(0.83)	1.9
				0.2mm	3.00(0.64)	3.27(0.04)	2.47(1.12)	1.5
High	AP	60	0.63	none	3.60(0.63)	3.51(0.04)	3.40(0.99)	5.9
				0.1mm	2.93(0.70)	2.78(0.21)	2.93(1.03)	4.6
				0.2mm	2.87(0.74)	2.51(0.33)	2.93(0.80)	3.6
	Oblique	68	3.2	none	3.67(0.82)	3.93(0.24)	3.13(1.30)	2.3
				0.1mm	3.20(1.15)	3.60(0.64)	2.67(1.29)	1.8
				0.2mm	3.33(0.98)	3.64(0.43)	2.80(1.21)	1.6

**Table 4:** Ribs imaget quality visual grading scores and CNR

Wrist	Projection	kV	mAs	Cu Filter	Overall Image quality score (SD)	VGA <sub>CSN</sub> (SD)	Fracture visibility (SD)	CNR
Low	Dorso-palmar	48	0.5	none	3.47(0.92)	3.29(0.10)	4.20(0.77)	10.4
				0.1mm	2.20(0.76)	2.27(0.07)	3.47(1.19)	5.5
				0.2mm	1.40(0.63)	1.33(0.12)	2.93(1.39)	3.7
	Lateral	52		none	2.80(0.68)	3.02(0.21)	3.60(1.12)	13.3
				0.1mm	2.20(0.94)	2.27(0.18)	2.93(1.22)	10
				0.2mm	1.60(0.74)	1.67(0.18)	2.60(1.35)	6.9
Medium	Dorso-palmar	48	1	none	3.73(0.80)	3.69(0.27)	4.27(1.08)	14.4
				0.1mm	3.13(0.70)	2.76(0.41)	4.07(0.82)	8.3
				0.2mm	2.20(0.77)	1.96(0.28)	3.33(0.92)	5.5
	Lateral	52		none	3.73(0.83)	3.71(0.27)	4.20(1.03)	15.1
				0.1mm	2.93(0.83)	3.00(0.32)	3.60(1.06)	12
				0.2mm	2.33(0.77)	2.22(0.38)	3.20(1.18)	10
High	Dorso-palmar	48	2	none	4.27(0.80)	4.13(0.17)	4.57(0.88)	16.2
				0.1mm	3.40(0.74)	3.00(0.10)	4.27(0.96)	11.4
				0.2mm	3.00(0.77)	2.78(0.14)	4.20(1.18)	7.6
	Lateral	52		none	4.13(0.59)	4.07(0.17)	4.13(0.77)	16.3
				0.1mm	3.60(0.70)	3.6(0.20)	3.87(0.99)	15.6
				0.2mm	3.13(0.90)	2.91(0.27)	3.60(1.08)	11.4

protocol, 1.4 for the medium dose protocol, and 1 for the high dose protocol. A decrease is also noted in overall image quality for both rib projections, however this is far less apparent, with a reduction of 0.87 for the low dose protocol, 0.6 for the medium dose protocol and 0.73 for the high dose protocol for the AP rib projection. For the oblique rib projection, there was a reduction of 0.33 for the low dose protocol, 0.87 for the medium dose protocol, and 0.34 for the high dose protocol.

Fracture visibility was minimally affected by beam filtration and projection variation. For the DP wrist, a difference of just 0.37 was noted between low and high dose protocols, with no added filtration. Similarly, a difference of just 0.53 occurred between low and high dose protocols for the lateral wrist, with no added filtration. A negligible difference of 0.2 was noted in fracture visibility for the AP rib projection between high and low dose protocols, and a difference of 0.4 was noted in the oblique rib projection.  $VGA_{CSN}$  scores follow a similar pattern to

overall image quality scores, with decreasing values as Cu filtration is added. For all projections, using all protocols, fracture visibility also decreased as Cu filtration was added. It is clear from these tables that overall fracture visibility was higher in the wrist than in the ribs.

### Visual and Physical Image Quality Measurements

For each of the four projections, the fracture visibility scores were correlated with both physical (CNR) and visual measurements ( $VGA_{CSN}$ ) (See Table 5). A strong correlation was found between CNR and fracture visibility for both DP and lateral wrist projections. CNR and fracture visibility for the AP rib projection also shows a strong correlation. Regarding the oblique rib projection, a moderate correlation was found between CNR and fracture visibility. Similar findings can be seen in the relationship between  $VGA_{CSN}$  and fracture visibility, with the strongest correlations occurring in the DP wrist, lateral wrist and AP rib projections. The weakest correlation was found in the oblique rib projection (See Table 5).

**Table 5:**  $R^2$  correlation coefficients between CNR,  $VGA$  and fracture visibility

Projection	CNR vs Fracture Visibility	$VGA_{CSN}$ vs Fracture Visibility
DP Wrist	0.7697	0.8908
Lateral Wrist	0.9067	0.9477
AP Ribs	0.7917	0.8577
Oblique Ribs	0.5384	0.6970

The distribution of mean ratings was the same across all fifteen observers, showing no significant statistical difference in  $VGA_T$  score between observers ( $p=0,450$ ). A strong correlation was found between the physical measurement of CNR and the visual analysis of each image. This correlation was weaker for the oblique rib view than for the remaining three projections.

### Discussion

This study aimed to reduce radiation dose without adversely affecting image quality, using a paediatric phantom with multiple bone fractures. This involved the variation of exposure parameters and beam filtration settings. The low dose images produced in this study have shown that reducing the dose has minimal impact on fracture visibility. However, the CNR values vary widely between dose protocols and anatomical regions. Similar findings were also reported in other studies (6). The CNR values reported for the rib projections are markedly lower than those of the wrist projections. This notable decrease was reflected in comments from the observers, reporting difficulty in fracture visualisation. However, this difficulty could also be due to phantom positioning and the superimposition of anatomical structures, particularly in the oblique view.

The results of this study show a strong correlation between visual and physical measurements for each projection, reinforcing our findings. This strong correlation poses the question: Are both physical and visual measurements needed for image quality analysis? Similarly, overall image quality scores were similar to  $VGA_{CSN}$  values, suggesting that overall image quality may be sufficient for predicting fracture visibility and image quality. Similar outcomes were found in other studies (30). The standard deviation for inter observer assessment is low, meaning that observers agreed with one another about each criterion.

The most striking result found in this study was the effect of Cu filtration on both dose and image quality, with added filtration consistently reducing patient dose, at the cost of image quality. The values for ESD and DAP found in this study mirror those found in published research (15)-(20). Physical measurements were calculated for each of the thirty-six images using the CNR, a common method of image quality measurement, whereas visual measurements were obtained as fifteen observers rated the images. However, this study used predominantly radiography students as observers and further research is suggested with the aid of experienced radiologists and radiographers to allow a comparison with clinical practice.

The primary focus of this study was on wrist and rib fractures as wrist fractures are among the most common paediatric fractures (32), and rib fractures are associated with high rates of misdiagnosis (15). In patients between the ages of two and four, the largest proportion of limb fractures occur in the upper limb (76.0%), the most common of which are in the distal humerus (22.0%) and the distal radius (21.3%) (32). Similarly, in children between the ages of five and eleven, the most common fracture location is the distal radius (40.3%) (32). In cases of abuse, however, many fractures occur in the ribs, the most acute of which are frequently missed on initial imaging (15). This constitutes an important topic for further research in the clinical context, regarding the optimization of exposure in the paediatric population.

The results of this research are valid in the context of this study and this constitutes the major limitation as cannot be valid in the clinical context. Although it has been well documented that DR detectors allow the production of good quality images at low exposures due to their high associated DQE, further research is suggested in clinical practice, using real paediatric patients. This will help to better determine the technical factor modifications needed to achieve safe radiographic practice at low exposure levels, while maintaining image quality. Secondly, the phantom used may not have been entirely anthropomorphic, with various different materials and their associated

X-ray absorption properties. However, the use of a phantom allowed multiple repeated exposures, with maintained absorption properties.

Furthermore, different hospitals may use different positioning methods, detectors and parameters for paediatric patients, when compared to those used throughout this study. However, this does not mean that the parameters used in this study cannot be adapted and applied in clinical practice.

### **Conclusion**

Using digital radiography, the variation of exposure parameters can achieve a reduction in dose, without impairing diagnostic image quality or fracture visibility. Superior image quality can be achieved for DP and lateral wrist projections at higher doses, without the use of Cu filtration. However, the addition of Cu filtration for the rib projections can reduce phantom dose with almost no impact on overall image quality. Overall, the addition of filtration reduced dose for all projections.

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# Aneurysm clips in brain imaging using CBCT: the development of a phantom and the influence of kvp and metal suppression on image quality.

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## Keywords:

Aneurysm clip, Artefacts, CBCT, Image quality, Metal suppression, Phantom.

## Abstract

**Purpose:** For this study, a phantom was produced to evaluate the influence of kVp and metal suppression on the image quality in CBCT brain imaging containing titanium aneurysm clips.

**Method and material:** A head phantom was constructed comprising of a pig skull with its neurocranium filled with butter to simulate the human brain. CBCT was used to scan the phantom. Three different aneurysm clips were used (two in different sizes and one with a different size and shape). Acquisitions were made using different values of kVp (80, 84, 88, 92, 96). Each acquisition was reconstructed in every anatomical plane, with and without metal suppression.

For post-processing, ImageJ was used to place ROIs in specific areas. Standard deviation, representing noise; data was analysed using T-tests.

**Results:** The phantom was suitable for aneurysm implant placement. The noise is most severe in the axial plane ( $p < 0.05$ ) and the larger clips produced more noise. Metal suppression resulted in a significant reduction of noise in all three planes ( $p < 0.05$ ). Compared to metal suppression, the reduction in noise with an increase in kVp is minimal.

**Conclusion:** Metal suppression is effective in reducing metal artefacts in CBCT brain imaging.

## Introduction

A cerebral aneurysm is a medical emergency and according to the Brain Aneurysm Foundation (2016), it is associated with an incidence of 500 000 deaths worldwide annually **(1)**. Bowles (2014) defines a cerebral aneurysm as a weak spot in a blood vessel of the brain that swells and fills with blood, having the potential of rupturing. This is known as aneurysmal subarachnoid haemorrhage **(2)**. According to Taha et al. (2006), the standard treatment option for cerebral aneurysms is surgical clipping **(3)**. The clips are made of titanium and vary in shape and size, depending on the type and location of the aneurysm (Louw et al. 2001) **(4)**. The presence of the clips in the brain results in severe artefacts in Computed Tomography (CT) brain imaging. These artefacts, known as beam hardening and streak artefacts, will decrease the

image quality, can mask pathology and may result in a false diagnosis **(5)**.

There is surprisingly little published research conducted into the effect of CT artefacts caused by different shapes and sizes of aneurysm clips in brain imaging. It is anticipated that larger aneurysm clips will create more artefacts, because there is more attenuation caused by the larger quantity of metal **(6)**. It is also expected that the claw-shaped clip, due to its shape, will produce more streaking artefacts on CT images compared to linear clips.

The aim of this study was to develop a phantom which will allow for placement of metal implants within the brain. Such phantom does not exist. To simulate the human head, a pig skull filled with fat was used. This phantom is used to answer the following question:

*What is the impact of Kilovoltage peak (kVp) and metal suppression on Cone-Beam Computed Tomography (CBCT) image quality of a head phantom which contains titanium aneurysm clips?*

## **Method and material**

### **Design of study**

In this study, images have been generated of a head phantom using 3 different shapes and sizes of aneurysm clips. A novel head phantom was constructed comprising of a pig skull with its neurocranium filled with butter, to simulate brain tissue. Images were produced using a Planmed Verity Extremity Scanner: a CBCT. The images were generated with and without metal suppression across a range of kVp values.

### **Production of the phantom**

No commercially available phantoms exist which allowed for the placement of metal implants in the brain, consequently a novel phantom had to be created. A pig head was used as the basis of our phantom. The pig was used for normal human consumption, and therefore ethics permission was not necessary in Norway (**Law 7**). The pig skull simulated the human skull and it is anticipated to behave radiologically similar to a human skull. The head was boiled to remove soft tissue. The skull was then soaked in ammonia for 1 week to ensure that it was free from micro-organisms. Different soft tissue

brain substitutes were then considered, a range of fats (margarine, refined coconut oil and butter). Using CT, these were assessed for attenuation and density and compared with human brain tissue. The Hounsfield Unit (HU) for butter is -94 (**8**) and for brain tissue is 40 (**9**). From the CT data all the fats proved viable, however butter proved to be most mouldable therefore minimising the occurrence of air artefacts. Therefore, butter was used as the medium to fill the pig's cranium to simulate brain tissue. The butter was melted and carefully placed within the skull ensuring that all the cavities were properly filled. With this phantom, a real bone density and a similar density to a human brain was created.

### **Phantom analysis**

Initial images were acquired to determine the visual homogeneity of the phantom. This was done to ensure that the phantom did not contain any air bubbles which may mimic artefacts on the image. Five Regions of interest (ROIs) were selected in areas which appeared visually homogenous and without bone artefacts. The signal and standard deviation were measured using Image J (**10**).

**Figure 1:** The three types of titanium aneurysm clips.



### **Titanium Implants**

Titanium implants were used in this study as they are commonly used in neurosurgery (11). The implants we used were three different titanium aneurysm clips, varying in shape and size (1, 2 and 3), (figure 1). The reason for using three different aneurysm clips was to evaluate the amount of streaking each clip produces.

### **Cone Beam Computed Tomography (CBCT)**

A Planmed Verity Extremity Scanner (Planmed Oy, 00880, Helsinki, Finland) was used to generate the images. This scanner is commonly used for imaging the viscero-cranium and upper and lower extremities (12). The reason why this CT scanner was used is because of the easy access to the CBCT laboratory at

the Oslo and Akershus University College of Applied Sciences, Norway. However, this CT scanner is not normally used for brain imaging and the limitations of using it are considered in the discussion section.

### **Quality Control**

To ensure the reliability of the study, the daily and weekly quality control tests were performed according to the Planmed Verity manual guidelines (2014). The following tests were performed: Visual Check, HU accuracy, HU uniformity, Noise (Standard Deviation) and no artefacts were visible. The results of these tests fell within the expected tolerances provided by the manufacturer (12).

## Acquisition and processing parameters for the phantom

### Parameters

The following parameters (Table 1) were used for image acquisitions.

### Constant parameters

The milliamperage second (mAs) used for normal brain imaging is more than 100mAs, depending on the type of CT (13). The highest option available on the Planned Verity programme was 10mAs, and therefore 10mAs was used. For filtering, a soft kernel was used as according to Yu et al (2016) it is generally used in brain imaging in order to reduce noise and enhance low contrast detectability (14). Due to the usage of a soft kernel, the resolution is reduced. To compensate for this, a high resolution was used. A small slice thickness improves image detail (15). 3mm slice thickness was chosen instead of 1mm slice thickness, as less data to process would be produced by the 3mm slices.

### Variable parameters

Metal suppression improves image quality and reduces artefacts caused by metal (Bechara et al, 2012) (16). Therefore, the images reconstructed with the metal suppression were expected to have a better image quality than the images produced without metal suppression. The HU for titanium is 2921(±218) (17). The metal suppression threshold used was 2700 HU. Besides the metal suppression, different kVps were used. According to Park et al. 2009, a higher kVp causes less noise and results in a better image quality (18). However, Tang et al. 2012 states that a higher kVp causes a higher dose (19). 80kVp was the lowest and 96kVp was the highest available on the Planned Verity programme. Therefore, the five kVp varied from 80kVp to 96kVp in order to observe any trends which might exist across them.

**Table 1:** Parameters for the CBCT

CONSTANT	VARIABLES
10mAs	kVp (80, 84, 88, 92 and 96)
3mm of slice thickness	Metal suppression (with an without)
3mm of interval	
Soft kernel	
High resolution	

### Experimental images

Aneurysm clips used for each acquisition series were placed in the sagittal orientation within the skull for subsequent experimental imaging.

The centre of the phantom was marked, and used as the centre of the field of view (FOV) for all images acquisitions. In series 1, the phantom was scanned using the smallest titanium aneurysm clip. In series 2, the phantom was scanned using the claw-shaped titanium aneurysm clip. In series 3, the phantom was scanned using the biggest titanium aneurysm clip.

Figure 2 illustrates all 3 clips in different anatomical planes.

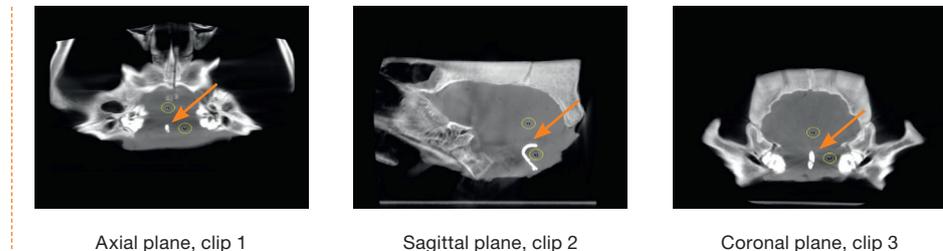
For calculating the mean and standard deviation inside the ROI, Image J, was used. All ROIs had a diameter of 8.2mm. For series 1-3, two ROIs were used. ROI 1 was closer to the clip and ROI 2 was further away from the clip in order to measure the amount of artefact in each respective ROI. In series 1 and 3, ROI 1 was at 4.7mm from the clip and

approximately 90 degrees to the middle of the clip. And ROI 2 was 9.4mm superior to the clip. The reason for having chosen these distances was to ensure that no bone was included in the ROI, and in these areas there were most artefacts visible. For series 2 in the sagittal plane, ROI 1 was in the middle of the hook and ROI 2 was at 9.4mm from the top of the clip (Figure 2). The slice which was evaluated in each series was the one on which the implant was best demonstrated. In the coronal and axial plane, the ROIs were in the same position as in series 1 and 3.

### Statistical analysis

A paired two-way T-test was used to establish whether significant differences exist between standard deviations with and without metal suppression and standard deviations between different planes. A p value <0.05 was considered statistically significant.

Figure 2: Aneurysm clips in anatomical planes.



## Results

### Phantom validation:

To choose the medium used to simulate brain tissue, 3 different fats were tested. It was established that many air artefacts were created on the images using the margarine and refined coconut oil. There were less air artefacts on the images containing butter and the butter was easier to mould at room temperature. Therefore, butter was chosen as the medium simulating brain tissue.

From the 5 ROIs measured, the homogeneity of the phantom was established.

### Experimental images

#### Image noise:

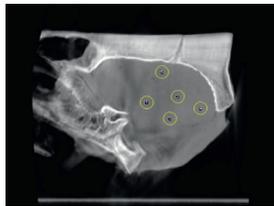
After placing the clips in the phantom and placing the two ROIs, the following results were obtained:

In **figure 4**, ROI 1 demonstrated that the noise is more severe in the axial plane compared to the sagittal and coronal planes, for all three clips ( $p < 0.05$ ).

In the axial plane there was the greatest reduction in noise for all three clips ( $p < 0.05$ ) compared to the sagittal and coronal planes. In the axial plane the greatest reduction in noise was for clip 2. In the

**Table 2:** Mean standard deviation

ROI	StdDv
ROI 1	29,735
ROI 2	23,735
ROI 3	31,434
ROI 4	18,673
ROI 5	27,857
Mean Value of all ROI's	26,2868



Axial plane, clip 1

**Figure 3:** Five ROIs for homogeneity.

coronal plane the greatest reduction in noise was for clip 2. In the sagittal plane the least reduction in noise was for clip 1. 80kVp was excluded for all clips in the study due to the fact that the phantom tilted during the acquisition of clip 1.

For all three planes there was a significant reduction in noise with the use of metal suppression ( $p < 0.05$ ).

For ROI 2, [figure 5](#) demonstrates that the noise was higher in the sagittal plane for clip 1 compared to clip 2 and 3 ( $p < 0.05$ ). For clips 2 and 3 there was no significant difference in severity of noise between the planes. Compared to the axial and sagittal plane, the greatest reduction in noise for all three clips was in the coronal plane ( $p < 0.05$ ). In the sagittal plane there was no significant reduction in noise for clips 1 and 3 ( $p > 0.05$ ). In the axial plane there was a significant reduction in noise for clip 3 ( $p < 0.05$ ).

#### **Impact of kVp:**

[Figures 4 and 5](#) illustrating negative trend lines is an indication that there is a minor decrease in noise with an increase in kVp.

#### **Discussion:**

The aim of this study was to produce a phantom and then evaluate the influence of kVp and metal suppression on image quality in CBCT brain imaging containing titanium aneurysm clips.

No literature was found on how to make this phantom. Successfully creating the phantom played an important role in this study. The phantom simulated a human cranium. The phantom was made from a pig skull which caused the same degree of artefacts as a human skull in CT brain imaging. This was observed with the control images. As previously mentioned, the HU of butter and brain is similar. Butter is easily mouldable and caused less air artefacts. Simulating brain tissue with butter was successful in ensuring that the butter remained contained within the skull throughout the data collection. On this basis the phantom was considered fit for purpose in this research. The fact that the phantom had an opening which allowed easy access to the brain, made it possible for implant placements. Challenges experienced while making the phantom included the temperature of the butter did not remain the same throughout the data collection. The shape of the pig skull was irregular, therefore there was a possibility of the phantom tilting during image acquisition. If this study is to be repeated, it will be difficult to place the clip in the exact same position as in this study as it difficult to visualise the exact placement of the clip.

The main results of the evaluation of kVp and metal suppression show the following. On inspection of the experimental images it is clear that metal suppression is effective; also the shape and size of the clip influences the amount and shape of metal artefacts

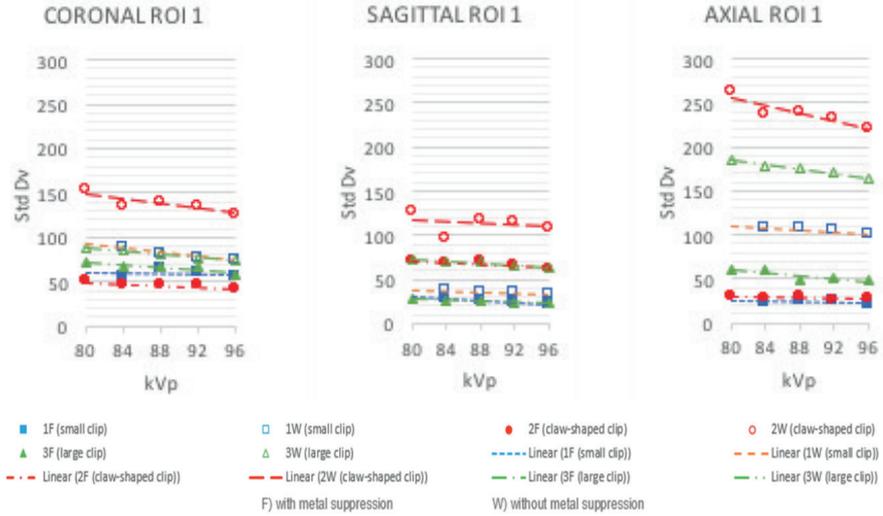


Figure 4: Results of ROI 1

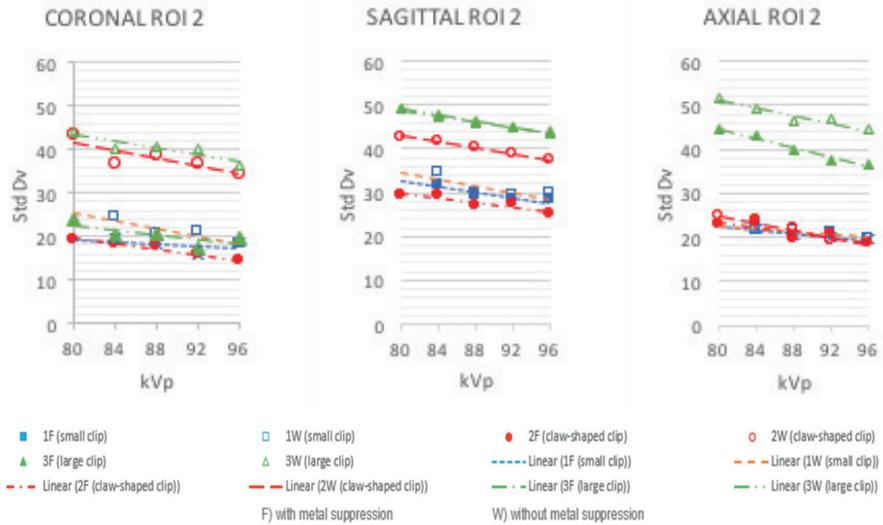


Figure 5: Results of ROI 2.

caused. Artefacts have different appearances in the anatomical planes. The difference in noise reduction by increasing kVp compared to metal suppression, is very small.

The biggest challenge in CT brain imaging containing aneurysm clips is the presence of metal artefacts. In the experimental images, for ROI 1, the noise was significantly higher in the axial plane than in the other planes for all three clips. In routine brain imaging diagnostic CT scanners are used and not CBCT, thereby presenting a limitation in our work. The CBCT has a limited kVp range, hence an accurate comparison in varying kVps was not possible. Therefore, the outcome of this study cannot be directly compared to brain imaging using CT.

In ROI 2 for clip 1 the standard deviation is the same as that of the control image. This indicates that no metal artefacts are caused at this distance from the small clip. This is supported by Elliot et al (2014) where they conclude that smaller pieces of metal cause less scatter **(6)**. In ROI 2 for clips 2 and 3 with and without metal suppression, there was a significant difference in the standard deviation in two planes, thereby indicating the effectiveness of metal suppression for the large and claw-shaped clips.

A reduction in noise was found when using higher kVps. This is in agreement with previous published studies which also demonstrate a reduction in metal artefacts when using higher kVps **(20, 21)**. However, when higher kVp values are compared to metal suppression, there is a minor decrease in noise with an increase in kVp.

In practice, patients with brain aneurysm can be treated with more than one clip in different directions resulting in artefacts in different planes. **(20, 22)**.

The findings of our study show that there are different degrees of artefacts in the planes caused by different clips. Therefore, we recommend that more planes are evaluated to investigate the impact.

## Conclusion

This study indicates the more metal present, the greater the noise produced. The noise produced is not the same for all the planes. Metal suppression is more effective for the large clip. Compared to metal suppression, the influence of increasing kVp on image quality is minimal.

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