

OPTIMAX 2016

Optimising image quality for medical imaging

University of Salford, Salford, Greater Manchester, UK

Edited by: Peter Hogg, Robert Hogg – Thompson, Carst Buissink

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Foreword

OPTIMAX 2016 was held at the University of Salford in Greater Manchester. It is the fourth summer school of OPTIMAX with other renditions having been organized at the University of Salford (2013), ESTeSL, Lisbon (2014) and Hanze UAS, Groningen (2015). For OPTIMAX 2016, 72 people participated from eleven countries, comprising PhD, MSc and BSc students as well as tutors from the seven European partner universities. Professional mix was drawn from engineering, medical physics/ physics and radiography. OPTIMAX 2016 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). One student from the United Kingdom was funded by the Nuffield Foundation. The summer school included lectures and group projects in which experimental research was conducted in five teams. Each team project focus varied and included: optimization of full spine curvature radiography in paediatrics; ultrasound assessment of muscle thickness and muscle cross-sectional area: a reliability study; the Influence of Source-to-Image Distance on Effective Dose and Image Quality for Mobile Chest X-rays; Impact of the anode heel effect on image quality and effective dose for AP Pelvis: A pilot study; and the impact of pitch values on

Image Quality and radiation dose in an abdominal adult phantom using CT. OPTIMAX 2016 culminated in 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 four chapters concern generic background information which has value to summer school organization and also theory on which the research projects were built. The second section contains the research papers in written format. The research papers have been accepted for the ECR conference, Vienna, 2017 as either oral presentations or posters.

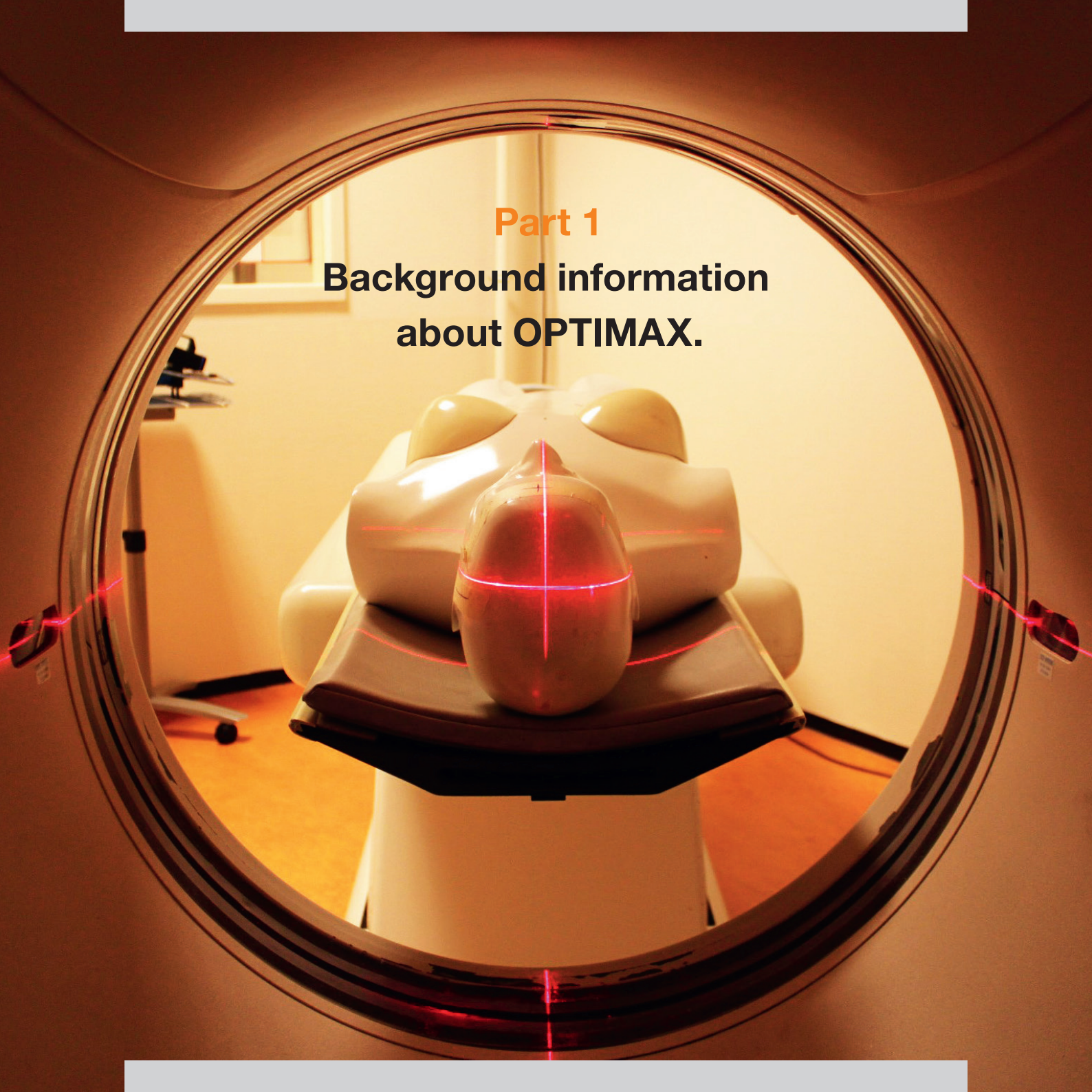
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Part 1

**Background information
about OPTIMAX.**



How to create your own OPTIMAX

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Introduction

OPTIMAX is recognised internationally as a valuable experience which exposes novice researchers, particularly BSc Radiography students, to a fairly complete journey through team-based multicultural and multi-professional research, from conception to dissemination. Whilst the primary focus of OPTIMAX is on radiography, disciplines such as physics, engineering, computer science and others participate. Today research is no longer seen as a local activity involving isolated researchers and this philosophy is reflected in OPTIMAX. Contemporary quality research is multi-professional, multi-national and multi-cultural^{1,2,3}. Recognising the value of OPTIMAX and the need for others to consider offering similar learning experiences this chapter outlines the details of what to do to recreate a similar learning experience in anticipation that similar schemes might develop around the world.

This chapter is broken down into time frames, commencing immediately after an OPTIMAX summer school has finished (end of August). The period of activities leading up to, during and beyond an OPTIMAX summer school continue for 18 months, the culmination of which is the production of an open access⁴ text book which is based upon the OPTIMAX activities within the residential summer school. Normally we run OPTIMAX summer schools on an annual basis and because of this there is a 6-month overlap of activities between two successive OPTIMAX events; the overlap period exists between September and February during the book writing period. From an organisational point of view, regular communication is essential and this is achieved through monthly meetings using via Skype; Skype is helpful as it achieves basic communication requirements whilst minimising cost.

September-October

Items to address

1. Establish a steering committee with representation from each partner organisation
2. Review what is required, in terms of actions and timescales, throughout the OPTIMAX planning and delivery cycle
3. Identify the university which will host OPTIMAX for the following year
4. For the steering committee member from the host, they should convene a local organising committee as there is too much work for one person to do
5. Agree the dates for the three-week residential summer school
6. Confirm the official language requirements
7. Agree the main tasks and who will be responsible for what on the OPTIMAX steering committee
8. Identify the student inclusion criteria
9. Identify the tutor inclusion criteria
10. The costing model should be agreed, to include all aspects
 - a. General principles
 - b. Transport
 - c. Accommodation
 - d. Subsistence
 - e. Registration fee, which might include costs associated with socio-cultural events

The steering committee would comprise of one person from each partner organisation. Each person should be acknowledged within their organisation as the 'go to person' for all things OPTIMAX. Within their organisation they would play a key liaison and communication role between their staff and students. During the first steering group meeting a list of actions and timescales should be drawn up and the actions should be distributed amongst steering committee members. The official language requirement is important to confirm, for OPTIMAX it is English. The level expected from all participants is that they must have a good level of conversational competence and have a reasonable ability to write in English. Writing is not as important as talking because support and advice about English grammar (writing) is always available within the OPTIMAX residential weeks.

Agreeing the dates for the three residential weeks is never an easy task as many factors need to be taken into account. This becomes even more complex when more partners are involved. For the students, re-sit examination dates should be avoided. For OPTIMAX we have always opted, as best we can, for holiday periods, such that students would give up a proportion of their holidays to attend it. We selected this approach to minimise the impact on their own individual programmes of study. OPTIMAX therefore has its residential component in August. For the tutors this has implications too, in that August is traditionally

a holiday period and for the host particularly the week prior to and the week after is normally used for OPTIMAX-related activities and also catch up after the three-week duration residential component. This has implications for the rest of the academic year, as tutors participating in the whole three weeks may find themselves having to take holidays at non-traditional times, perhaps within teaching weeks. Tutors should therefore negotiate with their university colleagues to ensure they receive a fair allocation of holidays and workload.

We have always had wide inclusion criteria for students; we accept BSc students at any level as well as masters and PhD students. A multi-professional approach is encouraged. Additionally, we have always given an opportunity for a 17-year-old college student to attend too. Students must attend all three weeks of the residential component, as activities are planned for each day and a team approach is used. Failure of an individual to contribute effectively could jeopardise the team effort. Students are warned that OPTIMAX is hard work and that 100% effort is required; this might involve the need to work during some evenings and also for part of the weekends. However, to counterbalance this they are informed that the socio-cultural programme is always fun and of great value and interest.

Tutors have the option to attend all of the residential component or part of it. However, for continuity enough tutors need to attend all of the residential component such that the same tutor is present with each team throughout the entire period. Additionally, a further one or two tutors will be responsible for organising the residential component to ensure its organisation is smooth and also to provide scientific advice to the teams. For the tutors who only attend part of the residential component they usually attend one or two 'complete weeks'. They join one team and play an active role within it, alongside the students and the tutors who are there for the full three weeks. Similar to students, the inclusion criteria for tutors is wide and a multi-professional approach is encouraged.

The costing model should be agreed early on. This is important for all concerned. For the first two years of OPTIMAX we won substantial grants from the European Union. However, grant funding for this sort of activity tends to be short-lived and the funders are always keen to see the activities continue after the grant funding has ceased. So far OPTIMAX has continued for two years beyond the grant funding and another summer school is being planned. This year the University of Salford hosted OPTIMAX and the following cost model was adopted:

- Some tutors used Erasmus (EU) funds to meet part of the travel, residential and subsistence costs. The remainder of the costs were underwritten by their own university, the tutor themselves or a mixture of the two.
- Tutors and students each paid a £90.00 registration fee. This covered the cost of food and drinks for the welcome event, farewell event and lunches each day throughout the summer school. It also paid for a cultural day out (coach trip to Wales) and heavily subsidised a meal out too in Manchester. The entire registration fee was spent on those who paid it; no profit was made.
- In order to minimise costs all students and some tutors stayed in university student residences. These were self-catered. Some tutors also did apartment shares in the centre of Manchester.
- Each steering committee member should work towards conducting a cost estimation, to include transport to and from the host, accommodation, subsistence costs and registration fee. This will become important later on when advertising OPTIMAX to potential students (and tutors) in their own university.

November to January

Items to address

1. Define and agree the research questions
2. Student liaison and recruitment
 - a. Marketing to students (BSc, MSc, PhD)
 - b. Agree on how many students in total can attend and how many from each country
 - c. Create a list of interested students
 - d. Advise students about OPTIMAX and what is to be expected from their point of view
 - e. Deciding which socio-cultural events will be organised

The core values of OPTIMAX should be considered together with the resources available within the host organisation when agreeing the research questions. OPTIMAX is intended to be a *learning and development experience* for BSc, MSc and PhD students, consequently the research questions should have direct value to these students. They should be pitched at a level which is attainable yet at the same time stretch the participants, presenting them with opportunities to problem solve and develop new knowledge and skills. A further core value surrounds the topic of research, primarily image quality and radiation dose optimisation; however, resource opportunities have and will continue to over-ride this ambition and limit options as what is available locally within the host organisation will restrict what research can be done. Finally resource available within the

host organisation will play a major part in the decision making. To supplement any resource deficiency, we have found it beneficial to involve commercial partners, as they have happily lent equipment for the duration of the summer school.

When the research questions have been written a decision needs to be made on whether ethical approval will be required. If the research involves humans or animals then ethical approval will be likely, if unsure then an Ethical Committee Chair should be approached for advice. The ethical principles and practices followed should be consistent with internationally agreed standards⁵ along with national/local requirements. The latter might have legal and/or professional⁶ backing. If ethical approval is required, then appropriate documentation should be prepared well in advance of the summer school so that time is available if any revision to the documents is necessary for approval to be granted. Once approval is granted then the research should be conducted in accordance with the approved documentation; if changes are required then the ethical committee should be approached with amended documentation for their approval.

The total number of students who can attend is dependent upon three key factors: the number of tutors who can attend OPTIMAX; the facilities / resources available for the research itself; the quality and quantity of student accommodation available and its price. Previously we have never exceeded 50 students, and normally the number ranges between 38 and 50.

Different approaches to marketing exist and no one answer is correct. Some of us have found that being proactive is important, such that new students are made aware of OPTIMAX in their induction week. At the University of Salford a research seminar is organised for previous participants of OPTIMAX, in which they present their research papers. All other students are invited to attend, making them aware of research outcomes and the opportunities provided by OPTIMAX. In some instances an email is sent to students to raise awareness and interested parties are requested to respond. In some instances those organisations on the OPTIMAX steering committee have partnerships with other universities (e.g. Groningen has a relationship with a South African University). In such cases the partner organisations should be included in marketing activities. Whatever approach is taken a list of interested students is compiled and then a meeting is arranged to talk to them about OPTIMAX. Points covered often include:

- Start and end dates for the summer school
- Approximate cost to individual students
- The use of a virtual learning environment (usually Blackboard)
- Facebook
- The need to create a PowerPoint slide set about 'your own country, where you are studying and also individual slides to let everybody in the summer school know about you (hobbies etc)
- A clear indication is given about the volume of work that all are expected to do (it's not a holiday), with days starting around 8.30 and finishing between 4.30 and 6pm.
- An explanation will be given about the nature of learning – in teams of 8-10 people; there are few lectures
- Socio-cultural activities – a review of the previous year is given as an indication of the type of activities which are likely to be organised in the coming year
- Sundays are always free, but often on at least one Saturday a cultural event is organised
- For the host a request is often made to ask if host students can assist in organising some socio-cultural events

February to March

Items to address

1. Liaise with lead tutors from each country about how many students and tutors will be attending OPTIMAX
2. Lead tutor from each country to organise all aspects for their students and also liaise with host, as required, for all arrangements e.g.
 - a. Accommodation
 - b. Transport
 - c. Travel / holiday insurance
3. Start preparation of socio-cultural activities and lunches, e.g.
 - a. Welcome event
 - b. Farewell event
 - c. Cultural visit on a Saturday
 - d. Arrange catering for weekday lunches
4. Book teaching and laboratory rooms

Within this time period the final numbers for tutors and students is agreed and booking arrangements can commence. We have found that travelling together as a group is beneficial because some students might be unfamiliar with international travel.

The host starts to prepare the socio-cultural activities. What is organised is largely down to the host themselves however in the past four years we have always had specific ones (3.a.-3.d., as above) as they add to the cohesion and experience of tutors and students.

The welcome event is held on the Sunday evening, prior to formal commencement on the Monday morning. This will be the first time that the students meet face to face and ice-breakers will be required. We always place them into their research teams for this activity. Ice breakers should allow for socialisation within the teams and also throughout all OPTIMAX participants. Tutors and students must all be involved. An evening meal is always provided. The farewell event is generally easier to organise than the welcome event because everybody knows one another and opinion can be solicited throughout the three week residential component about what form the event should take. We have always had a meal and often provision for dancing is made. In the farewell event a speech is always made, to reflect on the last three weeks, award certificates and look forwards to 'what next'. 'What next' includes announcing where the next OPTIMAX summer school might be held and also on whether abstracts, based on the summer school research, will be submitted to the European Congress of Radiology.

We have always offered one cultural visit on a Saturday and this typically involves a coach trip outside the host city. The decision on where to go is decided by the host, and factors like cost, distance and 'what there is to do and see' at the destination all play a part. Normally all the students and many of the tutors attend and the outings are always well received.

We normally organise lunch for the students and tutors during weekdays (Monday-Friday). This encourages cohesion and also it keeps us in control of timings throughout the three weeks. Given that OPTIMAX is intensive we always find that time is short and we cannot afford for tutors or students to leave the university complex to find their own lunch. Also, given OPTIMAX runs in the summer standard catering facilities within our universities are often closed so special arrangements need to be made.

May to July

Items to address

1. Produce student handbook, including the timetable and circulate it in advance of the residential component
2. Create outline research questions
3. Produce tutor notes / tutor handbook
4. Assignments
5. Invite lecturers to present and brief them
6. Book lecture and laboratory rooms
7. Create a list of tutor and student participants and assign them to research teams / research questions
8. Identify lead tutor and other tutors for each research team and inform them who is in their group, so they can make contact with their students in advance of the residential component
9. Create daily registers for tutors and students
10. Ensure all tutors and students have Eduroam enabled on their mobile / laptop devices to permit wifi access whilst at the host university; if Eduroam is not available then the host needs to be informed so temporary computer use accounts can be created
11. Create Blackboard and upload documents ready for the residential component; enrol students and tutors into Blackboard
12. Create Facebook and ask students and tutors to 'like it'
13. Ensure all technical equipment is operational and quality controlled ready for the experimental work
14. Preparation of the cultural presentation given by all participating countries

The handbook contains all the necessary information required by the students, this includes academic, social and emergency matters. The second page of our handbook indicates who to ring and what to do in an emergency; we always provide the mobile phone number of the lead host tutor just in case. Directions are important, from airport to accommodation and accommodation to venues (e.g. welcome event, farewell event, classrooms); also it is important to have maps to supermarkets which are close to student/tutor accommodation. The handbook should also contain other information directly related to the residential component and its content would be consistent with many university student programme handbooks. A sample timetable is illustrated below:

Date	Time	Activity	Building/Room
Sunday 31 st July	6:00 pm – 9:00 pm	Welcome event and team building activity.	
Monday 1 st August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 9:30am	Formal start; welcome and overview	Mary Seacole Building 2.43
	9:30am – 10:30am	Team working with Dr Leslie Robinson	
	10:30am – 11:00am	BREAK	
	11:00am – 12:00pm	Team working continued...	Mary Seacole Building 2.43
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
	1:00pm – 3:00pm	Lecture - Research methods (Dr Lucy Walton)	Mary Seacole Building 2.43
	3:00pm – 3:30pm	BREAK	
	3:30pm – 4:30pm	Groups meet to discuss their research focus	Mary Seacole Building 2.43
	4:30pm	Presentation on the UK	
Tuesday 2 nd August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 09:10am	Radiation Protection in the Laboratory (Prof Peter Hogg)	Mary Seacole Building 2.43
	09:10am – 10:30am	Project Management (Dr Leslie Robinson)	
	10:30am – 11:00am	BREAK	
	11:00am – 12:00pm	Group work – 'Define team roles'	Mary Seacole Building 2.43
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
	1:00pm – 3:00pm	All groups to continue with group work	Mary Seacole Building 2.43
	3:00pm – 4:15pm	Reflection on team working	
	4:15pm – 5:15pm	Presentation on Vietnam Presentation on Sweden	
	4:45pm	END OF DAY	

Date	Time	Activity	Building/Room
Wednesday 3 rd August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
	1:00pm – 3:00pm	Statistics by Audun	Mary Seacole Building MS 2.71
	3:00pm – 3:30pm	BREAK	
	3:30pm – 4:00pm	Group work	Mary Seacole Building MS 2.71
	4:00pm – 4:30pm	Reflection on team working	
	4:30pm – 5:00pm	Presentation about The Netherlands	
	5:00pm	END OF DAY	
Thursday 4 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	L609 & L627
	1:00pm – 3:30pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	3:30pm – 4:00pm	Reflection on team work	Mary Seacole Building MS 2.71
	4:00pm – 4:30pm	Presentation about Brazil	
	4:30pm	END OF DAY	

Date	Time	Activity	Building/Room
Friday 5 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00 – 1:00pm	LUNCH <i>Masterclass – confidence in public speaking, by Leslie Robinson</i>	Allerton L609 & L627
	1:00pm – 3:30pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	3:30pm – 4:00pm	Reflection on team working	Mary Seacole Building
	4:00pm – 4:30pm	Presentation about South Africa	MS 2.71
	7:30pm - late	Social Activity – ‘A night out in Manchester’	
Saturday 6 th August		BBQ and social event at Peter’s house. To be confirmed.	
Sunday 7 th August		DAY OFF	
Monday 8 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00 – 1:00pm	LUNCH	Allerton L609
	1:00pm – 3:30pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	3:30pm – 4:00pm	Reflection on team working	Mary Seacole Building
	4:00pm – 4:30pm	Presentation about Ireland	MS 2.43

Date	Time	Activity	Building/Room
Tuesday 9 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00 – 1:00pm	LUNCH <i>Masterclass – poster design by Claire Mercer</i>	Allerton L609 & L627
	1:00pm – 3:30pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	3:30pm – 4:00pm	Reflection on team working	Mary Seacole Building
	4:00pm – 4:30pm	Presentation about Portugal	MS 2.43
Wednesday 10 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 9:30am	Possible lecture by peter Hogg about conference preenting? (its in the OPTIMAX ebook 2015)	Mary Seacole Building MS 2.43
	9:30am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
	1:00pm – 4:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	4:00pm – 4:30pm	Presentation about Switzerland	Mary Seacole Building MS 2.43
Thursday 11 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
	1:00pm – 4:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	4:00pm – 4:30pm	Presentation about Norway	Mary Seacole Building MS 2.43

Date	Time	Activity	Building/Room
Friday 12 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
	1:00pm – 4:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	4.00-4.30	Presentation about Iraq	
Saturday 13 th August		Maybe an outing by coach? To be confirmed	
Sunday 14 th August		DAY OFF	
Monday 15 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609 & I627
	1:00pm – 5:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
Tuesday 16 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	8:30 – 4:30pm	Group work all day (make sure PowerPoint presentations, posters and articles are well on the way to completion)	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
Wednesday 17 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609
	1:00pm	Posters emailed to Peter	
	1:00pm – 4:30pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260

Date	Time	Activity	Building/Room
Thursday 18 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	9:00am – 12:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	12:00pm – 1:00pm	LUNCH	Allerton L609 & L627
	1:00pm – 4:00pm	Group work	Gp1 Gp2 Gp3 Gp4 Gp5 MS160 MS273 MS132 MS175 MS260
	4:00pm – 4:45pm	Online evaluation questionnaire	
	4:45pm – 4:59pm	Hand in assignments (before 5.00pm)	
Friday 19 th August	8:30am – 9:00am	Teachers gather for overview of the day	Allerton L609
	10:00am – 11:30am	Poster Exhibition Assessor: Claire Mercer	Allerton L626
	11:30am – 12:30am	LUNCH	Allerton L609 & L627
	12:30am – 3:00pm	OPTIMAX 2016 Conference Assessor: Peter Hogg	Mary Seacole Building MS 2.43
	6:00pm – 11:00pm	Farewell party, including Certificates of Attendance, food and entertainment.	
Saturday 20 th August		HOME	

A sample research question and outline method is given below in italics. When creating the research questions the facilities / equipment available at the host organisation must be considered carefully as there will be a need to make sure that the research question can be answered adequately with the available equipment.

Impact of anode heel effect on AP pelvis image quality and effective dose

The anode heel can create a range of beam intensities, from cathode and anode. Utilising this effect, research has demonstrated⁷ that gonad dose can be significantly lower in males with feet towards anode for AP pelvis. The impact of tube orientation on image quality, of feet towards anode and feet towards cathode, has not been investigated. Similarly its impact on effective dose has not been investigated either.

Using a phantom, determine the beam intensity, profile from anode to cathode, for adult AP pelvis. Then, using a range of exposures, determine whether phantom orientation (feet towards anode / cathode) has an impact on image quality and/or effective dose.

When designing your experiment you must consider measuring/estimating the following:

The effective dose using TLDs

The physical (e.g. SNR) and visual (e.g. 2 Alternate Forced Choice) measures of image quality

For this research you will probably use the adult ATOM phantom and the adult anthropomorphic phantom. Please liaise with group 1 about using the ATOM phantom as they will likely use it too.

Tutor notes tend to be less comprehensive than the student handbook, in fact to minimise the amount of administrative work to support OPTIMAX we tend to give student handbooks to the tutors too. Tutor notes indicate a range of information, including:

1. Support sessions for all tutors (which always occur 8.30-9.00 each day)
2. Training for using any facilities (e.g. X-ray lab) within the host organisation
3. Local Radiation Protection arrangements
4. A range of additional pieces of information that might be needed by the tutors

Teams are created at least one month in advance of the residential component. Teams comprise tutors and students. Within each team students are typically assigned based upon nationality, to make sure there is a good mix; also professional background can be taken into account such that physics and radiography students are mixed across all the teams. Once the team is created the lead tutor for each team makes contact with them via email and encourages they you introduce themselves to one another. Around the same time a Facebook page is created (e.g. <https://www.facebook.com/Optimax2016/?fref=ts>) and they are encouraged to like / join it. Throughout the residential component any photographs which are taken will be stored in Facebook.

A virtual learning environment (VLE; e.g. Blackboard) is set up to store any documents (e.g. PowerPoint slides, handouts, handbook, etc) which will be required within the residential component. The interesting thing about this is any of the participating organisations can create it if they have a VLE. Typically the organising who looks after the VLE is not the one who hosts the summer school.

The host organisation must ensure that all equipment to be used in the research must be quality controlled and operate within legal and manufacturer specifications. This should be assured by the host prior to residential component.

The final activity to be completed before the residential component is the creation of the cultural presentations. Typically these comprise of a series of PowerPoint slides, often with videos. Their purpose is to inform OPTIMAX participants about the countries and cultures that are represented. All tutors and students from each country are involved in developing their presentation, as well as its delivery. Aside the general slides about the country and the organisation from which they emanate, each student and tutor has one slide to talk about themselves – where they come from and their hobbies.

August

Everything should now be in place for a successful summer school. A few important matters do need explaining which have not yet been discussed. The overall organisation of the residential component requires input from two different aspects – scientific support and organisational support. On two occasions one person has played both roles in our summer schools but this has not been ideal as the time-demands on one person are too great. Scientific support should be offered to all teams on an equitable basis, from day 1 to the final day. This person would act as Principle Investigator and would be knowledgeable and experienced in theoretical and practical aspects of the types of research that will be conducted within the teams. They will offer advice on the sorts of methods which might be used

and how and as required direct tutors / students to learning materials. Organisational support involves making sure everything runs to plan, from the research components to the social-cultural aspects. It will involve identifying problems before they arise and trying to solve them; equally it will involve solving problems as they arise. The organisational supports should be employed by the host organisation; the scientific support person need not be employed by the host organisation.

If student work is to be assessed the students must be made aware of this. We assess the poster, article and presentation and award ECTS credits. At the end of the summer school, as part of the farewell event we award certificates of attendance along with ECTS marks. The final formal activity students and tutors do at the end of each summer school is to complete an evaluation questionnaire. This takes into account the academic and socio-cultural programme.

September – March

The following would occur in tandem with preparation for the 'next' OPTIMAX summer school.

After the summer school has been completed work on the OPTIMAX book can commence. Examples of former OPTIMAX books are stored on line^{8,9}. At the same time the abstracts are prepared for submission to the European Congress of Radiology¹⁰. In both

cases the lead tutor for each group takes the following responsibilities

- Acts as liaison person between scientific support person (see 'August', above) and team members (co-authors)
- Takes feedback from the scientific support person on the conference abstract / article / book chapter and makes changes as required
- Submits the abstract to the conference and ensures that all co-authors are indicated
- If an abstract is 'accepted' the lead tutor would repurpose the OPTIMAX conference slides to be suitable for presenting at ECR
- The lead tutor should ensure that all co-authors (and therefore students) for the ECR paper and the book chapter are informed of any changes to the chapter / abstract and approve them

The scientific support person reviews all work and may, if adequate intellectual input has been given, become a co-author on specific pieces of work. In all cases all students are co-authors on book chapters and conference papers. For the book, the scientific support person becomes the editor, along with others who have an involvement in the editing process.

From now on the scientific support person will be referred to as the [OPTIMAX] book editor.

The book editor proposes the chapters which will be included in the book. At a minimum all the articles produced by the students will be included. In addition new chapters will be commissioned, often based upon lectures given within the summer school. For these chapters proposed authors should be invited in good time to produce their chapters; their chapters should be reviewed by the editor and if needed additional work might be required. The editor also reviews the articles produced within OPTIMAX and at this stage further feedback might be given to improve them.

All draft chapters should be ready by mid-January ready for type setting to occur. Typically we have done type setting in-house, with one of our partner universities offering to support this activity. As this

is being done an ISBN number is arranged and included into the final version of the book ready for e-publishing. The book should be published into an Open Access forum to be available free of charge (e.g. University of Salford Institutional Repository¹¹); we normally publish the book online by 1st March following the OPTIMAX summer school. Beyond August, it normally takes around 6-months of work to develop the material, type set it and publish it. Once the OPTIMAX is published a strategy is adopted to promote it. Normally this could involve writing promotional news pieces for professional magazines and the lead tutor from each organisation should ensure this is done. Links to the book are placed onto institutional web-sites. Finally book reviews are organised so they can be published in national / international peer review journals.

References

- 1 <http://onlinelibrary.wiley.com/doi/10.1002/jmrs.178/pdf>
- 2 <http://www.jmirs.org/article/S1939-8654%2815%2900308-2/pdf>
- 3 http://ac.els-cdn.com/S1078817416300189/1-s2.0-S1078817416300189-main.pdf?_tid=a6953758-7a77-11e6-918b-00000aab0f6b&acdnat=1473856679_b892e30a83dbf20ef1bb630642496e61
- 4 https://en.wikipedia.org/wiki/Open_access
- 5 <http://www.wma.net/en/30publications/10policies/b3/>
- 6 <http://www.hpc-uk.org/aboutregistration/standards/standardsofconductperformanceandethics/index.asp>
- 7 http://ac.els-cdn.com/S1078817416300232/1-s2.0-S1078817416300232-main.pdf?_tid=bd58f9aa-3d07-11e6-9500-00000aab0f27&acdnat=1467101593_1450797bab86ab465a98fb36bddbec9a
- 8 <http://usir.salford.ac.uk/34439/1/Final%20complete%20version.pdf>
- 9 <http://usir.salford.ac.uk/38008/1/Ebook%20Hanze%202015.pdf>
- 10 http://www.myesr.org/cms/website.php?id=/en/ESR_ECR_news.htm
- 11 <http://usir.salford.ac.uk/>

OPIMAX 2015 – The Netherlands

By Phillippa Nightingale

When I participated in Optimax 2015 I was a seventeen-year-old A-level student studying maths, physics, chemistry and further maths with an AS level in biology at the Blue Coast School Oldham, Greater Manchester.

In spring 2015 I was awarded a six week Nuffield research placement with Professor Peter Hogg at The Directorate of Radiography, University of Salford. The first two weeks were spent at the University of Salford visiting the library, reading online journal articles and speaking with Professor Hogg to obtain some background knowledge into radiography and medical imaging. From this experience I not only

learned more about the basics of radiography but I also gained skills in how to search for relevant articles and find useful books in a large library. Hopefully these skills will come in very useful when I begin my undergraduate degree at Durham in October 2016.

I also spent three days at Tameside General Hospital in Greater Manchester with Helen Baxter to gain a broader knowledge and understanding of radiography in a clinical setting and I spent time in the general X ray, fluoroscopy, CT, MRI and nuclear medicine departments, all of which were really interesting and showed me the diversity of radiography that I hadn't quite realised previously.



After this I was fortunate enough to attend a three week summer school called 'OPTIMAX 2015', in the city of Groningen, the Netherlands with radiography students from the University of Salford, Norway, Portugal, South Africa, Switzerland and the Netherlands as well as university lecturers.

Those taking part in the summer school were divided into five research teams consisting of approximately six students and two tutors all from different countries per team. Each team was given a problem that they needed to solve. The three weeks were dedicated to the research process from the conception of a research idea and making hypotheses to delivering research papers within a formal conference at the end.

There were five groups in total each had approximately six students and two tutors all from different countries.

I was in team 5 which had two Dutch students, two Norwegian students, a Portuguese tutor and student, a Swiss tutor and myself. All the students other than me were completing a radiography degree in their home countries and one of the Norwegian students had already obtained a master's degree in neuroscience and a BSc in Psychology. I was the only person who spoke English as their first language however the quality of written and spoken English within the team was outstanding.



The first two days consisted of understanding your personality type by using the Myers-Briggs Type Indicator (MBTI) as well as the personality of others in your team. The purpose of this was to try to understand how the team will work together. Key to the success of OPTIMAX is the need to work effectively in research teams. I found working with others really enjoyable and learning about how teams operate / function made my team aware of how others in the team may behave due to the different personality traits such as introvert or extrovert.

Each team was provided with a research area of radiography and were then instructed to discuss and provide a research question to the organisers of the summer school. The purpose of the summer school was to produce a journal article, poster and presentation.

The first thing we had to do was start searching for literature related to the research question and then start to write an introduction using sources and references from previous article. This is when I first learnt to use Mendeley, a computer programme for managing and sharing research papers. I also learnt how to phrase a scientific article in a concise yet detailed manner. It was really good to learn these skills at a younger age as I have been able to practice them in preparation for university and I hope they will come in useful when referencing and writing

up scientific experiments for laboratory work and assignments.

The team split into two sub-teams in order to complete the method and introduction which allowed the work to be finished on time. It was a demanding experience, there was no downtime – we had to remain on-task constantly. After this the method was discussed as a team. Unfortunately the original software for the method didn't work adequately but the team quickly came up with solutions in order to solve the problem and I liked how everyone's suggestion made a small change to the method. I learnt that in research the situation can change quickly and dealing with uncertainty and making decisions in uncertain situations is a skill that I've started to develop.

After the data had been collected the data analysis began. Some members of the team felt particularly confident with the Statistical Package for Social Science (SPSS) and they taught the rest of the team how to use it to make graphs and carry out statistical tests which I thought was great as my new knowledge could be applied to create figures and tables which would be utilised in the final article. Whilst this was happening a couple of other team members started to write the results section of the article and make the poster as graphs had been created.

For the rest of the project, the team worked together to make sure that everyone was happy with what was being written for the results, data analysis in the discussion and conclusion.

On the final day every team presented their posters to a group of Dutch people who were connected to the university where we had been working. This was good as it gave the teams the chance to explain, and as required provide a robust defence, their research projects to people with a non-radiography background in addition to those who hadn't been immersed in the subject for three weeks unlike the teams.

Afterwards representatives from each team presented their research at a conference. Another team member and I represented team 5 and this was an enjoyable and fantastic experience because it gave the opportunity to share the work with others and also learn more about the other research that had been happening. After OPTIMAX our team leader presented at the European Conference of Radiology and I presented on behalf of the team in a research seminar at the University of Salford. OPTIMAX gave me the invaluable experience to present in two research conference events which helped me gain confidence to do similar things in future years.



The organisers of OPTIMAX also gave a cultural experience by making timeslots for everyone to do a presentation about their country and themselves in large teams.

Other cultural activities included a day trip to the local island of Schiermonnikoog on the first weekend. This allowed people to get to know each other from different teams and countries. Just by speaking to people from different countries every day you learn so much about their culture as well as the differences from your own. In addition every day we cycled from the accommodation to the university and back again just like the Dutch which was tiring but a great experience as it was a taste of a fundamental part of Dutch life. In the evening I met up with different

groups of people to go out for meals, visit the open air cinema and one Sunday we went kayaking on the canals. Living in the same place as all rest of the OPTIMAX was a great way to have a taste of university life and so I have chosen to live in halls at the University of Durham.

We also visited the university hospital and the city hospital whilst we were in Groningen which was good as it was a chance to see the different practices and similar equipment to compare to the UK hospital that I had visited a few weeks prior.

Working as part of an international research team is an amazing experience in itself but at 17 it is truly amazing and taught me that I would definitely like to



work in an international setting when I am older. One of the main benefits of working in an international team is the wide variety of perspectives and ideas for improving the research. Through this I learnt how to listen to everyone's ideas and opinions and try to incorporate them into the work.

I feel that my team was really supportive and worked well together. Everyone gave their opinion and the work would be adapted if the majority agreed with the amendment. There were a only few moments when language was a barrier but personally I feel everyone said what they wanted to in the end but I enjoyed the problem solving and using my own language to try and understand and help others to convey their opinions successfully.

The overall experience was fabulous from both an academic and cultural perspective. However, as an A level student experiencing OPTIMAX I particularly enjoyed the intensive quick paced feeling of the summer school. Every day brought new challenges and there was minimal time to do every task so I found that decisions were made much quicker and if there was a problem with the equipment then the solution was found much faster than I have previously experienced. OPTIMAX is a fabulous opportunity for all involved as it gives a real insight into the world of scientific research and article writing as well as giving an opportunity to learn about five different cultures.

Taking part in OPTIMAX confirmed my passion for the sciences and made me aware of all the different options there are within science. It also gave me an invaluable opportunity to see how scientific subjects transition from college to university and beyond. The summer school setting was a really enjoyable experience and has made me eager to take part in more in the future where I'm sure I will be able to apply all the experiences I gained from OPTIMAX.

METHODS FOR DIRECT MEASUREMENT OF RADIATION DOSE: TLD and MOSFET

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With a practical approach in mind this chapter explains how to use thermo luminescent detectors (TLD) and Metal Oxide Semiconductor Field Effect Transistor (MOSFET) for direct dose measurements in human phantoms. For an explanation of the theory of each is given.

Anthropomorphic phantoms made of tissue substitutes have been used extensively to represent human anatomy and mimic its radiation attenuation characteristics in dosimetric studies (1). The purpose of using phantoms in dosimetric studies is to simulate a patient's radiation exposure during specific radiological procedures in order to assess organ radiation dose or to mimic conditions for reference calibration of a dosimeter system or beam (e.g. radiotherapy beam calibrations by the use of water

phantoms) (2). Within the anthropomorphic phantoms, suitable dosimeters are used for *in vivo* organ dose measurements. Solid state dosimeters are the most commonly used dosimeters for this purpose. These are either thermo-luminescent dosimeters or Metal Oxide Semiconductor Field Effect Transistor (MOSFET) dosimeters.

Thermo-luminescence Detectors (TLD)

1. Principle

Thermo-luminescence was initially discovered in 1663 and is a phenomenon of light emission from an insulator or a semiconductor resulting from previous energy absorption from a source of ionising radiation. Since then, many theories have been proposed to explain it and the explanation which depends on the electronic energy band theory is the most widely accepted one (3).

In perfect semiconductor or insulator crystals most electrons occupy the valence band which is detached from the conduction band, the highest energy level, by a forbidden band gap (4). According to the one trap model, there are two levels in the forbidden band gap: T level, which is located in the conduction band above the Fermi level of equilibrium; and R level which is located above the valence band and below the equilibrium Fermi level. At equilibrium, both these levels are empty (4). The absorption of radiation energy by thermo-luminescent material may result in the liberation of valence electrons to the conduction band creating positive holes in the valence band. The negative charge carriers, the electrons, are trapped in T level and positive ones, the holes, are trapped in the R level. An increase in temperature speeds the return to equilibrium by un-trapping the electrons which are released to the conduction band and then recombine with holes at the luminescent centres in the R level.

Because this process involves electron movement from a high energy level to their ground state, an emission of energy as light quanta occurs (5). The ratio of emitted visible light energy to the absorbed ionising radiation energy is called the luminescence intrinsic efficiency (4). In order to increase the luminescence intrinsic efficiency of a material, more energy levels are localised in the forbidden band gap by adding impurities to that material (5). In other words more light quanta per unit dose are emitted.

In brief, the thermo-luminescence process occurs in several steps: a) the production of electron-hole pairs in thermo-luminescence material by the absorption of ionising radiation energy, b) the trapping of the charge carriers in R and T levels, c) the de-trapping of charge carriers by raising the temperature, d) light production by recombination of charge carriers in luminescence centres at R level (6).

2. Thermo-luminescence Dosimetry

The perfect dosimetric material should have an atomic number similar to that of human tissue (7.42) meaning the absorptive properties of the tissue and the measuring device are comparable (6,7). In addition to tissue equivalency, several characteristics are required for good thermo-luminescence dosimeters: a) linearity, a linear response with absorbed dose over wide range; b) high sensitivity, the amount of light produced per unit absorbed

dose; c) independency of radiation energy; d) simple glow curve, resulting in a simple heating protocol; e) good mechanical strength and static chemical activity; f) low fading (3,8). The fading composes of two components: pre-fade, which is the decrease in thermo-luminescence dosimeter response to radiation; and post-fade, which is the reduction in the storage signal in thermo-luminescence dosimeter with time (9).

Owing to their suitable dosimetric characteristics, TLDs are used extensively in many medical and personal monitoring applications (10). In diagnostic radiology, the main application of thermo-luminescence dosimeters is in personal dosimetry (11). TLDs are also used widely by many quality assurance programmes for radiation dose measurement because they can assess radiation doses with backscatter when they are placed on patients or phantoms (12,13). Since radiotherapy aims to maximise the radiation dose to tumour tissue and minimise it to normal tissue, it is necessary to use suitable dosimeters for assessing this. The most suitable dosimeters are TLDs because they have the ability for *in vivo* dose measurement (14).

There are currently several commercial groups of TL dosimeters. According to the material from which dosimeters are manufactured, they are classified into LiF, CaF₂, and Al₂O₃ groups. The LiF group include

TLD-100, TLD-100H, TLD-600, and TLD-600H. TLD-100; LiF was the first used TL dosimeter. It is characterised by its good tissue equivalency ($Z=8.04$), its sensitivity to low doses, its wide range of linear response (10 μ Gy-10Gy), and its low fading rate of around 5-10% per year. TLD-100H dosimeters can be used in diagnostic radiology and are around 20 times more sensitive than TLD-100 detectors. They have a wider dose range (1 μ Gy – 20 Gy), and lower fading rate of around 3% per year. The TLD-600 H dosimeter is used for neutron dosimetry. The main drawback of the CaF₂ group is their fading rate - 16% per 2 weeks and 15% per three months for TLD-200 and TLD-400, respectively. TLD-500 which is made of Al₂O₃ has a useful dose range of 0.05 μ Gy – 10 Gy, with a 3% per year fading rate (8). The selection of dosimeter depends on the application in which the dosimeter is to be used. For diagnostic radiology the required dose range is 0.001-10 mSv, while that for radiotherapy is 0.1-100 mSv (3).

The main advantage of TL dosimeters is their accuracy and precision. Their small physical size and availability in different forms and tissue equivalency make TLDs suitable for *in vivo* measurements and they can be used within phantoms to measure the radiation dose at different depths and locations. Moreover, TL detectors are easy to handle because they are not sensitive to light. Other important characteristics of TL detectors are

they are independent of radiation direction in their measurements, and consequently the backscatter is included in their readings.

Despite the advantages listed above, TL dosimeters do have limitations. Firstly, they cannot give instant measurements because calibration and readout processes are required. Secondly, TLDs allow only one time reading during heating because of signal efface during the readout procedure (3,11).

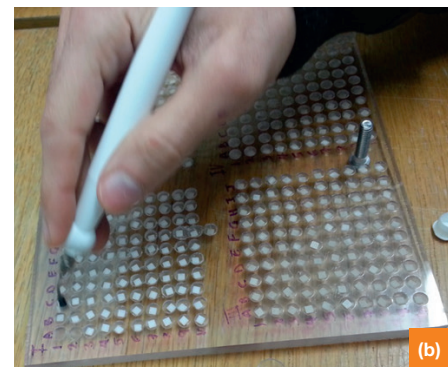
Organs Dose Measurement by TLD-100H

TLD-100H dosimeters are LiF:Mg,Cu,P chips characterised by their sensitivity, small size and tissue equivalency making them suitable for *in vivo* dose measurements. TLD-100H dosimeters are 20-50 times more sensitive than TLD-100. This high sensitivity is essential because of the relatively small radiation doses measured within diagnostic radiology

dosimetry. The small size (0.125 X 0.125 X 0.035 inches) of TLD-100H dosimeters minimises any X-ray field distortion. Another important characteristic of TLD-100H dosimeters is their tissue equivalency ($Z_{eff\text{TLD}} = 8.04$ compared to $Z_{eff\text{tissue}} = 7.42$) which makes them have similar response to radiation as human tissue (7,15). TLD-100H can measure radiation doses over a wide range, 1 pGy - 10 Gy, with a linear response across this energy range. The fading rate of these dosimeters is negligible, approximately 3% per year (16), making them suitable for dose assessment when the radiation dose measurement and TLD reading are achieved at different points. Consequently, systematic errors such as those resulting from dosimeter energy response, dosimeter size, and radiation field perturbation by dosimeters are minimised with the use of TLD-100H (17). Since the TLDs are sensitive to small scratches and surface contamination, which may affect the light emission

Figure (1) Illustrates TLD handling

- (a) Vacuum pump
- (b) TLDs handling by Dymax 5 vacuum tweezers.



process, they are carefully handled by the use of vacuum tweezers (such as Dymax 5 from Charles Austen Pumps, Surry, UK), see **Figure (1)**. Mechanical tweezers and fingers are not recommended to be used for TLD handling as physical damage or impurities will adversely affect any readings (16).

1. TLDs-100H Reading

The TLD reading system comprises of a TLD reader, such as Harshaw 3500 TLD reader (Thermo Scientific, USA), with associated software, for example WinREMS, on a personal computer (PC) (**Figure (2)**).

The reader consists of a drawer containing a metallic tray suitable for one or more TLDs where the irradiated TLD is heated and a photomultiplier tube (PMT) to receive the thermo-luminescent light emitted by the TLD. The PMT converts the light to an electronic signal which is recorded as a unit of charge (nano-Coulomb (nC)) by an electrometer.

The intensity of emitted thermo-luminescent light is related to the reader heating rate of the irradiated TLD. The graphical plot of light intensity recorded as the current from the PMT (blue area) versus temperature (red line) is the TLD glow curve is shown in **Figure (3)**. The area under the curve is a graphical representation of the charge generated by the PMT and is proportional to the dose absorbed by the TLD.

The use of a constant heating rate is essential for accurate dose measurements by TLDs (18). The TLD-100H reading process in the Harshaw 3500 TLD reader has four phases. The first phase, known as preheat phase, persists for approximately 12 seconds in which the TLD is heated to 134°C. After 134°C has been achieved the TLD light signal is detected. The acquisition phase ends at 239°C after 30 seconds. After this the annealing phase continues for 10 seconds. The purpose of the anneal phase

Figure (2) Shows the TLD reading system.



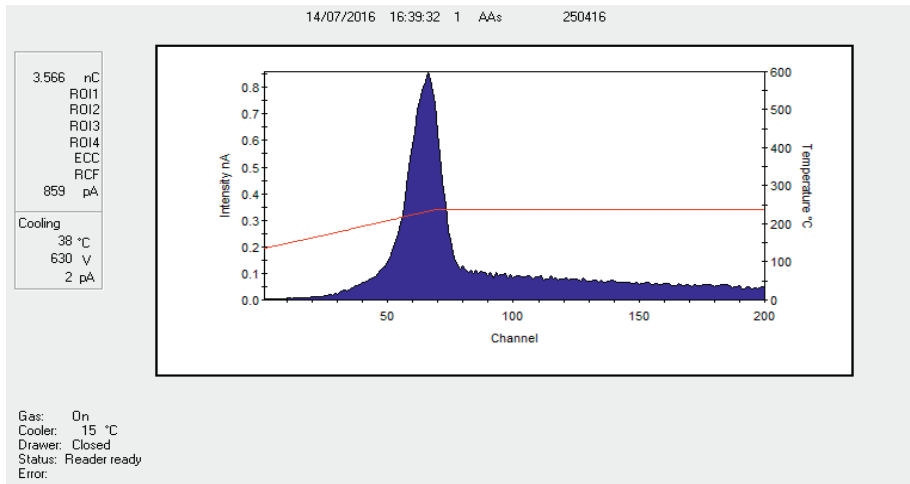


Figure (3) Shows a TLD 100H glow curve.

is to clear the TLDs of all residual stored energy (signal). Finally the cooling phase cools the annealed TLD from 239°C to 60°C. In order to provide a consistent temperature during reading and to avoid any background light signals being produced by the TLD reader metallic tray and by the impurities in the air, the TLDs are read in a constant pressure nitrogen atmosphere provided by a regulated compressor tank (19, 20). The Harshaw 3500 TLD reader is a manual type reader whereby TLD have to be loaded in turn. This is a time consuming process and when large numbers of TLDs are being read it is more efficient to utilise an automatic reader where batches of TLDs can be read with no operator interaction.

2. TLDs-100H Preparation

Prior to use, TLDs should undergo a process of preparation which includes annealing and determining/minimizing errors associated with their readings. These errors are mainly attributed to differences in sensitivity between TLDs and the consistency of TLDs. As recommended by the manufacturer (16), TLD-100H dosimeters should be annealed at 240°C for 10 minutes in a special rapid cooling high temperature oven, such as (TLD/3) model from Carbolite, England, UK using an annealing tray, see **Figure (4)**. This type of oven (TLD/3) is equipped with a Eurotherm 3508 temperature programmable controller which allows accurate annealing temperature regulation. The main purpose of the annealing process is to ensure that TLDs are free

Figure (4) Shows the TLD annealing equipment

- (a) Annealing oven
- (b) Annealing tray on an aluminum cooling block.



from any residual energy. TLD overheating should be avoided as this can affect TLD sensitivity and can lead to permanent damage (16). After annealing, an aluminium block is used to ensure a rapid cooling rate because the TLD cooling rate may affect its energy response (21). According to Furetta and Weng (1998) (22), TLD sensitivity is dramatically changed as the cooling rate changes. However the selection of best cooling rate depends on the TLDs material.

According to the European Commission (1996) (12), the total uncertainty in TLD dosimetric measurements should be less than 10%. Therefore, the TLDs sensitivity and consistency should be established. General radiography X-ray machines can be used to expose the TLDs to investigate their sensitivity and

consistency. For more accuracy before the exposing the TLDs, the X-ray beam uniformity of the X-ray machine should be tested using a suitable direct dose measurement dosimeter. The dosimeter reading is recorded at the four sides of the X-ray field for the same exposure factors, see **Figure (5)**. It has been found that there is a difference in dosimeter readings across the anode and cathode axis due to the anode heel effect but this was negligible across the other perpendicular axis. Therefore, during the exposure to calculate sensitivity and consistency, the TLDs have to be arranged as close as possible to the midline between anode and cathode sides to minimise anode-heel effect, see **Figure (6)**.

Figure (5) Illustrates dose measurements using Unfors Multi-O-Meter solid state dosimeter for X-ray beam uniformity investigation.

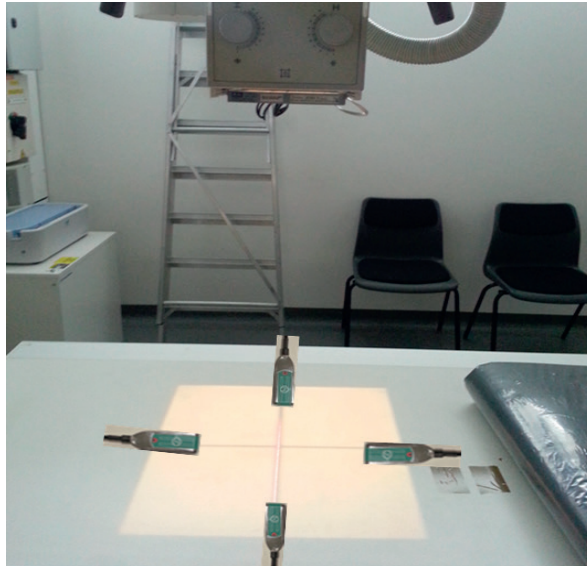


Figure (6) Illustrates the TLD positioning during exposure. The TLDs are positioned as close as possible to the central ray to minimise the impact of the anode-heel effect.



For improved TLD reading accuracy the sensitivity factor for each TLD can be estimated (23) using the following equation:

$$Ecc = \frac{R_i}{R}$$

Where Ecc is the correction coefficient for a given TLD, R is the individual TLD reading, and R_i is the average reading of all TLDs in the batch (24). However, an alternative method when a large number of TLDs need to be used, the TLDs can be divided into groups of similar sensitivity depending on the coefficient of variance (standard deviation divided by the mean). This way the acceptable level of error can be set by the researchers.

For TLD consistency estimation, all TLDs should be exposed and read at least three times with time intervals of around five days between each exposure. The TLD responses should be analysed using the SPSS to determine TLD consistency (Intra-class

Correlation). To improve accuracy further, the average background signal of three unexposed TLDs should be subtracted from the readings of exposed TLDs (25). As described by Tootell, Szczepura, and Hogg (2013) (26), the TLDs are calibrated against a calibrated direct dose measurement dosimeter placed on three slabs (1 cm thick each) of Perspex scattering material (**Figure (7)**). To minimise possible errors due to TLD response energy dependence, the calibration process should replicate as far as practicable the experimental method. For example the X-ray beam quality and filtration should be the same (27). The aim of the calibration process is to convert the output charge reading of TLDs to their equivalent radiation dose (nC/mGy).

Usually the calibration process is accomplished for a complete batch of TLDs because the calibration of individual TLDs is too time consuming and the individual approach shows only a minimal improvement in accuracy compared with the batch

Figure (7) Demonstrates the TLD calibration process against the Unfors solid state dosimeter on three Perspex slabs.



approach (the sensitivity difference of TLDs within any batch is very small) (28).

The establishment of the dose-TLD response curve requires TLD responses for at least five different radiation doses (e.g. at 10, 30, 50, 70, and 90 mAs) using the same beam quality (kV and filtration). In each case, the average of three TLD responses should be used to minimise random error. **Figure (8)** illustrates a calibration graph. In this figure solid state dose readings are presented on Y-axis against charge TLD readings on X-axis. The R^2 value gives an indication that TLDs response is near linear at this dose range (perfect correlation $R^2=1$) and the gradient of the line is the calibration factor (mGy/nC). Consequently, for TLD calibration a minimum of 15 TLDs are required in addition to another three for background measurement and correction. The whole process of TLD calibration should be repeated for each TLD group used in the organ dose measurement. For each organ the absorbed radiation dose is obtained by the averaging of TLDs' readings in that organ (28).

Metal Oxide Semiconductor Field Effect Transistor (MOSFET) Dosimeters

MOSFET as a radiation dosimeter was first proposed in 1974. However, MOSFETs have been applied only within the past ten years as a clinical dosimeter. They are capable of implementing almost real-time

dosimetry measurements. MOSFETs are able to measure cumulative radiation dose by relating the charge accumulated by the MOSFET to dose of radiation. This mechanism is established by employing thermally oxidized silicon. Currently, about 90% of the market of semiconductor instruments is taken up by MOSFET technologies in addition to its associated combined circuits (29).

The MOSFET is made up of four levels, which are the source, drain, gate and body. The source and drain are separated by about $1\mu\text{m}$. The remainder of the substrate area is encompassed by a thin oxide layer, usually around $0.05\mu\text{m}$ thick. The gate electrode is placed over the insulating oxide level and the body electrode is attached to this. The physical measurements of the detectors are an estimated 3 mm wide and 3mm thick, and they are enclosed within water material to generate a layer similar to tissue surrounding the detector. The kinds of MOSFET gate may be split into two categories, subject to the polysilicon material (N-type or P-type), which type the difference of polysilicon gate power trench MOSFET. Normally, the N-type trench power MOSFET comprises of a reduced gate resistance compared to P-type as a result of reduced sheet resistance from N-type in situ doped polysilicon (30), see **Figure (9) and Table (1)**.

Figure (8) Represents a sample of calibration curve of TLDs against Unfors solid state dosimeter.

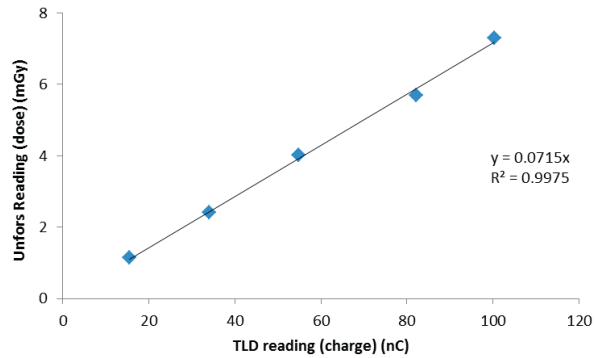


Figure (9) Basic Structure of MOSFET structures (N-type or P-type) (30).

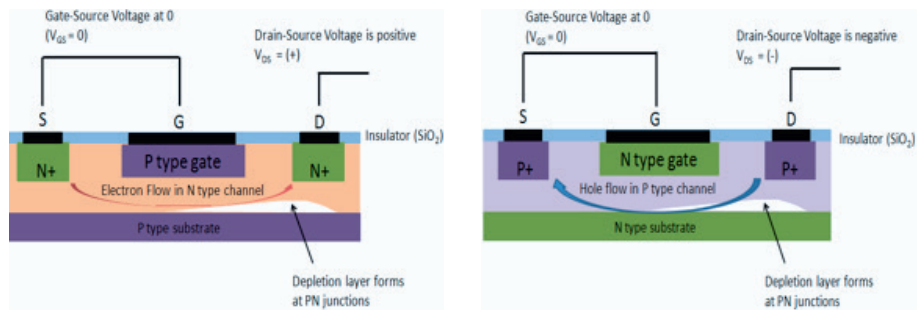


Table (1) Lists the structures of main types of MOSFET (N-channel and P-channel)

PARAMETER	N-CHANNEL	P-CHANNEL
Source / drain material	N-Type	P-Type
Channel material	P-Type	N-Type
Threshold voltage V_{th}	negative	doping dependent
Substrate material	P-Type	P-Type
Inversion layer carriers	Electrons	Holes

Comparison between P- and N-channel MOSFETs

When employed as a high side switch, the source voltage from an N-channel MOSFET will be at a raised potential. Therefore, to drive the N-channel MOSFET a separate gate driver or a pulse converter has to be employed. Additional power supply is required by the driver, while the transformer may at times generate incorrect conditions. Nonetheless, this is not true of P-channel³. It is simple to push a P-channel to elevated side switch using a level shifter circuit. Carrying this out eases the circuit and usually decreases the general cost. The P-channel chip tends to be 2 to 3 times bigger than the N-channel. Due to the greater chip size, the P-channel instrument will have a reduced thermal resistance and a raised current rating although its dynamic performance will be influenced in proportion to the chip size. Therefore,

an appropriate P-channel MOSFET has to be meticulously chosen, accounting for the gate charge. There are benefits using of P-channel MOSFETs such as low-voltage drives and non-isolated point of loads, these parameters becomes more important depending on the switching frequency (31).

Principle of MOSFET

The main idea behind the operation of MOSFET detectors is charging of the gate of the MOSFET detector, with build-up charge produced by ionising radiation. When MOSFET is exposed to ionising radiation, the formation of electron-hole pairs is brought about within the insulating layer of silicon dioxide. A number of the electrons will move towards the gate, and some will reintegrate with the holes. The holes which have not reintegrated with the electrons will flow towards the oxide-substrate

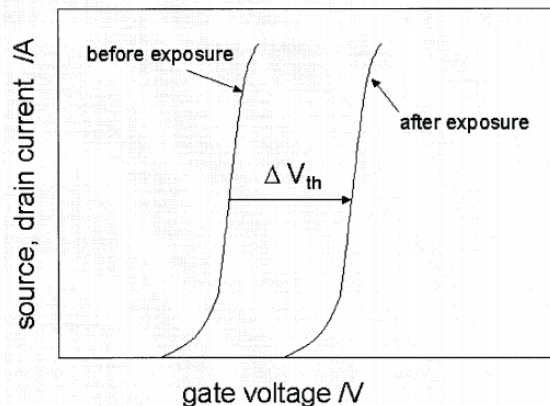


Figure (10) Change in threshold voltage with exposure to radiation (33).

interface, where a number of them will be held. The additional interfacial cost will result in a shift in the negative voltage that has to be employed amid the source terminals and the gate to form the conducting channel, and to achieve the same current flow as before the irradiation, as seen in **Figure (10)**. This difference in the threshold voltage (ΔV_{th}), from before to irradiation to after, ΔV_{th} , is proportional to the quantity of the radiation dose supplied to the MOSFET (32).

The sensitivity of a MOSFET detector may be enhanced by raising the number of holes at the interface. This may be achieved through employing a positive gate bias during irradiation, which may raise the amount of electrons gathered at the gate, reducing the quantity of recombination and thus raising the amount of positive holes remaining at

the oxide-substrate interface. Furthermore, the constructive gate bias pushes the holes in the direction of the oxide interface. An alternative technique is to reduce the breadth of the oxide layer, which raises the amount of electron-hole pairs formed within irradiation; this enhanced sensitivity reduces the life span of the detector (33).

Organs Dose Measurement by MOSFET

For organ dose measurements within a phantom, mobile MOSFET wireless dosimetry system (Model TN-RD-70-W, Best Medical Canada Ltd., Ottawa, Canada) can be used (34)-sensitivity TN-1002RD-H dosimeters, and TN-RD-75M software, **Figure (11)**. The TN-RD-16 reader modules can be independently set to control five dosimeters which are operated using the high bias voltage, 13.6 V, to obtain the best possible accuracy. A TN-RD-38 wireless transceiver



Figure (11) MOSFET reader and five dosimetries (34).

is used for data communication between the TN-RD-16 reader modules and a PC (Ottawa, Best Medical Canada Ltd.) (35). The MOSFET measures the difference in threshold voltage before and after an X-ray exposure. This difference in voltage is proportional to the absorbed dose (36). Threshold voltages are read immediately after each exposure. The accompanying software can handle up to 8 readers at any one time simultaneously meaning 40 dosimeters can be used during a single measurement measurement.

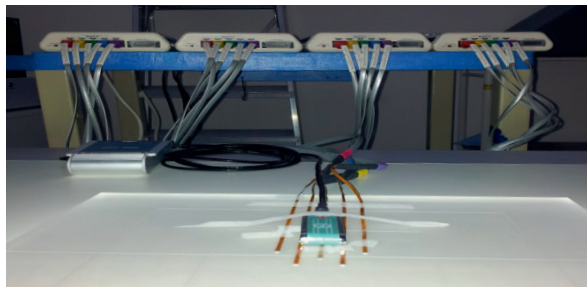
MOSFET Calibration

Like TLDs, MOSFETs must be calibrated to transpose the threshold voltage shift into a radiation dose. Often, the measured MOSFET calibration factors (mV/mGy) are used over the entire lifetime of the dosimeter. However an integrated dose dependence on the MOSFET calibration factor has been noted. Cheung et al. (37) observed an approximately linear decrease in the MOSFET calibration factor for diagnostic

energies (100 kVp and 250 kVp) using a standard sensitivity bias. The calibration factor decreased by approximately 30% and 15% over the lifetime of the MOSFET at 100 kVp and 250 kVp energies, respectively (37). Lavall'ee et al. (38) observed a nonlinear decrease in the MOSFET calibration factor for diagnostic energies (150 kVp) using a high sensitivity bias. The calibration factor decreased by 13.5% over the lifetime of the MOSFET (38).

MOSFET detector calibration utilises a supplied calibration jig in a process that is similar to that described for TLDs. Again a direct dose measurement solid state calibrated dosimeter is used. MOSFETs have to be exposed using high tube currents of 100, 160, 250, 360 and 450 mA. The MOSFETs are placed at a source-to-dosimeter distance of 60 cm, with the epoxy bulb down. Calibration factors for each MOSFET are determined by recording detector response in millivolts (mV) and normalising by absorbed dose (mGy).

Figure (12) First image shows MOSFET reader and 5 dosimetries and the second image illustrates calibration set up.



Further details on the calibration process are as follows:-

1. Calibration process is set up using the MOSFET calibration jig (**Figure 12**) and the bias sensitivity switch on the Reader Module is set to a high base sensitivity.
2. The number of readers that will be used for each calibration session are selected and assigned.
3. Each Reader can read up to five (5) dose points and with four readers being available this gives data from 20 dose points per acquisition.
4. The Reader will only read the MOSFET voltage in mV. The programme transforms the obtained voltage into dose according to User-defined Calibration Factors (CFs).
5. In order to provide the User-defined Calibration Factors (CFs) the obtained dose value from solid state dosimeter are entered to calculate the calibration factor then click “accept” to store the obtained CFs to “Raw CF Pool”.
6. The Final averaged CFs from the Raw CF Pool can be reviewed and may then apply save and/or print the calibration results.
7. All the steps mentioned above have been repeated for all four readers and the calibration factors obtained for all 20 dosimeters are summarised in **Table (2)**.

mAs	100	160	250	360	450
Unfors Dose mGy	9.875	15.430	24.110	34.780	43.660
Reader 1 (0737)	MOSFET #1	MOSFET #2	MOSFET #3	MOSFET #4	MOSFET #5
Calibration Factors mV/mGy	1.66	1.76	1.67	1.59	1.65
Unfors Dose mGy	9.875	15.45	24.14	34.84	43.73
Reader 2 (0738)	MOSFET #1	MOSFET #2	MOSFET #3	MOSFET #4	MOSFET #5
Calibration Factors mV/mGy	1.54	1.62	1.62	1.69	1.67
Unfors Dose mGy	10	15.65	24.44	35.26	44.26
Reader 3 (0735)	MOSFET #1	MOSFET #2	MOSFET #3	MOSFET #4	MOSFET #5
Calibration Factors mV/mGy	1.70	1.76	1.73	1.72	1.65
Unfors Dose mGy	9.947	15.53	24.27	35.04	43.96
Reader 4 (0736)	MOSFET #1	MOSFET #2	MOSFET #3	MOSFET #4	MOSFET #5
Calibration Factors mV/mGy	1.61	1.70	1.67	1.65	1.61

Table (2) Calibration factors summarised across four readers (1, 2, 3 & 4) and for 20 dosimeters.

CF Calculation is based on the following:

$$CF = \frac{\text{MOSFET mV reading (mV)}}{\text{Known Radiation Value (mGy/R/Gy)}}$$

Summary

This chapter has given background theory on the operation of TLD and MOSFET radiation detection systems which are suitable for phantom-based organ dose assessment and also other applications. Suggestions have then been made on how to use TLD and MOSFET in a practical setting, with minimisation of error and maximisation of accuracy in mind. We offer one final tip when you intend to use TLD or MOSFET – do get some training from people

who use them regularly because there are many simple short-cuts and suggestions which can be learnt in a practical setting.

An example of a method of CT dose measurement using with a dosimetry phantom and MOSFET dosimeters

The following is an example of an empirical method that was used to measure dose from CT examinations in a paediatric phantom. In this example 4 banks of 5 dosimeters were utilised. **Figure 13** illustrates a paediatric phantom with the MOSFET dosimeters located in specific organs and tissues. With only 20 dosimeters available the phantom is loaded and

Figure (13) Loading the phantom with MOSFET detectors and scan set up.



irradiated in order, locations 1-20, then 21-40 and so on. The obtained values (mV/mGy) are sent to the computer via wireless network and saved as an Excel file sheet. This was then repeated many times until all of the 167 or 271 dose locations had mV readings for

paediatric and adult ATOM phantoms, respectively. Once the data is gathered they are divided by the respective calibration factors (**Table 11**) for each MOSFET dosimeter in order to determine organ and tissues absorbed dose.

References

1. Winslow JF, Hyer DE, Fisher RF, Tien CJ, Hintenlang DE. Construction of anthropomorphic phantoms for use in dosimetry studies. *JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS*. 2009;10(3).
2. Green S, Palethorpe JE, Peach D, Bradley DA. Performance assessment of patient dosimetry services and X-ray quality assurance instruments used in diagnostic radiology. *Applied radiation and isotopes: including data, instrumentation and methods for use in agriculture, industry and medicine*. 1999;50(1):137-52.
3. Rivera T. Thermoluminescence in medical dosimetry. *Applied radiation and isotopes: including data, instrumentation and methods for use in agriculture, industry and medicine*. 2012;71 Suppl:30-4.
4. Bos AJJ. Theory of thermoluminescence. *Radiation Measurements*. 2007;41:S45-S56.
5. Bos AJJ. High sensitivity thermoluminescence dosimetry. *Nuclear Instruments and Methods in Physics Research B*. 2001;184(1):3-28.
6. Bos AJJ. On the energy conversion in thermoluminescence dosimetry material. *Radiation Measurements*. 2001;33(1):737-44.
7. Kitis G, Furetta C, Prokic M, Prokic V. Kinetic parameters of some tissue equivalent thermoluminescence materials. *Journal of Physics D: Applied Physics*. 2000;33(11):1252.
8. Kortov V. Materials for thermoluminescent dosimetry: Current status and future trends. *Radiation Measurements*. 2007;42(4-5):576-81.
9. Luo LZ. Extensive fade study of Harshaw LiF TLD materials. *Radiation Measurements*. 2008;43(2-6):365-70.
10. Moscovitch M, Horowitz YS. Thermoluminescent materials for medical applications: LiF:Mg,Ti and LiF:Mg,Cu,P. *Radiation Measurements*. 2007;41:S71-S7.
11. Olko P. Advantages and disadvantages of luminescence dosimetry. *Radiation Measurements*. 2010;45(3-6):506-11.
12. European Commission. European protocol on dosimetry in mammography. 1996.
13. Gaona E, Nieto JA, Góngora JAID, Arreola M, Enríquez JGF. TL dosimetry for quality control of CR mammography imaging systems. *Radiation Effects and Defects in Solids*. 2007;162(10-11):759-63.
14. Venables K, Miles EA, Aird EG, Hoskin PJ, Group STM. The use of in vivo thermoluminescent dosimeters in the quality assurance programme for the START breast fractionation trial. *Radiotherapy and oncology : journal of the European Society for Therapeutic Radiology and Oncology*. 2004;71(3):303-10.
15. Triolo A, Brai M, Bartolotta A, Marrale M. Glow curve analysis of TLD-100H irradiated with radiation of different LET: Comparison between two theoretical method. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*. 2006;560(2):413-7.
16. ThermoScientific. High Sensitivity LIF: Mg, Cu, P Thermoluminescent Dosimetry Materials, Chips 2015 [cited 2016]. Available from: <https://www.thermofisher.com/order/catalog/product/SCP18815#%2Flegacy=thermoscientific.com>.
17. Camargo-Mendoza RE, Poletti ME, Costa AM, Caldas LVE. Measurement of some dosimetric parameters for two mammography systems using thermoluminescent dosimetry. *Radiation Measurements*. 2011;46(12):2086-9.

18. Izewska J, Rajan G. Radiation dosimeters. In: Podgorsak EB, editor. Radiation oncology physics: A handbook for teachers and students. Vienna: IAEA; 2005.
19. Collins P. Assessment of effective dose in computed tomography using an anthropomorphic phantom. Galway: National University of Ireland; 2005.
20. Savva A. Personnel TLD monitors, their calibration and response. Surry: University of Surrey; 2010.
21. Lisa D, Claire H, Helen W-F, Mamoon H, Tomas K. Variations in dose response with x-ray energy of LiF:Mg,Cu,P thermoluminescence dosimeters: implications for clinical dosimetry. *Physics in Medicine and Biology*. 2004;49(17):3831.
22. Furetta C, Weng PS. Operational Thermoluminescence Dosimetry. Singapore: World Scientific; 1998.
23. Costa AM, Barbi GL, Bertucci EC, Ferreira H, Sansavino SZ, Colenci B, et al. In vivo dosimetry with thermoluminescent dosimeters in external photon beam radiotherapy. *Applied radiation and isotopes : including data, instrumentation and methods for use in agriculture, industry and medicine*. 2010;68(4-5):760-2.
24. Shirazi A, Mahdavi SR, Khodadadee A, Ghaffory M, Mesbahi A. Monte Carlo simulation of TLD response function: Scattered radiation field application. *Reports of Practical Oncology & Radiotherapy*. 2008;13(1):23-8.
25. Suleiman A, Theodorou K, Vlychou M, Topaltzikis T, Kanavou D, Fezoulidis I, et al. Radiation dose measurement and risk estimation for paediatric patients undergoing micturating cystourethrography. *The British journal of radiology*. 2007;80(957):731-7.
26. Tootell AK, Szczepura KR, Hogg P. Optimising the number of thermoluminescent dosimeters required for the measurement of effective dose for computed tomography attenuation correction data in SPECT/CT myocardial perfusion imaging. *Radiography*. 2013;19(1):42-7.
27. Olgar T, Bor D, Berkmen G, Yazar T. Patient and staff doses for some complex x-ray examinations. *Journal of Radiological Protection*. 2009;29(3):393.
28. M. Ali R, England A, McEntee MF, Hogg P. A method for calculating effective lifetime risk of radiation-induced cancer from screening mammography. *Radiography*. 2015;21(4):298-303.
29. Sze SM. Semiconductor devices: Physics and technology. 2nd ed: Wiley India Pvt. Limited; 2008.
30. Baliga BJ. Fundamentals of Power Semiconductor Devices. USA: Springer Science + Business Media, LLC; 2008.
31. Tamma PK. Selecting P-channel MOSFETs for Switching Applications 2013 [cited 2016]. Available from: <http://www.infineon.com/dgdl/Infineon++Application+Note++Power+MOSFETs++OptiMOS+P-channel.pdf?fileId=db3a304341e-0aed001420380cc13101b>.
32. Cygler J, Tanderup K, Beddar S, Pérez-Calatayud J. In Vivo Dosimetry in Brachytherapy. In: Jack Venselaar, Ali S. Meigooni, Dimos Baltas, Hoskin PJ, editors. *Comprehensive Brachytherapy. Imaging in Medical Diagnosis and Therapy*: Taylor & Francis; 2012. p. 379-96.
33. Manninen A-L, Kotiaho A, Nikkinen J, Nieminen MT. Validation of a MOSFET dosimeter system for determining the absorbed and effective radiation doses in diagnostic radiology. *Radiation Protection Dosimetry*. 2015; 164(3): 361-367.
34. Best Medical Canada. Operator's manual for the mobile MOSFET system. Wireless dosimetry system for use with mobile MOSFET Software Versions 2.2 and above; 2007 [cited 2016]. Available from: HEALTH CANADA:wireless dosimetry system
35. Koivisto JH, Wolff JE, Kiljunen T, Schulze D, Kortensniemi M. Characterization of MOSFET dosimeters for low-dose measurements in maxillofacial anthropomorphic phantoms. *Journal of Applied Clinical Medical Physics*. 2015; 16(4).
36. Soubra M, Cygler J, Mackay G. Evaluation of a dual bias dual metal oxide-silicon semiconductor field effect transistor detector as radiation dosimeter. *Medical Physics*. 1994; 21(4): 567-572.
37. Cheung T, Butson MJ, Yu P. Energy dependence corrections to MOSFET dosimetric sensitivity. *Australasian Physics & Engineering Sciences in Medicine*. 2009; 32(1): 16-20.
38. Lavallee M-C, Gingras L, Beaulieu L. Energy and integrated dose dependence of MOSFET dosimeter sensitivity for irradiation energies between 30kV and Co60. *Medical Physics*. 2006; 33(10): 3683-3689.

Part 2

**Empirical research conducted
during OPTIMAX 2016**



Optimization of full spine curvature radiography in paediatrics: impact of acquisition parameters

Reis C.S., Hårsaker V., Bregman A., Chêne R., Cordeiro B., Daniels T.L., Johannessen M., Vestli S.K., Widmer M., England A., Hogg P.

Abstract

Aim: Using a phantom, to optimize a set of acquisition parameters to study infantile scoliosis in antero-posterior (AP) digital radiography using low effective dose (E) while keeping image quality adequate to perform diagnostic visual evaluation using 1-year-old anthropomorphic phantom.

Method: 48 images of the full spine were acquired in AP position varying: beam energy (55-85 kVp), source-to-image distance (SID) (160-200 cm), beam intensity (6.3-0.8 mAs) applying the 10 kVp rule, air gap (with 20cm or without), added beam filtration (1mm Al + 0.2mm Cu or without filtration) to analyse the impact of E on image quality (IQ). IQ was evaluated by an objective approach using contrast-noise-ratio (CNR) and a perceptual approach using 6 observers. Monte-Carlo modelling (PCXMC software) was used to estimate the E . The Intraclass correlation

coefficient (ICC) was used to calculate intra and inter-observers consistency.

Results: The results show that CNR of thorax and abdomen are high at 55 kVp, with SIDs of 180cm; but the lowest E was achieved using 160cm SID, 85kVp, 0.8mAs, no air gap and with a filtration of 1mm Al and 0.2mm Cu. The intra-observer and inter-observer ICC for visualising the anatomical structures was moderate to good varying between 0.596-0.890 and 0.631-0.988, respectively

Conclusion: The observers were able to perform the task related to diagnostic performance in the group of images produced with the lowest effective dose. This study shows that it is possible to optimise radiography practice concerning infantile studies.

Introduction

Scoliosis is a condition involving an abnormal curvature of the spine. Scoliotic patients can be categorized by age: infantile (0-2 years old), juvenile (3-9 years old), adolescent (10-18 years old) and adult. They can be further categorized by cause: idiopathic, congenital and neuromuscular (1) however, the onset of scoliosis occurs much earlier than adolescence. Infantile scoliosis (ie, onset from birth to two years of age). A typical scoliotic patient is tall, female, with adolescent idiopathic scoliosis, and a convex right thoracic curve. However, in infantile scoliosis patients, the majority are male (2).

The modalities used for measuring the degree of spinal curvature include computed tomography (CT), magnetic resonance (MR), plain radiography and physical examination. Plain radiography is still the most used (3), with the advantages of it being cost-effective and widely available. Several techniques can be used to measure spine curvature based on antero-posterior (AP) or postero-anterior (PA) plain radiography images. The gold standard for diagnosis is the Cobb method, but others are still used, such as the Ferguson, Centroid, TRALL and Harrison posterior tangents methods. Every method uses its own anatomical structure references related to the start and end point of the curvature, such as vertebra endplates, pedicles and posterior vertebral bodies (2). But the use of plain radiography involves patient

exposure to ionizing radiation, which has been shown to increase risk of cancers, mainly in paediatric patients. Several studies showed that paediatric patients are more vulnerable to radiation than adults because of a higher cell division rate and longer life span in which to develop cancers or other radiation-induced pathologies (4,5,6) even though exposure to ionizing radiation must be kept especially low in young persons, because their tissues are highly radiosensitive. Children, who have many years left to live, are more likely than adults to develop radiation-induced cancer; also, as future parents, they are at risk for passing on radiation-induced genetic defects to the next generation. Whenever possible, radiological studies on children and adolescents should be of a type that does not involve ionizing radiation, such as ultrasonography or magnetic resonance imaging. Pediatric conventional X-rays and computerized tomography (CT). Infants with spine curvature are particularly vulnerable because they are monitored frequently using radiographic examinations, usually every 3 to 6 months. This condition requires long term follow-ups to monitor the treatment and other subsequent pathologies related to spine curvature (6,7).

The European Commission (EC) provide guidelines to support the selection of the acquisition parameters and image quality evaluation (7). However, these guidelines have not been updated for digital systems

and little research has been conducted to support them. Studies focused on the use of filters (8,9) and on air gap (6,10,11) have been conducted, however none have considered combining the two alongside other parameters: e.g. beam energy (kVp), beam intensity (mAs), and source-to-image distance (SID).

Digital Radiography has enabled production of images at a higher quality within a much wider range of exposure parameters than is possible with screen film systems. It is crucial to provide specific guidelines for practitioners to prevent dose creep in DR (13). This can be achieved through optimizing the technique that gives low radiation dose whilst producing images of an acceptable quality.

The aim of this paper is to identify the optimal technique to achieve low radiation dose while obtaining adequate image quality when imaging AP scoliosis in infants, using Digital Radiography (DR) systems. Adequate image quality (IQ) should allow to perform visual diagnostics, whilst adhering to the ALARA (As Low As Reasonably Achievable) principle.

Method

Data collection and analysis followed in this study is divided into four phases:

Phase 1: The acquisition of spinal radiographs while manipulating the acquisition parameters proposed by the European Commission (7)

Phase 2: The effective dose estimation using PCXMC software (Monte Carlo simulation).

Phase 3: The characterization of IQ using an objective approach, Contrast-to-Noise Ratio (CNR) and a visual, observational approach.

Phase 4: The identification of critical anatomical structures for spine curvature measurement, done by drawing lines along these structures.

Phase 1 - Image Acquisition

The experiment involved the acquisition of spine radiographs of a 1-year-old ATOM paediatric dosimetry verification phantom (704 B, **Figure 1**). To acquire the images, a Varian X-ray tube, with focal spot 0.6 mm/1.2 mm and 3 mm inherent filtration of Aluminum (Al) was used, and also a Konica Minolta Aero DR P11 System.

Figure 1: Example of 1-year-old ATOM paediatric phantom positioning during imaging acquisition

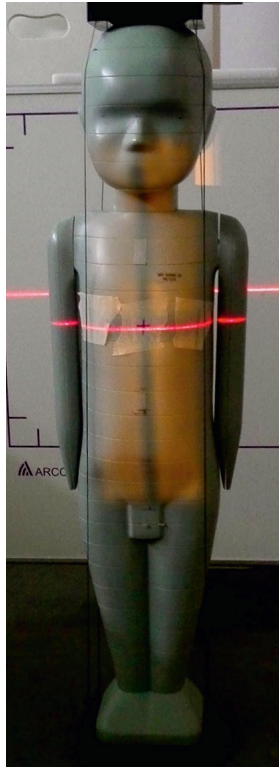


Image acquisition was performed in two stages. The aim of the first stage was to guarantee correct alignment of the phantom with the centre of the detector to determine the mAs baseline by using automatic exposure control (AEC) and also to define the collimation to include the whole spine from the skull to the sacrum. Collimation field was 40x12cm.

The second stage consisted of producing 48 images in the AP position. They were acquired in this position to be in accordance with clinical practice in paediatric imaging, which was the age simulated by the phantom (1 year old) (12,13,14). Moreover, for babies younger than 1 year, AP position for entire spine imaging should be the only age group in which a routine scoliosis series is performed supine (13).

Number of exposure performed	Phantom Position	Manipulated parameters Air Gap	Manipulated parameters			Added Filtration
			kVp range	mAs range	SID range [cm]	
12	AP	No	55	6.3	160	No
			65	3.2	180	
			75	1.6	200	
			85	0.8		
12	AP	No	55	6.3	160	1 mm Al + 0.2 mm Cu
			65	3.2	180	
			75	1.6	200	
			85	0.8		
12	AP	20 cm	55	6.3	160	No
			65	3.2	180	
			75	1.6	200	
			85	0.8		
12	AP	20 cm	55	6.3	160	1 mm Al + 0.2 mm Cu
			65	3.2	180	
			75	1.6	200	
			85	0.8		

Table 1: Sets of parameters used for image acquisition varying voltage (kVp), mAs, source-to-image distance (SID), filter and air gap.

The beam intensity for these 48 images was determined by using the 10kVp rule for three SID values (160, 180 and 200 cm). This rule states that when kVp is increased by 10, mAs is halved (14). The European guidelines (7) recommend a range between 65 and 90 kVp, but this recommendation is for a wide age range [10 months to 10 years old]. In our study we selected the middle range kVp (65-85 kVp) because the phantom simulates a 1year-old infant. Another

lower beam energy (55kVp) was selected outside the range to verify if it is possible to lower kVp for the biotype characteristics of an one year old infant (13).

All images were acquired with a broad focus and without a grid. The other variables considered in this study were added filtration of 1mmAl 0.2mm Cu and the use of an air gap (**Table 1**).

Phase 2 - Effective dose estimation

The effective dose (E) and the organ dose were calculated using PCXMC software. This software uses Monte Carlo modelling.(15)

By selecting the ICRP103 tissue weighting factors (mSv) (16), E was estimated using the exposure parameters (kVp, mAs), positioning, focal-skin distance, SID, age and beam size (collimation field).

Phase 3 - Image Quality Assessment

The images were analysed using two approaches: objective, using the CNR, and perceptual, using observers.

CNR was calculated for the objective measurement [Equation 1]. Four regions of interest (ROI) were marked on the images, using *ImageJ* software to obtain CNR in the thorax area and the abdominal area. For the thorax area, ROI1 was applied in the middle of the second thoracic vertebral body (T2) (maximum density) and ROI2 in the lung region with a homogenous density (background); for the abdomen, ROI1' was applied in the middle of the third lumbar vertebral body (L3) (maximum density) and ROI2' was applied in the abdomen region with a homogenous density (background) (**Figure 2**).

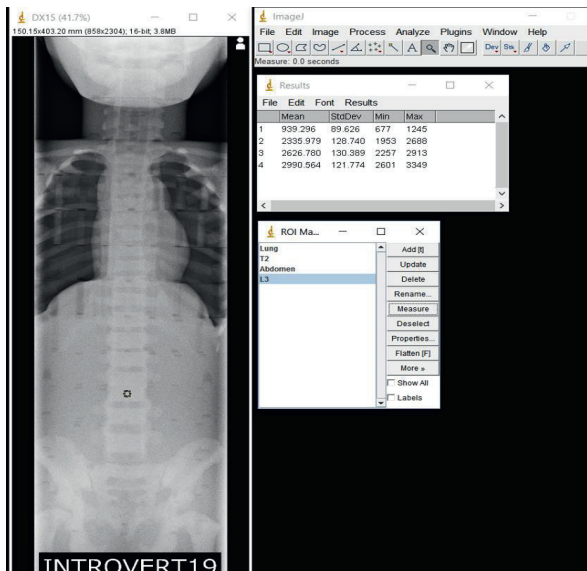
CNR is then obtained by applying the following formula (Equation 1) (11):

$$\text{CNR} = \frac{\mu_A - \mu_B}{\sigma_{BG}} \text{ (Equation 1)}$$

Where μ_A = mean pixel value; ROI in the middle of a vertebral body; μ_B = mean pixel value; ROI in a homogenous region (e.g. lung/abdomen); σ_{BG} = standard deviation of the background. Perceptual analysis required that the observers were chosen according to several criteria: willing to participate, experience in radiography/medical imaging analysis and if the vision was adequate by asking if observers had a vision test in the last 6 months. Three radiography students from their last academic year and three experienced radiographers were selected. Their clinical imaging experience range varied from one to seventeen years.

The method for perceptual analysis was two-alternative forced-choice (2AFC). This has the advantage of allowing the rapid evaluation of a large number of images, clearly showing the relationship between anatomical structures and contrast (17,18). The observers rated the images in comparison to a predetermined reference image on dual screens calibrated according to the DICOM greyscale standard (19). The reference image was selected using the middle range exposure parameters as per EU guidelines: SID of 180 cm, added filtration of 1mm

Figure 2: Contrast-to-noise Ratio measurement on ImageJ Software – ROI1: mean pixel value in the middle of T2 vertebral body; ROI2: mean pixel value in the lung region (homogenous density - background); ROI1': mean pixel value in the middle of L3 vertebral body; ROI2': mean pixel value in the abdomen region (homogenous density - background).



Comparing to the reference image...

Possible scores

1. the sharpness of C7 superior endplate is? _____
2. the sharpness of the superior endplates of each vertebras included between T1 and T3 is? _____
3. the sharpness of the superior endplates of each vertebras included between T4 and T7 is? _____
4. the sharpness of the inferior endplates of each vertebras included between T8 and T12 is? _____
5. the sharpness of L1 superior and inferior endplates is? _____
6. the definition of the intervertebral spaces between L5 and S1 is? _____
7. what do you think about the contrast of the image? _____
8. what do you think about the noise of the image? _____
9. the global image quality of the entire spine, from the skull to the sacrum is? _____

-2 = much worse
 -1 = worse
 0 = equal
 +1 = better
 +2 = much better

Table 2: Image quality scoring criteria and possible scores for each question.

Al and 0,2mm Cu, 75 kVp and 1.6 mAs, with no air gap (7). The images were scored using a five point Likert scale (much worse, worse, equal, better, much better) using predetermined criteria (**Table 2**). To validate the analysis from the observers the reference image, the two images with lowest dose and the two images with lowest CNR all appeared twice throughout the test.

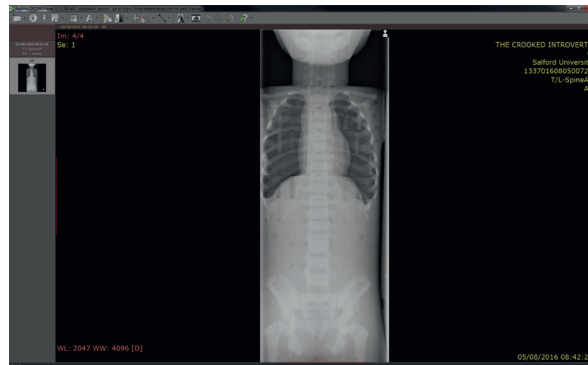
Phase 4 – Identification of critical anatomical points for scoliosis diagnostic in AP view

In this phase, five digital images were selected- the reference image and the 4 images with the lowest dose and CNR. The observers drew 3 parallel lines in three main anatomical structures on these images (20), using the Radiant DICOM Viewer. All the observers received instructions prior to the task.

The anatomical structures were selected according to clinical practice for the diagnosis of scoliosis using plain radiography (20). Literature highlights the thoracic region as the most susceptible to spinal curvature in paediatrics (12). Superior endplate of the first thoracic vertebra (T1) and inferior endplate of the ninth thoracic vertebra (T9) were selected to represent the thoracic region and intervertebral space between the last lumbar and first sacral vertebrae (L5-S1) was selected to represent the end of the spine that is used to identify the length.

This task was performed to evaluate the ability of observers to recognize relevant anatomical structures in noisy or low dose images drawing lines in specific regions. The possibility of using these exposure parameters in practice without compromising diagnostics could be examined.

Figure 3: Example of an image used to draw the lines in the three anatomical structures (T1 – superior endplate; T9 – inferior endplate; L5-S1 – intervertebral space) using the Radiant DICOM Viewer (white lines).



Statistical analysis

Descriptive statistical analysis was performed using Excel and Statistical Package for the Social Sciences (SPSS). Linear correlations (r^2) between variables were performed, and Intraclass Correlation Coefficient (ICC) were also used to report the degree of agreement within and between observers (21). The ICC scale used in this study was ICC value of 0.40 indicates poor reproducibility, ICC values in the region of 0.40–0.75 indicate fair to good reproducibility and an ICC value of 0.75 shows excellent reproducibility (22).

Results

Effective Dose

The E varied between 0.0018 mSv and 0.023 mSv. The lowest E was obtained using higher SID (180/200 cm), in 32 images out of the 48. For example, the image acquired with 160 cm SID, 55 kVp, 6.3 mAs and no air gap or added filtration resulted in 0.0171 mSv. Increasing the SID to 200 cm resulted in a 44% reduction of E (0.01184 mSv).

Introducing an air gap without changing other parameters does have a slight impact on E . When comparing the mean E values between using air gap and no air gap, the dose increased by 0.003 mSv with air gap.

Twenty-four images (out of 48) were acquired with added filtration of 1 mm Al + 0.2 Cu. Compared to the 24 images without added filtration; the result was

a reduction of E . For example, the image acquired with 180 cm SID, 55 kVp, 6.3 mAs, no air gap and no added filtration resulted in 0.01343 mSv. With added filtration there was a 187% reduction of E (0.00468 mSv).

Concerning beam energy, with the increase of the kVp (following the 10 kVp-rule), there is a constant decrease of E .

There were 6 combinations of parameters that resulted in a lower E than the reference image (**Table 2**). All 6 images were acquired using additional filtration of 1 mm Al + 0.2 mm Cu.

The lowest E images (0.001811 mSv) were acquired using 85 kVp, 0.8 mAs, a SID of 160cm and a filter of 1 mm Al + 0.2 mm Cu; and 85 kVp, 0.8 mAs, a SID of 180cm, a filter of 1 mm Al + 0.2 mm Cu and 20 cm of air gap.

Image quality assessment

Contrast-to-noise ratio

Regarding the CNR, the range of values in the thoracic area was between 3.8 and 42.3, and between 0.9 and 11.1 in the abdominal area.

The results show that the CNR in the thoracic and abdominal areas decrease in the same way. The CNR calculated in the abdomen was lower than in the thorax but they both decreased when the kVp increased.

Table 2: Acquisition parameters used in the highest IQ score image, the reference image and the images with the lowest effective dose: SID, kVp, mAs, air gap, added filtration – and their influence on CNR (thorax and abdomen areas); mean perceptual score and standard deviation, effective dose and change in effective dose

Image	SID (m)	Energy (kVp)	mAs	Air gap (20cm)	Filter 1mm Al + 0,2mm Cu	CNR thorax area	CNR abdomen area	Mean IQ score $\pm \sigma$ (2AFC)	Effective dose (mSv)	Change in effective dose (%)
Highest IQ score	1.8	55	6.3	No	Yes	17.2	4.2	0.9 \pm 0.4	0.00468	30
Reference image	1.8	75	1.6	No	Yes	11.5	3.3	-0.09 \pm 0.5	0.00360	0
Low dose 1	2.0	75	1.6	No	Yes	13.5	2.8	-0.85 \pm 0.2	0.00348	-3.3
Low dose 2	1.8	85	0.8	No	Yes	7.2	1.5	-1.04 \pm 0.2	0.00187	-48
Low dose 3	2.0	85	0.8	Yes	Yes	3.8	1.1	-1.85 \pm 0.3	0.00183	-49
Low dose 4	2.0	85	0.8	No	Yes	6.0	0.9	-1.72 \pm 0.4	0.00182	-49.5
Low dose 5	1.8	85	0.8	Yes	Yes	6.4	1.7	-1.5 \pm 0.5	0.00181	-50
Low dose 6	1.6	85	0.8	No	Yes	13.6	3.0	-1.39 \pm 0.3	0.00181	-50

Note: Reference Image was acquired according to European Guidelines on quality criteria for diagnostic radiographic images in paediatrics (7).

SID – Source-to-image distance

IQ – Image quality

CNR – Contrast-to-Noise Ratio

The decrease in both CNR were almost parallel when exposures were done with 200 cm SID (**Figure 4**).

In the abdominal area the different SID and kVp had minor impact on CNR. But in the thoracic area, the impact of SID and kVp was visible at 180 cm. By increasing kVp, the CNR decreased.

Perceptual image quality assessment

The images were scored by 6 observers. The ICC test for intra- and inter-observers showed a moderated to good agreement level. The ICC for intra-observers varied between 0.631 and 0.988 and inter-observers ICC varied between 0.596 and 0.890. The images were scored between -2 and 2. The results show that 87.5% of the images were rated as worse than the reference image and 12.5% of images were rated as

Figure 4: Influence of beam energy (kVp) and source-to-image distance (SID) on contrast-to-noise ratio (CNR) in the thorax and abdominal areas.

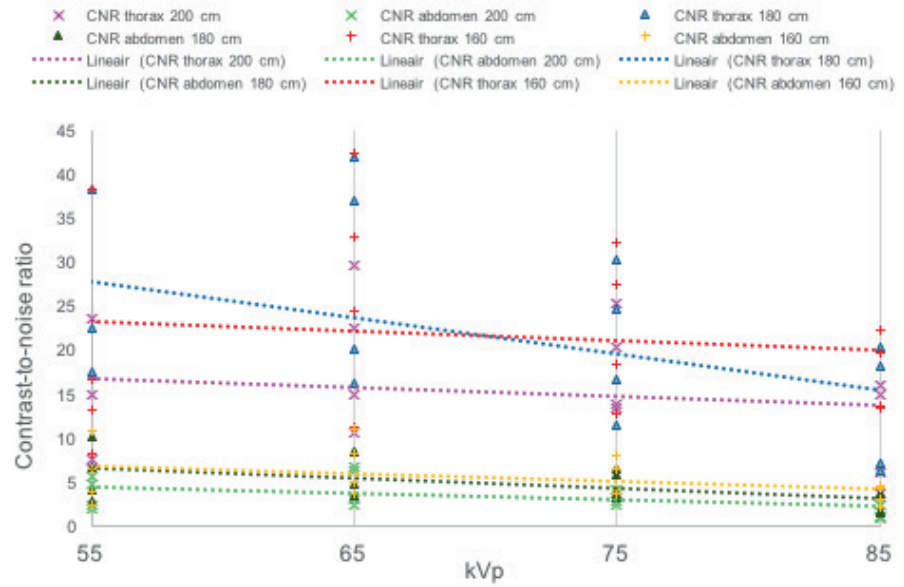
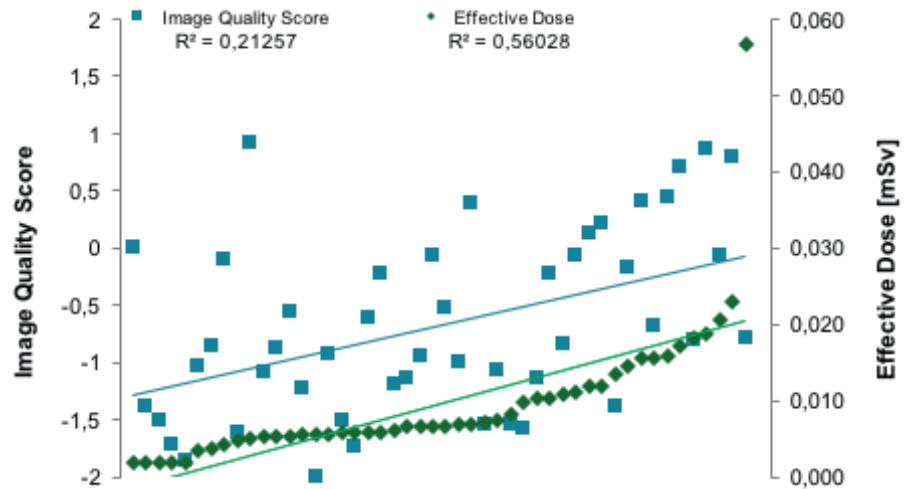


Figure 5: Trend line between mean image quality score (perceptual image quality analysis) and effective dose.



better. The highest rated image had an average score of 0.9, and it was acquired at 180 cm SID, 55 kVp, 6.3 mAs, used added filtration and no air gap.

The images with the lowest dose were given the worst image quality scores by the observers, but the observers could still perform the identification of the relevant anatomical structures (superior endplate of T1, inferior endplate of T9 and the intervertebral space between L5 and S1) (**Figure 3**).

Discussion

Several studies have been performed to optimize full spine curvature radiographs, but they are mainly focused on children, adolescents or adults and most do not combine as many parameters that can affect dose and IQ (8,9,10). In this study the EU guidelines (23) were used as a starting point for acquisition parameter combinations (mAs, kVp, SID, air gap and added filtration) in order to reduce E in infants while keeping IQ at an acceptable level.

Since infants are very sensitive to ionizing radiation and for spinal curvature assessment they often have many follow-up imaging examinations, it is very important to manipulate the parameters and achieve a decrease in E to reduce the induction of negative biological effects. Overall it was found, in this study, that radiation dose can be lowered compared to the one stated by the EU guidelines through manipulation of acquisition parameters; this might be due to the

wide age range for paediatric ages considered by the EU guidelines or that our work has been conducted on a phantom.

As shown in the results, E decreased with larger SID values. This was expected considering the inverse square law, where exposure drops with added distance. However, when correlating both parameters, it was possible to verify that with the increase in SID, the reduction in dose was modest ($\rho = -0.2$). This fact has been shown in different studies (24,25).

The introduction of an air gap did not have an impact on E when adjusting the SID accordingly. This is demonstrated in other studies focusing on lumbar spine and pelvic radiography optimization (10,26). The results showed that when adding an air gap, without changing the SID, there was a very slight increase in E . This can be explained by the fact that the source-to-object distance (SOD) decreased, which increased exposure following the inverse square law.

The use of additional filtration decreases E . This was expected due to low energy photon absorption by the filter instead of the imaged object. In the EU guidelines the use of added filtration is recommended (23). However, several studies have shown that this recommendation is not followed routinely in clinical practice (27,28).

This study shows that it is possible to reduce the dose using the 10 kVp-rule. Law *et al* (29) showed that in clinical practice low kVp was used for juvenile patients whereas high kVp was used for adults, resulting in a lower E for the latter age group. The average dose results for a 5-year-old male, in clinical practice, were 0.20 mSv using 68 kVp and 8 mAs. Increasing kVp on its own would increase patient dose, however an increase in kVp with a decrease in mAs results in an overall reduction of patient dose (14).

According to **Figure 4**, the highest CNR was calculated in images with the lowest kVp (55 kVp). This was expected, due to the combination of reduced scatter radiation, and higher intensity (mAs) (12). The opposite was true in images with high kVp: the combination of increased scatter radiation and lower intensity resulted in images with a low CNR. However, kVp only affected CNR in the thoracic area; in the abdominal area the CNR remained similar at different beam energies. This can be explained by the fact that there is a higher contrast between the main anatomical structures in the thoracic area than the structures in the abdomen. The same trend was observed with SID: longer SID resulted in lower CNR, due to the beam divergence.

The level of ICC was moderate to good. This could be due to the clinical experience of the observers regarding plain radiography. The variations in the

results could be explained by the use of a five-point Likert scale (-2 to 2). When the scale was compressed to a three-point scale (-1 to 1), the lowest inter-observer ICC value was improved from 0.596 to 0.678.

Based on another study (12), one of the expectations was that the image quality would increase with E . This was in fact observed in the results (**Figure 5**). The image with the highest IQ score (+0.9) gave a 30% increase in E compared to the reference image (**Table 1**). This showed that the guidelines already recommend parameters that reduce dose and provide adequate IQ. The main parameter in the guideline that affects E is the added filtration of 1mm Al + 0.2mm Cu. In this study, when filtration was added, the dose was reduced by 50%, when all other parameters were constant. The images with the lowest dose, including the reference image, were all taken with this filter.

All the observers were able to draw lines on the most important anatomical structures used in diagnosis, in the images with lowest E and image quality. This shows that it is possible to reduce the dose compared to what is recommended by the EU guidelines (7), while keeping adequate IQ allowing the identification of relevant anatomical structures. It is important to remember that the EU guidelines are based on screen film systems, and not DR systems. The latter have a wider dynamic range, which allows better optimization between dose and IQ (29,30,31).

The main limitation in this study was related to the use of a phantom. Using a phantom without spine curvature deformities did not allow performing an accurate full diagnosis. It also did not account for different body habitus, and did not simulate movement or breathing artifacts, which may have an impact on image quality. Consequently further work is suggested involving humans. Another limitation was related to the observers' limited paediatric imaging experience.

Conclusion


The purpose of this study was to determine the best technique to achieve lower radiation dose, while the image quality remains adequate to perform diagnosis of infantile scoliosis, in AP radiographs using DR systems. Results showed that by using higher kVp (75-85), higher SID (180-200cm) and low beam intensity (<1.6mAs), with added filtration (1mm Al + 0.2mm Cu), E can be reduced by approximately 50% when compared to the European guidelines. The image quality achieved was adequate enough to identify the anatomical structures used in clinical practice for scoliosis diagnosis. Further work is needed to include this technique in clinical practice, introducing other variables such as infantile patients, movement artifacts or gonadal and breast shielding.

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References

1. Wick JM, Konze J, Alexander K, Sweeney C. Infantile and juvenile scoliosis: the crooked path to diagnosis and treatment. *AORN J*. AORN, Inc.; 2009;90(3):347–76.
2. Anderson SM. Spinal Curves and Scoliosis. *Radiol Technol*. 2007;79(1):44–65.
3. Malfair D, Flemming AK, Dvorak MF, Munk PL, Vertinsky AT, Heran MK, et al. Radiographic evaluation of scoliosis: Review. *Am J Roentgenol*. 2010;194(3 SUPPL.):8–22.
4. International Commission on Radiological Protection (ICRP). Radiation protection in medicine. *Nihon Igaku Hshasen Gakkai zasshi Nippon acta Radiol*. 1995;55(13):517–23.
5. Alzen G, Benz-Bohm G. Radiation protection in pediatric radiology. *Dtsch Ärzteblatt Int [Internet]*. 2011;108(24):407–14. Available from: <http://www.pubmed-central.nih.gov/articlerender.fcgi?artid=3132617&tool=pmcentrez&render-type=abstract>
6. C. R. Jeukens, J. van Aalst, E. A. Maren, E. M. J. Cornips, A. G. H. Kessels, D. L. M. H. Soudant, J. W. Weber, A. Postma JSHV. Diagnostic Radiation Exposure in paediatric Spina Bifida Patients; an estimation of the Cumulative Effective Dose in a cohort of 135 patients from the Netherlands. *Eur Congr Radiol* 2012. 2012;1–14.
7. European Commission. European Guidelines on quality criteria for diagnostic radiographic images in paediatrics [Internet]. Eur 16261. 1996. 1-71 p. Available from: <ftp://ftp.cordis.lu/pub/fp5-euratom/docs/eur16261.pdf>
8. Perks TD, Trauernicht C, Hartley T, Hobson C, Lawson A, Scholtz P, et al. Effect of aluminium filtration on dose and image quality in paediatric slot-scanning radiography. *Proc Annu Int Conf IEEE Eng Med Biol Soc EMBS*. 2013;2332–5.
9. Hansson B, Finnbogason T, Schuwert P, Persliden J. Added copper filtration in digital paediatric double-contrast colon examinations: effects on radiation dose and image quality. *Eur Radiol*. 1997;7(7):1117–22.
10. Chan CTP, Fung KKL. Dose optimization in lumbar spine radiographic examination by air gap method at CR and DR systems: A phantom study. *J Med Imaging Radiat Sci [Internet]*. Elsevier Inc; 2015;46(1):65–77. Available from: <http://dx.doi.org/10.1016/j.jmir.2014.08.003>
11. Bourne R. Fundamentals of Digital Imaging in Medicine [Internet]. London: Springer London; 2010. Available from: <http://link.springer.com/10.1007/978-1-84882-087-6>
12. Reis C, Ndlovu J, Serrenho C, Akhtar I, Haan S de, Garcia JA, et al. Optimisation of exposure parameters for spinal curvature measurements in paediatric radiography. Radiation dose and image quality optimisation in medical imaging. 2015. 37-42 p.
13. Davey E, England A. AP versus PA positioning in lumbar spine computed radiography: Image quality and individual organ doses. *Radiography [Internet]*. Elsevier Ltd; 2015;21(2):188–96. Available from: <http://dx.doi.org/10.1016/j.radi.2014.11.003>
14. Allen E, Hogg P, Ma WK, Szczepura K. Fact or fiction: An analysis of the 10 kVp “rule” in computed radiography. *Radiography*. 2013;19(3):223–7.
15. Gyekye P, Geoffrey E-R, Engmann C, Simon A, Johnson Y, Stephen I, et al. Radiation dose estimation of patients undergoing lumbar spine radiography. *J Med Phys [Internet]*. 2013;38(4):185. Available from: <http://www.jmp.org.in/text.asp?2013/38/4/185/121196>
16. ICRP. ICRP 103: The 2007 Recommendations of the International Commission on Radiological Protection. *Ann ICRP [Internet]*. 2007;37:330. Available from: <http://ani.sagepub.com/lookup/doi/10.1016/j.icrp.2007.10.001>
17. Burgess A, Jacobson F, Judy P. Mass discrimination in mammography. *Acad Radiol*. 2003 Nov;10(11):1247–56.
18. Leong DL, Rainford L, Haygood TM, Whitman GJ, Geiser WR, Adrada BE, et al. Trend of Contrast Detection Threshold with and without Localization. *J Digit Imaging*. 2013 Mar;
19. Hogg P, Blindell P. Software for image quality evaluation using a forced choice method. United Kingdom Radiological Congress. Manchester; 2012. p. 139.
20. Rolton D, Nnadi C, Fairbank J. Scoliosis: A review. *Paediatr Child Heal (United Kingdom) [Internet]*. Elsevier Ltd; 2014;24(5):197–203. Available from: <http://dx.doi.org/10.1016/j.paed.2013.09.014>

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21. Corona J, Sanders JO, Luhmann SJ, Diab M, Vitale MG. Reliability of radiographic measures for infantile idiopathic scoliosis. *J Bone Joint Surg Am* [Internet]. 2012;94(12):e86. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/22717838>
 22. Chan TY, England A, Meredith SM, McWilliams RG. Radiologist variability in assessing the position of the cavoatrial junction on chest radiographs. *Br J Radiol* [Internet]. 2016 Sep;89(1065):20150965. Available from: <http://www.birpublications.org/doi/10.1259/bjr.20150965>
 23. Kohn M, Moores B, Schibilla H, Schneider K, Stender H, Stieve F, et al. European guidelines on quality criteria for diagnostic radiographic images in paediatrics. European C. European Commission, editor. Luxembourg: European Commission; 1996.

Ultrasound assessment of muscle thickness and muscle cross-sectional area: a reliability study

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Keywords

Muscle size
Rectus Femoris
Reliability
Ultrasound
Cross-Sectional Area

Abstract

Purpose: Previous studies showed that ultrasound imaging is reliable when measuring the cross-sectional area (CSA) of a muscle. However, measurements of muscles could be affected by the level of experience of the observer. The aim of this pilot study was to investigate the reliability of observers when measuring the CSA and thickness of the rectus femoris (RF).

Methods and Materials: Seven observers assessed eight different images of RF. On each image the CSA and thickness was measured three times using ImageJ. The measurements were analysed using IBM SPSS. Intraclass Correlation Coefficient (ICC) and Bland-Altman plots were used to analyse reliability. A Paired

Sample T-Test was used to investigate any differences between the first and mean measurement recorded by the observers.

Results: No significant differences were found between the first and mean of the repeated measures for CSA and thickness respectively ($p = 0.217-0.817$, $p = 0.337-0.897$). Intra-observer reliability shows excellent agreement between measurement one and the mean for each observer (CSA ICC = 0.987-1.000, thickness ICC = 0.996-1.000). High inter-observer reliability was found for both CSA (ICC = 0.938, 95% CI = 0.845-0.985) and thickness (ICC = 0.9774, 95% CI = 0.934-0.994). Agreement between an experienced and inexperienced observer was excellent (ICC = 0.991, 95% CI = 0.959-0.998).

Conclusion: This pilot study shows that there is a high level of inter- and intra-observer reliability among the observers in measuring the CSA and thickness of the RF. It also shows that experience in ultrasound measurements is not a factor in reliability.

Introduction

National statistics showed that ultrasound was the second most popular imaging examination technique in England from the 1st April 2012 – 31st March 2013. Out of a total of 41.1 million imaging examinations, 9.3 million were ultrasound.[1] Ultrasound is a non-invasive, quick, low cost and non-ionising imaging technique.[2] Furthermore, ultrasound is mobile, and this advantage makes it possible to perform scans in the patient's home setting. Nowadays ultrasound is mainly used to visualise the anatomy and pathology of internal structures, such as the abdominal area, pelvic

area and muscles.[3] In research settings ultrasound is used to quantify muscles.[4]–[7]disuse and ageing. The considered 'gold standard' for cross-sectional area measurements of muscle size is magnetic resonance imaging (MRI) Quantifying muscles is important as the estimated weight loss of muscle mass after 50 years of age is around 1 - 2% per year. [8] This loss of muscle mass and muscle function is called sarcopenia. The prevalence of sarcopenia ranges from 10 to 50 per cent of people over the age of 65, and can result in disability and hospitalisation. [9]

Sarcopenia preferentially affects lower limb muscles and it is therefore important to assess these muscles in an early stage.[10]–[14] One of the muscles affected by sarcopenia is the rectus femoris (RF). In previous studies the reliability of ultrasound in measuring the RF anatomical cross-sectional area (CSA) has been found to be excellent, with ICC ranging between 0.72 and 0.97.[15] However, one of the limitations of ultrasound is that it is highly dependent on the observer's performance.[16]

In addition, the observer's level of experience may be an influential factor on the reliability of the measurements. To the best of our knowledge, only one study has been done on the reliability of ultrasound measurements across observers, in which a novice observer has been compared with an experienced observer.[17] This study found that the novice observer demonstrated high reliability for some measurement conditions. However, it remains unclear as to what degree the experience of the observer may affect the reliability of the results.

Besides reliability in the results it is also important for them to have a high accuracy and validity. In practice, it is common to take the measurements a minimum of three times and then calculate the mean in order to minimise random error.[18]

Nevertheless, it remains unclear as to whether repeated ultrasound measurements are more accurate than a single measurement.

As part of a larger study on the reliability of ultrasound when measuring muscle mass, and its relationship with muscle function, this pilot study will investigate the inter- and intra-observer reliability of measuring muscle size of the RF. The findings will be used in the larger study as assurance that the data collected is accurate and reliable. The first aim of this pilot study is to investigate the inter- and intra-observer reliability of ultrasound. Secondly, this pilot study aims at investigating whether there is a significant difference between the first and the mean of the repeated measurements.

Materials and methods

Image Acquisition

Out of the 28 OPTIMAX 2016 summer school participants, eight were selected. Prior to the ultrasound, the participant's gender and age were recorded (**Table 1**) in order to acquire a group which contained two young adult females, two young adult males, two middle-aged adult females and two middle-aged adult males. The inclusion criteria were ambulant adults aged between 18 and 65 years. The exclusion criteria were participants who had surgery or an injury their legs within the last three months.

The participants for this research were given oral and written information about the study. The aim of the pilot study was explained to the participants, including the risks and benefits of the ultrasound procedure. This was done so the participants were able to give fully informed consent.[19] Each participant had the right to withdraw from the pilot at any point without any consequences. This pilot study was approved by the Salford University Ethics Committee.

The image acquisition was performed by one radiographer who had two days of preparation, where they practised scanning the RF. A portable Venue 40 musculoskeletal ultrasound system (GE healthcare, UK), which had a 5-13 MHz wideband linear array probe with 12.7x47.1 mm footprint area, was used to scan the participants.

In order to reduce the risk of error, the conditions of the ultrasound suite remained constant throughout the examinations. For example, the lights of the room were turned off.

During the ultrasound procedure the participant laid relaxed in supine position. To ensure the images were taken from the same anatomical region, the length of the participant's upper leg was measured, and marked two-thirds from the anterior superior iliac spine down to the upper pole of the patella.

Image evaluation

The eight ultrasound images were analysed by seven observers. The observers all had varying levels of experience and knowledge on ultrasound. Five of the observers were currently studying radiography, one had recently graduated in diagnostic radiography and one was studying A-Levels in college. In order to reduce bias, the observers all had the same amount of basic training on how to find the echogenic border of the RF muscle on ultrasound images and how to measure the muscle using ImageJ.

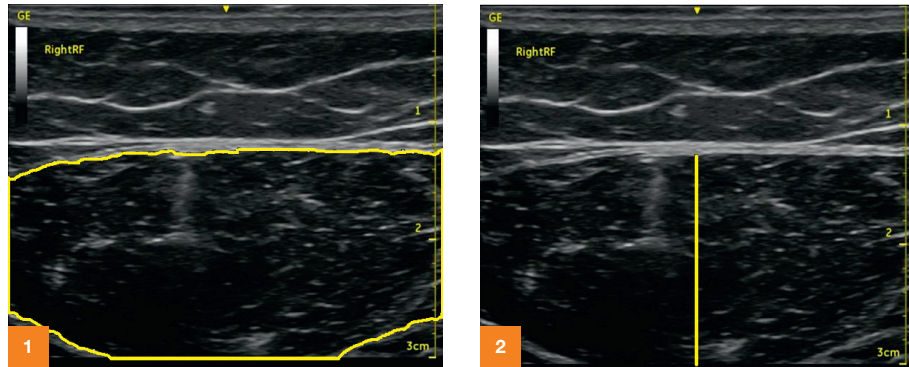
A 5 MP computer screen with a resolution of 2048 x 2560 pixels, calibrated to the DICOM greyscale standard, was used to evaluate the images. The distance between the screen and the observer remained at 60 cm; the ultrasound images were evaluated on full-screen; the lighting was turned off and temperature of the viewing room was kept the same at all times, in order to reduce the risk of error.

For every ultrasound image each observer drew a 'Region of Interest' (ROI) to calculate the CSA (cm²) (**Figure 1**) and drew a straight line to measure the muscle thickness (cm) (**Figure 2**). This procedure was repeated two more times. The straight lines that were used to measure the muscle thickness were drawn in the middle of the image, because that is where ultrasound image quality is at its best.[20]

Table 1: Patients characteristics

	N or Mean \pm SD
Number of patients	8
Gender (male / female)	4 / 4
Age (year)	33.88 \pm 12.96

Figure 1: CSA measurement
Figure 2: Thickness measurement



In order to reduce bias, the observers were blinded for their own previous measurements, and those of the other observers. The observers then had to verbalise their measurements to an external observer who recorded it. In order to minimise errors, the external observer had to reiterate the measurements.

Data Analysis

IBM SPSS Statistics Version 24 was used to analyse all the data. The Intraclass Correlation Coefficient (ICC) was used to analyse the inter- and intra-observer reliability of the measurements of CSA and of thickness. Beside this, the Paired Sample T-Test

was used to analyse the data of the measurements. A p -value of <0.05 for the measurements of the size thickness and CSA is considered significant.[21]

Results

In **Table 2**, the t - and p -values are shown for every observer. These were calculated using the Paired Sample T-Test. For the measurement of the CSA and thickness the t -values were close to zero ($t = -1.356-0.767$, $t = -0.869-1.030$). There were no significant differences between the first measurement and the mean of the three measurements for CSA and thickness ($p = 0.217-0.817$, $p = 0.337-0.897$).

Table 2: Paired Sample T-Test to compare measurement 1 with the mean of three measurements of CSA and thickness.

Observers	CSA		Thickness	
	t-value	p-value	t-value	p-value
1	0.767	0.468	-0.440	0.673
2	-0.656	0.533	-0.445	0.663
2	-1.356	0.217	-0.443	0.671
4	-1.070	0.320	0.875	0.410
5	-1.351	0.219	-0.869	0.414
6	-0.240	0.817	1.030	0.337
7	-0.282	0.786	-0.134	0.897

Table 3: Intraclass Correlation Coefficient (ICC) for the intra-observer reliability.

Observers	CSA		Thickness	
	ICC	95% CI	ICC	95% CI
1	0.994	0.975-0.999	1.000	1.000-1.000
2	0.999	0.994-1.000	1.000	0.999-1.000
3	0.995	0.978-0.999	0.996	0.983-0.999
4	0.989	0.949-0.998	0.998	0.990-1.000
5	0.987	0.938-0.997	0.998	0.991-1.000
6	1.000	0.999-1.000	0.998	0.992-1.000
7	1.000	0.999-1.000	1.000	0.998-1.000

Table 4: Intraclass Correlation Coefficient (ICC) for the inter-observer reliability.

CSA		Thickness	
ICC	95% CI	ICC	95% CI
0.938	0.845-0.985	0.974	0.934-0.994

Table 5: Intraclass Correlation Coefficient for the inter-observer reliability of several observers.

CSA		
Observers	ICC	95% CI
3 and 4	0.909	0.585-0.981
5 and 6	0.904	0.487-0.981
3 and 7	0.949	0.742-0.990
Thickness		
Observers	ICC	95% CI
1 and 3	0.991	0.959-0.998

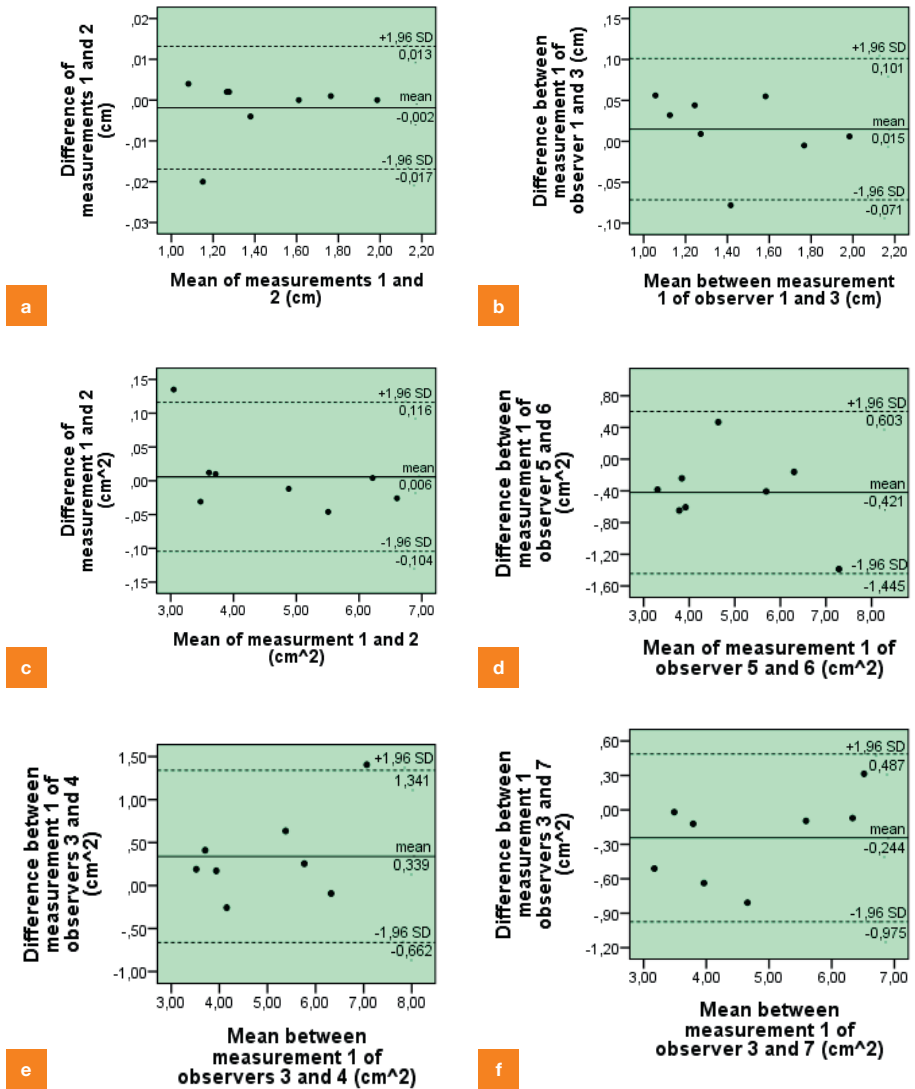
For the CSA and thickness an ICC score was calculated to determine the intra-observer reliability. The first measurement and the mean were compared for each observer and showed excellent agreement (CSA ICC = 0.987-1.000, thickness ICC = 0.996-1.000) (**Table 3**). ICC calculations were made to determine the inter-observer reliability for the CSA and thickness, wherein the first measurement for each observer was compared, also showing excellent agreement (CSA ICC = 0.938, thickness ICC = 0.974) (**Table 4**).

Several Bland-Altman plots were performed to ensure the accurate reporting of the ICC. The data of observer 1 was tested because it had an excellent ICC value for the thickness measurements (**Figure 3a**). The data of the thickness measurements for observer 1 and 3 were also tested (**Figure 3b**). In both figures, the data was shown to be within the limits of agreement and close to zero. For one

data point in each figure there seemed to be an outlier, but there were no t-values that could be considered statistically significant (a: $t = 0.746$, $p = 0.484$; b: $t = -0.751$, $p = 0.481$). This means there was no proportional bias and there appears to be a consistent level of agreement. The majority of the data fell between the limits of agreement, with no outlying trends. If you look at clinical relevance, the difference is a few cm.

The CSA ICC indicates that the inter- and intra-observer reliability was high (**Table 3** and **5**). For **Figure 3c**, observer 6 was chosen because of an excellent ICC value for the CSA measurements (**Table 3**). CSA measurement 1 was compared to measurement 2. For **Figure 3d**, CSA measurement 1 of observer 6 was compared to that of observer 5. Observer 5 was used for comparison because they showed the lowest ICC-score (**Table 3**). **Figure 3e** was devised to evaluate if experience in drawing

Figure 3: Bland Altman's plot for a) Thickness measurement 1 and 2 of observer 1, b) Thickness measurement 1 of observers 1 and 3, c) CSA measurement 1 and 2 of observer 6, d) CSA measurement 1 of observers 5 and 6, e) CSA measurement 1 of observer 3 and 4, f) CSA measurement 1 of observer 3 and 7



ROIs was an influential factor. Observers 2, 4 and 5 all had the same amount of experience in drawing ROIs. Observer 4 was selected because their ICC scores were between the scores of observers 2 and 5. Measurement 1 of observer 4 was compared to that of observer 3, who had no experience at all. The inter-observer reliability between these observers is shown in **Table 5**. To determine if the level of ultrasound-specific experience was an influential factor, **Figure 3f** was made. In **Figure 3f**, observer 7 was compared to observer 3, because observer 7 had recently graduated from studying radiography, whereas observer 3 was studying in college.

For **Figures 3c** and **3e**, most of the data points were between the limits of agreement and near zero. In both figures, one data point seems to be an outlier, but there were no *t*-values that could be considered statistically significant ($t = -1.589, p = 0.170$; $t = 1.497, p = 0.185$). Similarly, all of the data points were between the limits of agreement and near zero in **Figure 3d** and **3f**. In both figures, two data points are closer to the limits of agreement. Once again, there were no *t*-values that could be considered statistically significant ($t = -1.004, p = 0.354$; $t = 1.486, p = 0.188$).

For **Figure 3a, 3b, 3e** and **3f**, the *t*-values showed no proportional bias and there appeared to be a level of agreement. There was no trend in data points above or below the mean difference line. If you look

at clinical relevance, the difference between the data above, below or close to the mean difference line was only a few cm^2 .

Discussion

The aim of this research was to investigate the inter- and intra-observer reliability of ultrasound by measuring the CSA and muscle thickness of the RF on ultrasound images. The pilot study found that for both measurements of the RF CSA and RF muscle thickness, the inter- and intra-observer reliability were both very high (**Table 3** and **4**).

Results Evaluation

The main finding of this pilot study was that there was a high inter- and intra-observer reliability and this demonstrates excellent agreement within the observers and between each observer's measurements. This finding was supported with a study by Abe et al[2], which shows that the inter- and intra-observer reliability for the measurement of the lower extremity muscle thickness was good to high.

This pilot study also found that there were no significant statistical differences between measurement one and the mean measurement for the RF CSA and RF muscle thickness. Therefore, this result proposes that one measurement is accurate enough and as a result, this would save time and money. However, Hoskins et al[22] suggests that

repeated measurements can minimise random error and produce a more accurate mean. This result can lead to further investigations which look at whether the risk of increased random error in the measurements is a good compromise for the time and money that would be saved.

This research also investigated whether the experience of each observer could be considered a factor which would affect the reliability of the results. The Bland-Altman plots were used to demonstrate that there was no bias in the measurements and to support the ICC scores. The plots in **Figure 3e** show that the level of experience of the observer in drawing ROIs showed no significant statistical difference. This suggested that with good basic training before the evaluation of ultrasound images, the observers will perform similarly, even if they have different levels of experience. This result is supported by Teyhen et al[23] which showed that novice researchers can assess the trunk muscles reliably when they are properly trained.

Overall, these results can be used in the larger study to determine whether the muscle size affects muscle function and strength. Furthermore, it can also be applied into practice by using ultrasound as the main imaging examination technique for sarcopenia.

Strengths

There were a number of factors in the method which increased the reliability of the results. Firstly, the margin of error on ultrasound machines was significantly small. It differed from manual measurements by approximately 0.01 cm.[2] This error margin made it a more accurate and reliable imaging technique. Secondly, a group of participants were carefully selected so that there was less bias in the selection. This was done to avoid selecting people with similar physical characteristics, such as more matured adults, who typically have reduced muscle tissue and function. Therefore, this sample is more representative of the target population, none of whom who were physically disabled or outside the age range of 18-65 years.

Finally, some variables were controlled in the image viewing room in order to increase the reliability of the results. For example, the images were viewed in a dark room so that the image was clearer, allowing more accurate measurements to be conducted. The observers were blinded from the measurements as this could have caused them to perform differently and affect the reliability of the results. The observers also calculated the CSA and then the thickness, for each image and this was done to prevent the observer from remembering their previous drawing which could influence the results.

Limitations

A weakness of this pilot study was that the image had to be in full screen whilst the measurements were calculated. This reduced the image quality which could have affected the accuracy as the observers had to rely on the echogenic border of the muscle in the image. Along with image size, the ultrasound image did not display a clear, continuous echogenic line, which could have affected the reliability of the measurements. However, the image would have been too small for a precise reading, if it was not displayed in full screen. For some participants, the whole RF was not visible on the ultrasound image due to the size of their RF and the size of the probe and this could have affected the observers' interpretations of the muscle borders.

Another weakness was that the measurement scale was in centimetres which resulted in very high ICC scores. Therefore, the use of millimetres could be better for future research to enable more precise measurements and to identify smaller differences between each measurement.

An additional weakness was that the measurements were performed a day after image acquisition. Therefore, this pilot study lacks ecological validity because in daily practice the measurements are performed shortly after image acquisition.

Conclusion

The use of ultrasound to measure muscle CSA and thickness has been proven reliable in previous studies. The results of this pilot study adds to the current knowledge of ultrasound because it shows that the use of ultrasound is also reliable when measuring the RF CSA and RF thickness. Furthermore, it demonstrates that performing one measurement is as reliable as performing three and this can be applied into practice in order to save time and money thus increase efficiency.

Acknowledgments

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References

- [1] National Health Service, "NHS Imaging and Radiodiagnostic activity in England," no. August, pp. 1–7, 2013.
- [2] T. Abe, J. P. Loenneke, and R. S. Thiebaut, "Morphological and functional relationships with ultrasound measured muscle thickness of the lower extremity: a brief review," *Ultrasound*, vol. 23, no. 3, pp. 166–173, 2015.
- [3] "WHO | Ultrasound," *WHO*, 2013.
- [4] N. D. Reeves, C. N. Maganaris, and M. V. Narici, "Ultrasonographic assessment of human skeletal muscle size," *Eur. J. Appl. Physiol.*, vol. 91, no. 1, pp. 116–118, 2004.

- [5] J. M. Seymour, K. Ward, P. S. Sidhu, Z. Puthuchear, J. Steier, C. J. Jolley, G. Rafferty, M. I. Polkey, and J. Moxham, "Ultrasound measurement of rectus femoris cross-sectional area and the relationship with quadriceps strength in COPD.," *Thorax*, vol. 64, no. 5, pp. 418–423, 2009.
- [6] T. Thomaes, M. Thomis, S. Onkelinx, W. Coudyzer, V. Cornelissen, and L. Vanhees, "Reliability and validity of the ultrasound technique to measure the rectus femoris muscle diameter in older CAD-patients.," *BMC Med. Imaging*, vol. 12, p. 7, 2012.
- [7] L. S. Giles, K. E. Webster, J. a. McClelland, and J. Cook, "Can ultrasound measurements of muscle thickness be used to measure the size of individual quadriceps muscles in people with patellofemoral pain?," *Phys. Ther. Sport*, vol. 16, no. 1, pp. 45–52, 2014.
- [8] A. J. Cruz-Jentoft and J. E. Morley, *Sarcopenia*. Wiley-Blackwell, 2012.
- [9] R. a. Fielding, B. Vellas, W. J. Evans, S. Bhasin, J. E. Morley, A. B. Newman, G. Abellan van Kan, S. Andrieu, J. Bauer, D. Breuille, T. Cederholm, J. Chandler, C. De Meynard, L. Donini, T. Harris, A. Kannt, F. Keime Guibert, G. Onder, D. Papanicolaou, Y. Rolland, D. Rooks, C. Sieber, E. Souhami, S. Verlaan, and M. Zamboni, "Sarcopenia: An Undiagnosed Condition in Older Adults. Current Consensus Definition: Prevalence, Etiology, and Consequences. International Working Group on Sarcopenia.," *J. Am. Med. Dir. Assoc.*, vol. 12, no. 4, pp. 249–256, 2011.
- [10] G. a Borkan, D. E. Hulth, S. G. Gerzof, A. H. Robbins, and C. K. Silbert, "Age Changes in Body Composition Revealed by Computed Tomography," *J. Gerontol.*, vol. 38, no. 6, pp. 673–677, 1983.
- [11] D. Gallagher, M. Visser, R. E. De Meersman, D. Sepulveda, R. N. Baumgartner, R. N. Pierson, T. Harris, and S. B. Heymsfield, "Appendicular skeletal muscle mass: effects of age, gender, and ethnicity.," *J Appl. Physiol*, vol. 83, no. 8750–7587 (Print), pp. 229–239, 1997.
- [12] I. Janssen, S. B. Heymsfield, Z. Wang, R. Ross, T. a Kung, P. S. Cederna, J. H. Van Der Meulen, M. G. Urbanek, M. Kuzon, J. a Faulkner, J. G. a Biol, S. Med, D. Morton, P. Rankin, L. Kent, and W. Dysinger, "Skeletal muscle mass and distribution in 468 men and women aged 18 – 88 yr Skeletal muscle mass and distribution in 468 men and women aged 18 – 88 yr.," *J. Appl. Physiol.*, pp. 81–88, 2014.
- [13] W. K. Mitchell, J. Williams, P. Atherton, M. Larvin, J. Lund, and M. Narici, "Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review.," *Front. Physiol.*, vol. 3 JUL, no. July, pp. 1–18, 2012.
- [14] M. V. Narici and N. Maffulli, "Sarcopenia: Characteristics, mechanisms and functional significance," *Br. Med. Bull.*, vol. 95, no. 1, pp. 139–159, 2010.
- [15] K. M. M. E Lima, T. T. da Matta, and L. F. de Oliveira, "Reliability of the rectus femoris muscle cross-sectional area measurements by ultrasonography," *Clin. Physiol. Funct. Imaging*, vol. 32, no. 3, pp. 221–226, 2012.
- [16] M. Backhaus, S. Ohrndorf, L. Naumann, J. Grundey, T. Scheel, A. K. Scheel, and C. Werner, "Is musculoskeletal ultrasonography an operator-dependent method or a fast and reliably teachable diagnostic tool? Interreader agreements of three ultrasonographers with different training levels," *Int. J. Rheumatol.*, vol. 2010, 2010.
- [17] J. a Hides, T. Miokovic, D. L. Belavý, W. R. Stanton, and C. a Richardson, "Ultrasound imaging assessment of abdominal muscle function during drawing-in of the abdominal wall: an intratester reliability study.," *J. Orthop. Sports Phys. Ther.*, vol. 37, no. 8, pp. 480–486, 2007.
- [18] "Increasing the Ability of an Experiment to Measure an Effect." [Online]. Available: http://www.sciencebuddies.org/science-fair-projects/top_research-project_signal-to-noise-ratio.shtml.
- [19] J. Maltby, G. Williams, J. McGarry, and L. Day, *Research methods for nursing and healthcare*. Harlow: Pearson Education, 2010.
- [20] K. Seip, R. Brekken, and T. a N. Hernes, "Real time ultrasound simulation Application to a medical training simulator," no. June, 2008.
- [21] "P Values (Calculated Probability) and Hypothesis Testing - StatsDirect." [Online]. Available: http://www.statsdirect.com/help/default.htm#basics/p_values.htm.
- [22] Hoskins, P. R., Martin, K., & Thrush, A. (Eds.). (2010). *Diagnostic ultrasound: physics and equipment*. Cambridge University Press.
- [23] Teyhen, D., & Koppenhaver, S. (2011). Rehabilitative ultrasound imaging. *Journal of physiotherapy*, 57(3), 196.

The Influence of Source-to-Image Distance on Effective Dose and Image Quality for Mobile Chest X-ray Imaging

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Keywords:

DR, image quality, effective dose, mobile chest radiography, SID

Abstract

Aim: To investigate the effect of source-to-image distance (SID) on effective dose and image quality at a fixed mAs. Furthermore, to determine whether effective dose varies as SID is varied after compensating mAs for the inverse square law.

Method: A chest phantom with a simulated pathology was imaged at varying SIDs at a fixed mAs and kV. Observers visually compared the experimental images with a reference image using criteria divided into 3 categories: anatomy, noise and nodule image quality. A 2AFC program was used to display the images. A 5-point Likert scale was used ranging from 'much worse' to 'much better'. PCXMC 2.0

was used to estimate effective dose. At each SID, a new mAs was calculated using inverse square law correction. Effective dose was estimated again.

Results: Modal response for 2AFC visual evaluation of anatomy image quality was 'equal' for every SID, implying no observable change. Modal response for 2AFC visual evaluation of noise changed from 'better' to 'worse' as SID increased. Modal response for visual evaluation of nodule image quality was 'worse' at the smallest SIDs and 'better' at the largest SIDs. Decreasing SID from 190-100 cm: increased effective dose by 247%; compensating mAs reduced the effective dose by 36%.

Conclusion: For variable SIDs used in this study, there is little perceived difference in anatomical image quality. Nodule image quality may decrease at shorter SIDs while effective dose increases. Therefore, when shorter SIDs are necessary due to lack of space, practitioners must be aware of patient dose.

1. Introduction

Mobile chest x-ray imaging are a crucial tool in critical care. In radiology service routine, chest radiography is the most prevalent tool for monitoring a patient's condition, particularly in intensive care units (ICU), wards and for trauma evaluation in the emergency room¹.

In standard radiological practice, chest x-ray images should ideally be taken at a source-to-image distance (SID) of approximately 180 cm. This reduces mediastinal magnification and geometric unsharpness^{2,3}. However, in mobile radiography, SID varies due to the limitations on available space^{4,5}.

According to the inverse square law, decreasing the SID of mobile radiographic projections results in an increased patient dose. Since the introduction of digital radiography, any increase in patient dose can go unnoticed due to its minimal effect on image quality^{6,7}.

This study aims to investigate whether the SID of chest x-ray images has an effect on image quality and the effective dose delivered to a phantom. Furthermore, to investigate whether the effective dose alters when SID is varied after manually compensating the mAs for the inverse square law.

2. Material & Methods

For this study, a multi-purpose anthropomorphic male chest phantom (N1 “LUNGMAN”, Kyoto Kagaku Co., Ltd., Kyoto, Japan) was used. This phantom has been used in earlier studies for assessing image quality in chest x-ray imaging⁷. A pathology was simulated through the insertion of a sphere of 12 mm diameter, with a soft tissue density equivalence of 100 Hounsfield units. It was inserted into the right lung, medially towards the hilum and posteriorly, close to the detector and the central ray, in order to minimize magnification and distortion. The phantom was placed in an erect position on a trolley, with the image receptor plate in contact with its posterior surface (**Figure 1**). A horizontal x-ray beam was

centred midway between the xiphoid sternum and the manubrium².

A Wolverson Acroma General X-ray unit (Wolverson X-Ray Ltd, Willenhall, West Midlands, UK) with a Varian X-ray tube (Varian medical systems, Salt Lake City, UT, USA) and a 35 cm × 43 cm Konica Minolta Aero DR detector (Konica Minolta Medical Imaging USA INC, Wayne, NJ, USA) was used. To mimic mobile radiography, an anti-scatter grid was not used³. The x-ray tube has a Tungsten-Rhenium anode with an angle of 12°, and an inherent filtration of 3.0 mm Aluminium equivalent (for 75 kV). For this study, a broad focal spot size of 1.2 mm and an added filtration of 2.0 mm Aluminium was used.

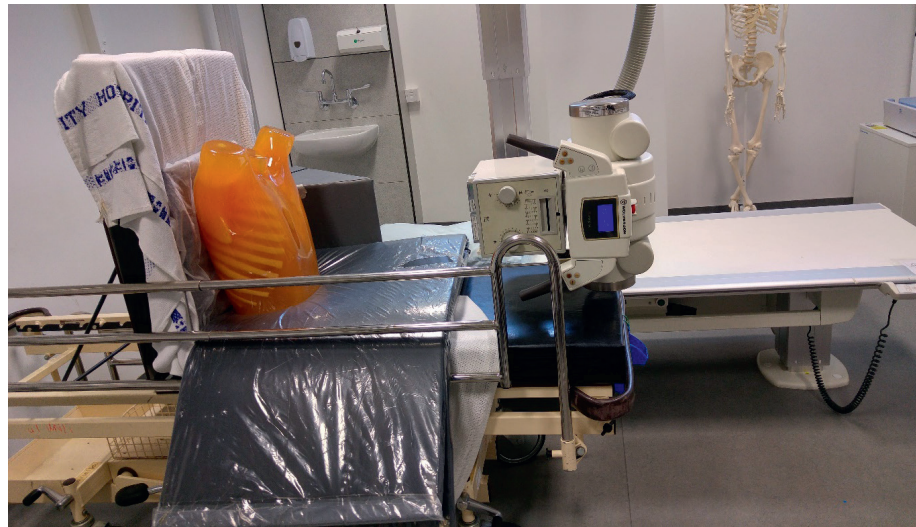


Figure 1. Chest phantom and x-ray tube setup.

A chest anterior-posterior (AP) projection protocol was selected prior to every exposure. There was no additional post-processing. 10 images were taken with a fixed 1.6 mAs for visual image analysis. For each experimental condition, three exposures were taken and averaged to determine DAP. This was to minimise random error. For each SID, a new mAs was calculated to compensate for the inverse square law⁸ (Equation 1).

$$mAs_{\text{new}} = 1.6 \frac{SID^2}{180^2} \quad (1)$$

All images were taken at 95 kV which is within the normal kV range used for AP chest radiography in the UK⁹. An exposure of 1.6 mAs was chosen as it resulted in a deviation index (DI)¹⁰ of 0.04 at 180 cm SID. This is close to the optimal DI of 0 for this x-ray machine. The SID was then increased from 100 cm to 190 cm at 10 cm intervals.

Image quality was assessed using two alternative forced choice comparisons (2AFC) to evaluate the relationship between SID and image quality¹¹. The images were cropped to ensure that the same anatomy was visible on each image.

Table 1: Image criteria adapted from Mraity et al. (2014)¹² and European Commission (1996)¹³.

Criteria

1. The pulmonary vascularisation is visually sharp
2. The trachea is visually sharp
3. The proximal portion of the bronchi are visually sharp
4. The left diaphragm is visually sharp
5. The right diaphragm is visually sharp
6. The left costophrenic angle is visually sharp
7. The right costophrenic angle is visually sharp
8. The heart is visually sharp
9. The aorta is visually sharp
10. The lung markings are visually sharp
11. There is clear differentiation between soft tissue, air and bone
12. The image has low noise
13. For the nodule, the contrast against the background is good
14. For the nodule, the edge is visually sharp

14 volunteers with varying radiological experience, ranging from 2nd year radiography undergraduate to PhD level in Radiography, were selected. For viewing the images, the 2AFC-program was used on a dual screen computer with two full HD NEC monitors EA243WM (NEC Europe, London, UK). The monitors were set at 100% brightness and 50% contrast with the remaining parameters set to default. Room lighting was constant: lights were switched off and there were no windows.

The image with 140 cm SID was chosen as a reference as it is the midrange distance. The observers had to compare each of the 9 images against the reference image using 14 criteria (**Table 1**). A 5-point Likert scale was used, ranging from 'much worse' to 'much better'. The observers were shown anonymised images in a random order alongside a printed version of the reference image, which was provided to help identify the anatomy and the nodule.

The data collected was analysed in 3 categories (**Table 1**): anatomy (1-11), noise (12) and nodule (13-14). The modal response was recorded for each category at every SID in accordance with Keeble et al.¹⁴.

The effective dose was estimated using the Monte Carlo simulation software PCXMC 2.0^{15,16}. The virtual phantom was set at a height of 165 cm and weight of

75 kg to correspond with the Lungman's dimensions. SID, field size, beam placement, kV, anode angle and filtration were entered into the software and kept constant for each SID. A DAP value for each SID was entered to produce a beam spectrum with 20,000 photons. This was used to estimate the effective dose based on ICRP 103¹⁷.

A Pearson's R test was used to calculate the correlation coefficient between SID and effective dose using IBM SPSS Statistics 22.0 (IBM, New York, USA).

3. Results

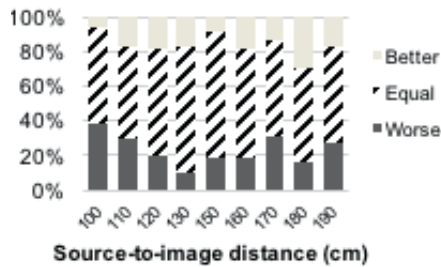
The anatomy images' modal response was 'equal' for every SID, implying there was no visible difference in anatomical image quality (**Table 2**). The spread of the response data is shown in **Figure 2**.

However, for image noise, the modal response changed from 'better' to 'equal' to 'worse' as the SID increased. This shift can be seen in **Figure 3**.

The modal response for the nodule image criteria varied between 'worse' and 'equal' at SIDs 120 cm to 160 cm. However, there was a strong agreement on the image quality being 'worse' at the smallest SIDs and 'better' at the largest SIDs. The spread of the response data is shown in **Figure 4**.

Table 2: Modal responses for image quality

SID (cm)	Anatomy	Noise	Nodule
100	Equal	Better	Worse
110	Equal	Better	Worse
120	Equal	Better	Equal
130	Equal	Equal	Worse
150	Equal	Equal	Equal
160	Equal	Worse	Equal
170	Equal	Worse	Worse
180	Equal	Worse	Better
190	Equal	Worse	Better

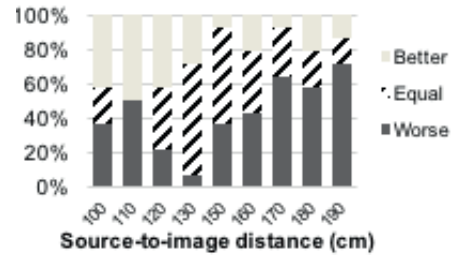


2

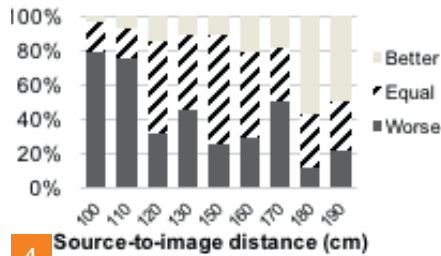
Figure 2: Spread of observer response for anatomy image quality at different SIDs.

Figure 3: Spread of observer response for evaluating noise at different SIDs.

Figure 4: Spread of observer response for nodule image quality at different SIDs.



3



4

Figure 5: Effective dose results for fixed and compensated mAs.

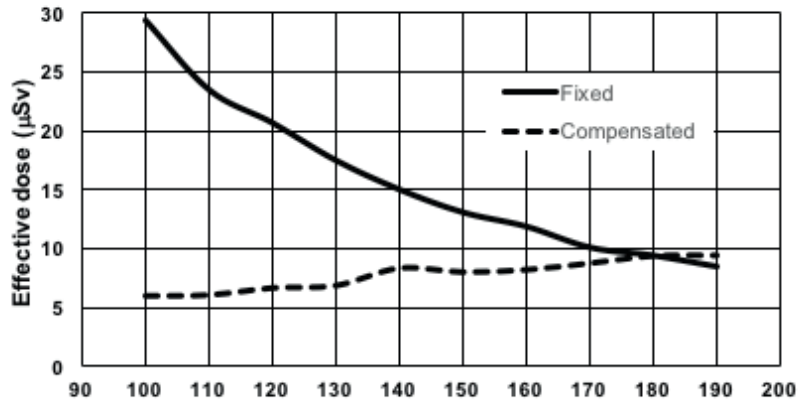


Table 3. Effective dose at different SIDs for fixed and compensated mAs.

SID (cm)	Fixed mAs	Effective Dose (mSv)	Compensated mAs	Effective Dose (mSv)
100	1.6	29.46	0.50	6.07
110	1.6	23.55	0.60	6.14
120	1.6	20.72	0.70	6.74
130	1.6	17.53	0.80	6.94
140	1.6	15.06	1.00	8.41
150	1.6	13.11	1.10	8.07
160	1.6	11.90	1.20	8.27
170	1.6	10.13	1.40	8.82
180	1.6	9.44	1.60	9.44
190	1.6	8.50	1.80	9.48

The DAP average was inputted into PCXMC to estimate the effective dose for each SID (**Figure 5**) with an error of <1%. When the SID decreased from 190 cm to 100 cm, the effective dose increased by 247% (**Table 3**). When the mAs was compensated for using the inverse square law, the dose reduced by 36% as the SID decreased (**Table 3**).

The Pearson's R correlation factor between SID and effective dose was -0.972 for the fixed mAs; the correlation factor between SID and effective dose was 0.970 for the compensated mAs. These values have a p-value <0.0001 which indicates they are statistically significant.

4. Discussion

This study was carried out to investigate whether the SID variation in simulated mobile chest radiography has a significant effect on the x-ray image quality and effective dose.

For fixed mAs, the majority of observers reported no difference in anatomical image quality for the range of SIDs selected in this study, when compared with the reference (**Figure 2**). Currently, there are few similar studies analysing chest x-ray image quality using direct radiography. However, Ma. W.K. et al.⁷ also found that there is little change in chest x-ray image quality when the SID is changed using computed radiography. There is a similar study on

pelvis x-ray image quality which also confirms this finding¹⁸.

This study shows that observers reported more visual noise when SID increased at a fixed mAs. This is consistent with a study by Tugwell et al.¹¹, which reported that signal-to-noise ratio decreased as the SID increased for pelvic x-rays at a fixed mAs. This suggests that there is a small benefit in decreasing SID in ICU settings. Alternatively, this may mean that the mAs can be reduced slightly whilst maintaining image quality. Further research is necessary to examine its effect on image quality.

Observers reported that the image quality of the lung nodule decreased when the SID decreased. This may be a result of geometrical unsharpness which can arise from shorter SIDs⁹. These results support the use of the 180 cm SID in chest radiography, and why it may be beneficial for diagnostic use. In addition, using an SID of under 120 cm could be detrimental to image quality.

As expected, the effective dose increased as the SID decreased at a fixed mAs. When the SID was changed from 180 cm to 140 cm, the dose increased by approx. 60%. When the SID was reduced further, to 100 cm, the dose was increased by another 100%. This would result in a higher dose to radiosensitive tissues such as the lungs and breasts¹⁷. However, when the mAs

was compensated for, the dose decreased as the SID decreased. As the beam was collimated to the detector size, a decrease of SID led to a decrease of irradiated volume due to the divergence of the beam. This may be an explanation for the decrease in the effective dose.

5. Conclusion

This study suggests that for the varying SIDs used in chest radiography there is little visible difference in anatomical image quality. However, the data suggests that the nodule image quality decreases at shorter SIDs, even though the level of visible noise decreases. Therefore, SIDs shorter than 120 cm should be avoided. As SID decreases, effective dose increases. Thus, when shorter SIDs are necessary due to a lack of space, practitioners should be aware of the increased patient dose.

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References

1. Bentz MR, Primack SL. Intensive Care Unit Imaging. *Clinics in chest medicine*. 2015;36(2):219-34.
2. Bontrager KL, Lampignano J. *Textbook of radiographic positioning and related anatomy*. 10th ed. St. Louis, MO: Elsevier Health Sciences; 2013.
3. Schaefer-Prokop C, Neitzel U, Venema HW, Uffmann M, Prokop M. Digital chest radiography: an update on modern technology, dose containment and control of image quality. *European radiology*. 2008;18(9):1818-30.
4. Jensen L, Meyer C. Reducing errors in portable chest radiography. *Applied Radiology*. 2015 Available from <http://appliedradiology.com/articles/reducing-errors-in-portable-chest-radiography> (Accessed 4th August 2016)
5. Joyce M, O'Leary D. The Increased Source to Image-receptor Distance Technique: What Is Preventing Implementation in Clinical Practice?. *Journal of Medical Imaging and Radiation Sciences*. 2014;45(3):260-8.
6. Grewal RK, Young N, Collins L, Karunaratne N, Sabharwal R. Digital chest radiography image quality assessment with dose reduction. *Australasian Physical & Engineering Sciences in Medicine*. 2012;35(1):71-80.
7. Ma WK, Hogg P, Tootell A, Manning D, Thomas N, Kane T, Kelly J, McKenzie M, Kitching J. Anthropomorphic chest phantom imaging—the potential for dose creep in computed radiography. *Radiography*. 2013;19(3):207-11.
8. Bushong SC. *Radiologic science for technologists: physics, biology, and protection*. 8th ed. Houston, TX: Elsevier Health Sciences; 2013.
9. Hart D, Hillier MC, Shrimpton PC. *Doses to patients from radiographic and fluoroscopic X-ray imaging procedures in the UK: 2010 review*. Health Protection Agency; 2012. Report HPA-CRCE-034
10. Seibert JA, Morin RL. The standardized exposure index for digital radiography: an opportunity for optimization of radiation dose to the pediatric population. *Pediatric radiology*. 2011;41(5):573-81.
11. Tugwell J, Everton C, Kingma A, Oomkens DM, Pereira GA, Pimentinha DB, Rouiller CA, Stensrud SM, Kjelle E, Jorge J, Hogg P. Increasing source to image distance for AP pelvis imaging—Impact on radiation dose and image quality. *Radiography*. 2014;20(4):351-5.
12. Mraity H, England A, Akhtar I, Aslam A, De Lange R, Momoniati H, Nicoulaz S, Ribeiro A, Mazhir S, Hogg P. Development and validation of a psychometric scale for assessing PA chest image quality: a pilot study. *Radiography*. 2014;20(4):312-7.
13. Commission of European Communities. *European guidelines on quality criteria for diagnostic radiographic images*. EUR 16260EN. Brussels, Belgium: The European Commission; 1996.
14. Keeble C, Baxter PD, Gislason-Lee AJ, Treadgold LA, Davies AG. Methods for the analysis of ordinal response data in medical image quality assessment. *The British journal of radiology*. 2016;89(1063). Available from: <http://dx.doi.org/10.1259/bjr.20160094>
15. Servomaa A, Tapiovaara M. Organ dose calculation in medical x ray examinations by the program PCXMC. *Radiation Protection Dosimetry*. 1998;80(1-3):213-9.
16. Tapiovaara M, Siiskonen T. *PCXMC 2.0. User's Guide*. Radiation and Nuclear Safety Authority Helsinki: STUK; 2008.
17. ICRP, *The 2007 Recommendations of the ICRP*, in *ICRP Publication 103*. 2007, Ann. ICRP p.2-4.
18. England A, Evans P, Harding L, Taylor EM, Charnock P, Williams G. Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. *Radiologic technology*. 2015;86(3):246-56.

IMPACT OF THE ANODE HEEL EFFECT ON IMAGE QUALITY AND EFFECTIVE DOSE FOR AP PELVIS: A PILOT STUDY

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Key Words:

anode heel effect
image quality
effective dose
AP pelvis.

ABSTRACT

Purpose: Using phantoms, this pilot study aims to outline a method and generate initial data to determine whether the anode heel effect has an impact on image quality and the effective dose.

Methods and Materials: A dosimetry phantom and an anthropomorphic adult phantom were positioned with feet towards anode and then cathode and exposed using 75, 80 and 85 kVp; using 18, 22 and 28 mAs. Twelve images were taken and assessed for physical and visual quality by signal to noise ratio and two alternative forced choice (2AFC) with 19 observers.

Results: From 2AFC data, no significant statistical differences ($p=0.811$) were found in image quality. Effective dose results show no significant statistical difference ($p=0.207$) between the two orientations.

Conclusion: No significant reduction in visual image quality or effective dose exists between the two orientations. Limited data has been provided by this pilot study so the results should be treated with caution. However the method appears to generate useful information for the aim of the study and we suggest larger datasets of 2AFC and dose values should be generated to determine whether differences exist.

Introduction

Due to the biological effects of radiation, it is essential to achieve the lowest patient radiation dose whilst acquiring clinically acceptable images (1). To achieve this, optimisation studies need conducting with the factors that affect image quality and radiation dose being manipulated in a controlled fashion. Examples of the factors include: exposure factors, source to image distance (SID), grid / no grid, filtration, detector characteristics and image processing options (2,3). Patient orientation across the anode-cathode axis could also have an impact on image quality and dose to patient. This is because radiation dose is not uniform across this axis with the radiation field intensity decreasing towards the anode from the cathode (4,5). This intensity variation is often referred to as the anode heel effect. According to Harding et al (2013), patient orientation should be considered

for each examination and with the anode heel effect in mind this could have consequences for image quality and dose to patient (6)source-to-skin distance and kVp data facilitated the calculation of entrance surface dose (ESD).

Research into AP pelvis by Mraity et al (2016) (7) was the most significant study found during the literature review; it investigated the impact of the anode heel effect on gonad radiation dose. Mraity et al established there is a significant difference in testicular dose between *feet towards anode* and *feet towards cathode*; no significant difference existed for the ovaries. Mraity et al recommended further work be conducted to determine whether there is a difference in effective dose and image quality for the two orientations.

Our work builds on that of Mraity et al. Using an anthropomorphic pelvis phantom and an ATOM adult dosimetry phantom, our paper aims to present a method and initial data to determine whether image quality and effective dose differences exist between feet towards anode and feet towards cathode for AP pelvis imaging using Digital Radiography (DR).

Methods and materials

An anthropomorphic pelvis phantom was imaged with feet towards cathode and then feet towards anode using a DR (Aero DR System, Konica Minolta) system; the images were evaluated for quality (IQ) using physical and visual measures. An adult dosimetry phantom (ATOM, 701B, CIRS) using TLDs (TLD-100H (Li F Mg, Cu (P-100H) and TLD reader (Harshaw TLD reader) were exposed with feet towards anode and then feet towards cathode and effective dose was calculated (8,9)

Acquisition conditions for ATOM and anthropomorphic phantoms are indicated in **Table 1**.

Estimation of effective dose using TLDs

TLDs were inserted into an adult male ATOM phantom. TLDs were used as they are sensitive and give accurate measurements of the radiation received by organs within the phantom. The ATOM phantom consists of multiple slices, each slice containing multiple holes to locate TLDs in order to accurately estimate organ doses (10). After each exposure a Harshaw 3500 TLD reader (Thermo Scientific, USA) was used to read the exposed TLDs. Prior to exposure, TLD quality control tests were conducted (8).

TLDs were only loaded into the area in and around the pelvis. Initial AP pelvis exposures identified which holes did not need filling (eg chest / head) as no exposure was recorded into the TLDs. In only using a limited number of TLDs the experimental process was speeded up. The time to conduct one

Table 1: Phantom acquisition conditions

Anthropomorphic pelvis phantom		Atom phantom	
Additional Filtration	0	Additional filtration	0
SID	110cm	SID	110cm
kVp	75,80,85	kVp	75,80,85
mAs	18,22,27	mAs	18,22,27
Collimation	43x45	Collimation	43x45
Image receptor type	DR	Image receptor type	DR

adult ATOM phantom dose measurement using all TLDs and not just the pelvis area, including TLD insertion, removal and reading is approximately one full day. For our experiment TLDs were read on the same day as exposure in order to reduce the risk of additional error caused by background radiation or the fading of charge within the TLD. TLDs were also used to establish background radiation; these were not loaded into the ATOM phantom. For each set of acquisition factors three exposures were made and then averaged to minimise random error.

Organ dose was calculated by summing the TLDs charge/dose values in each organ and dividing by the total numbers of TLDs in that organ; this value was multiplied by the relevant tissue weighting factor, W_T (see **Figure 1**).

Figure 1: Tissue weighting factors defined by ICRP1034.

Organ	Tissue weighting factor
Gonads	0.08
Bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Breast	0.12
Bladder	0.04
Liver	0.04
Oesophagus	0.04
Thyroid	0.04
Skin	0.01
Bone (surface)	0.01
Salivary glands	0.01
Brain	0.01
Remainder	0.12
Total	1.00

Summation of calculated organ doses for the entire body gives the Effective Dose, E (mSv),

$$E = \sum_T W_T \cdot H_T$$

Where

E is the effective dose absorbed by the entire body

W_T is the tissue weighting factor defined by ICRP1034

H_T is the equivalent dose absorbed by tissue T

Equation 1: Calculation for effective dose⁴

Physical analysis of IQ

The signal-noise ratio (SNR) was calculated with ImageJ (10–12). Regions of interest (ROI) were placed at various points around the pelvis as illustrated in **Figure 2**. Given that exact positioning of the anthropomorphic phantom for ‘feet to anode’ and ‘feet to cathode’ could not be replicated exactly, ROIs had to be positioned manually for each orientation so that for feet to anode and feet to cathode were similar for all images in both conditions (13).

Visual assessment of image quality

Images were processed on an Agfa Digital radiography (DR) unit; the pelvis look up table was used for image display. Observers were not allowed to alter display settings during visual assessment of image quality. Visual assessment was conducted in

Figure 2: Position of ROIs within the anthropomorphic phantom



Criteria

1. Clear visualisation of the right and left trochanters.
2. Clear visualisation of the femoral necks.
3. Clear visualisation of the left and right iliac crest.
4. Clear visualisation of the left and right ischial rami.
5. The noise ratio in the image is.
6. The overall image quality.

Table 2: Criteria used to evaluate the image quality

dimmed lighting which remained constant throughout the experiment. Various approaches exist to the visual assessment of image quality; these include absolute visual grading (14) and two alternate forced choice (2AFC) (15). 2AFC has many benefits, including the potential to minimise inter and intra observer variability through the provision of a reference image against which all experimental images are compared

(16). Using 2AFC, images were visually assessed using quality criteria derived from various sources (17,18). The criteria used for judging image quality are indicated in **Table 2**. A 5 point Likert scale was used for scoring as seen in **Table 2**.

The 2AFC reference image was chosen by calculating the SNR for all images, with use of different regions of

interest from the pelvic area (L5, iliac crest, sacrum, pubis, femur head and femur). The average SNR was selected as the reference image. The reference image was acquired as follows- feet to anode, 75kVp and 18 mAs.

Twenty-four observers evaluated the images. These included 19 student radiographers and 5 qualified radiographers. Prior to evaluating the images the observers were given an explanation of what they were required to do. Images were displayed on two 2.4 MP HD NEC monitors EA243WM (NEC Europe, London, UK) which had been calibrated to the DICOM Grey Scale Standard. As a quality control measure for observer performance, the reference image was reviewed on a blinded basis by the observers against itself; this provided a simple method to assess intra-observer reliability. From the original twenty-four observers, five assessed the reference image with a higher error than the allowed 5.56% error margin and were excluded from the analysis, resulting in a total of 19 observers. In order to evaluate the reliability of the observers, the Intra Class Correlation (ICC)

was calculated. ICC proves beneficial in providing a method for calculating the inter-rater agreement measures between observers for all images graded as specified by Cicchetti et al as can be seen in **Table 3** (19).

Before statistical analysis of the data could be performed, a normality test was used (Shapiro-Wilk) to determine the type of data acquired during the experiment; this determined the statistical tests which could be used (parametric / non parametric). The results for the effective dose, testes dose, physical and visual image quality data were normally distributed justifying the use of a parametric T-test.

Results

Effective dose

Figure 3 shows the percentage change in effective dose between feet to cathode and feet to anode. The difference between the two orientations is not significant ($P=0.207$). Dose to testes was compared using T-test and no significant difference was found between the two orientations.

Table 3: Corresponding levels of significance for ICC inter-rater agreement measures

ICC inter-rater agreement measures	Level of significance
< 0.40	Poor
0.40 - 0.59	Fair
0.60 - 0.74	Good
0.75 - 1.00	Excellent

Figure 3: Percentage error difference in Effective Dose vvs exposure

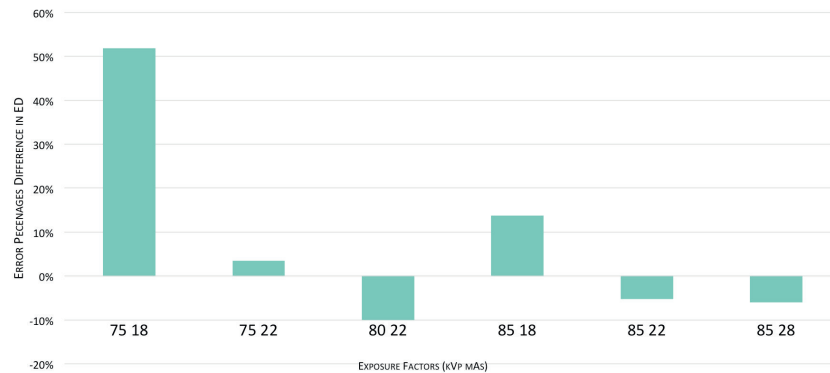


Table 4: Average SNR values for the two orientations across the central ray.

kVp/mAs	Orientation	
	Feet to anode Average SNR	Feet to cathode Average SNR
75/18	40.691	37.277
75/22	40.416	39.752
80/22	41.888	39.631
85/22	42.167	40.004
85/18	41.875	41.643
85/28	42.147	41.784

Physical assessment of image quality

The average SNR values were calculated for each exposure as can be seen in **Table 4**. Through the calculation of these averages, differences between varying exposure parameters for physical image quality were analysed for the entire image, allowing a comparison to be made between the physical and visual methods of analysis.

Table 5 illustrates SNR for all exposure factors for both orientations. A significant difference ($P < 0.05$) was found between the two orientations for the SNR. The regions of interest data towards the extreme edge of the central ray, where the anode heel effect is pronounced, this can be seen in **Table 5**.

Table 5: NR P-values for both phantom orientations

(P) values of SNR for all the regions of interest			
Region of interest	SNR average feet to Anode	SNR average feet to cathode	*(P) values
Area 1 - Femur head	33.469	30.290	0.04
Area 3 - Pubic	30.718	27.033	0.01
Area 4 - Sacrum	28.613	25.666	0.06
Area 5 - L5	34.413	31.059	0.25
Area 6 - Iliac	29.115	25.989	0.06
Area 7 - Femur	22.850	19.175	0.00

Visual assessment of image quality

Analysis of the image quality was performed using paired T-test in SPSS. Analysis showed there is no statistically significant difference ($P = 0.811$) in visual quality for either orientation.

In order to increase the reliability of the data provided by the observers, measurements of the Intra-Class correlation (ICC) of the observers was found to be fair at 0.506 (inter observer variability).

Evaluation of observer variability

The reference image was included to assess intra observer variability. The error margin was set to 6% as there were only 6 criteria for each pair of images to be evaluated, resulting in a 5.56% error by evaluating a single image criteria in comparison to the reference image. Of the 24 observers, 16 assessed the reference image as being equal to itself on all 6 criteria. Three observers had a 5.56% error and

were therefore included. Five observers, consisting of four students and one qualified radiographer, assessed the reference image either much better or much worse compared to itself, with errors ranging from 11% to 33% and were therefore excluded from the final analysis. **See figure 4.**

Discussion

The aim of this pilot study was to investigate the impact of anode heel effect on image quality and effective dose. Overall, the outcome demonstrates that there is no statistical difference in both visual image quality and effective dose for either orientation, however a significant difference for SNR was found.

This result could be beneficial in the clinical setting, where images are judged for image quality using visual techniques as ultimately diagnoses are made visually. It is likely, based on the results from the visual

Figure 4: Percentage Error in observers' performance

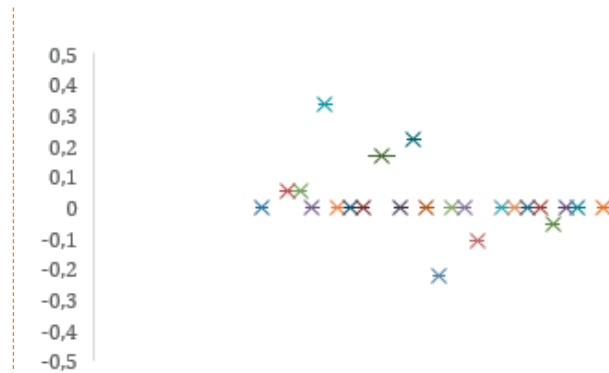


image quality assessment, placing a patient in either orientation should result in the same visual image quality. However, it should be noted that due to this study involving a singular anthropomorphic phantom with no pathology, a human/clinical study perhaps using cadavers should be performed as to assess the applicability of the study findings within a clinical setting.

Although no statistical difference was found in visual image quality, SNR contradicted the visual image quality results showing a statistically significant difference between the orientations. This finding is expected because the dose to the detector varies from anode to cathode, because of the anode heel effect; in turn this variation will impact on noise. Whilst the physical method of assessing image quality has demonstrated a significant difference in image quality it is probably not important clinically

as it is likely there will be no impact on visual image quality or lesion detection performance, though the latter still needs to be established in a further study. However the difference between the visual and physical measures is important to highlight, because this suggests that a physical measure such as SNR in isolation of a visual measure could have limited value and lead to a false conclusion.

For the SNR measurement, ROI number 8 was placed on L3. When comparing the image collimation to collimation that would be used in clinical practice, the upper limit was found to be under L3 ruling the area of ROI8 not diagnostically relevant and was therefore excluded. Closer collimation may have improved the overall image quality and would be the main point of focus if the study were to be repeated.

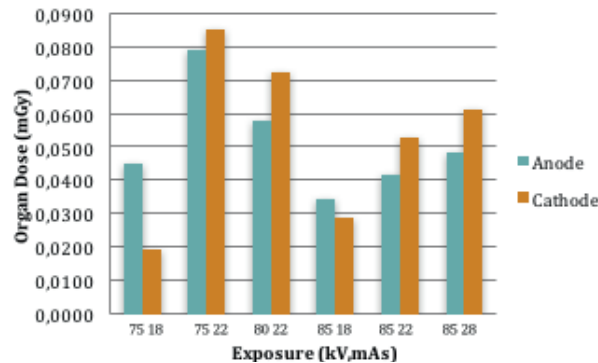


Figure 5: Dose to testes (mGy) from varying exposures

For the set of effective dose data, one exposure with 75 kV and 18 mAs was cathode dominant by 48.25%. 75 kVp and 22 mAs represented the lowest value of this side, where 85 kVp and 18 mAs scored inbetween. The other exposures were anode dominant for effective dose. Apart from the 75 kVp and 18 mAs exposure which showed a much larger ED percentage difference which may be due to miss-centring or miss-collimating the dosimetry phantom. Despite accurate marking of the centre and collimation area, there is still room for error to occur. This may be the reason behind obtaining different ED values over the set of exposure factors.

Figure 5 highlights the considerable difference in testes dose between 75 kVp /18 mAs. Although this is different to Mraity’s results, this outcome was most likely caused by a limitation in the amount of available

data - in comparison with Mraity et al we performed very few measurements.

Future Work

Our study reports on a limited set of acquisition conditions in comparison to those reported in Mraity’s work. We propose our work be extended to include all the acquisition conditions indicated in Mraity’s work and SNR, 2AFC and effective dose be recalculated and assessed statistically to determine whether significant differences do exist. Despite this limitation in our work the method for data acquisition and analysis appears to be fit for purpose and an extension to our study using the same approach is warranted. A larger number of observers would also help to verify the reduction in dose to testes noted by Mraity, removing one of the main limitations from this study.

Conclusion

There is no statistical difference in both visual image quality and effective dose for either orientation, however a significant difference for SNR was found. Given we performed our work on a phantom, further research should be considered before directly implementing in practice, consequently we recommend a human study to consider image quality on anode heel orientation using cadaver. We also suggest extending the work to include a lesion detection performance study to assess whether any difference exists for anode-cathode orientation. Given the limited data collected in our study the results should be treated with caution.

References

1. Honey I, Hogg P. Balancing radiation dose and image quality in diagnostic imaging. Radiography [Internet]. The College of Radiographers; 2012;18(1):e1–2. Available from: <http://dx.doi.org/10.1016/j.radi.2011.10.005>
2. Decoster R, Mol H, Smits D. Post-processing, is it a burden or a blessing? Part 1 evaluation of clinical image quality. Radiography [Internet]. Elsevier Ltd; 2015;21(1):e1–4. Available from: <http://dx.doi.org/10.1016/j.radi.2014.06.003>
3. Tugwell J, Everton C, Kingma A, Oomkens DM, Pereira GA, Pimentinha DB, et al. Increasing source to image distance for AP pelvis imaging - Impact on radiation dose and image quality. Radiography [Internet]. Elsevier Ltd; 2014;20(4):351–5. Available from: <http://dx.doi.org/10.1016/j.radi.2014.05.012>
4. Fung KKL, Gilboy WB. “Anode heel effect” on patient dose in lumbar spine radiography. Br J Radiol. 2000;73(869):531–6.
5. Mearon T. Anode heel affect in thoracic radiology: a visual grading analysis. Proc SPIE [Internet]. 2006;6142:61423D – 61423D – 9. Available from: <http://link.aip.org/link/PSISDG/v6142/i1/p61423D/s1&Agg=doi>
6. Harding L, Manning-Stanley AS, Evans P, Taylor EM, Charnock P, England A. Optimum patient orientation for pelvic and hip radiography: A randomised trial. Radiography [Internet]. Elsevier Ltd; 2014;20(1):22–32. Available from: <http://dx.doi.org/10.1016/j.radi.2013.09.002>
7. Mraity H, England A, Hogg P. Gonad dose in AP pelvis radiography: Impact of anode heel orientation. Radiography [Internet]. Elsevier Ltd; 2016;1–5. Available from: <http://linkinghub.elsevier.com/retrieve/pii/S1078817416300232>
8. Rivera T. Thermoluminescence in medical dosimetry. Appl Radiat Isot [Internet]. Elsevier; 2012;71(SUPPL.):30–4. Available from: <http://dx.doi.org/10.1016/j.apradiso.2012.04.018>
9. Bowdler M. Minimising effective radiation dose received by patients with a scoliosis of the spine through x-ray collimation, Unpublished Masters Thesis. University of Salford; 2016.
10. Mraity H. Optimisation of radiation dose and image quality for AP pelvis radiographic examination College of Health and Social Care Submitted in Partial Fulfilment of the Requirements of the Degree of Doctor of Philosophy, November 2015. 2015;(November).
11. Bath M. Evaluating Imaging Systems : Practical Applications. 2010;139(1):26–36.
12. Lanca L, Franco L, Ahmed A, Harderwijk M, Marti C, Nasir S, et al. 10kVp rule - An anthropomorphic pelvis phantom imaging study using a CR system: Impact on image quality and effective dose using AEC and manual mode. Radiography [Internet]. Elsevier Ltd; 2014;20(4):333–8. Available from: <http://dx.doi.org/10.1016/j.radi.2014.04.007>
13. Thevenaz P, Ruttimann UE, Unser M. A pyramid approach to subpixel registration based on intensity. IEEE Trans Image Process. 1998;7(1):27–41.
14. Ludewig E, Richter A, Frame M. Diagnostic imaging--evaluating image quality using visual grading characteristic (VGC) analysis. Vet Res Commun [Internet]. 2010 Jun [cited 2014 Dec 9];34(5):473–9. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/20461455>
15. Burgess AE. Visual perception studies and observer models in medical imaging. Semin Nucl Med [Internet]. Elsevier Inc.; 2011 Nov [cited 2015 May 15];41(6):419–36. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/21978445>
16. Pelli, D. G., & Farell B (1995). Psychophysical methods. 1995. 4-5 p.
17. Gur D, Rubin D a, Kart BH, Peterson a M, Fuhrman CR, Rockette HE, et al. Forced choice and ordinal discrete rating assessment of image quality: a comparison. J Digit imaging Off J Soc Comput Appl Radiol. 1997;10:103–7.
18. Communitie Commission of the European, (CEC). European guidelines on quality criteria for diagnostic radiographic images. Biochem Biophys Res Commun [Internet]. 1996 Jun;319(1):72–7. Available from: <http://www.sprmn.pt/pdf/RP154.pdf>
19. Cicchetti, D. Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instruments In Psychology. Psychological Assessment 1994;6(4):284-290

The impact of pitch values on image quality and radiation dose in an abdominal adult phantom using CT

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phantom study

Abstract

Purpose: To identify the impact of different pitch values on image quality and effective radiation dose for axial and coronal plane in abdominal adult CT.

Methods and materials: Three scans were conducted on an abdominal phantom using a Toshiba Aquilion 16-slice CT scanner with three different pitch values: standard (0.938), detail (0.688) and fast (1.438). Slices were taken from the upper, middle and lower abdomen in the axial plane and anterior, middle and posterior in

the coronal plane. The six different anatomical structures were liver, intrahepatic vessels, spleen, pancreas, kidneys and renal vessels, retroperitoneum, aorta and vena cava. A two-alternative forced-choice (2AFC) method was used to evaluate images for each pitch with 8 observers using a 3-point Likert scale. SNR was calculated in every plane, slice and pitch factor using the ImageJ software. To estimate effective radiation dose the CT Expo software was used.

Results: Detail pitch factor provides superior image quality compared to standard in axial plane when evaluating the liver ($p<0.034$) and pancreas ($p=0.008$). However, the results for spleen, kidney, renal vessels, retroperitoneum, aorta and vena cava are not significant when comparing detail vs standard. Standard provides a 26.3% reduction in effective radiation dose (mSv) compared to detail. Fast had the worst image quality in both the axial and coronal plane but the lowest dose. In the coronal plane, standard was superior to both detail ($p=0.026$) and fast ($p=0.023$) in terms of image quality. The differences in SNR results were not significant except in standard vs detail in the coronal plane ($p=0.03$).

Conclusion: Detail pitch factor provides superior image quality to standard and fast in the axial plane. Standard had superior image quality to both detail and fast in the coronal plane. The augmentation of effective doses has been inversely proportional to the pitch factors. The most irradiant pitch mode was detail and the less was fast.

Introduction

Since its development in the 1970s, the number of computed tomography (CT) examinations has grown rapidly. Nowadays, CT is responsible for 60-70% of the patient radiation dose received by radiological examinations (1). CT abdomen scan is one of the most

frequently performed examinations and its effective dose varies between 2.6 and 28.7 mSv per year for different European countries (2). Radiation dose can cause stochastic effects, which occur by chance and are related to genetic modification and pathogenesis of cancer (3). To minimise the occurrence of

stochastic effects, it is important to limit the radiation dose as much as possible whilst maintaining adequate image quality for diagnostic purpose, as suggested by ALARA (4).

Different parameters on CT can be used to reduce the patient radiation dose. One of these parameters is the pitch, which is defined as the table movement per 360 degrees rotation time divided by the beam width (5). The use of a high pitch can reduce the radiation dose and the scan time (5). When the CT scan is acquired within a shorter time, possible motion artefacts can be reduced. This is useful when scanning areas in which there is a lot of involuntary movement, such as the cardiac or the lung regions. However, it is important to consider the effect of a higher pitch on image quality, particularly on the spatial resolution (6).

On the other hand, a low pitch might be chosen when high image quality is needed. A consideration has to be made when deciding whether the effective radiation dose counterbalances the image quality. This study will estimate the $CTDI_{vol}$, DLP, effective radiation dose and the image quality in order to make a justification for the use of a high, standard or low pitch.

The research question of this study was: “How do different pitch values affect image quality and effective patient radiation dose in coronal and axial planes in abdominal CT?”

The research aim is to: identify differences in image quality and radiation dose due to the use of different

pitch values for coronal and axial planes in abdominal CT.

The objectives were:

- To acquire CT images using abdominal phantom with three different pitch factors
- To give physical and perceptual measurements on image quality
- To estimate differences in $CTDI_{vol}$, DLP and effective radiation dose.

Methods

Image Acquisition

This study was performed in the Susan Hall Imaging Facility at the University of Salford. An adult-sized, abdomen anthropomorphic phantom (PH-5 CT Abdomen Phantom, Kyoto Kagaku Company, Japan) was scanned on a Toshiba Aquilion 16 MDCT scanner (Toshiba Medical Systems, Minato-ku, Japan), configured according to commonly used parameters in clinical practice. To keep the results relevant to a clinical setting, automatic tube current was used. The tube voltage was fixed to 120 kV and a rotation time of 0.5 s was set. Three different pitch values were used; fast (pitch factor 1.438), standard (pitch factor 0.938) and detail (pitch factor 0.688).

The scan range was 261 mm and covered the entire upper abdomen. Images were acquired with a thickness of 1 mm and reconstructed to 3 mm thick slices, resulting in 88 images.

Perceptual image quality evaluation

The European Guidelines (7) were used to inform the development of criteria for the visual image evaluation. The acquired axial volume for each pitch factor was reconstructed in the coronal plane. Both the axial and coronal planes were then divided into three different slice regions focusing on the anatomical structures that were included in the European Guidelines criteria. Upper axial slices and anterior coronal slices contained the spleen, liver parenchyma and intrahepatic vessels. The middle slices in axial and coronal planes contained the pancreas, kidneys and renal vessels. Lower axial slices and posterior coronal slices contained the aorta, vena cava and retroperitoneum.

Observers were asked to score the anatomical structures for sharpness of reproduction. To ensure that they would rate the images appropriately, a short presentation was given before the start of the image scoring. This presentation showed the criteria, the selected anatomy and an explanation of the rating system (Likert). The selected images were then scored against images acquired with a different pitch but within the same slice region using two-alternative forced-choice (2AFC) method. This method allowed the observers to rate the evaluated image as worse, equal or better compared to the control image. A 3-point Likert scale was chosen, as it often forces the observer into a particular direction (better, equal or worse). This removes the ambiguity which exists in a

5-point scale where the difference between 'better' and 'much better' is often difficult to distinguish (8) or might differ between observers (9). Each criteria could be scored as -1 meaning worse, 0 meaning equal and +1 meaning better. All the scores from different observers were combined and divided by the number of observers to obtain a mean score for all the different structures.

The researchers windowed the images within guidelines (10) ensuring that the images were visualised under the same settings for all observers. Two NEC MultiSync monitors model EA243WM were calibrated to the DICOM grey scale standard. Both monitors were switched on for twenty minutes before use, as recommended by the manufacturer (10) and had their parameters adjusted according to the recommended settings: 100% of brightness, 50% of contrast, auto-brightness and eco modes off, and colour scheme in native mode. Lighting conditions were dimmed and consistent throughout the observations. The results given by the observers were inserted into a spreadsheet.

Physical Image Quality Evaluation

A physical evaluation of the image quality was made using RadiAnt DICOM Viewer. Multiple regions of interest were selected in the anatomical structures described in European Guidelines. The standard deviation was measured in the exact same region for all the different pitches using RadiAnt DICOM

Viewer with the Hounsfield unit to ensure accuracy. To minimise bias, the mean of multiple regions within the same slice was calculated instead of using a single region of interest. The mean attenuation value was acquired in the same way. The signal-to-noise ratio (SNR) was then calculated using the mean attenuation value and dividing it by the standard deviation (11), as shown in the equation below.

$$SNR=S/\sigma \text{ (1)}$$

Observers

In order to have a visual/perceptual evaluation, eight observers were invited to analyse the images. They were included in this study based on their level of experience in CT and their knowledge of the cross-sectional anatomical structures. Observers were asked how many years of experience they had, whether their eyesight was corrected with glasses, contact lenses or other means, and when they last underwent an eyesight test. The eight observers consisted of three males and five females. The mean age of those selected was 39. The experience of the observers with CT ranged between 1 and 28 years. Five of the observers used glasses or contact lenses and the other three did not require any eyesight correction. All of the observers had their eyes checked within the last six months.

Calculation of CTDI_{vol}, DLP and effective dose

The different technical parameters such as the tube current and overall scan time were acquired from the CT scanner after the scan had concluded. The Monte Carlo based dose calculation software CT-Expo v. 2.3.1 (12) was used to calculate CTDI_{vol}, DLP and effective dose. The effective dose was calculated according to ICRP 103 (3) and transferred to a spreadsheet.

Statistical Analysis

Data was transferred to SPSS (13) for statistical analysis. Cronbach's Alpha was used to measure the internal consistency of the observers. Intraclass correlation coefficient was used as a measurement for the reliability of the ratings of the observers at 95% confidence level. A paired Student's t-test and Wilcoxon test was also used to determine the *p*-value with a significance level of 0.05.

Mean and standard deviation were calculated for the perceptual image evaluation ratings and a normality test was performed (Shapiro-Wilk test).

After calculating the SNR values, the same normality test was utilised to evaluate data distribution.

The significance was calculated between all SNR values and a *p*-value less than 0.05 was considered statistically significant.

Results

Internal consistency and intraclass correlation coefficient

Internal consistency was measured between the eight participating observers using Cronbach's Alpha. The Alpha value was 0.937 for axial images and 0.955 for coronal images, indicating an excellent internal consistency within the observer's group.

For the axial plane, intraclass correlation coefficient indicates highly reliable measures between observers with a range of 0.879-0.974 (95% confidence interval). Concerning the coronal plane, the range was 0.915-0.981 (95% confidence interval). Inter-item correlations between observers ranged from 0.287 to 0.949, indicating the existence of a correlation between the eight observers' choices. Although the inter-item correlations were lower for one observer

(0.287), the decision was made to include this observer into the study. This was done because the observer fitted the criteria and the same situation could occur in a clinical setting.

Perceptual image quality evaluation

The mean and standard deviation (SD) of the perceptual image quality scoring were calculated. Both standard and detail pitch modes performed significantly better than fast mode in both the axial and coronal plane.

The overall ratings obtained for subjective perceptual image quality evaluation showed that there was no statistically significant differences between the overall abdomen images obtained with standard and detail pitch acquisition modes in the axial plane. In spite of that, after analysing each criteria separately, detail

Visually sharp reproduction of the following structures	Standard vs. Detail		Detail vs. Fast		Fast vs. Standard	
	Axial	Coronal	Axial	Coronal	Axial	Coronal
Liver parenchyma and vessels	-0.750	1.000	1.000	0.125	-0.625	-1.000
Spleen parenchyma	-0.375	0.875	1.000	0.000	-0.250	-1.000
Pancreatic contours	-0.875	1.000	1.000	0.875	-1.000	-1.000
Kidneys and renal vessels	0.500	1.000	0.750	0.875	-0.875	-1.000
Retroperitoneum	0.000	0.750	0.625	0.625	-0.875	-0.625
Aorta and vena cava	0.325	0.750	0.750	0.375	-0.750	-0.625
Mean	-0.208	0.896	0.854	0.479	-0.729	-0.875
± Standard Deviation	± 0.552	± 0.123	± 0.166	± 0.374	± 0.267	± 0.194
p-value	p = 0.42	p = 0.026	p = 0.026	p = 0.042	p = 0.001	p = 0.023

Table 1. Subjective image scoring.

Figure 1. Axial images for Detail, Standard and Fast pitches, respectively.



Figure 2. Coronal images for Detail, Standard and Fast pitches, respectively.

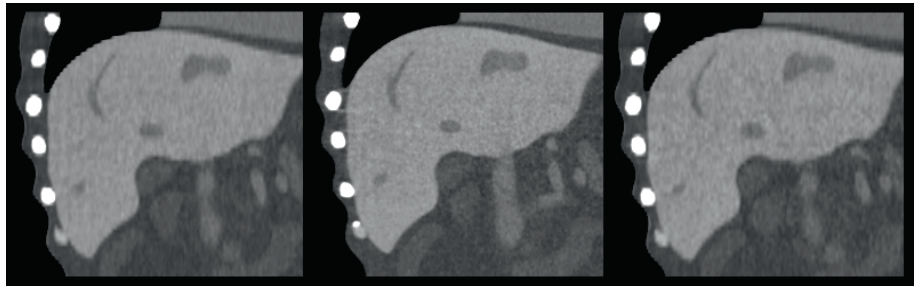


Table2. Standard vs. Detail (axial) p-values.

Visually sharp reproduction of the following structures	p-Value
Liver parenchyma and vessels	0.034
Spleen parenchyma	0.180
Pancreatic contours	0.008
Kidneys and renal vessels	0.102
Retroperitoneum	0.956
Aorta and vena cava	0.351

Table 3. Average SNR values for the three pitch modes.

Slice Group	Axial			Coronal		
	Standard	Detail	Fast	Standard	Detail	Fast
Upper	7.36	11.00	7.64	9.38	13.22	8.38
Middle	6.32	5.57	4.59	7.66	14.33	6.00
Lower	5.37	3.95	3.65	3.37	4.72	3.20

Table 4. Radiation doses for the three pitch modes.

Pitch Modes	Scanner Doses		Estimated Doses (CT-Expo)		
	CTDI _{vol} (mGy)	DLP (mGy.cm)	CTDI _{vol} (mGy)	DLP (mGy.cm)	Eff. Dose (mSv)
Standard	25.3	585.8	23.1	608.0	10.0
Detail	34.4	728.2	31.5	829.0	13.6
Fast	20.6	534.9	15.6	409.0	6.7

pitch performed better for liver parenchyma, vessels image and pancreatic contours as well. These results are shown in **table 2**.

Figure 1 shows the upper axial slices using the three different pitch factors.

For the coronal reconstruction (**Figure 2**), standard pitch mode generated images with better quality than both detail and fast modes ($p=0.026$ and $p=0.023$, respectively). Detail was slightly better than fast and although there was a high standard deviation for the scores, the p -value showed a statistically significant difference.

Physical image quality evaluation

Mean SNR values for the three pitch factors are shown in (**table 3**). No difference amongst the SNR values for axial images was found, considering that all calculated p -values were higher than 0.05. However, for coronal images there was a significant difference in SNR between standard and detail pitch acquisition modes ($p = 0.03$).

Calculation of CTDI_{vol}, DLP and effective dose

In **table 4**, both the values acquired from the CT scanner and the calculated values were included.

The most common values for CTDI_{vol} and DLP were recorded for 72% of the 36 European countries (14). In literature, it was found that the mode CTDI_{vol} was 25 mGy and the mode DLP was 800 mGy.cm. CTDI_{vol} values found in this study for standard (23.1 mGy) and fast (15.6 mGy) were below the modal CTDI_{vol}. Detail (31.5 mGy) was above. The DLP values for standard (608 mGy.cm) and fast (409.0 mGy.cm) pitch were below the modal DLP. Detail pitch (829 mGy.cm) was above the modal DLP for European countries.

The fast pitch resulted in the lowest effective dose, the detail pitch resulted in the highest effective dose and standard had a value in between both.

Discussion

The overall perceptual image quality evaluation showed no statistically significant differences between standard and detail acquisition modes in the axial plane. This corresponds with available literature which suggests perceptual image quality remains equivalent when images acquired with different pitch are evaluated (15-19). Standard acquisition mode was worse than detail for the liver parenchyma and vessels and pancreatic contours. Nonetheless, it's important to keep the ALARA principle in mind. This means that the technical parameters that produce low dose, which may acquire a comparable image quality, can be chosen to reduce radiation dose without compromising diagnostic value of the image. For example, a general abdomen CT examination might be made with the standard pitch mode to acquire the same overall image quality with a lower radiation dose than with a detail pitch mode. On the other hand, our results also suggest that if the purpose of the abdominal CT scan is to analyse the liver parenchyma and vessels or the pancreatic contours, a detail pitch mode could be a better choice.

Despite its poor image quality score compared to standard and detail, a potential benefit of using a fast pitch is reducing the effective radiation dose. Fast pitch also limits the potential motion artefacts in specific population subgroups, such as children, that tend to struggle holding their breath and remaining stationary (20).

For the coronal plane, the observers scored standard pitch acquisition mode as better than both the detail and fast modes. A possible explanation is the presence of a stair-step artefact on the coronal images (**figure 2**). This artefact likely appeared due to the non-overlapping reconstruction intervals which were used (21). The reconstruction software is likely optimised for a standard pitch, which could also explain the higher image quality scores.

In researched literature, higher pitches generate images with increased objective noise and lower signal-to-noise ratio (SNR) (15; 18; 22). However, the results in our study does not show a statistically significant difference for SNR values in the axial plane with all p -values being greater than 0.05.

In the coronal plane the results are similar although, when comparing standard vs detail there is a statistically significant difference ($p=0.03$). Even though detail has a higher SNR, observers still rated the image as worse compared to the images with a standard pitch. A possible explanation is the presence of the stair-step artefact in the coronal plane. Verdun et al. describe that the noise in a CT image only has a minor dependence on the pitch (11) and this could explain the similar SNR levels for different pitch factors (**table 3**).

The differences between scanner doses ($CTDI_{vol}$, DLP) and the estimated doses from CT-Expo might be due to errors of the CT-Expo software, considering it allows a range to $\pm 15\%$ (12). Furthermore, the z-axis

dose modulation might be different when using the CT-Expo software compared to the CT scan because the used phantom might differ from the reconstruction of the abdomen in the CT-Expo software. As expected, the augmentation of effective doses is inversely proportional to the pitch factors. The most irradiant pitch mode is detail and the less is fast, this is in accordance with found literature (15; 17; 18; 20). Even though the recorded $CTDI_{vol}$ and DLP values indicate that detail pitch is above the common recorded values, some factors should be taken into consideration. The most common value for $CTDI_{vol}$ and DLP in abdomen CT in European countries is a combination of the values acquired for different abdomen scans. This means that different parameters were used for the scans, for instance different pitch factors. Furthermore, different CT scanners from different manufacturers were included. Another factor that influences the mean values is the difference between patients. The discrepancy between these values should be taken into consideration before forming a conclusion about the values found in this study. Using a phantom creates an artificial and controlled research environment which is usually not the same as seen in clinical practice although, a phantom allows for a high level of control which is a benefit in experimental science.

Study limitations

This study has some limitations that need to be considered. Furthermore, the results of our study refer specifically to a 16-slices CT Toshiba scanner using filtered back projection (FBP) reconstruction method. Iterative reconstruction algorithms are being studied to be an alternative in overcoming the conflict between image reading quality and high radiation doses (23; 24). Although the observer data showed a strong interrater agreeability, qualitative image analysis can be subjective. This should be taken into consideration when implementing these results. No identical comparison between same pitch images (e.g. detail vs detail) was made during image evaluation, therefore it is impossible to determine whether the results are valid. Despite this, the large number of observers participating in our study revealed a high level of internal consistency.

Conclusion

Our results suggest that in the axial plane standard (0.938) and detail (0.688) pitch factors are superior to a fast (1.438) pitch factor in terms of image quality; however, the effective radiation dose for the fast pitch was 33% lower than standard and 50.8% lower than detail. Detail was superior to standard pitch when looking at the liver and pancreatic contours. No significant differences were noted in the spleen, kidney, renal vessels and lower abdomen between

these pitches. Standard had a lower dose of 26.3% compared to detail.

In the coronal plane standard was superior to both detail and fast in terms of image quality and fast was worse than detail. No significant difference was noted between SNR values in the axial plane, except between standard and detail ($p=0.03$) in the coronal plane.

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References

1. International Atomic Energy Agency (IAEA). Dose Reduction in CT while Maintaining Diagnostic Confidence: A Feasibility/Demonstration Study. Confidence MD; 2009.
2. European Union. Radiation Protection N° 180 Medical Radiation Exposure of the European Population. Luxembourg: Publications Office of the European Union; 2015. p. 180
3. Valentin J, editor. The 2007 recommendations of the international commission on radiological protection. Oxford, UK: Elsevier; 2007.
4. Bevelacqua JJ. Practical and effective ALARA. Health physics. 2010 May 1;98(2):39-47.
5. Huda W. CT radiation exposure: an overview. Current Radiology Reports. 2015 Jan 1;3(1):1-6.
6. Matsubara K, Koshida K, Suzuki M, Hayashi N, Takata T, Tsujii H, Yamamoto T, Matsui O. Contrast resolution in multidetector-row CT with 16 detector rows: phantom study. Radiological physics and technology. 2008 Jan 1;1(1):13-9.
7. Jessen KA, Panzer W, Shrimpton PC, Bongartzm G, Geleijns J, Golding S, Jurik AG, Leonar M, Tosi G. EUR 16262: European guidelines on quality criteria for computed tomography. Luxembourg: Office for Official Publications of the European Communities. 2000.
8. Jacoby J, Matell MS. Three-point Likert scales are good enough. Journal of Marketing Research. 1971 Nov 1;8(4):495-500.
9. Keeble, C., P. D. Baxter, et al. (2016). "Methods for the analysis of ordinal response data in medical image quality assessment." Br J Radiol 89(1063): 20160094.
10. NEC. MultiSync EA243WM User's Manual. Available at: http://www.necdisplay.com/documents/UserManuals/EA273WM_EA243WM_UserManual.pdf
11. Verdun FR, Racine D, Ott JG, Tapiovaara MJ, Toroi P, Bochud FO, Veldkamp WJ, Schegerer A, Bouwman RW, Giron IH, Marshall NW. Image quality in CT: From physical measurements to model observers. Physica Medica. 2015 Dec 31;31(8):823-43.
12. Stamm G, Nagel HD (2014) CT-Expo V2.3.1: a tool for dose evaluation in computed tomography. Hannover. Available at: <https://blogg.hioa.no/victdel4/files/2015/04/CT-Expo-Manual-E-V2.3.pdf>
13. IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp
14. European Commission. (2010). DDM2 Project Report Part 2: Diagnostic Reference Levels (DRLs) in Europe. Available at http://ddmed.eu/_media/news/ddm2_project_report_part_2_final_rb_16052014.pdf

15. Tacelli, N., M. Remy-Jardin, et al. (2010). "Dual-source chest CT angiography with high temporal resolution and high pitch modes: evaluation of image quality in 140 patients." *Eur Radiol* 20(5): 1188-1196
16. Sahani, D., S. Saini, et al. (2003). "Comparison between low (3:1) and high (6:1) pitch for routine abdominal/pelvic imaging with multislice computed tomography." *J Comput Assist Tomogr* 27(2): 105-109
17. Han, B. K., J. Lindberg, et al. (2011). "Accuracy and safety of high pitch computed tomography imaging in young children with complex congenital heart disease." *Am J Cardiol* 107(10): 1541-1546.
18. Zhang, L. J., Y. E. Zhao, et al. (2015). "Seventy-Peak Kilovoltage High-Pitch Thoracic Aortic CT Angiography without ECG Gating Evaluation of Image Quality and Radiation Dose." *Acad Radiol* 22(7): 890-897.
19. Sun, Z. and C. Ng (2010). "Dual-source CT angiography in aortic stent grafting: An in vitro aorta phantom study of image noise and radiation dose." *Acad Radiol* 17(7): 884-893
20. Kim, S. H., Y. H. Choi, et al. (2016). "Comparison of Image Quality and Radiation Dose between High-Pitch Mode and Low-Pitch Mode Spiral Chest CT in Small Uncooperative Children: The Effect of Respiratory Rate." *Eur Radiol* 26(4): 1149-1158
21. Barrett J.F., Keat N. Artifacts in CT: recognition and avoidance 1. *Radiographics*. 2004 Nov;24(6):1679-91.
22. Schindera, S. T., R. C. Nelson, et al. (2007). "Abdominal multislice CT for obese patients: effect on image quality and radiation dose in a phantom study." *Acad Radiol* 14(4): 486-494.
23. Kahn J, Grupp U, Kaul D, Böning G, Lindner T, Streitparth F. Computed tomography in trauma patients using iterative reconstruction: reducing radiation exposure without loss of image quality. *Acta Radiologica*. 2015 Mar 1;57(3):362-9.
24. Thompson, J. D., Chakraborty, D. P., Szczepura, K., Tootell, A. K., Vamvakas, I., Manning, D. J., & Hogg, P. (2016). Effect of reconstruction methods and x-ray tube current-time product on nodule detection in an anthropomorphic thorax phantom: A crossed-modality JAFROC observer study. *Medical physics*, 43(3), 1265-1274.

OPTIMAX 2016: Peer observation of facilitation

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Introduction

In August 2016, a 3-week research Summer School was delivered at University of Salford. The Summer School, known as 'OPTIMAX' was in its fourth year of delivery. Previous iterations were held in the Netherlands (2015), Portugal (2014) and Salford (2013).

The purpose of OPTIMAX is to facilitate collaborative international and interdisciplinary research between university academics and students. This offers an exceptional opportunity not only for students, but also for tutors who want to develop their facilitation skills.

The project reported here used tutor observers (i.e. tutors who attend the summer school, in an observational capacity only, to develop their own skills as teachers) to observe, identify and reflect on a range of facilitation practices for managing the diverse OPTIMAX research groups. The project presents a description of the peer-observation method we used and highlights a number of findings related to facilitator strategies that appeared to influence group dynamics and learning. These observations are then used to make recommendations about how OPTIMAX tutors can be prepared for their facilitation experience.

Background

Education literature regarding Peer Observation of Teaching (PoT) suggests this method of training new teachers is more effective than de-contextualised didactic approaches (Martin and Double 1998). This is perhaps not surprising since new teachers witness real-life examples of teaching in action rather than reading about them in textbooks.

Nevertheless, PoT is not without its problems. Those being observed can feel intimidated and respond negatively if they feel their practice is being judged. This is particularly true when PoT is undertaken by more experienced peers for the purpose of Quality Assurance (Cockburn 2005). Although the aim of our study was not to review the quality of facilitation but to support new teachers to learn from examples of good practice it was still very important to prepare everyone appropriately to ensure a collaborative approach was achieved.

In order to facilitate this we positioned the study within an Appreciative Inquiry framework (Cooperrider & Whitney 2005). In Appreciative Inquiry observers are only permitted to identify and celebrate good practice. The principle is that by identifying what it is that makes something good, these ideas can be used to move forward, rather than concentrating on a deficiency model of what doesn't work, where people are required to let go and be coerced to change.

We used Siddiqui et al (2007) 12 tips for peer observation of teaching to guide the process, as this provides a useful overview for considering the PoT process from the perspectives of all involved.

In order to help new tutors identify examples of good practice an observational template was required. Although many such templates exist for “teaching” activities it proved difficult to find a template specifically targeted to good practice in small group facilitation. We therefore designed our template by amending the standard PoT form used at the University of Salford (University of Salford 2016/17) to include qualities identified in the literature as being supportive of group facilitation. These covered being supportive of group (peer-to-peer) learning interactions, managing group dynamics and managing conflict (Bosworth 1994, Barkley, Howell Major, Cross 2014, Johnson, Johnson & Smith 2014) (see Appendix 1).

Purpose of our work

To explore new tutors' reflective observations of small group facilitation learning activities, in order to:

1. develop a tool for the peer-observation of small group facilitation
2. develop a set of tutor guidelines on small group facilitation in a multicultural context
3. make recommendations to the OPTIMAX organising committee about preparation of tutors

Participants

All new tutors who had registered to attend the summer school for the purposes of improving their facilitation skills were invited to take part in the study as tutor-observers. Six out of seven agreed; the seventh was required to participate as an ‘experienced’ group tutor as she had specific statistics skills which were needed to support the research. She felt this would influence her ability to step back into the role of ‘inexperienced’ tutor and would therefore bias her observations.

Of the 6 participants, two were from Sweden, two from the UK, one from Ireland and one from Switzerland. Observation took place through a number of permutations: paired; singly; during week one only; during week 3 only and over the length of OPTIMAX (see **table 1**). This helped limit the influence of intra and inter-observer differences, group dynamics, and changes in facilitator behaviour over time. Tutor-observers did not observe tutors from their own place of work. All experienced tutors consented to being observed.

Observation Case	Observer	Tutor observed (number protects anonymity)	Dates of observation	Working day of summer school	Description
1	JL	1	3/8/16	3	One observer observed two different tutors on subsequent days of week 1
2	JL	2	4/8/16	4	One observer observed same group at beginning and middle of summer school
3	CM	3	2/8 /16 3/8/ 16 11/8/16	2,3, 9	Pair of observers observed two different groups in week 1
4	PT/CP	4	2/8/16 3/8/16	2,3	One observer observed one tutor in final week of summer school
5	PT/CP	5	3/8/16	3	One observer observed one group in final week of summer school over 3 days
6	SdL	6	16/8/16	12	
7	JC	7	15/8/16 16/8/16 17/8/16	11-13	

Table 1 Configuration of Observations

Method

Stage 1: Information and consent

Experienced tutors being observed and tutor-observers were informed about the project and asked for consent to participate on-line before the tutors attended the summer school.

Stage 2: Teaching about group facilitation and peer observation

Tutor-observers were briefed via a tutorial with the project lead (who has teaching and research experience and published on small and intercultural group learning (Robinson 2015, Robinson, Harris and Burton 2015, Schillemans and Robinson 2016)) about what is considered good practice in small group facilitation. This helped them understand the observation tool. Tutor-observers were also made aware of the principles of peer-observation and the requirement for good ethical conduct during the process.

Stage 3: Observation

Tutor-observers were allocated to a group to carry out observation. This was based on pragmatic issues related to the length of time the tutor-observer was available for the summer school. To avoid difficulties an observer may have had in feeding back to a more experienced colleague they were placed with a tutor from a different country. This also kept the field

‘anthropologically strange’ maximising the ability to detect new and unfamiliar practices (Delamont 2014).

Stage 4: Interview and debrief with tutor

Tutor-observers then met with the tutor/s they had observed for feedback and discussion about the observations. This is good practice in peer-observation (HEA 2006) but also enabled the tutor-observer to explore any further issues such as why a particular intervention was or was not undertaken, i.e. enriching their notes with an emic perspective.

Stage 5: Reflective write-up

Tutor-observers then wrote a reflective account of their observations. As well as supporting their own development as tutors the reflective report formed the main document for data analysis.

Stage 6: Tutor observer analysis, discussion and consensus meeting

Finally, all tutor-observers met to compare their notes and thereby identify important themes and sub-themes emerging from the reflective accounts (see **Table 2**). These themes formed the basis of a framework analysis.

Analysis

The framework was constructed according to the method described by Ritchie and Spencer (1994). The themes formed columns and each reflective account formed the cases that were attributed to the rows. The cells were then populated with examples and comments by the tutor-observers. The project leader compared and contrasted these comments to arrive at the study findings and recommendations.

Results and discussion

In order to propose a set of guidelines and recommendations to prepare tutors for OPTIMAX facilitation we first highlighted the good practices observed in terms of supporting learning interactions in groups and managing group dynamics.

Student versus tutor centred

OPTIMAX is designed to be student-led. Experienced tutors were seen to facilitate this through the use of open language which was encouraging and non-condescending; they were respectful towards the students and attempted to position themselves as equal members of the team rather than being in a position of power.

They were also seen to encourage the students to think for themselves by using open questions in response to requests for information and by paraphrasing and reflecting the question back to

the group for other members to help resolve. One particular good example was a tutor who used an approach that forced students to summarise the project progress and their own understanding rather than attempting to summarise the learning for them. For example instead of asking “is everyone clear on this”, the tutor would ask “tell me what you understand about what you have found” (tutor 4).

Encouraging participation

The more experienced tutors were not afraid of silences, allowing the group to resolve issues for themselves rather than stepping in too early. The tutor-observers who witnessed more than one facilitation style were able to contrast this with tutors who stepped in to fill a silence, the consequence of which was subsequent student reliance on the tutor to direct the learning.

One experienced tutor was shown to make effective use of body language to engage all students in the discussion by making eye contact with each student individually in order to encourage participation.

Group Dynamics

Experienced tutors demonstrated a range of strategies to positively influence group harmony. In particular, some tutors used humour to good effect ensuring there was a congenial atmosphere despite the pressure of the learning task. One tutor took a

Key themes	Sub-themes
Roles of OPTIMAX tutors: facilitators and non-facilitators	<ul style="list-style-type: none"> • Influence of OPTIMAX programme lead • Clarification of roles of each facilitator when there is more than one • OPTIMAX facilitator as team leader • Previous experience of OPTIMAX facilitation - was this important? • Should facilitators be knowledgeable about the subject? • Facilitator works as a group member
Students and student group	<ul style="list-style-type: none"> • Group dynamics • Personalities • Individual student confidence • Group diversity
Facilitator style and strategies	<ul style="list-style-type: none"> • Humour as strategy by facilitator • Facilitator personality influences group • Facilitator mood influences group • Allowing natural group processes to work to resolve problems without stepping in too soon • Does not answer student questions directly but guides students to answer them themselves • Use of open language to encourage discussion • Non-condescending language • Positive language, encouraging • Respects students and doesn't interrupt them • Paraphrases students' comments to make sure everyone understands • Gets students to clarify daily objectives and responsibilities • Uses metaphors in explanation • Lets students lead the group and project processes • Uses body language and eye contact • Prepared to challenge dominant students rather than avoid conflict • Ensures breaks included
Group processes	<ul style="list-style-type: none"> • Decision-making • Splitting into sub-groups • Rules • Choice of team leader
Peer observation method and evaluation	<ul style="list-style-type: none"> • Preparation • Methodology • Feeding back to the facilitator being observed • Value to facilitator being observed • Value to observer • Other

Table 2 Key themes and sub themes

more proactive approach by ensuring breaks were scheduled and including social activities during this time.

The tutor mood was observed to have a strong influence on the group dynamic. A number of experienced tutors purposefully chose to demonstrate a calm and relaxed demeanour and the groups were consequently calm and relaxed, whereas tutors who were stressed or unenthusiastic (only occasionally seen) appeared to transfer these qualities to the group.

Group Processes

There were a number of challenges identified by the observers which, whilst managed well by the tutors, could have been avoided or better supported through adherence to group management processes. As part of the preparation for their OPTIMAX research project, the groups were introduced to the concept of project and group management. This involved creating a set of ground rules, identifying roles and responsibilities, agreeing the decision-making strategies to be used and the creation of a project plan managed through a process of daily reflective logs. These processes were only observed in the initial set-up (week 1) but rarely returned to throughout the project. The observers felt this was a missed opportunity.

For example, in one incident of conflict (where two students dominated one particular group and ignored advice from the tutor), the tutor managed the problem by remaining calm, and using strategies to retain group harmony. The research output was not negatively influenced. However, the tutor had a less than satisfactory experience of OPTIMAX. Returning to the ground rules and agreed decision-making strategy may have helped to address the problem in a more satisfactory way.

In other groups, dynamics changed when new tutors joined half way through the summer school, and when groups were split into smaller groups to divide up the tasks. This left the students unclear about everyone's roles, positions and responsibilities. Again, returning to the ground rules would have been useful to aid clarification.

Group make-up was identified as being a potential barrier to progress despite effective facilitation strategies. For example, in some groups the tutor was also nominated the group leader. This tended to happen because the students' personality styles¹ did not favour the leadership role. In order to progress the research the tutor therefore stepped into the role.

1 On day 1, all OPTIMAX participants (staff and students) complete a Myers-Briggs (Malpascoe Team Dynamics ND) personality type indicator test to establish team roles and individual group member differences.

Although this did not appear to affect the quality of the group's work, it would have limited the opportunity for students to practice leadership skills.

Groups that were diverse appeared to be more dynamic. This included a mix of personality types, ages, qualifications and countries, as well as having two tutors, rather than one, who each brought different qualities to the group. Tutor-observers suggested that considering these things before the make-up of each group was determined might be useful, i.e. to purposefully configure the group to maximise diversity.

Objective 2: Guidelines and recommendations for OPTIMAX facilitation

From the above observations we make the following recommendations

1. Groups could be configured before the start of OPTIMAX to ensure a diverse mix with regard to age, qualification, discipline, country of study, personality type, research and associated skills. This could be achieved through the development of a registration form which requests the above demographic and personality details. Students would need to complete the Myers-Biggs test prior to OPTIMAX attendance.
2. Student groups to be introduced online before commencement of OPTIMAX using an appropriate Social Media platform.
3. There should be two tutors per group and where possible one of these should have group management skills/experience. The tutors should agree their roles before meeting with the students.
4. Tutors should be provided with a handbook on i) facilitating group learning and ii) managing groups before commencing OPTIMAX.
5. Effective strategies for facilitating group learning to be included in the handbook include:
 - a. Asking students to lead process and clarify daily tasks
 - b. Asking students to articulate their own understanding
 - c. Praising and encouraging students, and helping students who have not been understood by the others to re-phrase their statements/questions
 - d. Establishing equal power through use of supportive and non-condescending language
 - e. Proactively engaging students who are not participating
 - f. Using silence to provide students the opportunity to think through solutions
 - g. Being mindful of actions which threaten group learning such as lack of task clarification, especially when sub-groups are used

6. Effective strategies for managing groups to be included in the handbook include:
 - a. Having daily reflective report on progress of task but also each person's contribution (including tutor)
 - b. Establishing ground rules, roles and responsibilities and referring to these regularly
 - c. Considering the social development of the group by identifying opportunities for doing 'off-task' activities
 - d. Being mindful of tutor mood on the dynamic and development of the group

Objective 3: developing a tool for the peer-observation of small group facilitation

As Martin and Double (1998) also reported in their work, both tutor-observers and expert tutors found the experience useful for professional development. The observers highlighted strategies such as effective use of silences, eye contact and humour as things they would take away and embed within their own practices. Those being observed appreciated feedback and confirmation that their practices were supportive of student learning.

The template was a useful guide. The tutor-observers felt that the only additional information that could be captured might be detail about the experienced facilitator's previous experiences of facilitation

and any aspects of their practice they would like feedback on. Tutor-observers also felt they would like to have had a pre-observation interview with their experienced tutor in order to identify specific issues to look out for. This is certainly identified as good practice in most PoT schemes (HEA 2006) but may have rendered this research project less valid since being directed to specific issues may have meant the observers were biased in what they observed. Nevertheless, future recommendations would include a pre-observation interview with new tutor learners, along with a space to capture this information on the template.

Observers did suggest that students could be better informed about the PoT scheme so that the students did not feel they were being assessed in any way. This was also recommended by Siddiqui, Jonas-Dwyer and Carr (2007).

Tutor-observers felt that maximum benefit would be gained from attending the full three weeks since they could identify changes in the group dynamics and the ways the experienced tutors managed this.

Limitations

This has been a descriptive overview of the reflections and observations of less experienced tutors. We have not attempted to qualify their observations against student or group outcomes to determine whether

what they suggested was good practice could be verified as such. However, the template used was derived from pedagogical theory on group facilitation and this therefore goes some way to supporting the assumptions made. The multiple permutations of paired, repeated and longitudinal observations, observer consensus meetings and comparison of notes has provided a rich data set which demonstrates data saturation around most practices observed and reported here. Finally, the observers were asked to verify their interpretations with the expert facilitators at the post-observation meeting adding trustworthiness to the data.

References

- Barkley EF, Howell Major C, Cross, KP (2014) *Collaborative Learning Techniques: a handbook for college faculty* Jossey-Bass. San Francisco, Ca
- Bosworth K (1994) Developing collaborative skills in college students. In K.Bosworth & SJ Hamilton (eds) *Collaborative learning: Underlying processes and effective techniques* (pp25-32) New Directions in Teaching and Learning no 59. San Francisco: Jossey-Bass.
- Cooperrider, D.L. & Whitney, D (2005) A positive revolution in change: Appreciative inquiry. In
- Cooperrider, D. L. Sorenson, P., Yeager, T. & Whitney, D. (eds.) *Appreciative Inquiry: Foundations in Positive Organization Development* (pp.9-33). Champaign, IL: Stipes.
- Creswell, J. W. (2009). *Research Design*. Thousand Oakes, California, Sage.
- Delamont Sara (2014) Key themes in the ethnography of education. London. Sage,
- HCPC (2016) *Standards of Conduct, Performance and Ethics* [available at] <http://www.hpc-uk.org/aboutregistration/standards/standardsofconductperformanceandethics/>
- HEA (2006) Peer Observation [available at] <http://escalate.ac.uk/resources/peerobservation/05.html>
- Hogg H and Lança L (eds) (2014) *Erasmus Intensive Programme OPTIMAX#2014 Radiation dose and image quality optimisation in medical imaging* Lisbon, Portugal
- Hogg, P, Blakeley, C and Buissink, C 2015 OPTIMAX 2015 : *Multicultural team-based research in radiography, a holistic educational approach*. University of salford, Groningen, the Netherlands
- Johnson DW Johnson RT & Smith KA (2014) *The power of cooperative learning for university classes: The interrelationship among theory, research, and practice*. Journal on Excellence in College Teaching (25) 4
- Malpascoe Team Dynamics using MBTI Leadership Development Series <http://www.slideshare.net/malpascoe/mbti-team-dynamics> [accessed 18/12/16]
- Martin, G. A. and J. M. Double (1998). "Developing Higher Education Teaching Skills Through Peer Observation and Collaborative Reflection." *Innovations in Education & Training International* 35(2): 161-170.
- Morse, J. M. and Field, P. A. (1996). *Nursing Research the Application of Qualitative Approaches*. Cheltenham, Nelson-Thornes.
- Ritchie J, Spencer L (1994) Qualitative data analysis for applied policy research in *Analyzing Qualitative Data* Eds Bryman A and Burgess RG (pp 173-194). Taylor and Francis Books Ltd
- Robinson L., Harris S., Burton R. (2015) Saving face: Managing rapport in a Problem-Based Learning group Active Learning in Higher Education March 16: 11-24, doi:10.1177/1469787415573355
- Robinson L. (2015) Age difference and face-saving in an inter-generational Problem Based Learning group Journal of Further and Higher Education
- Schillemans Kitty and Robinson Leslie (2016) Team and project management skills in OPTIMAX 2015 : Multicultural team-based research in radiography, a holistic educational approach.
- Hogg, P, Blakeley, C and Buissink, C (Eds) University of Salford, Groningen, the Netherlands [available at] <http://usir.salford.ac.uk/38008/>
- Siddiqui Zarrin Seema., Jonas-Dwyer Diana., Carr Sandra E (2007) Medical Twelve tips for peer observation of teaching Teacher 2007; 29: 297-300 University of Salford (2016/17 version) Observation of Teaching Optional Template [available at] <http://www.salford.ac.uk/qeo/academic/observation#>

Appendix 1

Context details

Name of tutor/s being observed

Name of peer observer

Name of group being observed

Date and time of observation

Brief explanation of task/s being observed
(e.g. what stage of the project was the group engaged in?)

Observation Notes

Whilst observations are not a process of checking against a checklist, which cannot encompass all the complexities of the teaching situation, there are some common features that do exist and therefore can be used as a guide to provide feedback. The session should focus on the student learning experience as facilitated by the teaching approach. The observer's role is not to focus on the academic content of the session.

Introducing the activity

Task clarification

- Explain/remind the students about the activity
- Clarify objectives for the session/day
- Outline the procedure
- Provide the prompts/examples
- Check the students for understanding

Process clarification

- Remind group of the rules for group interaction
- Check group has considered time limits for the session/day

Supporting learning

- Be available to clarify instructions, review procedures, and answer questions
- Paraphrase or ask a question to clarify what a student has said
- Compliment the student on an interesting or insightful comment/contribution
- Elaborate on a student's statement or suggest a new perspective
- Energise by using humour or by asking for additional contributions
- Gently disagree with a comment or contribution when necessary
- Summarise the group's learning/support the group leader in doing this

Managing group interactions

- Help group to use decision making techniques
- Ensure all students participate
- Encourage equal participation
- Bring in quiet, disengaged students
- Manage students who dominate the group

Managing conflict

- Encouraging the group to solve their group difficulties
- Mediate between students
- Return to group ground rules and contract

Additional notes:

References: Items on this template have been adapted from

Barkley E.F., Howell Major C. and Cross
K.P. (2014) Collaborative Learning
Techniques. A handbook for College
Faculty. Chapter 6 Facilitating
Student Collaboration p90-94 &
Chapter 8 Avoiding and Resolving
Common Problems. Jossey-Bass San
Francisco, CA.

University of Salford Observation of
Teaching template

After the observation

Following the observation it is important for both tutor and observer to take some time to reflect on how the session went, and to prepare for the post-observation discussion.

Please use the following interview guide (which has been approved by the University of Salford Research, Innovations and Academic Engagement Ethical Approval Panel)

Peer observation interview schedule

1. Thank you for allowing me to observe your practice.
2. I would like to feedback my comments.
3. (Go through peer-observation sheet)
 - a) Introducing the activity
 - b) Supporting the learning
 - c) Managing group Interactions
 - d) Managing conflicts
4. Could you comment on my observation and interpretation of what I saw?
5. Is there anything else you would like to highlight about this group or session/s that I have observed that you think I have missed?
6. Thank you for your time

Interview Notes

Reflection

Using your observation notes and the notes from your de-briefing meeting with the tutor/s please provide a brief reflection of your experience. Try to identify the strengths and limitations of the facilitation you have seen and highlight the key learning points that you will use to improve your own facilitation style. **If you, and the tutor/s you have observed, have consented to be part of the research, this observation template and reflection should be submitted to Leslie Robinson l.robinson@salford.ac.uk before you leave the UK.**

Reflection

Key Learning points

How will you use this experience to improve your own facilitation?

