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The Use of Social Media Platforms in Implementing Quality Improvement Initiatives for Quality Assurance of Paediatric Chest Radiographs in Radiological Departments of Varying Radiographer Expertise

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The Use of Social Media Platforms in Implementing Quality Improvement Initiatives for Quality Assurance of Paediatric Chest Radiographs in Radiological Departments of Varying Radiographer Expertise

Linda Tebogo Hlabangana

A Thesis submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy in Diagnostic Radiology

Johannesburg, 2024

Declaration

I, Linda Tebogo Hlabangana, declare that this research report is my own work. It is being submitted for the degree of PhD Diagnostic Radiology at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University. I further declare that all sources that I have used or quoted has been indicated and acknowledged by means of complete referencing.



Linda Tebogo Hlabangana

On this 30th day of October 2024

Dedication

I dedicate this work to my husband Abraham and to our three princesses Lisakhanya, Mihlali and Amyoli. In this work I hope to pave the way for you to dream bigger and achieve greater as you follow your passions as I have followed mine.

I also dedicate this work to my parents Thabo and Priscilla Hlabangana who instilled in me an insatiable passion for reading and learning. You taught me to value education, the key that has opened many doors and opportunities.

Publications and presentations

This work has been published in a number of papers as listed below:

Publications

1. Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays. Hlabangana LT, Elsingergy M, Ahmed A, Boschoff PE, Goodier M, Bove M, Andronikou S. J Med Imaging Radiat Sci. 2021 Sep;52(3):427-434. doi: 10.1016/j.jmir.2021.04.002. Epub 2021 May 3.PMID: 33958315
2. Response to the letter to the editor re: Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays. Elsingergy M, Kidd M, Hlabangana LT, Andronikou S. J Med Imaging and Radiat Sci. 2021 Dec 1;52(4):659-60. doi: 10.1016/j.jmir.2021.09.002. Epub 2021 Sep 30. PMID: 34602374
3. Short-term impact of pictorial posters and a crash course on radiographic errors for improving the quality of paediatric chest radiographs in an unsupervised unit - a pilot study for quality-assurance outreach. Hlabangana LT, Andronikou S. Pediatr Radiol. 2015 Feb;45(2):158-65. doi: 10.1007/s00247-014-3115-9. Epub 2014 Aug 17. PMID: 25129339
4. Tailoring REDCap to incorporate radiographic images for an offsite quality assurance tool. Hlabangana, L. T.; Andronikou, S.; Maré, I.A.; Maré, W.T. Journal of The Colleges of Medicine of South Africa, 2019; 63(2): 87-89.

Presentations

1. The use of social media in quality improvement of paediatric chest radiographs. Linda Tebogo Hlabangana. 5th ASR and 54th ESRNM Conference, Cairo, Egypt. January 2019

2. The Use of Social Media Platforms in Implementing Quality Improvement Initiatives for Quality Assurance of Paediatric Chest Radiographs in Radiological Departments of Varying Radiographer Expertise. Linda Tebogo Hlabangana. RSSA/ASNR/ESNR Neuroradiology Symposium 2018, Spier, Cape Town, October 2018. As part of the JN and WLS Lectureship Award from the College of Radiology of South Africa.

Abstract

Introduction

Chest radiographs are the most widely performed diagnostic imaging test in children. Good quality radiographs assist in making the correct diagnosis. In resource limited settings, such as in Africa, there are several limiting factors that affect the quality of the radiograph which go beyond the availability of equipment and human resources, including geopolitical and socioeconomic challenges. Novel innovations are required to overcome these challenges by leveraging off technology and the widespread distribution of smart phones.

Aim

The aim of the study was to evaluate the improvement in the quality of chest radiographs performed in children after initiating quality improvement interventions at three radiology departments. The interventions used the Internet, Facebook® and Twitter®) to remotely communicate with the radiographers.

Methods

A longitudinal, descriptive study was performed at three radiological centres in South Africa. They study had a retrospective phase (before intervention), and a prospective phase. Over a period of six months, communication on quality factors of chest radiographs and how to improve quality were sent out using Facebook and Twitter. Thereafter, radiographs were collected and the quality assessed.

Results

A total of 966 radiographs were included in the study. The most common errors overall were “scapula in the way” (38.7%), “rotation” (34.7%) and “poor collimation” (22.2%). The errors “parts cut off” (1.3%) and “wrong/no left/right marker” (1.7%) were the least common. Rahima Moosa Mother and Child Hospital demonstrated non-significant improvement in the quality of radiographs over the duration of the study. The other two centres demonstrated no significant or sustained improvement in the quality of chest radiographs performed. The research did not demonstrate a significant benefit from the intervention. There was

low engagement with the social media platforms. A total of six radiographers followed the Twitter handle and the Facebook page had 37 friends/followers, eight of these were radiographers participating in the study.

Conclusions

Although social media have demonstrated impactful use in education and communication, the usage by radiographers in South Africa to improve the quality of chest radiographs is limited. . There was no significant benefit demonstrated from the use of Facebook and Twitter as educational and information tools. Further research using low-data consumption social media apps to create locally relevant and sustainable solutions for quality assurance and quality improvement in radiography are required.

Key words: Quality assurance, social media, Facebook, Twitter

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List of Abbreviations

AAPM	American Association of Physicists in Medicine
ACR	American College of Radiology
AI	Artificial intelligence
ALARA	As low as reasonably achievable
ANOVA	Analysis of Variance
ARRS	American Roentgen Ray Society
AP	Anterior posterior
CHBAH	Chris Hani Baragwanath Academic Hospital
CQI	Continuous quality improvement
CR	Computed radiography
CT	Computed tomography
CSV	Comma-separated values
DICOM	Digital imaging and communications in medicine
DRL	Dose reference level
ESD	Estimated skin dose
GUID	Globally unique identifier
HIC	High-income countries
HIV	Human immunodeficiency virus
ICRP	International Commission on Radiation Protection
IQR	Inter-quartile range
ICT	Information and communications technology
ICU	Intensive care unit
JPEG	Joint photographic experts group
KH	Khayelitsha Hospital
LMIC	Low- and middle- income countries
MRI	Magnetic resonance imaging
mHealth	Mobile health
GB	Gigabyte
NGO	Non-governmental organisations
PA	Postero-anterior
PACS	Picture archiving system
PI	Principal investigator
QA	Quality assurance
QC	Quality control
QI	Quality improvement
REDCap	Research electronic data capture
RMMCH	Rahima Moosa Mother and Child Hospital
RSNA	Radiological Society of North America
RSSA	Radiological Society of South Africa
SADOH DRC	South African Department of Health Directorate Radiation Control
SNR	Signal-to-noise ratio
SRH	Sexual and reproductive health
TB	Tuberculosis
WFPI	World Federation of Paediatric Imaging

CHAPTER 1: Introduction

1.1 Background

Chest radiography is the most regularly performed diagnostic radiological examination (1–10) representing 30–40% of all radiological examinations that have been performed (11). Despite the advances in imaging technology and the diagnostic advantages of cross-sectional imaging techniques available to assist with the diagnosis and follow up of respiratory disease, chest radiography continues to be the mainstay of chest imaging (1–7,9). Although the dose of radiation acquired by the patient during the examination is relatively low, its frequent use results in a considerable collective dose. Good radiographic technique results in good quality images, which allows for accurate image interpretation (3,7,12,13). Good technique also supports radiation protection, which aims to obtain the image at the lowest reasonably achievable dose (ALARA principle) (3,4,11–19). This requires optimisation of the whole imaging process, which involves the detector, image acquisition, processing and display (14). Dose-saving practices such as adequate collimation, correct patient positioning, correct source-to-image distance (SID) and focal spot size are important in children, due to the increased radiosensitivity of immature organs (3,12,14). Children have a higher risk of developing a malignancy compared to adults who have received a similar dose. They also have a longer life expectancy that gives more time for the expression and the injurious effects of radiation (11,15).

Quality assurance (QA) in radiography is the proactive effort made to improve the diagnostic quality of the image produced, while actively reducing the radiation dose to the patient, radiographer and support staff (20–22). It is important to identify weaknesses in diagnostic practices – it plays an important role in identifying deficiencies in radiographic practice and it helps with planning interventions for quality improvement (13,21). It is an on-going process that

requires interventions and monitoring (2,5,21,23). This is particularly true in paediatric radiography where further technical challenges are experienced when producing diagnostic quality imaging (5) due to challenges related to communication and varying patient cooperation (3,12). Such challenges are more likely to result in technical errors related to patient positioning, inspiratory effort and penetration (3) which increase diagnostic difficulty. Technical errors on a radiograph may warrant repeat imaging which increases patient radiation dose (2). The use of immobilisation (24,25) devices, physical restraint by a radiology staff member (ideally) or a caregiver, distraction techniques, imaging of children while asleep or after a feed, are some of the methods used to assist to ensure correct positioning.

Various mechanisms have been used to increase diagnostic accuracy of radiographs. These include ensuring that the equipment used is functioning according to the manufacturer's specifications, national standards and regulations (11,26). Radiography machines used on children – if not specifically designed for children – need to be modified. Modifications need to include dose reduction processes such as the use of an additional copper filter, virtual collimation, low attenuation table tops and mechanisms to reduce blooming, to mention a few (11). The use of dose reference levels (DRLs) has provided a guide to practice, and when these levels are frequently exceeded, an investigation is required (11). DRLs "are defined as dose levels for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. They are specified as entrance skin air kerma (ESAK, measured in air without backscatter) or as entrance skin dose (ESD, measured in specified material with backscatter (14). DRLs are typically set at the third quartile (75% value) of the dose distribution, derived from a suitable patient dose survey. The DRLs specified are not to be exceeded with routine practice" (14).

Regular audits on referral patterns, image quality and radiographic technique are necessary to identify skill gaps and direct corrective measures. Quality improvement (QI) initiatives necessitate significant time investment and often require the input and guidance of experts. Such efforts may seem impractical and unfeasible in low- and middle-income countries (LMICs) such as South Africa,

where significant patient numbers and disease burden take up much of the staff's time. In South Africa, this matter is compounded by staff shortages with respect to both the number of qualified and skilled human resources and subspecialist level expertise.

Innovative approaches are required for enabling a single QA provider to reach geographically widespread institutions, while bearing in mind the variety of local experience and available equipment. Other fields of medicine have used electronic media and social media platforms to improve patient compliance of patients, and the administration of medication by health workers in radiography. Such platforms to convey information to improve radiographic quality do not exist. This type of innovation would be helpful for assessing the quality of radiographs, implementing initiatives for improving the quality of radiographs, and collecting local information on challenges experienced.

1.2 Hypothesis

Using social media platforms as educational and communication tools will improve the quality of frontal chest radiographs in children.

1.3 Preview and organisation of the thesis

This thesis follows a standardised format as per the style guide of the University of the Witwatersrand.

First there are introductory chapters, comprising the background and an introduction to the study. This is followed by a literature review with information on QA of paediatric chest radiographs, important quality factors regarding paediatric chest radiography, social media, advantages and challenges of social media, public engagement with social media in South Africa, and the usage of social media in radiology.

Then follow the central chapters, that include a comprehensive discussion of the methodology and results of this particular research.

Lastly, there are the concluding chapters, encompassing a discussion of the results, a detailed description of limitations, a conclusion and recommendations. The thesis ends with the appendices and a list of references.

CHAPTER 2: Literature review

The literature review will provide a background to respiratory diseases in children and the importance of early detection and treatment. Focus will be placed on quality assurance in radiography and paediatric chest radiography. Social media and its use in medicine and radiology will be highlighted, as well as the benefits, disadvantages and challenges related to its use.

2.1 Background

Respiratory diseases and the early detection and treatment thereof are important in children (27,28). The most important cause for childhood mortality and morbidity in Africa and LMICs is respiratory disease (29–36), which is responsible for a projected 15–20% of deaths in children in the under of 5 age group (31,32,37). Risk factors for acquiring respiratory infections include a combination of host and environmental factors (38–40). These include poverty, overcrowding, inadequate vaccination programmes, malnutrition, low birth weight and the absence of exclusive breastfeeding (31,32,36,38,40,41). In low- and middle-income countries (LMICs),due to the human immunodeficiency virus (HIV), the incidence, morbidity and mortality from pneumonia have increased significantly, in those both infected and uninfected by the virus (32,36,37). HIV has also altered the scope of microorganisms accountable for childhood pneumonia and responsiveness to treatment (37,42,43). Diagnosing specific infections, for example pulmonary TB, is more challenging in children (especially those infected with HIV) as clinical signs are often non-specific (34,36,37,42,44). Tuberculosis is a significant cause of respiratory disease, with the majority of children with tuberculosis (TB) living in the LMICs (29,42).

Pneumonia is an acute respiratory infection caused by bacterial, viral and fungal organisms. It is the main cause of childhood mortality in the world

(30,35,39,40,42,45–48). Globally, pneumonia is responsible for up to 15% of childhood deaths in the under 5 age group (47). Although there has been an overall decline in the worldwide incidence of childhood pneumonia (38,45,46,48), most pneumonia-related deaths (over 90%) still occur in the LMICs (35,38,39,45). In children that survive, pneumonia can cause significant morbidity and lifelong disability by affecting long-term lung function resulting in chronic lung pathology (38,45,49).

The British Thoracic Society and American College of Radiology (ACR) guidelines only recommend the use of chest radiographs in complicated cases of pneumonia (28,50), however, they are often included in patient diagnosis, evaluation and management, especially in resource-limited settings of LMICs (50–52). Sputum samples from the respiratory system are also not always helpful as identification of causative organism in children is difficult (30,36,39). This is because children do not typically acquire bacterial infections, and instead they are often colonised naturally by the pathogenic bacteria (30). Additionally, the required diagnostic tools are not always readily available in LMICs (32,35,36).

2.2 Quality assurance in radiography

Quality assurance in radiology is an organised effort and commitment to the high performance of radiology equipment and radiology staff in the production of high quality and reproducible diagnostic images at the most economical cost and lowest radiation dose (25,53–55). There are national and international guidelines and standards regulating the approval, operation, quality control (QC) and quality assurance (QA) of radiology equipment (14,25). The South African Department of Health Directorate Radiation Control (SADOH DRC) accepted the International Commission on Radiation Protection (ICRP) guidelines on radiation protection in 2001, and compulsory QC (involving performance testing and calibration of equipment) was instituted in 2009 (23). The patient radiation dose should be as low as reasonably achievable (ALARA), while producing diagnostically accurate

images (1,25,56,57). The diagnostic requirements of an image vary according to the clinical problem that needs to be resolved (1).

Quality assurance programs need to be established and maintained in all diagnostic imaging departments and they should include regular QA and QC audits of the equipment and radiological images produced, as well as quality improvement initiatives (22,23,25,26,58). Radiographers can perform the automatic daily calibrations of equipment through software programs installed on radiology equipment (23,25,26). Further in-depth testing should be performed at stipulated intervals by trained technicians and physicists. Findings of QC testing should be analysed and recorded (23,25,26).

Poor image quality may be as a result of shortcomings in the capability of the radiographers, equipment failures or a culmination of both. The role of diagnostic radiography is to apply the basic principles of radiography to produce images of high diagnostic quality (59–61). It requires the technologist/radiographer to have the technique and experience to consistently perform radiographs that align with established quality standards (25,60). Experienced and dedicated staff is a key factor, as good radiographic technique is the best way to improve quality without the cost of increased dose (3,5,13,62). Quality assurance in unsupervised radiology units (i.e. no paediatric radiologists or paediatric trained radiographers) is often compromised due to personnel, technological and financial shortages (2). Insufficient human resources are a common limiting factor in a LMICs such as South Africa. Research performed in Kwa Zulu Natal, South Africa by Willemse et al. in 2020, revealed that radiographers in South Africa and several developing nations experienced a number of barriers in performing QA and QC, which included the absence of guidance and support from management (23). The radiographers also cited lack of adequate training on QA and QC processes, both during training and while on the job (23). Studies in Ghana, Nigeria and Iran revealed similar experiences, and also indicated shortages in time allocation to perform QA/QC, which were further compounded by shortages of radiographers and medical physicists (23,53,63,64). Lack of financing or budgeting for QA was often cited as a limiting factor to perform adequate QC, due to equipment that was not purchased with maintenance contracts because of the high costs related to

these vendor-specific services (23). The lack of manufacturer-designed digital phantoms (handmade phantoms are often used) to perform QC further compromises QA efforts (23).

2.3 Quality assurance of radiography equipment

Quality control (QC) regarding the diagnostic radiography equipment involves the appropriateness of its selection, acquisition and its correct installation (including acceptance testing and release for clinical use) (53,55,65). Thereafter QA and quality improvement (QI) involve regular assessment of the performance of the equipment along the entire imaging chain. This includes the assessment of the detector, the process of image acquisition, image processing and image display. It also involves assessment of the optimal use of the equipment and the radiation dosage received by the patient (13,23,59,66,67). Digital imaging systems are flexible, enabling optimization of imaging parameters, as well as the easy adjustment of acquisition dose and image quality (14). Digital systems provide options for dose reduction as they offer the option of lower exposure factors (14,68). However, there is a risk of inadvertent patient dose increases, due to the disconnect between image acquisition and visual display, a concept known as dose creep (1,14,19,25,62,69). Similar to film-based radiography, under-exposure in digital radiography results in a grainy image, due to the low signal-to-noise ratio (SNR), however, over-exposed images have a higher SNR producing a better quality image (1). Dose creep occurs when radiographers opt for higher exposure factors that produce a crisp and sharp image, which is preferred by radiologists (1,14,15,19,25,62,68–70).

Several QA and clinical audits are performed in radiography and radiology to identify the baseline. These include a study by Nocum et al. which investigated parameters that could reduce the total dose received by a patient during uterine artery embolization. This study identified that the primary predictor of dose during this procedure was digital subtraction angiography, and dose reduction could be achieved by reducing the number of images acquired, technically improving image

acquisition and decreasing screening time during the procedure (71). Reject analysis of radiographs performed in an Australian emergency department (18) revealed that the most commonly rejected radiographs were of the hip and knee (18). A study by Tsitsiou et al. that reviewed the quality of lateral chest radiographs in children, revealed that most quality errors were related to patient factors of rotation and poor inspiration. The study also created a tool for assessing the quality of lateral chest radiographs, which could prove to be very helpful in LMICs where the diagnosis of pulmonary tuberculosis in paediatric patients is often aided by the identification of lymph nodes, which are often best visualised on the lateral chest radiograph (72). A study by Hlabangana et al. that was performed in a teaching hospital in South Africa, assessed the impact of a radiographer education on the important quality factors of paediatric radiography, the impact of quality errors on image interpretation, and how to technically avoid these errors. The teaching was supplemented by strategically placing posters depicting the most common radiographic errors within the paediatric radiology department. The improvement in the quality of the frontal chest radiographs in the first month after the intervention was statistically significant, but this was not sustained in the subsequent 2 months. The study identified the need for novel interventions for continuous remote QA in LMICs (2).

QA audits would benefit from longitudinal follow-up to review the sustainability of the interventions introduced, based on the lessons learned from the audit (21). These are often referred to as continuous quality improvement (CQI) processes. They are used to address identified areas that need to be improved, planning improvement tests and interventions, assessing the outcomes of these and implementing the lessons learned. This cycle is then continuously repeated until best practice is achieved. A commonly used CQI framework is the Plan-Do-Study-Act (PDSA) cycle. CQI assesses the baseline (where you are) by performing a retrospective analysis followed by a prospective arm for quality improvement (21).

2.4 Reject Analysis

Quality control and quality assurance also involves the analysis of rejected images (24,25,66,67,73,74). Rejection of radiographs is most often performed by the radiographer who has acquired these, based on personal judgement of quality immediately after acquisition (10,16,24,25,75). Rejects and the need for retakes increase the unnecessary radiation dose (10,16,24,25,75) to patients by up to 3 times (16). The most common causes of retakes are due to patient positioning (10,16,18,24,74–76). Other errors are related to incorrect exposure (10,16,18,24,74–76), errors due to patient motion, the presence of artefacts and equipment problems (10,24,75,76). Image rejections occur in 2–15% of digital radiographic examinations (10,16,18,76) compared to an incidence of 10–15% in traditional film-based imaging. The difference is due to the limited dynamic range of film-based techniques resulting in errors in exposure. The American Association of Physicists in Medicine (AAPM) recommends a repeat rate of between 6–10% (74). The reject rate in paediatric imaging should be within the 3–7% range (24). Adopting computed radiography (CR) imaging potentiates improved image quality compared to film-chemical radiographs, due to the ability of the technology to enhance image quality and display (11,13), thus reducing the need for repeat radiographs (11,24,77). Digital imaging has reduced the incidence of exposure errors by 40–60% (16). Often in LMICs and resource-limited settings there is a greater lenience, and tolerance for poor quality imaging is for several reasons including resource and staff shortages, high patient volumes and cost involved in repeat imaging (10). Assessment and reviewing the rejects/retakes is a very good QA tool for identifying competence gaps and highlighting areas for quality improvement, extended education and training (10,18,24,78). According to Waaler and Hofmann (2010), reject analysis is also used for monitoring patient radiation doses (24,78).

2.5 Technical evaluation and quality assurance of the frontal chest radiograph

When performing frontal chest radiography on a paediatric patient, the radiographer needs to consider several factors to obtain a good quality image. There are several books, manuals and guidelines with information on techniques for correct image acquisition (5,79), of which the guidelines published by the Commission of the European Communities in 1996 are the most comprehensive (5,79). Chest radiographs are performed to assess the lung, tracheobronchial tree, cardiovascular system, mediastinal structures, pleura, diaphragms and the bony thorax (7). The challenge of chest radiography is the need to capture the broad attenuation differences between the different densities of the structures of the chest, which includes air, fat, soft tissues and bone (1,7,25), while also demonstrating small contrast differences of fine structures (25). It is therefore necessary for radiography equipment to have a wide dynamic range to demonstrate pathologies positioned within the mediastinum and retrocardiac regions, as well as parenchymal lesion which require high local contrast (1). Furthermore the machines need to provide special high resolution to demonstrate interstitial lung disease (1).

2.5.1 Patient identification and indicators of laterality

Capturing patient information correctly and ensuring correct placement of anatomical markers on the left or right side of the patient to correctly situate features (3,7,25) such as the position of the cardiac apex, aortic knuckle and gastric air-fluid level, are paramount (3,7). It is also imperative that the markers do not obscure important anatomical landmarks (7). The anatomical markers should be placed before taking the radiograph instead of placing or writing them on the radiograph after the exposure. This is important for patient management and protection against medical malpractice (7,25).

2.5.2 Exposure

Correct exposure of a radiograph is vital to ensure that important structures and pathology are well visualised (7,10,25). On an adequately exposed chest radiograph there should be adequate contrast resolution to sufficiently distinguish different structures (25). The upper- and mid-thoracic vertebral bodies and posterior ribs are faintly seen behind the cardiac and mediastinal shadows (5,7,8,10,80). The pulmonary vessels should be well visualised at the hilum, centrally extending to involve the central two-thirds of the lungs (5,7). The pulmonary vessels should be well visualised behind the heart and in the lung bases; beyond this point lung markings are less easily visualised (7). The trachea and the proximal bronchi should be well visualised, as should the paraspinal structures (Figure 2.1) (5).

An under-exposed film looks very white, thus obscuring the visualisation of structures (8,10,25,81), particularly those in front of or behind the mediastinum and heart. Conversely, when a film is overexposed, it appears diffusely dark, and fine structures such as the lung markings are not well visualised (25,81).

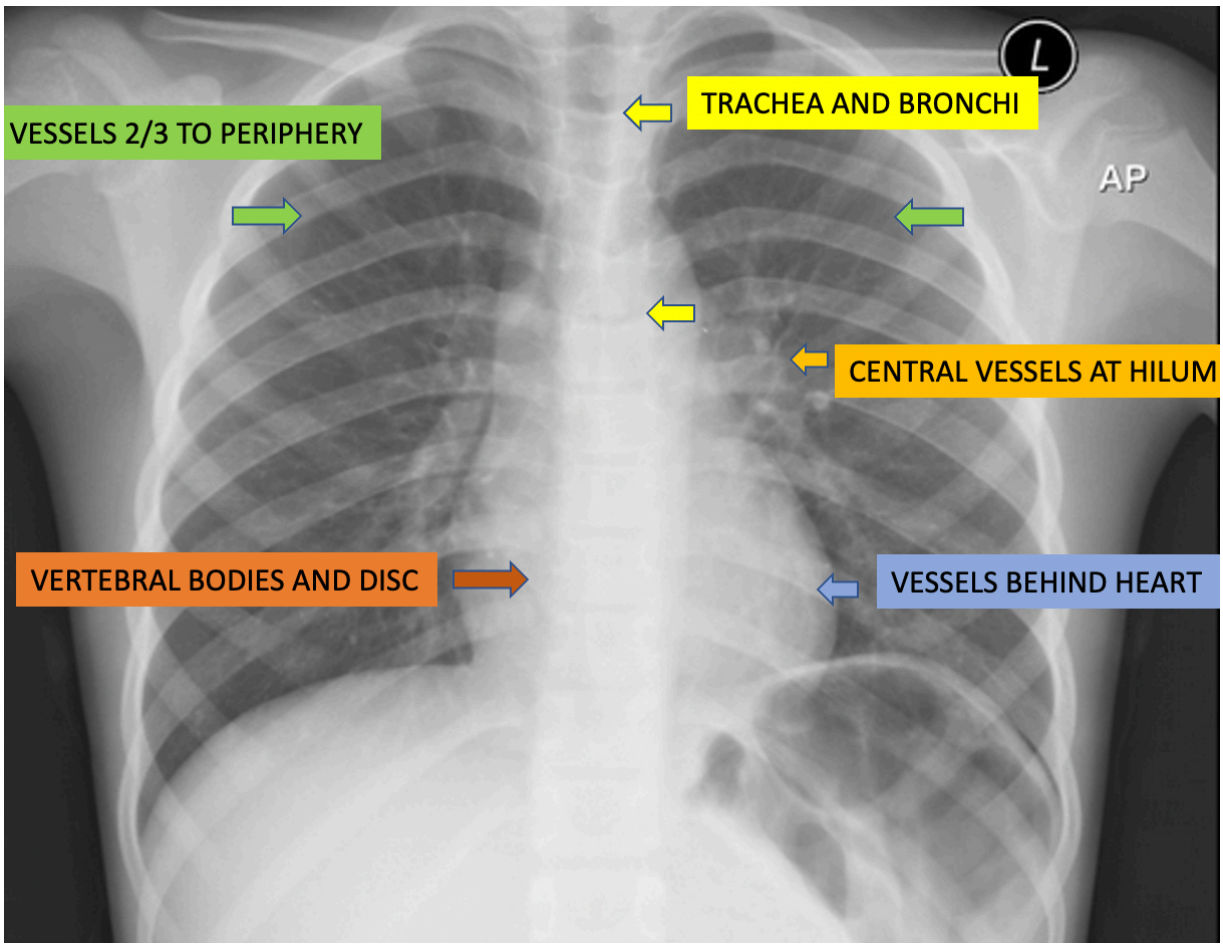


Figure 2. 1 A well-exposed film, clearly showing the central vessels at the hilum (orange arrow) and the vascular pattern involving the central 2 thirds of the lungs (green arrows). The trachea and the proximal bronchi (yellow arrows) are clearly visible, as are the spine and paraspinal structures (bronze arrow). The bronchovascular markings and mediastinum behind the cardiac shadow (blue arrow) are also clearly visible.

2.5.3 Patient positioning and immobilisation

In a correctly positioned frontal projection chest view radiograph taken in the erect or supine position, the thorax should be reproduced with no rotation or tilting of the patient (3,7,10,11). In the case of young children, rotation in the horizontal plane is assessed by measuring the length of the anterior ribs, where asymmetry of the lengths of these ribs indicates patient rotation (5,7,82). In older children (and also adults), it can be assessed by measuring the symmetry of the distance between the medial borders of the clavicles and the thoracic spinous process at the level of the thoracic inlet (Figure 2.2 below) (5,7,82). Rotation in the horizontal plane (towards the left or right side of the patient) results in differential density of the two

hemi-thoraces (5,7), obscuration of lung parenchyma (8), as well as positional misrepresentation of mediastinal structures, both of which affect diagnostic interpretation significantly (5,7,10). Rotation in the vertical (cranio-caudal) plane is assessed by the position and angulation of the clavicles which should normally be positioned horizontally at the level of the thoracic inlet /T1 vertebral body (5,7). Rotation in the vertical plane (patient tilting towards the head or feet) results in **lordotic or kyphotic** positioning of the patient on the film, respectively, thus distorting the anatomy (3). Inadequate positioning also results in the overprojection of the scapulae over the lung fields, resulting in the obscuring lung parenchyma (7,8,10) or simulation of pathology (7). In positioning the patient any overlying objects should be removed from the field of view (lines, tubes, equipment, zippers) as much as possible to avoid the obscuring or normal anatomical structures and pathology (10).

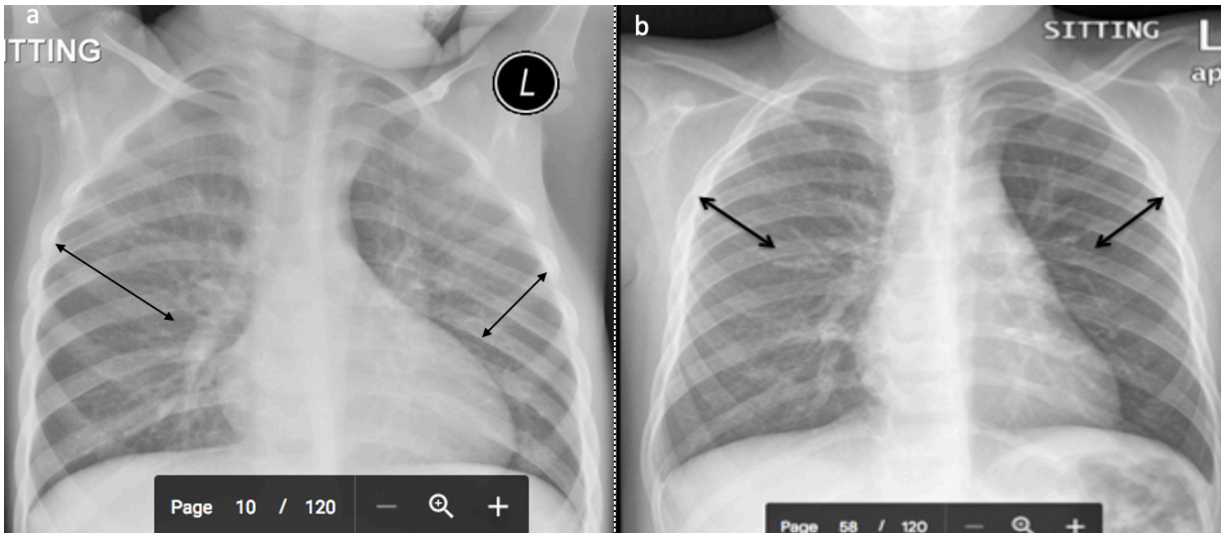


Figure 2. 2 Chest radiograph showing a horizontally rotated radiograph(a) with asymmetrical lengths of the anterior ribs (thin arrows) and a well-positioned (not rotated) radiograph (b) with anterior ribs (thick arrows) of symmetrical lengths.

2.5.4 Lung volume

The chest radiograph should be performed at peak inspiration (5,7) to ensure the lung bases are well visualised (8). Even in adults this may be difficult to achieve, however, this often proves to be more challenging in younger children who may be crying or experiencing dyspnoea (5,81). In the case of adults, the literature

recommends that a minimum of ten posterior ribs need to be visualised above the right hemidiaphragm, whereas in the case of children there are varying opinions with regard to the assessment of inspiration (5). Arthur et al. describe a well-inspired radiograph as one where the diaphragms are projected between the 5th and 7th anterior ribs (82), while Chand et al. state that on an adequately-inspired film one can see at least six anterior and ten posterior ribs above the right hemidiaphragm (80), or eight posterior ribs in children below three years. In children between the ages of 3–7years, nine posterior ribs should be above the right hemidiaphragm (5) (see Figure 2.3 below).

The degree of inspiration on a chest radiograph is paramount in the diagnosis of pathology such as air-trapping, hyperinflation and the identification of volume loss (81). Conversely, an under-inspired radiograph may hide or mimic disease (8,81,82), resulting in the opacification of normal lungs and the enlargement of a normal heart (81,82).

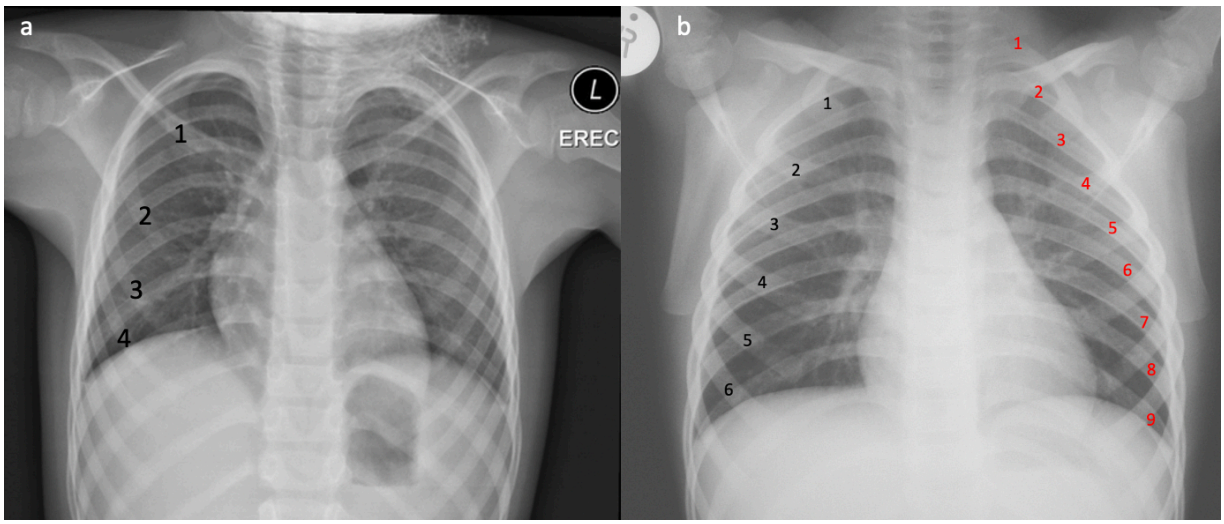


Figure 2. 3 A poorly inspired radiograph with only 4 anterior ribs above the right hemidiaphragm (a). Figure 2.3 (b) demonstrates a well-inspired radiograph showing the right 6th anterior rib and > 8 posterior ribs above the diaphragm.

2.5.5 Field of view

In children, the minimal size of the field for anterio-posterior (AP) and postero-anterior (PA) projection radiographs should extend from just superior to the apex

of the lung to the level of the T12/L1 vertebral bodies, or to just below the level of the costophrenic angles with a 20 mm tolerance level at each end (5,7,79). The costophrenic angles and hemidiaphragms should be sharp and clearly visible (5,7). Laterally, the soft tissues just outside the thoracic cage (1–2 cm) should be included, although this has not been specifically described (see Figure 2.4 below) (5). Collimation restricts the field size to only include the region of anatomical interest (2,5,10,11,25). This requires accurate patient positioning and restricted patient motion (2,5,11,25). This is often a challenge, particularly with children (2,5,11,83), as the total area of a child is small, thus the tolerable variation in radiation area is also reduced.

Accurate collimation helps to reduce unnecessary irradiation by reducing the amount of scatter radiation. Scatter radiation decreases the SNR, resulting in poor image contrast and resolution (5,11,17,20,84). Over- collimation can potentially exclude important anatomical structures (5). The most frequently reported radiographic error is inadequate collimation (2).



Figure 2. 4 Well-collimated chest radiograph with minimal imaging of unnecessary structures outside the maximum field of view (yellow rectangle).

2.6 Conclusion

Quality assurance is essential to ensure high image quality, which reinforces radiation protection (85). It involves regular quality control testing of the equipment and quality assurance of the radiographic images provided. An adequate chest radiograph should be taken with adequate exposure factors, correct patient positioning and good inspiratory effort by the patient to enable correct identification and visualisation of both normal anatomical structures and pathology. The radiographers should ensure that the correct siting markers have been used and that there are no structures on the patient that could obscure any part of the radiograph. Radiographers are responsible for ensuring good image quality during and after image acquisition. Radiologists assess image quality prior to

interpretation of the radiograph to ensure diagnostic accuracy and to assess the need for repeat or additional imaging. In the ideal setting, it is recommended that QC and QA should be performed at regular intervals which can be daily or on continuous basis depending on the specific test performed, as this will result in the reduction of the radiation dose to both patients and radiographers (3,23). With limited expert staff in paediatric imaging, LMICs need to innovate to develop affordable, simple and sustainable strategies that can be introduced across a variety of service level platforms to maintain or improve image quality. Quality improvement initiatives can be used effectively to improve performance, and to achieve high standards of patient care in the health sector, and more specifically in radiography (86).

2.7 Social media

Defining what social media are is challenging as the definition is broad and constantly changing (87,88). Social media are Web 2.0-based Internet applications that have changed how people interact online and with other users (87–92). They are user-centric platforms and virtual spaces where individuals, companies and organisations can easily and quickly participate and collaborate in creating and sharing content (88,93–97). User-specific profiles are easily generated on social media platforms and these facilitate the creation of links with different platforms to create diverse virtual social networks that can extend all over the world (88,95–97). Social media are widely available, cost-effective and relatively easily accessible tools for user-generated communication and dissemination of information (93,96,98–100). They are effective in bridging knowledge and distance gaps (98). The advances in mobile and tablet technology, the improved connectivity of cell phones and the increased access to the Internet have assisted and facilitated the exponential use of social media (89).

2.7.1 Uses of Social media in healthcare

2.7.1.1 Health communication and education programmes

Organisation involved with public health have conventionally used printed media, radio broadcasting and social marketing structures to disseminate health information to healthcare providers and the general public. Mobile phone (device) technology is increasingly being used worldwide to improve access to health (101–109), as well as increasing the efficiency and reach of healthcare workers – this is often referred to as mHealth (101–105,107). Such services include telemedicine, email or telephone based consultations, text messages, the monitoring of devices remotely (110), mobile apps which can have diagnostic, self-monitoring, disease modification and educational applications (107). The challenge with mHealth initiatives is the paucity of research that assess the efficacy in achieving the desired outcomes in both acute and chronic settings, and the utility of these apps in different population groups (107–109).

Progressively, over the past few decades, electronic media have increasingly been used for communication (98,105) and have changed the patterns of communication worldwide (96,111). They have also influenced communication strategies in health, which are evolving to take advantage of the social media revolution (92,98,112,113). Tools harnessing the power of information and communications technology (ICT) can often be the silver lining to tackling and improving healthcare delivery (92,104,107,108). The increase in mobile phone penetration and the growth in the reach and coverage of mobile networks make them the modality of choice creating a ready platform to ameliorate, overcome and address challenges. These include the rural-urban divide, lack of infrastructure, staff shortages, barriers to communication and access of information and healthcare (102,104–106,110,114,115) that are frequently encountered in LMICs such as South Africa. The extensive engagement with social media by the public creates opportunity and a ready platform for its utilisation in health (104,116,117) – to improve access and affordability (110). The Web has facilitated a culture of collectivism, reciprocity and a respectful, noncompetitive environment (89,117). Cell phones enable the connection to Web 2.0 sites which facilitate clinician-to-patient, organisation-to-patient and patient-to-patient (100) interaction via social

networking services (91,118,119). Clinician-to-patient interaction includes monitoring patient response and adherence to treatment plans, online consultations and patient education. Organisations are able to quickly and easily disseminate information to patients and patients are able to form support groups to assist in their disease journey (105).

The first reports of mHealth were in 2009 and included programs that encouraged individuals to stop smoking (120). In 2011 and 2012 chat groups on Twitter were created to support and provide information on breast cancer and brain tumours, respectively (121). Since then, Twitter and other social media have increasingly used disease-specific hashtags, which are user-generated tags that assist with information and content aggregation to facilitate patient and clinician participation in relevant online conversations and groups (100,121) There have been programs that have used social media and mobile devices for health initiatives to encourage compliance for the management of acute illness such as malaria (115) and chronic illnesses management (e.g. diabetes, hypertension, cardiovascular disease, cancer and HIV) (100,102,110). Initiatives have supported pregnant women and the elderly, as well as extending services to resource-limited environments (102,110). In China several doctors in rural areas are able to access medical records and treatment data bases on mobile devices; in India telemedicine on mobile devices enables the remote diagnosis and treatment of patients in the comfort of their homes. In Malawi rural health workers were able to text routine symptoms onto a software application developed by Medic mobile which provided a diagnosis and suggested possible treatment options (110). In 2014, a program in South Africa used timed SMS messages to provide support and reduce anxiety to women who were having home-based abortions (122). Since then further studies have used SMS communication for patient support and communication and to improve access in the primary healthcare, reproductive and mental health space (102,123,124), as well as managing the referral patterns of burn patients from rural communities (101). In 2015 further research on social media use in breast cancer patient support and education demonstrated good uptake and appreciation by patients (125). In 2017 a study by Ippoliti et al demonstrated that use of social media on mobile phones for sexual and reproductive health (SRH) education programmes for youth in LMICs was gaining traction (126). The study showed that

the use of mobile phones was efficient and cost-effective, ensuring discretion and privacy (except in cases of shared phones) and overcoming several access barriers in these countries (126). Social media have also been used to recruit patients for clinical trials and online studies, as well as for public surveillance and the tracking and mapping of diseases, epidemics and breakouts (87,110,112,113). A study in Kwa Zulu Natal, South Africa in 2019 demonstrated the potential of mHealth-directed HIV testing, education and care (127). The Covid-19 pandemic in 2019–2020 demonstrated the world-wide use of mHealth and social media to provide live, actionable coverage of the pandemic, as well as to educate, track, notify, identify trends and hotspots and unify efforts to control the spread of the virus (128,129). Concerns on responsible data collection, data protection and privacy were some of the ethical issues raised during the pandemic (129,130). Data collection needed to be scientifically justified and confined to what was necessary for the public health objectives (129,130). Accessing data from mobile devices for contact tracing – to warn people of possible contact and to advise self-isolation was justifiable, because of the potential to save lives and the immense suffering that could be reduced. It had to take place under strict guidelines and restrictions, while ensuring data protection and privacy (129,130) as such practices could result in public mistrust (129).

Alsobayel et al. and Desai et al. state that social media have been used successfully in creating social change (113,131). The impact of social media on social change has been shown in countries such as Tunisia and Egypt where social media was a powerful journalistic tool during the Arab spring of 2010 (132,133), empowering previously marginalised communities and sections of the population including women and the youth (132). We have seen the coercive power of social media in the presidential campaigns of Barak Obama in 2008 where social media was used to mobilise the youth (132,133). Donald Trump's campaign in 2016 maximised the advertising and analytical powers of Facebook to help drive messaging (133,134). However, despite being easily adaptable to local needs (101), the effectiveness and cost-saving aspects of such interventions in health are not always easy to quantify (105,135). In a systematic review by Marcolini et al. and research by Hamsphire et al., mHealth was found to be most successful in initiatives that addressed chronic diseases (105,109) with

improvements related to compliance, clinical outcomes and behaviour change (105,109,132). More recently we observed the use of social media and its effectiveness in communication, health education, creating awareness and modification of behaviour during the COVID-19 pandemic (131,135). Social media, at this time, was also shown to be an effective medium for spreading propaganda and incorrect information on the virus (91,131,134,136).

The continued and proactive development of research-based guidelines to ensure best practice for the use of social media in health is crucial (91,92,98,106,120,137). Continuous training and support for medical personnel is important to ensure its ethical, effective and impactful use (91).

2.7.1.2 Professional education

Health organisations and higher education institutions are still using mostly the traditional educational and communication platforms, but there is a rapid (100) move towards capitalising on the educational affordances of social media (99,138–141). Enabling users to share information and resources relating to professional practice (87,91,92,96,113,140,141) and research (92). Participants are able to request and offer assistance and advice to others in similar fields (91,137,141).

2.7.1.3 Professional networking

Social media are valuable resources that have created platforms for healthcare workers to join online professional communities where networking (91,92,96,113,141,142), self and organisational promotion can increase visibility, products and services (87,96,112).

2.7.2 Social media in radiology

Social media has in the past decade offered valuable and creative support to radiologists and physicians for medical education (87,96,100,119,143). This has taken on several forms including online resources for teaching and training, as well as self-directed learning (87,100,118,141) such as Radiopedia.org. The social media platforms which can be opened on smart phones, tablets, laptops and

desktops enable access to journal articles, interesting radiological cases, various tools that assist with daily radiological practice (e.g. calculators) and facilitate registration for courses and congresses (87,118) (e.g. https://www.rsna.org/ and https://radiologyassistant.nl/).

Social media offer unequalled opportunities for professional development (100,142), facilitate networking for employment, interact with other radiologists and clinicians for clinical and research purposes as well as connecting with patients (90,91,96). A survey of 577 radiologists from all over the world (58% were from Europe, 27% North America, 8% South America, 4% Asia and 3% from Africa) revealed that Twitter and LinkedIn (www.linkedin.com) were preferred platforms for professional networking while Facebook was mostly for general purposes (118,144). A study by Guerra et al. surveyed 285 respondents from 35 countries. The results revealed that the top 3 platforms from professional interaction were LinkedIn (60.8%), Twitter (55.1%) and Facebook (49.5%). Online interactions with clinicians has improved relationships and reintegrated the radiologist into the medical team (90).

The use of social media in radiology professional meetings has grown, demonstrating the developing trend of its use as a teaching tool (100,145,146). Future growth is expected as most users of social networks are radiology trainees/registrars (147). Many radiological societies such as the Radiological Society of North America (RSNA) (https://www.rsna.org/), the American Roentgen Ray Society (ARRS) (https://www.arrs.org/), the American College of Radiology (ACR) (https://www.acr.org/) and Radiological Society of South Africa (RSSA) (http://rssa.co.za/) provide access to education and training resources through social media. These societies also facilitate the sharing of information, ideas and comments on their websites, which has increased connectivity and interaction among radiologists and other specialists (87). The most favoured platform for education on social media for radiologists is the Radiopaedia Facebook page (https://www.facebook.com/Radiopaedia.org/) (144). Most of these portals have links to social networking platforms such as Twitter (119,143) and Facebook (119). The ability to embed links, images and videos within tweets makes Twitter an ideal education delivery tool (144). Crowd-sourcing and discussing challenging, rare or

interesting cases via a video chat (Skype, Apple Facetime) are helpful in obtaining input from 'radiology greats' or experts in a particular field, in real time thereby assisting in collaborative image interpretation and quicker report formulation (87,119). Examples include the RSNA Diagnosis Live (https://live.rsna.org) (66), Radiolopolis (http://radiolopolis.com) and RadRounds (www.radrounds.com) all three of which are online communities that enable communication between members, as well as providing a network platform and educational material such as lectures and cases (90). There are several ethical considerations that one needs to be aware of such as ensuring the protection of individual patient information by anonymising patient information and obtaining prior consent from patients presented in these forums is good ethical practice (96). Avoiding copyright infringement, ensuring that content shared is litigation averse, and not compromising individual careers are paramount (96). It is important for institutions to educate users, provide guidelines and teach professional online etiquette (100).

Video chat platforms can also be used to create virtual seminars for research sharing and collaboration (145), as well as online micro-lessons similar to those from the Khan Academy (https://www.khanacademy.org) (99). Another online research platform is ResearchGate (www.researchgate.net) which has created a forum for mutually beneficial collaboration and networking in research (90,96), as well as enabling recognition as an expert in a specific field (96). Twitter has been shown to enrich the learning environment and improve educational experience of attendees at conferences by using conference hashtags (144,145), for example, #RSNA14, #JACR. Such hashtags facilitate the sharing of information on lectures and other activities. They also enable people not attending the conference to follow and contribute to the conversation (144,145). Microblogging has the potential to create collaborative learning environments while enhancing the presented content (119,143).

Online- and cloud-based sharing of DICOM images is possible on applications such as Dropbox. However, patient data confidentiality needs to be maintained (119). Figure 1 (http://www.figure1.com), is one of several new platforms that enable the safe sharing of images while maintaining patient confidentiality. Such

platforms will potentially improve collaborative teaching internationally, however, many of these platforms are still largely unknown (144).

Social media and online media in radiology have also been used to increase patient awareness with physician-to-patient communication. In 2015 Twitter was used successfully to inform patients of the need to remove inferior vena cava filters (IVCFs) (148). Twitter and Facebook have also been used as branding and marketing tools to promote radiology department services, expertise, lectures and activities (96,99). These promotional activities assist patients in finding the best physicians as more and more patients are taking it upon themselves to select specialist care rather than relying on traditional referral processes (100,148). This has increased patient-to-physician contact and resulted in customer growth that may not have happened if not for social media (90,100,121,148).

Further investigation is required into the use of social media in radiology (143) and radiologists need to look into leveraging off social media to maximally incorporate it into everyday practice (119).

2.7.3 Benefits and advantages of social media

With the rise of Web 2.0, social networking sites have become increasingly popular (149) and these sites have also infiltrated the medical arena both at the undergraduate and postgraduate levels (139). Students are spending a lot of time on social media (5,142,150) and medical educators and health promoters are increasingly using social networking platforms to share content (91,142,151). Web-based tools can overcome geographic and time-related barriers (117,126,139,152). Studies have shown that social media have been adopted across socio-demographic groups (116), they have been socially accepted and they are firmly established across different racial, cultural and age groups (139,153). Flexibility of access and use (116) on several mobile devices including tablets, smart phones and laptops (99,151), as well as the ability to choose which platform to engage with on specific sites (e.g. options to engage on Facebook, Twitter, Instagram or email are often choices given on websites), allows

customization to fit the need (139). Social media facilitate real time or time-lagged two-way communication outside of the classroom and work place, they enable connection with medical experts and facilitate collaborative opportunities (151). Social media have proven to be affordable (116), effective and efficient communication tools (98), sharing and rapidly disseminating information (98,151,154). When used properly they are time and resource efficient (98).

Emerging technologies like social media have facilitated good models of learning, which encourage global collaboration, sharing and active participation in the co-creation and co-construction of knowledge (91,120,138,139,149,151,155,156).

Social media networks have also enabled participants to enhance and take ownership of the learning process, empowering them to co-create and contribute to online conversations (97,119,151), and to intentionally enhance knowledge and practice (137,138). This type of learning environment fosters a more effective flow of knowledge and support (97,139).

2.7.4 Challenges in using social media

Despite the great potential for health promotion and education, careful application of social media are required to ensure that the desired outcomes are achieved (116), which may be related to study design and affected by socioeconomic factors. The findings on the effectiveness and success of an mHealth initiative for non-communicable diseases in Sub-Saharan Africa were inconclusive, due to a lack of differences in the outcomes with control groups not involved in the mHealth initiatives; the absence of control groups in several studies; the lack of comparisons with or the reporting on long term results; and the lack of clearly defined clinical outcomes (102,157). Low- and middle income communities in Africa, Eurasia and Latin America use mobile phone programs to ensure ease of access and privacy, which are important for the youth, however, the factor of shared phones in some families compromised participant access and privacy (126).

Questions related to the violation of patient confidentiality, ethics and governance, the risks related to the distortion and mixing of personal and professional information, as well as licensing, conflict of interest and legal issues, need to be addressed and answered (87,89,91,92,100,110,112,118,140,142,144,145) at both individual and institutional levels (90). Information integrity, quality control and the posting of inferior quality and unreliable information is a problem that is difficult to manage (131,146). The creation of two separate identities for personal and professional use (90,91,142) and limiting interactions on social media to secure platforms such as LinkedIn, or those specifically related to physicians or radiology, might assist in separating personal and professional information (90,91). Use of sites with extensive security settings where users can limit access to the viewing of personal profiles are preferable (90).

Challenges such as computer literacy and uneven access are real issues (90,120,149,158–160) that are faced in several LMICs and in South Africa. Another barrier used for educational purposes by public health include the lack of or paucity of access to the Internet in rural and remote areas (90,116,126,158,160). Due to resource limitations, information technology (IT) skills are often not taught in the majority of low- and middle-income schools or communities, resulting in high levels of computer illiteracy for both students and teachers (159,160). Informal employment rarely involves the use of computers, resulting in further alienation (161).

There are several challenges to overcome when innovating a program for QA promotion, education and communication using social media (116). Measurement metrics are limited with challenges experienced in measuring the desired impact of an intervention, such as the increase and retention of knowledge and its application (99,116). It is difficult to determine whether participants are 'just stopping by' a site or actually meaningfully engaging with content as intended (100,116). Published research and the understanding of the available metrics to assess user engagement has increased since 2018 (162). The effectiveness of education programmes on social media are measured by the number of users who have either only viewed content (i.e. number of impressions) and those who have engaged with the content by either commenting, liking and sharing it, as well as

clicking on associated links (99). Engagement is a stronger indicator for success, as it requires more interaction by the user (99,162). There may also be a blurring of boundaries between education and social activities engendered by the use of social media platforms (155).

In several countries another barrier to engagement is lack of reimbursement for mHealth and social media-based services by medical health insurance providers (110). Furthermore, policies and guidelines to use social media in health without compromising professional reputation or the patient are lacking. The possibility of medicolegal repercussions and damage to one's reputation adds to the reluctance of healthcare professionals to interact directly with patients on social media (91,144). Another drawback to social media is that healthcare workers perceive a shortage of time to interact on these platforms (94,144) during working hours.

2.7.5 Public engagement with the Internet in South Africa in context

South Africa is one of the most technologically developed countries on the Continent (163) and has demonstrated an exponential increase of mobile phone connectivity and penetration (i.e. the number of mobile numbers and sim cards in use) over the past 10–20 years (111,163–169). In 2015 South Africa had the third highest average mobile penetration in Africa with an 85.94 index – out of every 100 individuals in the country 86 had cell phones. The first and second highest mobile penetration were Libya and Mauritius which had a 91.61 index and 87.30 index, respectively (168). It is estimated that over 97% of households have access to a mobile phone (170), however, in 2018 most people in South Africa did not have access to smart phones (165,171), i.e. phones that have access to several apps and connect with the Internet. In 2012 six million South Africans (approximately 12% of the population) had access to the Internet on personal phones, of these 39% were urban users and 27% were rural users (165). By 2018 this had grown to 40% (171), and as predicted this has significantly increased (169,171,172) with reports of 74 –79 % of the population having Internet access on mobile phones in 2023–24 (169,173). It is predicted that Internet access on mobile phones will reach 98% penetration by 2029 (174). In 2013 a report by

Statista in 2024 also revealed that just over 42% of the population used social media (173). However, despite these advances, there continues to be a significant decrease in the number of information and communications technology (ICT) ownership, access and use, (111,158,164,170). This is due to inequality caused by racial, socioeconomic and geographical divides (158,164,166). Over 90% of families do not have a working landline in their homes (106,111,169) because of ITC infrastructure inequality and increased mobile phone access (169).

The availability of low cost of SIM cards, cheap handsets and prepaid subscriptions have helped bridge the rural–urban gap and enabled price-sensitive, resource-limited users to digitally communicate and access information (164,167,175).

The mobile industry in Africa and LMICs have enabled and fostered the growth of economic development (106,109,164,166,168) in the educational, agricultural, banking and healthcare space (106,164,166,168). Other characteristics, not unique to the South African digital landscape, include problems with language (South Africa has 11 official languages) and education and literacy, as most social networking platforms provide content in English only (114,164).

2.8 Summary

Quality assurance (QA) in paediatric chest radiography is important for diagnosis, and good radiographic technique is the cornerstone to achieve this (5,24). The role of social media in programs and initiatives related to public health was relatively new and not well-documented in 2014 when the study was performed, (98,151), however, this has significantly changed since the COVID-19 pandemic in 2020 (91,176). Social media have contributed considerably to increase access to healthcare and information through the removal of geophysical limits (98) and the ability to provide an increasing scope for collaboration and connectedness (97,98). There has, however, been very low adoption in healthcare in LMICs such as South Africa, with paucity of literature assessing the extent, depth and sustainability

outcomes of mHealth initiatives (98,104,105,107,109). There is a great need for the creation of policies and guidelines that will benefit and protect patients, healthcare workers and the health industry (91,92,112). We hope to set a precedent in combining QA and social media in this QI initiative and uncover how to practically use social media as a tool in the health sector.

2.9 Aim of the study

The aim of the study was to evaluate the improvement in the quality of chest radiographs performed on children after implementing interventions to improve radiographic quality in 3 geographically distant radiology departments, each with different resources (personnel and equipment), using the internet and 2 social media platforms (i.e. Facebook and Twitter).

2.10 Objectives of the study

- To do QA analysis using a prescribed tick sheet on paediatric chest radiographs in 3 different centres with varying resource-related levels of radiographic service, before and after a number of interventions using social media.
- To compare the QA scores of the radiographs reviewed from the 3 participating radiology departments at baseline – that is before any interventions – and after initiating a series of QI interventions using various social networks.

2.11 Conclusion

This chapter reviewed literature. The literature provided insight into the importance of quality assurance with specific focus on paediatric chest radiography, the

potential power of social media, its current use in medicine and radiology, as well as the challenges related to its use as a teaching and educational tool in South Africa.

CHAPTER 3: Methods

3.1 Study design

A longitudinal, descriptive study comprising of a retrospective phase (before intervention) and a prospective phase was performed at three radiological departments in South Africa. The three centres each had different levels of radiographic staff expertise, i.e. those who had only received training in general radiography and those who had been specifically trained in paediatric radiography after qualifying as radiographers. The radiologists at the centres also had varying levels of paediatric radiology exposure and expertise (Table 3.1).

3.2 Study setting

The study took place at three different hospitals, namely Chris Hani Baragwanath Academic Hospital (CHBAH), a central hospital (level 3) and Rahima Moosa Mother and Child Hospital (RMMCH), which is a regional hospital (level 2) which functions more as a tertiary hospital, both are located in Johannesburg, in the Gauteng Province, and Khayelitsha Hospital (KH) which is a district hospital (level 1) located in the city of Cape Town, in the Western Cape Province of South Africa. In 2014 when the study was performed, very few public hospitals had a functioning picture archiving system (PACS). The above three hospitals were primarily selected, because all 3 of them had a PACS system to facilitate collections of chest radiographs.

The next criterion that was used to select these hospitals was to identify hospitals that fell into the different classification levels: level 1, 2 and 3.

South Africa has 4 categories of hospitals commonly referred to as district, regional, tertiary and central hospitals (177). The Government has moved to a new classification, using the names level 1, 2, 3 and 4 hospitals, each providing a

different level of service and care (177). Table 3.1 summarises the different characteristics and services provided by each of the different level hospitals.

Table 3. 1 Summary of the characteristics of the different levels of hospitals in South Africa

Level Hospital	District Hospital (Level 1)	Regional Hospital (Level 2)	Tertiary Hospital (Level 3)	Central Hospital (Level 4)
Number of beds	50-600	200-800	400-800	Maximum 1200
GP Services/Clinical nurse practitioners	Yes	Yes	Yes Specialised nursing	Yes Specialised nursing
Intensive care services	No	Short-term ventilation in a critical care unit	ICU supervised by a specialist or specialist intensivist	ICU supervised by a specialist or specialist intensivist
Affiliation to Teaching Hospitals	Possibly	Yes	Yes	Yes
Basic services	PHC	Paediatrics	Paediatrics, Anaesthesia	Paediatrics, Anaesthesia
	In-patient, ambulatory health services	Obstetrics and Gynaecology	Obstetrics and Gynaecology, Diagnostic radiology	Obstetrics and Gynaecology, Diagnostic radiology
	Emergency health services	Internal Medicine	Internal Medicine, Psychiatry	Internal Medicine, Psychiatry
		General Surgery	General Surgery, Emergency department, Orthopedic Surgery	General Surgery, Emergency department, Orthopedic Surgery
Specialist services	Paediatrics	Anaesthesia	Plastic Surgery, Neurology, Neurosurgery, Urology, maxilla-facial surgery, Cardiology, Paediatric Surgery	Highly specialised and expensive services e.g. transplant units. Requires scarce skills and super specialised staff
	Obstetrics and Gynaecology	Orthopedic Surgery		
	Family Practitioner	Psychiatry		
	Internal medicine	Diagnostic Radiology		
	General Surgery	Emergency and Trauma		
		ICU short-term ventilation		
Referrals/Outreach	Local clinics Community health centres	Provincial boundary limited referral drainage District hospitals	Regional hospitals - no provincial boundaries	Regional and national referrals
Supported by	NGOs General specialists from regional hospitals provide outreach and support	Tertiary Hospitals	Central Hospitals	Linked to a Medical School. Refers to super-specialised national referral units
Training for healthcare providers	Where practical	Where practical	Yes	Yes
Conduct Research	No	No	Yes	Yes - Innovation and research

(178,179)

District hospital (Level 1)

District hospitals are the first level of referral from primary healthcare clinics. These are operational every day (24 hours) of the week and provide a variety of in- and outpatient services. District hospitals have between 30–200 beds and also offer a 24–hour emergency service. It provides basic services – diagnostic and therapeutic – including baseline laboratory tests and plain radiography that (provided by radiographers) are available. An operating theatre is also available at a Level 1 hospital (177). Characteristically the medical staffing is at a generalist level (Medical Officer), thus there are no discipline specialists.

Khayelitsha Hospital is a 230 bed district hospital situated in the Khayelitsha District in Cape Town (167,180). It services a growing population of approximately 500 000 (181) which comprises some of the poorest people in the region. The average monthly income for a family of five in 2011 was $110 (167). Population unemployment rates are high and the community is plagued by the quadruple burden of disease which includes hypertension, diabetes, tuberculosis and HIV (181). The hospital was opened in 2012 and provides 24-hour emergency/casualty services and it has medical, surgical, maternity, gyneacological and paediatric wards. As a district Hospital, Kayelitsha Hospital's services are directly linked with, and fully support primary healthcare initiatives in the region (182), which include diagnostic and treatment care, counselling and rehabilitative services (182). Doctors and nurse practitioners provide most of the services (183). In 2014 the radiology department was staffed by eleven radiographers which included two senior and four junior and five community service radiographers. There were no qualified radiologists (184), and none of the radiography staff have had received training (formal and informal) for a paediatric radiology post qualification. The radiological studies that should be provided at a district level include plain film imaging of the body (e.g. limbs, abdomen and chest), basic contrast studies, including a barium meal or enema and basic ultrasound services (182).

Regional hospital (Level 2)

Regional hospitals provide a level of care that is supported by the services rendered by general practitioners and medical specialists. Level 2 hospitals have permanent specialist staff "in at least five of the following eight basic specialties: surgery, medicine, orthopaedics, paediatrics, obstetrics and gynaecology, psychiatry, diagnostic radiology and anaesthetics" (177).

Rahima Moosa Mother and Child Hospital is classified as a regional (level 2) hospital. It is a child and obstetric specialist hospital and has developed subspecialties within paediatrics, neonatal and maternity care. The hospital has 146 beds and was opened in 1944. It was initially intended to serve the Coloured (mixed race) and Indian (South Asian) communities of Newclare, Noordgesig and Coronationville (185). The population in these regions are in the low income bracket and unemployment is also high. Rahima Moosa Mother and Child Hospital is a teaching hospital affiliated to the University of the Witwatersrand School of Health Sciences. The hospital had three qualified radiologists as well as a paediatric radiologist at the time of the study, and all of the radiographers had received informal training for a paediatric imaging post qualification.

Tertiary hospital (Level 3)

"A Level 3 facility provides specialist and sub-specialist care. These hospitals receive patients from, and provide sub-specialist support to, a number of regional hospitals" (177,183).

Central hospital (Level 4)

Central hospitals are the highest level of health care. These hospitals receive patients from tertiary hospitals. They offer multi-speciality clinical services and are a rich environment for innovation and research (178,179).

Chris Hani Baragwanath Academic Hospital, South Africa's largest hospital, has approximately 1800 beds and employs over 6000 staff members. In June 2014 the radiology department had 14 qualified radiologists, one of which had an interest in paediatric radiology, but had no subspecialist training. The paediatric trained

radiologist had left in 2013 to pursue a PhD full time. In August of 2014, the beginning of phase 3 of the study, a radiology consultant who had an interest in paediatric radiology (and later went on to do a fellowship in paediatric radiology the following year), was assigned to oversee the paediatric radiology unit and was assigned to work in the paediatric radiology department 2–3 days of the week. One of the 66 radiographers had informal training in paediatric radiography. CHBAH is a teaching hospital affiliated to the School of Health Sciences at the University of the Witwatersrand.

In 2014 the Diploma in Diagnostic Radiography was a 3-year course. A fourth year could be added to convert the diploma into a degree. Currently in 2024 only a Bachelor in Diagnostic Radiography is available which is a 4-year course (186). Thereafter all qualified radiographers are required to do a year of compulsory service to the South African Department of Health, which is called community service. A junior radiographer is radiographer who has up to three years of experience including the community service year. They are expected to be able to perform basic radiography, fluoroscopy and computed tomography (CT). A senior radiographer is required to have at least 3 years of experience. They are expected to be proficient in basic radiography as well as quality control (QC) and quality assurance (QA).

The staffing complement of each of the different hospitals are summarised in Tables 3.2–3.5 below. The identities of the individual radiographers who performed the radiographs were kept anonymous. The radiographers at RMMCH and KH remained consistent during the 3 phases of the study. At CHBAH there were two radiographers who worked consistently throughout the duration of the study, however, 2–3 student radiographers rotated through the department on a monthly basis. The purpose of the research was to review the overall image quality of paediatric radiographs at each centre.

Table 3. 2 Total number of radiographers at each radiology department (In June 2014)

Radiology Department	Number of radiographers	Number of Student radiographers
Chris Hani Baragwanath Academic Hospital	66	30
Rahima Moosa Mother and Child Hospital	13	6
Khayelitsha Hospital	11	0
Total	90	36

Table 3. 3 Information provided on the radiographers at Chris Hani Baragwanath (CHBAH) Academic Hospital (no staff demographics or years of experience were made available)

CHBAH Radiographers (66) with rank	
Community service	3
Grade 1 Diagnostic radiographers	26
Grade 2 Diagnostic radiographers	5
Grade 3 Diagnostic radiographers	1
Chief radiographers	28
Assistant directors	2
Deputy director	1
TOTAL	**66**

Key: CHBAH = Chris Hani Baragwanath Academic Hospital

The Head of Radiography declined to provide further demographic information on the radiographers at CHBAH as they believed this would be a violation of the Protection of Personal Information Act (POPIA).

Table 3. 4 Demographics and years of experience of the radiographers at RMMCH

RMMCH Radiographers (13)		
Gender	Female	13
	Male	0
Age range (years)		19.9–63.8
Mean age (years)		29.9
Range of years of experience		0.5– 41.3
Mean years of experience		11.6

Key: RMMCH = Rahima Moosa Mother and Child Hospital

Table 3. 5 Demographics and years of experience of the radiographers at Khayelitsha Hospital (KH)

KH Radiographers (11)		
Gender	Female	10
	Male	1
Age range (years)		23.5–35.8
Mean age (years)		28.20
Range of years of experience		0.5–14.5
Mean years of experience		3.9

Key: KH = Khayelitsha Hospital

Each of the three radiology departments chosen to participate in the study had different hospital classifications, service delivery demands, equipment and human resources. Table 3.6 below provides a summary of the hospital classification of each site and the different imaging modalities available and the average number of imaging studies/procedures performed each month at the different centres. The purpose of providing this information is to contextualise the workload and service demands at each centre. Specific information on workload per radiographer and the ratio of paediatric to adult radiography was not available. Table 3.7 demonstrates the types of equipment used to perform paediatric chest radiographs at each hospital.

Table 3. 1 Summary of the average number of studies performed per month according to modality for the 3 different hospital centres

	CHBAH Tertiary (Level 3) 2800 Beds	RMMCH Regional (Level 2)* 146 Beds	KH District (Level1) 300 Beds
Plain Film **(excluding mobile and theatre radiographs)**	15000	648	2650
Fluoroscopy	510	36	12
Ultrasound	3000	93	935**
CT	3000	169	Not available
MRI	340	Not available	Not available
Vascular intervention	100	-	-
Body intervention	500	-	-
Mammography	400	-	-
DXA scans	180	37	-

- *Although RMMCH is classified by the Health Department as level 2, it is a child and obstetric specialist hospital, thus it has developed subspecialties within paediatrics.
- ** Ultrasounds at KH were performed by independently employed sonographers
- CHBAH = Chris Hani Baragwanath Academic Hospital
- RMMCH = Rahima Moosa Mother and Child Hospital
- KH = Khayelitsha Hospital
- CT-Computed Tomography
- MRI- Magnetic resonance imaging
- DXA- Bone density scan

Table 3. 2 Equipment used to perform paediatric radiographs at each of the hospitals

Make of Equipment	Type of Modality	Installation Date	Serial Number
Equipment at CHBAH			
Stephanix N65FDigital Bucky	Paediatric Bucky Room 1	2010	858/202
Shimadzu	Paediatric Bucky Room 2	2012	858/206
Equipment at RMMCH			
Second Opinion Systems - Stephanix	Digital Bucky Unit	2012	G-40600
AXIM – Shimadzu - Radspeed	Chest Unit	2006	UD 150L-40E
Equipment at KH			
Shimadzu	Ceiling Mounted fixed unit with table bucky and erect Bucky	2011	0366M86918
Shimadzu	Ceiling Mounted fixed unit with table bucky and erect Bucky	2011	0366M86409

None of the hospitals included in the study had access to free Wi-Fi or provided Internet access to radiography staff, which was the norm for most public (and private) hospitals in South Africa in 2014. The radiographers participating in the study had to use personally purchased mobile data to engage with the social media platforms.

3.3 Sampling

3.3.1 Sample size

"Sample size calculations were carried out in G*Power" (187). The sample size was estimated based on the research questions, which included (1) the determination of the inter-rater reliability for the three reviewers; (2) the comparison of adherence to a given quality factor between three centres (or three phases); and (3) the comparison of the quality score between three centres (or three phases);

Question 1: "For all kappa-like agreement coefficients, the required number of subjects (n) depends on the relative error (r), the number of subjects in the entire population (N) and the difference p_a-p_e between the overall agreement probability p_a and the chance agreement probability p_e" (188) that is as follows:

$$n = \frac{n^*}{1+\frac{n^*}{N}}, where\ n^* = \frac{1}{r^2(p_a - p_e)^2}$$

"Assuming that N is very large, that the chance-agreement probability is 0, that the overall agreement probability is at least 0.6, and a relative error of 20%. The required n is 69 in each 3 groups" (188).

Question 2: This requires utilisation of a chi-square test, for a 3x2 table (for three categories of phase or centre and a binary quality factor). Sample sizes of 964, 108 and 39 are required for the identification of a small, medium and large effect size (w=0.1, 0.3 and 0.5, respectively) with power set at 80% at the 5% significance level, sample sizes of 964, 108 and 39 are required, respectively. Aiming for the detection of no less than a medium effect size required a minimum of 108 radiographs to be sampled per centre or per phase.

Question 3: This requires the use of a one-way Analysis of Variance (ANOVA).The identification of small, medium and large effect size (d=0.2, 0.5 and 0.8, respectively) with power set at 80% and at the 5% significance level, required sampling of 969, 159 and 64 radiographs, respectively. Aiming for the detection of

no less than a medium effect size required a minimum sample size of 159 per centre or per phase.

The sample size of 360 per centre (and per phase) is thus more than adequate for the purposes of the study.

3.3 2 Sampling Techniques

The study comprised three phases (refer to Table 3.8). The first phase formed the baseline and involved the collection and review of radiographs taken prior to any interventions taking place. The first three months (months 1–3) after the site visit (phase 1) represented phase 2 of the study and the subsequent three months (months 4–6) constituted phase 3 of the study.

One hundred and twenty radiographs were reviewed at each of the three radiology departments (total of 360) prior to any interventions taking place. The radiographs were consecutively collected, retrospectively from the start date of the study, working backwards until the required sample size was obtained. This formed the baseline for comparison and represents phase 1 of the study (refer to Section 3.6 for detailed information of data collection). The radiographs collected included those taken during normal working hours and after hours. Thereafter, 120 radiographs performed at each centre during the first three months (i.e. months 1–3) and 120 radiographs performed during the second three months (i.e. months 4–6) were reviewed. The total number of radiographs reviewed at each centre was 360, and 1080 radiographs in total reviewed for the three centres together (refer to Table 3.8 below). No adjustments were made to the radiographs (i.e. adjustment of exposure or penetration) prior to collection.

Table 3. 3 Summary of the number of radiographs to be reviewed at each phase of the study

	Baseline PHASE 1	PHASE 2	PHASE 3	TOTAL
CHBAH	120	120	120	360
RMMCH	120	120	120	360
KH	120	120	120	360
Total	360	360	360	1080

- CHBAH = Chris Hani Baragwanath Academic Hospital
- RMMCH = Rahima Moosa Mother and Child Hospital
- KH = Khayelitsha Hospital

3.3.3 Inclusion criteria

1. Chest radiographs from children aged 1 month to 13 years.
2. Frontal chest radiographs on the Picture Archiving System (PACS) of each site. We were not able to assess or determine if any radiographs had been deleted before being sent to PACS.

3.3.4 Exclusion criteria

1. Radiographs taken using mobile units including those taken in ICU. (There is a different degree of tolerance in quality of the radiographs from neonatal and intensive care units, as these fragile children can often not be moved or positioned for the radiograph, and because radiographs are often performed multiple times with specific goals in mind such as assessing support devices and lines)

3.4 Materials and methods

There were three phases in the study. The first phase, a baseline assessment of the quality of radiographs at each of the radiology departments, was carried out by reviewing a total of 120 radiographs that were performed at the centre before any visits were made. The second phase (months 1–3) of the study began when the principal investigator and social media assistant visited each of the radiology departments to meet with the staff members and share information on the platforms and the way they would be used as educational and communication tools during the study. This visit was also used to demonstrate how to use the social media platforms. It was also used as an opportunity to assist the staff members to create accounts on the different platforms (if they did not have accounts already). Thereafter the social media platforms were used to communicate with the radiographers at the different centres. The third and final stage of the study (months 4–6) was included to assess the sustainability of the interventions and continued radiographer engagement

3.4.1 Phase 1: Baseline (pre-intervention)

One hundred and twenty consecutive chest radiographs, meeting inclusion and exclusion criteria, were collected from each site, beginning from the start date of the study (1 June 2014) and working backwards in time. This created the baseline, phase 1 data, prior to any interventions.

3.4.2 Phase 2 (months 1–3) and phase 3 (months 4–6) after site visit

On the start date of phase 2, the principal investigator (without the supervisor) visited each research site to introduce herself and the social media assistant to the radiography staff and explain the aims and objectives of the study.

All radiographers from RMMCH and KH were in attendance. Only 7 out of 66 radiographers at CHBAH attended the presentation.

The radiographers were given a lecture (PowerPoint presentation), which included the quality factors in chest radiography, the importance of good quality radiographs and the effects of poor quality factors on image interpretation and diagnosis. Examples of good and poor quality radiographs were shown. The radiographers were also shown how to create a Facebook and Twitter account and how to sign in to these social media platforms. Thereafter, a demonstration of the contents of the Facebook page was given and the Twitter handle was announced. The study's Facebook page was designed and used specifically for the study; it was not used for any personal/private interaction.

3.5 Social media platforms

The two social media platforms used in the study were Facebook (https://www.facebook.com/profile.php?id=100083611201 60&mibextid=LQQJ4d) and Twitter (https://x.com/quality_xray?s=11&t=omEIJzerWcXJbVv1UzuM9w) for the period May – December 2014. Two mediums were used to provide alternative platforms for interaction. Similar material was posted on both sites. The Facebook page was used to communicate with the radiographers who had consented to participate at each site during phases 2 and 3. Initially the Facebook pages were open to all radiographers, even to those who had not consented to be involved in the study. Seven weeks into the study stage closed Facebook pages were created for the radiographers. The email addresses of the staff members from RMMACH and KH were provided by the head of the radiography departments. The head of the radiology department at CHBAH declined to release the email addresses of her staff members and a closed group was therefore not created for CHBAH. The original Facebook page was therefore kept open, and it was found that more interaction occurred on this page. Facebook was used as a long-distance communication and education tool. Study participants would be able to post comments anonymously or they could be identified. The purpose of choosing Facebook as a communication tool was to provide the study participants with an interactive tool that would facilitate the sharing of daily experiences, tips on technique, and the voicing of any challenges faced, including the commenting on

the progress of the study (140) (Figure 3.1). Facebook posts were made on average twice a week.

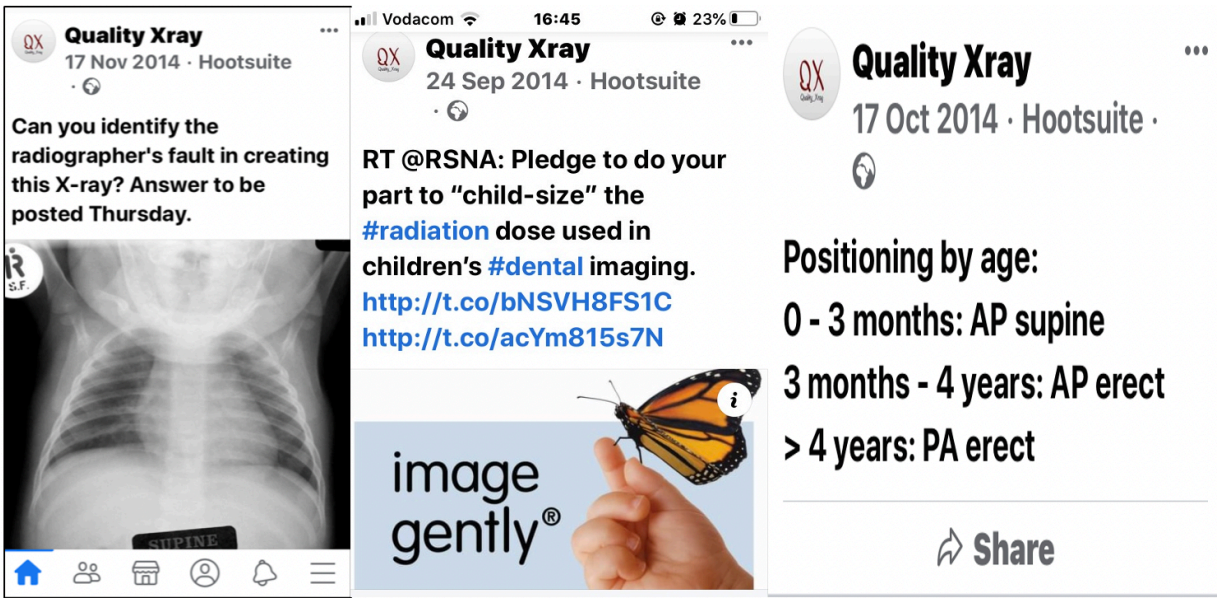


Figure 3. 1 Snapshots of examples of the quizzes and educational material posted on Facebook.

The Twitter handle (Quality Xray) was used during phases 2 and 3 to send regular (2–3 times a week) QA messages and tips to all the participating radiographers based at the different sites. The answers of the quizzes were also posted on Twitter, typically on a Thursday. It was hoped that the Twitter handle would be a channel for the radiographers at each of the sites to communicate with and get quick responses from one another (140) (Figure 3.2).



Figure 3. 2 Snapshots of examples of the quizzes and educational material posted on Twitter.

Engagement on the social media platforms was low. There were very few likes, reposts or comments made on both social media platforms. This was identified in the first month of the study, and the principal investigator and social media assistant met with a social media expert, Mark Stopforth, in Johannesburg, South Africa, who advised the following:

- Create closed Facebook groups and invite individuals to join
- Introduce quizzes to encourage participation/interaction

We created closed Facebook groups for RMMCH and KH. The head of radiography at CHBAH declined to provide the list of the radiographers working at the hospital, their contact numbers or email addresses and a closed group was therefore not created for CHBAH. None of the KH radiographers accepted the invitation to join the closed Facebook page. There was limited engagement with the closed Facebook page that was created for RMMCH with only 27.3% (3/13) accepting the invitation to join. Notwithstanding, overall, there was no meaningful engagement or adequate engagement with content as intended. We made the Twitter posts short and tried to make them interesting by including useful tips to improve the quality of radiographs or the positive impact of quality radiographs on image interpretation. Even though the suggested changes were instituted, the

changes engagement did not improve on Twitter (Table 4.37), however, there was slightly more activity on the Facebook page (Table 4.40).

Table 4.34 below which has been adapted from Nieger and colleagues, highlights the differences between low, medium and high engagement (189).
The frequency that content on social media is viewed is referred to as exposure. Engagement measures the active response to social media. Low engagement occurs when individuals acknowledge the content or indicate a preference. When people are involved with content creation, sharing and when they are potentially able to influence others, it is referred to as medium engagement. High engagement is associated with partnering with social media behind the scenes as a funder, volunteer or consumer (189).

Table 3. 4 Types of engagement with social media platforms (189)

Low	Acknowledge/agreement Preference for content
Medium	Content creation and dissemination Ability to influence
High	Participation in offline intervention Creating content Program partner Volunteer Sponsor

3.6 Collection and processing of data

A research assistant was appointed to coordinate the collection of the radiographs from each centre. All paediatric frontal chest radiographs were transferred from the digital work station/modality or PACS and loaded onto external hard drives. The external hard drive from Khayelitsha Hospital was couriered to and from Johannesburg but since the other two hospitals are located in Johannesburg courier services were not necessary. Thereafter, the principal investigator and research assistant retrieved 120 images from the total images/radiographs on

each external hard drive for each of phases 2 and 3 (phase 1 comprised consecutive radiographs meeting the inclusion and exclusion criteria collected retrospectively). The 120 radiographs were retrieved as follows: for sites with more than 120 paediatric chest radiographs performed in the 3-month period, the 120 radiographs were retrieved by systematically taking intermittent radiographs from the entire number of radiographs performed during the three month period. For example, from a total of 240 radiographs performed, every 2nd one would be retrieved and from 480 radiographs, every 4th radiograph would be sampled. Only the first radiograph of a series was assessed. No prior adjustment to the quality of the image was made before the radiographs were stored in JPEG format. When viewed by the reviewers it was not possible to adjust penetration or exposure. Each radiograph was systematically anonymised, coded and loaded on to the research electronic data capture (REDCap) platform (190). REDCap is a user-friendly software solution created by Vanderbilt University for the "development and deployment of electronic data capture tools to support clinical and translational research" (190,191). The application is web-based, making it an ideal platform on which to conduct multi-site studies that are geographically distant from each other (50,190,191).

On REDCap, each radiograph was displayed on the screen with an electronic tick sheet adjacent to it. This enabled the reviewers to perform quality assurance (QA) reviews of the technical quality of the radiographs as specified by the QA tick sheet (Appendix A) (190). Reviewers were then able to review each of the 12 quality factors of each radiograph by ticking 'yes' or 'no' for each quality factor that was assessed. The diagnostic component, exposure factors and radiation doses were not assessed. The quality factors assessed were described in Section 2.5 and are listed below:

1. Parts cut off
2. Under Inspiration (< 6 ant ribs)
3. Rotation in the horizontal plane
4. Scapula projecting over the radiograph
5. Rotation in the vertical plane resulting in a kyphotic or lordotic view
6. Artefact or foreign body on the radiograph
7. Central vessels not well seen

8. Peripheral vessels not well seen
9. Poor collimation
10. Trachea and bronchi not clearly seen
11. Vessels behind heart not well seen
12. Wrong (or no) Left/Right marker

Considering the logistical issues involved in obtaining images from each site, processing and de-identifying them at the main study site and then sending them to each reviewer by courier, the decision was made to rather make the processed images available for download by each reviewer from a secure central repository. The quality assurance tick sheet developed by Hlabangana et al. (2) from a previous study, was converted to an online data capture form on REDCap, with each image linked to a specific record on the system (190). The record identifier was randomly generated by using a GUID (Globally Unique Identifier) substring (190).

The radiographs obtained from each study site were converted to PDF files, with unique embedded hyperlinks pointing to each image's corresponding tick sheet on REDCap (190). The PDF files were securely transmitted to the reviewer by using REDCap's Send-It function. The reviewers logged onto the system with a personal username and password (i.e. the reviewers did not have access to the QA assessments performed by the other reviewers) (190). Review of the PDF image could be performed, and by clicking on the hyperlink in the image reviewers were able to record the QA assessment findings on the QA sheet (Figure 3.3) (190).

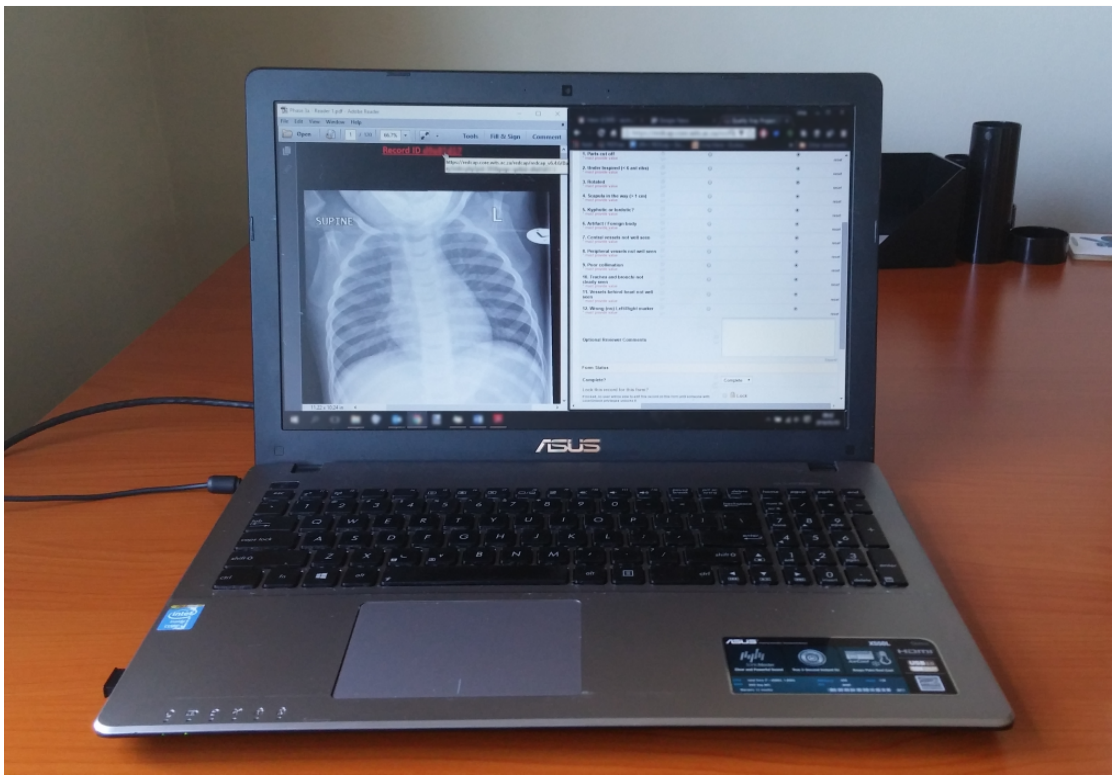


Figure 3. 3 Photograph of the computer-based QA system, with the radiograph and hyperlink on the left, and the REDCap tick sheet that opens when the hyperlink is clicked, on the right (190).

The reviewer was not able to move on to review the next radiograph if the review was not complete. Validation was included into the design of the QA sheet so that warning messages were received if a field was left blank (190). The data manager was able to follow the progress of each reviewer. The custom reporting tools enabled the data manger to identify any missed images, and to provide a summary of these to each reviewer (190). Reviewers were also able to communicate any problems or give feedback to the data manager via email (190).

Once the reviewers completed the QA sheets for images obtained before and after the intervention, the data manager exported the results as a comma-separated values (CSV) file (190). The data were then converted into an Excel document for review and analysis (190). Each reviewer's QA results were recorded separately and then they were put together. A final decision was formed using the majority rule for errors detected by the three reviewers (i.e. positives from two or more

reviewers for a particular assessment was considered present), and this was recorded and used for statistical analysis.

The PI monitored the activity on Facebook page and Twitter using the social media management tool called HootSuite. HootSuite allows efficient tracking of the number of views, length of views and interaction on social media platforms. It was initially hoped to obtain all the activity metrics from Hootsuite, however, at the time of review it was found that the metrics provided were not detailed enough and the PI then performed content review of both the Facebook pages and Twitter handle to obtain more detailed information.

3.7 Reviewers for the study

Three reviewers (independent qualified radiologists, one of whom was a paediatric radiologist) performed the QA review on all of the radiographs from each centre. The reviewers were asked to identify the radiographic quality errors on each radiograph. The reviewers were blinded to the origins and order of each set of radiographs. The three reviewers were then provided with access usernames and passwords to enable remotely logging onto REDCap to review the quality of the radiographs on this digital platform. The reviewers were given training with examples on how to use the tick sheet on REDCap. A tick sheet with images depicting the radiographic errors was available on REDCap for the reviewers to click on for review of the errors being assessedd. This was shown to the reviewers during training (Appendix A). The training took place before the study started. No retraining of the reviewers was required.

3.8 Study participation

Participation in the social media interaction was completely voluntary and no radiographer was forced or coerced to participate in the study. All radiographers who chose to participate in the social media interaction were able to view all

comments made on the Facebook page and read all the messages on Twitter. The interventions ran concurrently at the 3 sites to ensure that the comments made were relevant to all 3 sites.

3.9 Security

The principal investigator (PI) and research assistant were the only people able to post information on the site. The participants were invited onto the page at the initial on-site visit to each hospital and at a later phase via email to a private Facebook page. The research assistant monitored the site frequently to remove or block unwanted/irrelevant comments on the site.

3.10 Review of radiographs by principal investigator

The protocol committee recommended that the principal investigator also review the quality of all images performed in the study and to compare her findings with the majority outcome of the reviewers. The principal investigator reviewed the radiographs after the 3 phases were completed and was blinded to the source hospital and phase of the study at the time of review to reduce further bias. It was found that there was poor inter-rater bias between all reviewers, including the principal investigator, and it was decided to proceed with data analysis using the most popular vote by the initial 3 reviewers.

3.11 Bias

The radiographs reviewed in the study were mostly from an hospital-based population where some of the children were possibly very ill, increasing the probability of obtaining radiographs that had multiple errors. Very ill patients are sometimes less cooperative, and this may result in radiographs with more errors than if the review was solely performed on outpatients. The radiographs of very ill

patients are usually performed at the bedside as portable radiographs and these were likely excluded as part of the exclusion criteria. It is acknowledged that some of the radiographs were taken by student radiographers at RMMCH and CHBAH (there were no student radiographers at KH), and due to inexperience the positioning and quality could be expected to be suboptimal. The number of radiography students present at each hospital during the duration of the study is reflected in Table 3.2. Information on the percentage of radiographs performed by students was not available. The three reviewers were not informed of the quality improvement aspect, the hospital or phase of the study to reduce bias. When the principal investigator reviewed all the images included in the study, blinding was performed to ensure that the source hospital and phase of the study were unknown to reduce further bias.

3.12 Data categorisation

Each radiograph was reviewed for a possible total of 12 errors. The reviewers identified each quality factor as being present (1) or absent (0). Using the majority decision of the three reviewers (i.e. if 2 or more reviewers identified a specific error as present or absent on a radiograph), an error rate was determined for each site at each phase. The lower the error score the better the quality of the radiograph. The radiographs were also categorised as ‘perfect’ (no errors), ‘diagnostic’ (4 or less errors but not perfect) and ‘not diagnostic’ (5 or more errors) (2). The categories ‘perfect’ and ‘diagnostic’ were also combined into a ‘high quality’ category for some calculations. In addition, each individual type of error frequency was determined from the total number or from radiographs reviewed in each stage. This was performed for each phase of the project and represented in bar graphs that compared the results from the different phases of the study at each site. The reviewers assessed the radiographs at the end of each phase of the study.

3.13 Data analysis and statistics

The data was analysed as follows:
The quality score for each radiograph was calculated as number of radiographic errors / 12 * 100. The range of the quality score was thus 0–100%.

The data was summarised and described using descriptive analysis: Categorical variables were summarised as frequencies and percentages which were tabulated and illustrated using bar charts. Continuous variables were sumarised using the mean and standard deviation or the median and interquartile range. The distribution were demonstrated by histograms.

To determine the inter-rater reliability for each quality factor between all three reviewers, the "Brennan-Prediger coefficient of agreement for more than two reviewers (κ_{BP}) was used, while inter-rater reliability between pairs of reviewers was determined by the Brennan-Prediger coefficient of agreement for" two reviewers (κ_2) (188). "The inter-rater results were defined as *closely similar* if the difference in the frequency between all reviewers was less than 2%, *relatively similar* if the difference was less than 5%, and *discrepant* if more than 5%" (192).

The magnitude of the estimated "kappa values was interpreted according to Landis and Koch" (193). "Inter-rater bias among the three reviewers was determined using Cochran's Q statistic; McNemar's test was used to determine inter-rater bias among pairs" (192) of reviewers. A Kappa value of 0.8 was accepted as good; a value of 0.7– 0.79 was accepted as fair; and a value below 0.7 was considered to be poor. "The intraclass correlation coefficient (ICC) was used to determine the Inter-rater reliability for" (72) each quality score.

Comparisons of each quality factor between centres (for a given phase) and between phases (for a given centre) were carried out using Fisher's exact test, with the critical p-value adjusted to 0.048 to adjust for multiple comparisons using

Sidak's method. The phi coefficient was used to measure the strength of the associations.

The following scale of interpretation was used:

0.50 and above	high/strong association
0.30 to 0.49	moderate association
0.10 to 0.29	weak association
Below 0.10	little if any association

Comparison of the quality score between centres (for a given phase) and between phases (for a given centre) was carried out using the Kruskal-Wallis test. The strength of the associations was measured by r.

The following scale of interpretation was used:

0.80 and above	large effect
0.50 to 0.79	moderate effect
0.20 to 0.49	small effect
Below 0.20	near zero effect

"Data analysis was carried out using SAS v9.4 for Windows (North Carolina State University, Raleigh, NC). The 5% significance level was used" (192) unless otherwise specified (i.e. for multiple comparisons).

The Chi-squared test was used to independently assess each error at baseline (phase 1), and those during the second and third phases for each **individual hospital.**

The Kruskal and Wallis test was used to independently assess the errors **between groups** (i.e. the different hospitals) at baseline and those during the first and second QI cycles.

Fisher Test for 2x2 analysis **compared the errors between hospitals** at baseline, first and second QI cycles. This test was also used to compare the errors recorded by the reviewers with the errors recorded by the principal investigator.

Popularity of the various social media platforms was monitored using Hootsuite, a tool that assists in the management of social media. Using a dashboard enables one to socially integrate with Twitter and Facebook (194). This application measured the number of interactions (i.e. twitter messages sent using the study hash tag and the viewership on the Facebook page) that took place on each social media platform. The medium with the most hits/views at each phase of the study determined popularity.

3.14 Ethical considerations

The Human Research Ethics Committee of the University of the Witwatersrand approved the study– Ethics clearance certificate number M130665 (Appendix B). Approval was also obtained from the chief radiographers and the radiology heads of department from the relevant hospitals, as well as approval from the Department of Health in the Western Cape.

Radiographs that were assessed were those performed for clinical indications. No further radiographs were performed despite errors being detected. The diagnostic evaluation of the radiographs was not performed and no diagnostic reports were generated.

The radiographers at each site were invited to take part in the study and were provided with information on the study and informed consent forms to sign. No radiographers were forced or coerced to participate.

Data was recorded using a numbering code to ensure anonymity. The code was only accessible to the primary investigator, supervisor and research assistant.

3.15 Data safety

A random identification code was allocated to each patient to ensure that data was collected anonymously. Access to this code is only available to the principal investigator, supervisor and research assistants.

3.16 Conclusion

The research methodology used in this study was described in this chapter. The study design, materials and methods, data collection and processing and the ethics were discussed. The study results will be presented in the next chapter.

CHAPTER 4: Results

4.1 Introduction

This chapter outlines the information retrieved from analysis of the data collected from REDCap of the 966 images that were reviewed by the three reviewers. Descriptive statistical analysis was performed to summarise and present the data.

4.2 Data Preparation

The original sample size was 1080 radiographs. The three reviewers scored the radiographs after each phase of the study. Three lateral radiographs were removed from the sample during the review by the three reviewers (reduced sample size = 1077). The PI assessed the radiographs once all three phases were complete. During the PI review a further 111 radiographs were excluded from the sample, resulting in a final sample size of 966 (Table 4.1–4.2, Figure 4.1): Twenty-four of these radiographs were excluded as they were labelled 'portable' and portable films formed part of the exclusion criteria. There were a total of 78 films where the pathology on the film was so significant and severe that it was deemed that these films could not have been performed in the radiology department, but were likely performed at the patient's bedside as the patients would have been too sick to be moved (Figure 4.3). These films gave no indication that they were performed in the ward, i.e. they were not labelled 'portable' or 'BSU' (bedside unit) and they did not have the exposure factors written on the film. Four radiographs were excluded as they had duplicate identification codes and a further five radiographs were excluded as the tick sheets were not accessible on REDCap. The omitted cases came mostly from CHBAH in phases 1 and 2. Inter-rater agreement between each of the original three reviewers and the PI was determined for 966 cases that were retained for the main analysis (Figure 4.1).

Table 4. 1 Reasons for additional image exclusion from initial sample of 1080

Reason for image exclusion	Excluded films (Total 114)	Sample size reduction from initial n=1080
Lateral radiographs	3	1077
Radiographs Labelled 'Potable'	24	1053
'Sick child' (Assumed portable)	78	975
Duplicated IDs	4	971
Unable to access tick sheet	5	966

Table 4.2 below shows the distribution of the remaining 966 cases between centres and phases. The omitted cases were mostly from CHBAH in phases 1 and 2.

Table 4. 2 Distribution of the remaining 966 cases between centres and phases

Phase		Centre				
		CHBAH	RMMCH	KH	Total	Total %
1	n	79	115	113	307	31.8
	% of Phase	25.7	37.5	36.8		
	% of Centre	28.2	32.6	33.9		
2	n	81	120	117	318	32.9
	% of Phase	25.5	37.7	36.8		
	% of Centre	28.9	34.0	35.1		
3	n	120	118	103	341	35.3
	% of Phase	35.2	34.6	30.2		
	% of Centre	42.9	33.4	30.9		
Total	n	280	353	333	966	
	%	29.0	36.5	34.5		

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

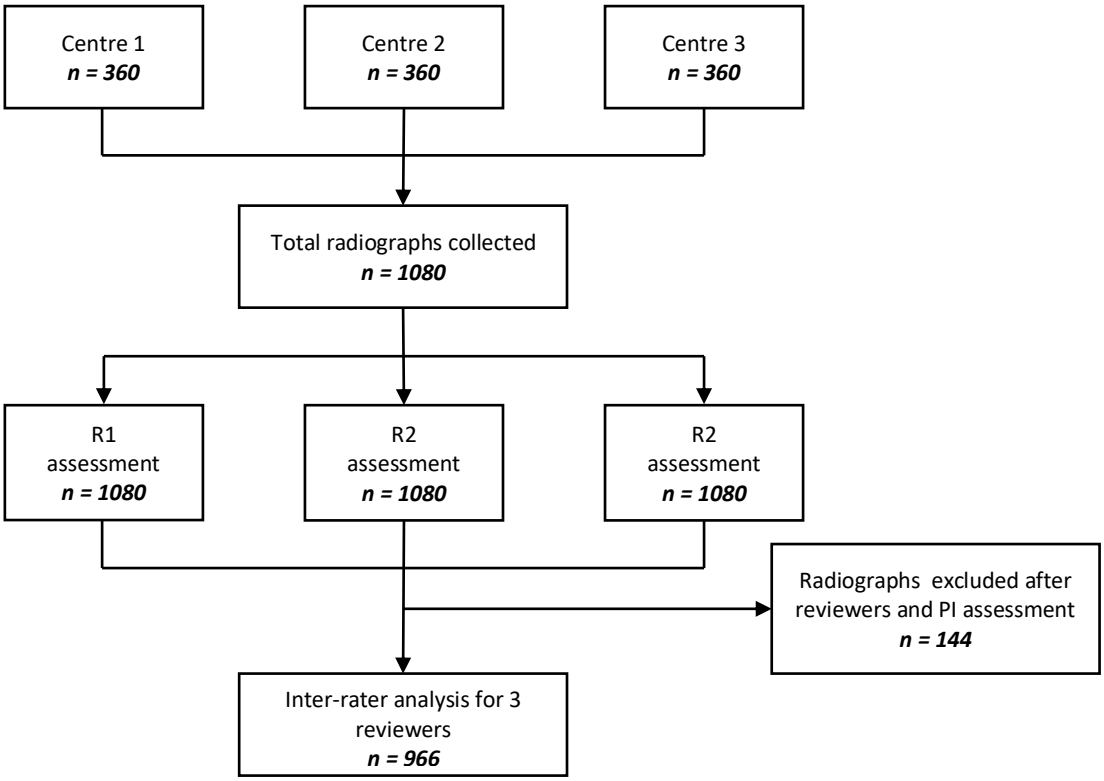


Figure 4. 1 Flowchart showing the sample size changes from collection, and after review with additional exclusions resulting in the final sample used for analysis (Hlabangana et al. 2021).

Figure 4.2 demonstrates radiographs that were excluded from the study because they were performed as portable radiographs, and Figure 4.3 demonstrates radiographs of patients that were excluded because the patients were deemed to be too sick for the studies to have been performed in the radiology department.

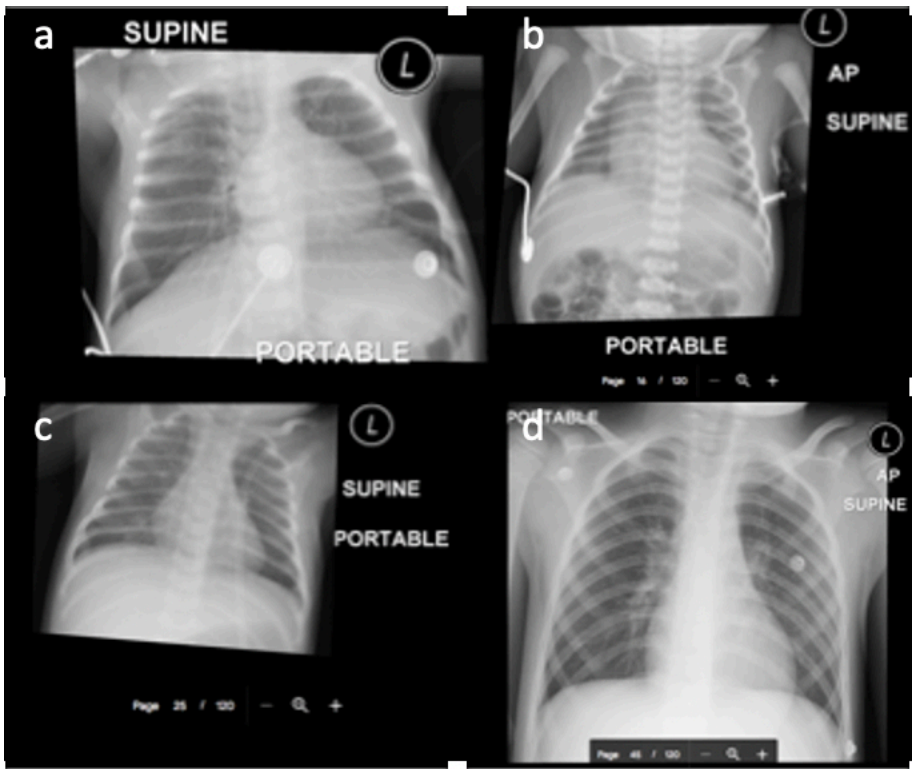


Figure 4. 2 (a, b, c and d) are examples of the portable radiographs that were excluded from the study.

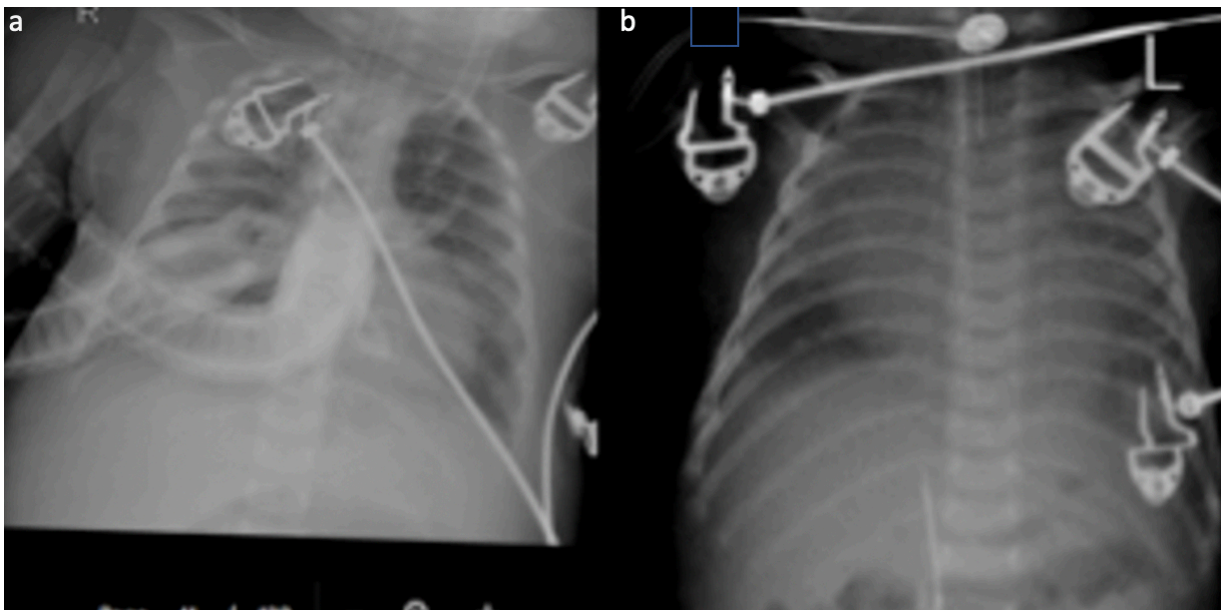


Figure 4. 3 (a and b). Examples of the radiographs that were excluded from the study where the findings on the film indicated that films could not have been performed in the radiology department but at the patient's bedside. (a) Shows an intubated and ventilated patient and (b) demonstrates a child with an endotracheal tube and an umbilical venous catheter in situ.

4.3 Inter-rater analysis

Inter-rater agreement between the PI and each of the original three reviewers was determined for 966 cases and retained for the main analysis. The frequency of each error (represented in percentages) identified by each of the reviewers, including the PI, across the 966 radiographs reviewed, is represented in Table 4.3 below. If the difference in the frequency between reviewers was less than 2%, the inter-rater results were then defined as *closely similar*. If there was a difference of less than 5%, it was called *relatively similar* and *discrepant* if the difference was more than 5% (192).

Table 4. 3 Percentage of cases with errors identified by each of the reviewers including the principal investigator (PI) for the 966 cases retained for the main analysis

Quality factor	% Error identified (n=966)			
	Reviewer 1	Reviewer 2	Reviewer 3	Principal Investigator
1. Parts cut off	1.5 (14/966)	1.8 (17/966)	2.4 (23/966)	1.0 (9/966)
2. Under Inspired (< 6 ant ribs)	2.0 (19/966)	20.0 (193/966)	52.6 (508/966)	31.1 (300/966)
3. Rotated	24.0 (232/966)	28.1 (271/966)	73.6 (711/966)	45.2 (437/966)
4. Scapula in the way (> 1 cm)	29.6 (286/966)	35.8 (346/966)	59.2 (572/966)	43.2 (417/966)
5. Kyphotic or lordotic?	17.6 (170/966)	14.3 (138/966)	13.9 (134/966)	35.7 (345/966)
6. Artefact/Foreign body	6.4 (62/966)	12.5 (121/966)	11.4 (110/966)	21.1 (204/966)
7. Central vessels not well seen	9.2 (89/966)	7.9 (76/966)	5.6 (54/966)	8.8 (85/966)
8. Peripheral vessels not well seen	24.0 (232/966)	22.9 (221/966)	5.9 (57/966)	44.8 (433/966)
9. Poor collimation	32.4 (313/966)	32.4 (313/966)	7.8 (75/966)	45.3 (438/966)
10. Trachea and bronchi not clearly seen	12.0 (116/966)	38.9 (376/966)	23.2 (224/966)	23.5 (227/966)
11. Vessels behind heart not well seen	9.4 (91/966)	14.2 (137/966)	13.7 132/966)	33.2 (321/966)
12. Wrong (no) Left/Right marker	0.8 (8/966)	1.9 (18/966)	2.1 (20/966)	0.93 (9/966)

There were significant differences (>5%) in the error percentages between all the reviewers (including the PI) for the quality factors *(2) under-inspiration*; factors related to patient positioning and preparation: *(3) patient rotation*, *(4) scapula on the way, (5) patient kyphosis/lordosis, (6) artefact/foreign body* and *(9) poor collimation*. Including factors related to exposure: (8) *peripheral vessel visualisation*, *(10) trachea and bronchi visualisation,* and *(11) post cardiac vessel visualisation*. Relatively close similarities (<5% difference) were found between reviewers for factor *(7) central vessel visualisation.* There were close similarities (<2% difference) between the PI and reviewers in the error frequency for quality

factors *(1) absent patient body parts from FOV* and *(12) absent or wrong image orientation marking*.

Significant inter-rater bias and poor inter-rater agreement, was demonstrated between PI and each of the original three reviewers on most quality factors (Tables 4.4 and 4.5). There was moderately unbiased agreement between the PI and reviewers 1 (p=0.28) and 2 (p=0.52) for the quality factor *(1) absent body parts from FOV.* There was also moderately unbiased agreement between the PI and reviewers 1(p=0.65) and 2 (p=0.35) for the quality factor *(7) central vessel visualisation*. For factor *(10) trachea and bronchi visualisation* there was moderately unbiased agreement between the PI and reviewer 3 (p=0.83,).

There was no reviewer that consistently scored very similarly to the PI. Therefore we continued with the majority decision data of the three original reviewers.

Table 4. 4 Brennan-Prediger coefficient of agreement between each reviewer and the PI for the 966 cases retained for the main analysis

Quality factor	Brennan-Prediger coefficient of agreement								
	Reviewer 1 vs. PI			Reviewer 2 vs. PI			Reviewer 3 vs. PI		
	Coef	95% confidence interval		Coef	95% confidence interval		Coef	95% confidence interval	
1. Parts cut off	**0.98**	0.97	0.99	**0.98**	0.97	0.99	**0.96**	0.94	0.98
2. Under Inspired (< 6 ant ribs)	**0.41**	0.35	0.47	**0.67**	0.62	0.72	**0.49**	0.44	0.54
3. Rotated	**0.42**	0.36	0.48	**0.37**	0.31	0.43	**0.33**	0.27	0.39
4. Scapula in the way (> 1 cm)	**0.36**	0.30	0.42	**0.39**	0.33	0.45	**0.39**	0.33	0.45
5. Kyphotic or lordotic?	**0.44**	0.38	0.50	**0.24**	0.18	0.30	**0.29**	0.23	0.35
6. Artefact / Foreign body	**0.67**	0.62	0.72	**0.76**	0.72	0.80	**0.75**	0.71	0.79
7. Central vessels not well seen	**0.83**	0.79	0.87	**0.81**	0.77	0.85	**0.84**	0.81	0.87
8. Peripheral vessels not well seen	**0.48**	0.43	0.53	**0.38**	0.32	0.44	**0.20**	0.14	0.26
9. Poor collimation	**0.60**	0.55	0.65	**0.41**	0.35	0.47	**0.22**	0.16	0.28
10. Trachea and bronchi not clearly seen	**0.66**	0.61	0.71	**0.48**	0.43	0.53	**0.62**	0.57	0.67
11. Vessels behind heart not well seen	**0.50**	0.45	0.55	**0.49**	0.44	0.54	**0.51**	0.46	0.56
12. Wrong (or no) Left/Right marker	**0.97**	0.96	0.98	**0.98**	0.97	0.99	**0.97**	0.96	0.98

KEY:

0.00–0.19 Slight agreement
0.20– 0.39 Fair agreement
0.40–0.59 Moderate agreement
0.60–0.79 Substantial agreement
0.80–0.99 Almost perfect agreement

Table 4. 5 P-value for inter-rater bias between each reviewer and the PI for the 966 cases retained for the main analysis

Quality factor	p-value for inter-rater bias (Cochran's Q or McNemar's test)		
	Reviewer 1 vs. PI	Reviewer 2 vs. PI	Reviewer 3 vs. PI
1. Parts cut off	0.28	0.052	0.0029
2. Under Inspired (< 6 ant ribs)	<0.0001	<0.0001	<0.0001
3. Rotated	<0.0001	<0.0001	<0.0001
4. Scapula in the way (> 1 cm)	<0.0001	<0.0001	<0.0001
5. Kyphotic or lordotic?	<0.0001	<0.0001	<0.0001
6. Artefact / Foreign body	<0.0001	<0.0001	<0.0001
7. Central vessels not well seen	0.65	0.35	0.0003
8. Peripheral vessels not well seen	<0.0001	<0.0001	<0.0001
9. Poor collimation	<0.0001	<0.0001	<0.0001
10. Trachea and bronchi not clearly seen	<0.0001	<0.0001	0.83
11. Vessels behind heart not well seen	<0.0001	<0.0001	<0.0001

The three reviewers had close similarities in the identification of errors related to quality factors *(1) absent patient body parts from FOV* and *(12) absent or wrong image orientation marking*. The reviewers demonstrated relatively close similarities for factors *(5) patient kyphosis or lordosis, (7) central vessel visualisation* and factor *(11) post cardiac vessel visualisation*. There were, however, pronounced differences between the three reviewers in the frequency of the errors for some of the quality factors related to patient preparation and positioning: (*2) under-inspiration, (3) patient rotation, (4) scapula in the way, (6) artefact/foreign body, (9) poor collimation*, and those related to exposure: *(8) peripheral vessels visualisation (10) trachea and bronchi visualisation*. The Brennan-Prediger coefficient of agreement between the three reviewers for the 966 radiographs is demonstrated on Table 4.6.

Table 4. 6 Brennan-Prediger coefficient of agreement between the 3 reviewers for the total 966 radiographs

Quality factor	Brennan-Prediger coefficient of agreement											
	Overall			Reviewer 1 vs 2			Reviewer 1 vs 3			Reviewer 2 vs 3		
	Coef	95% CI		Coef	95% CI		Coef	95% CI		Coef	95% CI	
1. Parts cut off	**0.96**	0.95	0.97	**0.96**	0.94	0.98	**0.96**	0.94	0.98	**0.96**	0.94	0.98
2. Under Inspired (< 6 ant ribs)	**0.31**	0.00	1.00	**0.63**	0.58	0.68	**0.00**	0.00	0.06	**0.32**	0.26	0.38
3. Rotated	**0.21**	0.00	0.97	**0.60**	0.55	0.65	**0.00**	0.00	0.06	**0.06**	0.00	0.12
4. Scapula in the way (> 1 cm)	**0.36**	0.03	0.69	**0.52**	0.47	0.57	**0.24**	0.18	0.30	**0.33**	0.27	0.39
5. Kyphotic or lordotic?	**0.54**	0.37	0.71	**0.63**	0.58	0.68	**0.48**	0.43	0.53	**0.52**	0.47	0.57
6. Artefact / Foreign body	**0.86**	0.77	0.95	**0.82**	0.78	0.86	**0.86**	0.83	0.89	**0.89**	0.86	0.92
7. Central vessels not well seen	**0.86**	0.82	0.90	**0.85**	0.82	0.88	**0.87**	0.84	0.90	**0.86**	0.83	0.89
8. Peripheral vessels not well seen	**0.63**	0.52	0.74	**0.68**	0.63	0.73	**0.59**	0.54	0.64	**0.61**	0.56	0.66
9. Poor collimation	**0.47**	0.35	0.59	**0.52**	0.47	0.57	**0.47**	0.42	0.52	**0.45**	0.39	0.51
10. Trachea and bronchi not clearly seen	**0.49**	0.16	0.82	**0.41**	0.35	0.47	**0.66**	0.61	0.71	**0.40**	0.34	0.46
11. Vessels behind heart not well seen	**0.78**	0.70	0.86	**0.80**	0.76	0.84	**0.80**	0.76	0.84	**0.74**	0.70	0.78
12. Wrong (no) Left/Right marker	**0.98**	0.98	0.98	**0.98**	0.97	0.99	**0.97**	0.95	0.99	**0.98**	0.97	0.99

KEY:

0.00–0.19 Slight agreement
0.20– 0.39 Fair agreement
0.40–0.59 Moderate agreement
0.60–0.79 Substantial agreement
0.80–0.99 Almost perfect agreement

Table 4. 7 P-value for inter-rater bias for the total 966 radiographs

Quality factor	p-value for inter-rater bias (Cochran's Q or McNemar's test) (we want this to be non-significant)			
	Overall	Reviewer 1 vs 2	Reviewer 1 vs 3	Reviewer 2 vs 3
1. Parts cut off	0.11	0.49	0.039	0.18
2. Under Inspired (< 6 ant ribs)	<0.0001	<0.0001	<0.0001	<0.0001
3. Rotated	<0.0001	0.0052	<0.0001	<0.0001
4. Scapula in the way (> 1 cm)	<0.0001	0.0003	<0.0001	<0.0001
5. Kyphotic or lordotic?	0.030	0.017	0.023	0.79
6. Artefact / Foreign body	<0.0001	<0.0001	<0.0001	0.12
7. Central vessels not well seen	0.0001	0.13	<0.0001	0.0086
8. Peripheral vessels not well seen	<0.0001	0.38	<0.0001	<0.0001
9. Poor collimation	<0.0001	>0.99	<0.0001	<0.0001
10. Trachea and bronchi not clearly seen	<0.0001	<0.0001	<0.0001	<0.0001
11. Vessels behind heart not well seen	<0.0001	<0.0001	<0.0001	0.65
12. Wrong (no) Left/Right marker	0.0004	0.0016	0.0013	0.48

Our results show that The Brennan-Prediger chance-corrected measure of agreement was substantial or better (>=0.70) for factors *(1) absent body parts from FOV* (κ score of 0.96)*, (6) artefact/foreign body* (κ score of 0.86)*, (7) central vessel visualisation* (κ score of 0.86)*, (11) post cardiac vessel visualisation* (κ score of 0.78) and *(12) absent or wrong image orientation marking* (κ score of 0.98) between the three reviewers and between each pair of reviewers (bold black in table 4.6). The only factor that had no significant inter-rater bias was factor *(1) absent body parts from FOV* (Table 4.7).

There was substantial, unbiased agreement for factors *(5) patient kyphosis or lordosis (p=0.79), (6) artefact/foreign body (p=0.12), (11) post cardiac vessel visualisation (p=0.65)* and *(12) absent or wrong image orientation marking (p=0.48)* between reviewers 2 and 3 (Tables 4.6 and 4.7). There was unbiased agreement between reviewers 1 and 3 for factors *(7) central vessel visualisation (p=0.13), (8) peripheral vessels visualisation (p=0.38)* and *(9) poor collimation (p>0.99).* There was no agreement for all factors between reviewers 1 and 3.

Poor agreement (<0.70) between reviewers and each pair or reviewers was demonstrated for several factors by the Brennan-Prediger chance-corrected measure of agreement. These included factors related to patient positioning and preparation: *(2) under-inspiration* (0.31), *(3) patient rotation* (κ score of 0.21), *(4) scapula on the way* (κ score of 0.36*), (5) patient kyphosis/lordosis* (κ score of 0.54*)* and *9) poor collimation* (κ score of 0.47). As well as factors related to exposure: (8) peripheral vessel visualisation (κ score of 0.63) and *(10) trachea and bronchi visualisation* (κ score of 0.49) (Table 4.4). Significant interrater bias in the above factors between all pairs of reviewers was demonstrated for factors *(2) under-inspiration, (3) patient rotation, (4) scapula on the way* and *(10) trachea and bronchi visualisation.* There was moderately unbiased agreement for factor *(5) patient kyphosis/lordosis* between reviewers 2 and 3 (p=0.79). There was moderate and worse agreement between reviewers 1 and 2 for factors *(8) peripheral vessel visualisation* (p=0.38), and *(9) poor collimation (* p=>0.99), respectively (Tables 4.6 and 4.7).

The intra-class correlation coefficient for the quality score was 0.61, which represented substantial agreement between the reviewers. Ideally this value should be >0.7. It was then decided to regard the PI quality evaluations not as a gold standard, but as a 4th reviewer and try and find three reviewers (out of 4) with good inter-rater reliability.

4.4 Prevalence of each error type overall

We then considered the prevalence of each error type (using the majority decision data of the three original reviewers) at the overall level, i.e. throughout the three phases of the study (Table 4.8 and Figure 4.4). The most common error types were ‘scapula in the way’ and ‘rotation’ (present in more than 30% of the radiographs) and ‘poor collimation’, which was identified in 22.2% of the radiographs. The least common errors were ‘wrong/no left or right marker’ in 1.7% and ‘parts cut off’ which was present in 1.4% of the radiographs.

Table 4. 8 Overall frequency of the individual radiographic errors

Quality factor	% of cases with error
Scapula in the way	38,7 (374/966)
Rotated	34,7 (335/966)
Poor collimation	22,2 (214/966)
Trachea and bronchi not clearly seen	19,6 (189/966)
Under-inspired	19,4 (187/966)
Peripheral vessels not well seen	16,4 (158/966)
Artefact/foreign body	10,1 (98/966)
Vessels behind heart not well seen	10,(97/966)
Kyphotic / lordotic	9,1 (88/966)
Central vessels not well seen	6,6 (64/966)
Wrong (no) Left/Right marker	1,7 (16/966)
Parts cut off	1,4 (13/966)

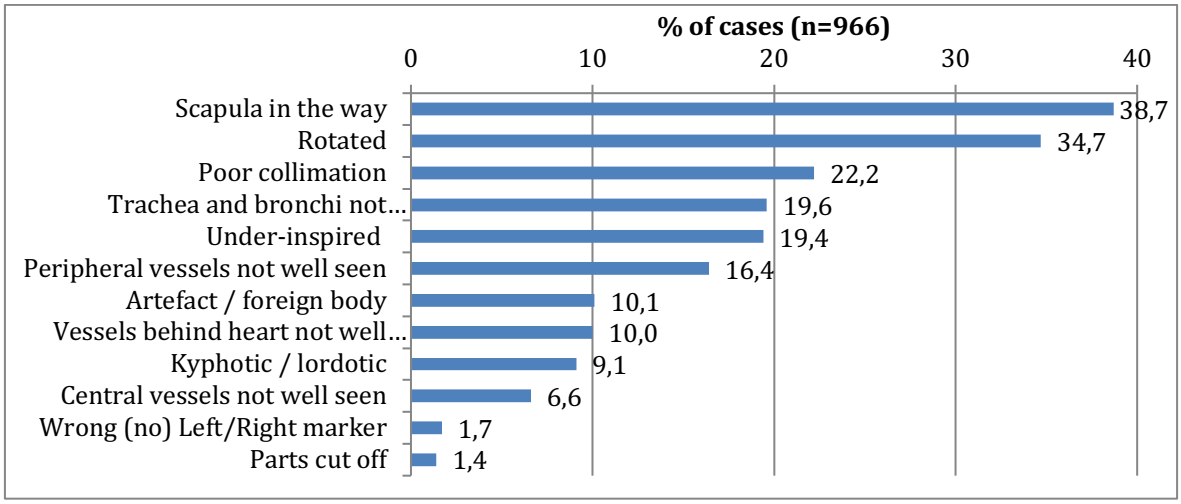


Figure 4. 4 Overall prevalence of each error

The research did not demonstrate a significant benefit from the intervention. A summary of the total number of errors overall and for each of the individual hospitals during each phase of the study are summarised in Table 4.9 below.

Table 4. 9 Summary of the total number of radiographs and errors identified at each centre during each phase of the study.

Phase	Centre	Number of radiographs	Number of errors
1	CHBAH	79	185
	RMMCH	115	142
	KH	113	232
2	CHBAH	81	431
	RMMCH	120	171
	KH	117	224
3	CHBAH	120	194
	RMMCH	118	109
	KH	103	145
Total		966	1833

KEY: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The radiographs at CHBAH had the highest number of errors overall in phase 2 (431) and phase 3 (194). RMMCH consistently had the lowest number of errors identified throughout the study.

The number of errors overall and for each individual hospital have been represented in further detail in Tables 4.10 to 4.13. Please note that the lower the score (number of errors out of a possible total of 12 errors), the better the quality of the radiograph. Subcategories where created for further classification; radiographs with five or more errors were characterised as ’poorly diagnostic’. Those with four or less errors (but not perfect) were placed in the ‘diagnostic’ category, and those with no errors were categorised as ‘perfect’.

Table 4. 10 Summary of the overall number of errors and those in each phase, and categorising frequency of each level of quantity of errors, overall and for each phase

	Overall		Phase 1		Phase 2		Phase 3	
n(radiographs)	**966**		**307**		**318**		**341**	
Number of errors	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
0 (perfect)	183/966	18,9	53/307	17,3	40/318	12,6	90/341	26,4
1	307/966	31,8	93/307	30,3	83/318	26,1	131/341	38,4
2	237/966	24,5	73/307	23,8	87/318	27,4	77/341	22,6
3	115/966	11,9	58/307	18,9	35/318	11,0	22/341	6,5
4	44/966	4,6	18/307	5,9	12/318	3,8	14/341	4,1
5	16/966	1,7	4/307	1,3	9/318	2,8	3/341	0,9
6	28/966	2,9	6/307	2,0	20/318	6,3	2/341	0,6
7	15/966	1,6	1/307	0,3	12/318	3,8	2/341	0,6
8	14/966	1,4	0/307	0,0	14/318	4,4	0/341	0,0
9	5/966	0,5	0/307	0,0	5/318	1,6	0/341	0,0
10	1/966	0,1	0/307	0,0	1/318	0,3	0/341	0,0
11	1/966	0,1	1/307	0,3	0/318	0,0	0/341	0,0
5 or more errors (poorly diagnostic)	80/966	8,3	12/307	3,9	61/318	19,2	7/341	2,1
1-4 errors (diagnostic)	703/966	72,8	242/307	78,8	217/318	68,2	244/341	71,6
Any error	783/966	81,1	254/307	82,7	278/318	87,4	251/341	73,6

Overall, 183 out of the 966 (18.9%) radiographs included in the study had a ‘perfect’ score, i.e. they did not have any errors. The phase with the lowest number of radiographs with the perfect score was phase 2 (12.6%), and the phase with the highest number of perfect scores was phase 3 (26.4%). The majority of the radiographs reviewed in the study were of ‘diagnostic’ quality (72.8%), i.e. less that 4 errors but not ‘perfect’. Within the phases, phase 1 had the highest number of ‘diagnostic’ radiographs (78.8%) and phase 2 had the lowest number (68.2%). The ‘poorly diagnostic’ radiographs which had more than five errors identified constituted 8.3% (80/966) of the radiographs. The phase which had the most number of ‘poorly diagnostic’ quality radiographs was phase 2 where 19.2% (61/318) of the radiographs fell into this category.

We then looked at the error rate at each of the individual hospitals. These are shown in Tables 4.11, 4.12 and 4.13.

Table 4. 11 Summary of the overall number of errors in each phase as well as the prevalence of a specific number of errors per each radiograph overall and for each phase of the study at CHBAH

	CHBAH					
	Phase 1		Phase 2		Phase 3	
n(radiographs)	**79**		**81**		**120**	
Number of errors	**n**	**%**	**n**	**%**	**n**	**%**
1	22/79	27,8	5/81	6,2	48/120	40,0
2	14/79	17,7	8/81	9,9	34/120	28,3
3	19/79	24,1	6/81	7,4	7/120	5,8
4	9/79	11,4	6/81	7,4	7/120	5,8
5	1/79	1,3	4/81	4,9	2/120	1,7
6	5/79	6,3	20/81	24,7	2/120	1,7
7	1/79	1,3	11/81	13,6	1/120	0,8
8	0/79	0,0	12/81	14,8	0/120	0,0
9	0/79	0,0	5/81	6,2	0/120	0,0
10	0/79	0,0	1/81	1,2	0/120	0,0
11	0/79	0,0	0/81	0,0	0/120	0,0
5 or more errors (poorly diagnostic)	7/79	8.9	53/81	65.4	5/120	4.2
1-4 errors (diagnostic)	64/79	81	25/81	30.9	96/120	80
0 (perfect)	8/79	10.1	3/81	3.7	19/120	**15.8**
High quality radiographs (diagnostic + perfect)	72/79	91.1	28/81	34.6	115/120	**95.8**
Any errors	71/79	89,9	78/81	96,3	101/120	**84,2**

CHBAH had the highest number of ‘perfect’ scores in phase 3 (15.8%) and the lowest in phase 2 (3.7%). Eighty percent or more of the radiographs reviewed in phase 1 and phase 3 had between 1–4 errors and therefore fell into the ‘diagnostic’ category. Phase 2 had the most errors with 65.4% of radiographs

having five or more errors ('poorly diagnostic'). The highest number of errors identified on a single radiograph was 10 from phase 2.

Table 4. 12 Summary of the overall number of errors in each phase as well as the prevalence of a specific number of errors per each radiograph overall and for each phase of the study at RMMCH

	RMMCH					
	Phase 1		Phase 2		Phase 3	
n(radiographs)	**115**		**120**		**118**	
Number of errors	**n**	**%**	**n**	**%**	**n**	**%**
1	43/115	37,4	40/120	33,3	50/118	42,4
2	21/115	18,3	36/120	30,0	16/118	13,6
3	14/115	12,2	14/120	11,7	5/118	4,2
4	1/115	0,9	3/120	2,5	3/118	2,5
5	0/115	0,0	1/120	0,8	0/118	0,0
6	0/115	0,0	0/120	0,0	0/118	0,0
7	0/115	0,0	0/120	0,0	0/118	0,0
8	0/115	0,0	0/120	0,0	0/118	0,0
9	0/115	0,0	0/120	0,0	0/118	0,0
10	0/115	0,0	0/120	0,0	0/118	0,0
11	1/115	0,9	0/120	0,0	0/118	0,0
5 or more errors (poorly diagnostic)	1/115	0,9	1/120	0,8	0/118	0,0
1-4 errors (diagnostic)	79/115	68,7	93/120	77,5	74/118	62,7
0 (perfect)	35/115	30,4	26/120	21,7	44/118	**37,3**
High quality radiographs (diagnostic + perfect)	114/115	99	119/120	99.2	118/118	**100**
Any error	80/115	69,6	94/120	78,3	74/118	62,7

RMMCH had the highest number of 'perfect' scores compared to the other centres. In phase 1, 35/115 radiographs (30.4%) had a 'perfect' score. This decreased to 21.7% (26/120) in phase 2, and increased in phase 3 to 37.3% (44/118). In phase 1 there was 1 (0.9%) radiograph that had 11 errors. Most of the radiographs reviewed in all 3 phases had between 1–4 errors and therefore fell

into the ‘diagnostic’ category. Less than 1% of the radiographs had more than 5 errors in each phase of the study.

Table 4. 13 Summary of the overall number of errors in each phase as well as the prevalence of a specific number of errors per each radiograph overall and for each phase of the study at KH

	KH					
	Phase 1		Phase 2		Phase 3	
n(radiographs)	**113**		**117**		**103**	
Number of errors	**n**	**%**	**n**	**%**	**n**	**%**
1	28/113	24,8	38/117	32,5	33/103	32,0
2	38/113	33,6	43/117	36,8	27/103	26,2
3	25/113	22,1	15/117	12,8	10/103	9,7
4	8/113	7,1	3/117	2,6	4/103	3,9
5	3/113	2,7	4/117	3,4	1/103	1,0
6	1/113	0,9	0/117	0,0	0/103	0,0
7	0/113	0,0	1/117	0,9	1/103	1,0
8	0/113	0,0	2/117	1,7	0/103	0,0
9	0/113	0,0	0/117	0,0	0/103	0,0
10	0/113	0,0	0/117	0,0	0/103	0,0
11	0/113	0,0	0/117	0,0	0/103	0,0
5 or more errors (poorly diagnostic)	4/113	3,5	7/117	6,0	2/103	1,9
1-4 errors (diagnostic)	99/113	87,6	99/117	84,6	74/103	71,8
0 (perfect)	10/113	8,8	11/117	9,4	27/103	26,2
High quality radiographs (diagnostic + perfect)	109/113	96.5	110/117	94	101/103	98
Any error	103/113	91,2	106/117	90,6	76/103	73,8

KH had 27 out of 103 radiographs with ‘perfect’ scores in phase 3 (26.2%), which was the highest number in all 3 phases. The lowest number of perfectly scoring radiographs was in phase 1 (8.8%, 10/113). The majority of the radiographs (over 70%) reviewed in all 3 phases had 1–4 errors and therefore fell into the ‘diagnostic’ category. Less than 7% of all radiographs reviewed in all phases had more than five errors identified (‘poorly diagnostic’). The highest number of errors

identified on a radiograph was eight. This was found in two radiographs from phase 2 (1.7%, 2/117). The highest number of errors identified on a radiograph in phase 1 were six errors and in phase 3 were seven errors.

When combining the percentage of radiographs with no errors, i.e. 'perfect' score, and those that were of 'diagnostic' quality (1–4 errors), RMMCH was the only hospital to show continued improvement in the quality of radiographs throughout the study, with 99.1% of radiographs falling into the 0–4 errors category in stage 1, 99.2% in stage 2 and 100.0% in stage 3. Both CHBAH and KH demonstrated a decline in overall quality in phase 2. The decline in quality at KH was 1.6%, however, the decline at CHBAH was significant with a fall from 91.1% in phase 1 to 34.8% in phase 2, although the quality at CHBAH improved to 96.6% in phase 3 (Table 4.14). All three hospitals demonstrated the highest percentage of 'perfect' score and those that were of 'diagnostic' quality (1–4 errors), i.e. 'high quality' radiographs in phase 3.

Table 4. 14 Combination of the percentage of radiographs that obtained 'perfect' and 'diagnostic' scores at each centre and for each phase of the study, and a combination of these into the 'high quality category'

Phase		Centre		
		CHBAH	KH	RMMCH
1	n	79	113	115
	0 Errors (perfect) % of Phase	10.1 (8/79)	8.8 (10/113)	30.4 (35/115)
	1-4 Errors (diagnostic) % of Phase	81.0 (64/79)	87.6 (99/113)	68.7 (79/115)
	Combined 'high quality'	91.1% (72/79)	96.5% (109/113)	99.1% (114/115)
TOTAL	**%**	**(72/79) 91.1**	**(109/113) 96.4**	**(114/115) 99.1**
2	n	81	117	120
	0 Errors (perfect) % of Phase	3.7 (3/81)	9.4 (11/117)	21.7 (26/120)
	1-4 Errors (diagnostic) % of Phase	30.9 (25/81)	84.6 (99/117)	77.5 (93/120)
	Combined high quality	34.6% (28/81)	94% (110/117)	99.2% (119/120)
TOTAL	**%**	**(28/81) 34.8**	**(110/117) 94.0**	**(119/120) 99.2**
3	n	120	103	118
	0 Errors (perfect) % of Phase	15.8 (19/120)	26.2 (27/103)	37.3 (44//118)
	1-4 Errors (diagnostic) % of Phase	80.8 (96/120)	71.8 (74/103)	62.7 (74/118)
	Combined high quality	95.8% (115/120)	98% (101/103)	100% (118/118)
TOTAL	%	**(115/120) 96.6**	**(101/103) 98.0**	**(118/118) 100.0**

For each phase, comparison of all study errors between centres was performed. For each centre, comparison of all study errors between phases was performed. Please refer to Appendix C for the Tables representing the p-value.

The quality score for each radiograph was calculated as the number of quality failures/ 12 * 100. The range of the quality score was thus 0–100%. The median of the quality score overall was 8% (IQR 8–16%; range 0–92%). Figure 4.15 demonstrates the distribution of the quality score overall – just over 50% of the radiographs fell into the 0–10% quality score and over 70% or the radiographs were in the 0–20% quality score. The median was more representative of the outcomes and was the preferred measure of central tendency as the distribution of

the data was skewed (Figure 4.5). The distribution of the data is depicted in Table 4.15.

Table 4. 15 The mean and median quality score overall and in each centre during each phase

Phase	Centre	N	Mean	Std Dev	Median	Interquartile range		Minimum	Maximum
Overall		966	15,8	15,1	8,3	8,3	16,7	0,0	91,7
	CHBAH	280	24,1	20,3	16,7	8,3	33,3	0,0	83,3
	RMMCH	353	10,0	9,7	8,3	0,0	16,7	0,0	91,7
	KH	333	15,0	11,2	16,7	8,3	16,7	0,0	66,7
1		307	15,2	12,3	16,7	8,3	25,0	0,0	91,7
2		318	21,6	19,4	16,7	8,3	25,0	0,0	83,3
3		341	10,9	10,3	**8,3**	0,0	16,7	0,0	58,3
1	**CHBAH**	79	19,5	13,8	16,7	8,3	25,0	0,0	58,3
1	**RMMCH**	115	10,3	11,4	8,3	0,0	16,7	0,0	91,7
1	**KH**	113	17,1	10,2	16,7	8,3	25,0	0,0	50,0
2	**CHBAH**	81	44,3	21,4	50,0	25,0	58,3	0,0	83,3
2	**RMMCH**	120	11,9	9,0	8,3	8,3	16,7	0,0	41,7
2	**KH**	117	16,0	12,0	16,7	8,3	16,7	0,0	66,7
3	**CHBAH**	120	13,5	11,2	**8,3**	8,3	16,7	0,0	58,3
3	**RMMCH**	118	7,7	7,9	**8,3**	0,0	8,3	0,0	33,3
3	**KH**	103	11,7	10,6	**8,3**	0,0	16,7	0,0	58,3

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

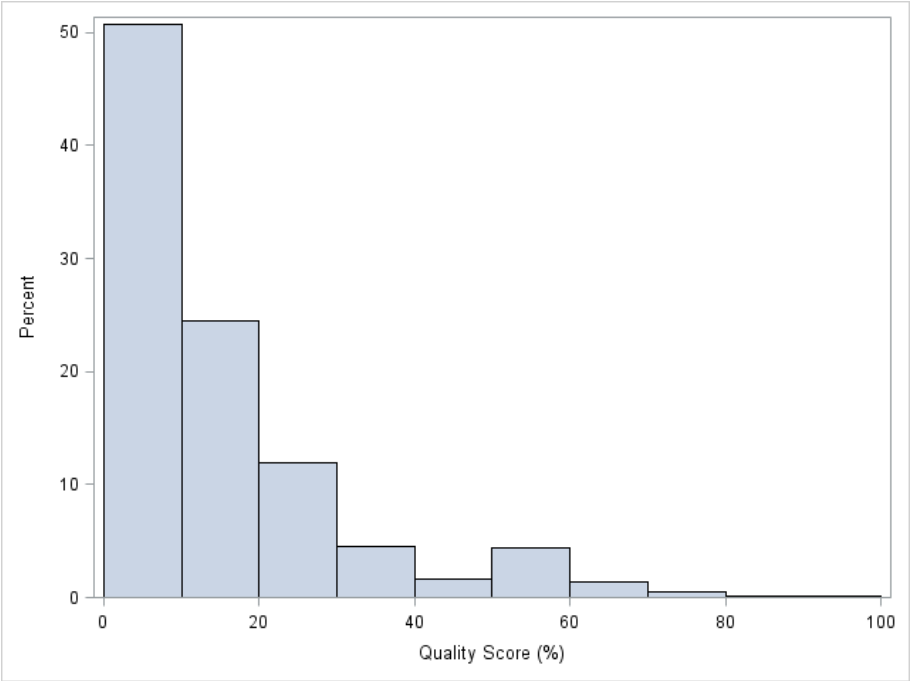


Figure 4. 5 Distribution of the quality score overall

Figure 4.6 and Table 4.15 demonstrate the comparison of the median scores during each phase and among hospitals for each of the 3 hospitals.

Within phase 2, the median quality score decreased in the order CHBAH > KH > RMMCH. Within phases 1 and 3, the median quality score percentages at CHBAH and KH was higher than that at RMMCH (Table 4.15). The median quality score remained unchanged at KH in phases 1 and 2 (16.7%), and stable throughout all 3 phases at RMMCH (8.3%). The highest median quality score percentage was at CHBAH in phase 2 (50%).

At CHBAH, the median quality score decreased in the order phase 2 (50%) > phase 1 (16.7%) > phase 3 (8.3%). At CHBAH there was a statistically significant increase in the median score between phase 1 and 2 ($p<0.0001$) and a statistically significant decrease in the median error rate between phase 1 and 3 ($p=0.0011$) and phase 2 and 3 ($p=<0.0001$) . For KH, the median quality score was lower in phase 3 (8.3%) compared to phases 1 (16.7%) and 2 (16.7%), and the change was statistically significant. There was a statistically significant decrease in the median quality score between phases 1 and 3 ($p=<0.0001$) and phases 2 and 3 ($p=0.0038$) at KH.

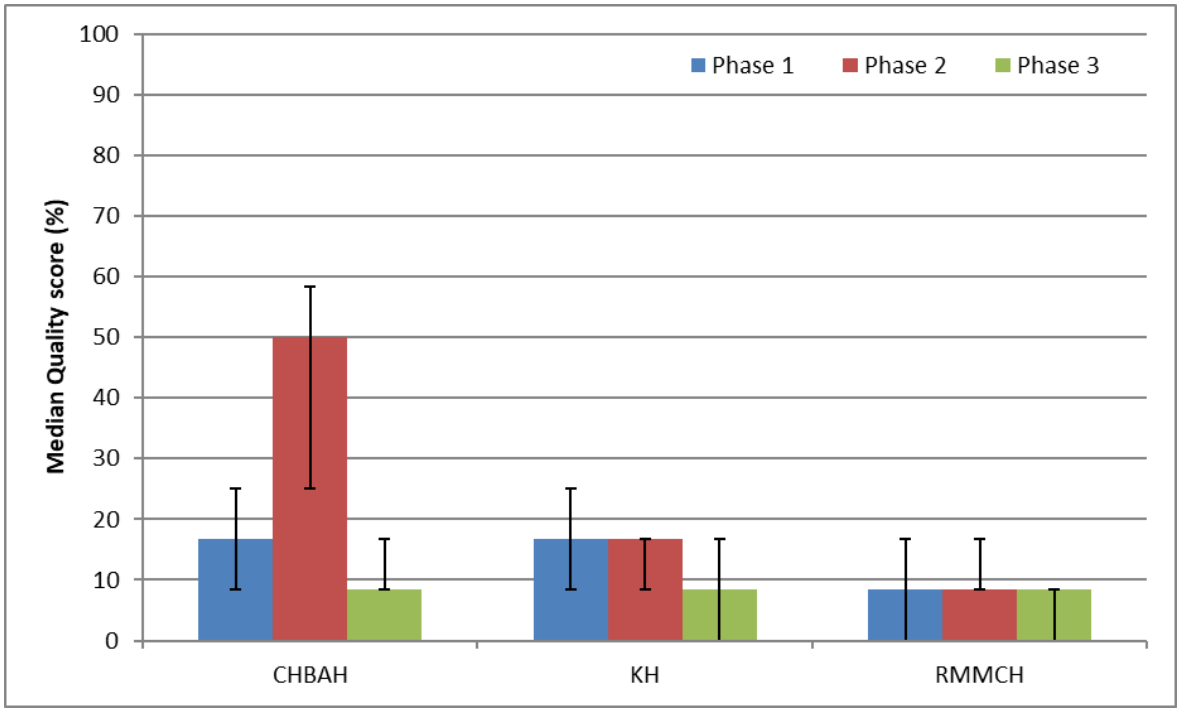


Figure 4. 6 The median quality score at each centre, during each phase of the study.

Error bars denote the IQR.
KEY: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

4.5 The prevalence of each type of error at each centre during each phase

We calculated the prevalence of each of the 12 quality factors/variables overall and also by phase and hospital. These are summarised below.

4.5.1 Variable (1) – Parts cut off

The number of radiographs with the quality error '*parts cut off*' overall, at each centre, during each phase and expressed as a percentage of the total number of radiographs reviewed during each phase is shown in Table 4.16.

Table 4. 16 The number of radiographs with the quality error '*parts cut off*' overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with '*parts cut off*'	
			n	%
Overall		966	13/966	1,3
1	all	307	6/307	2,0
2	all	318	2/318	0,6
3	all	341	5/341	1,5
all	CHBAH	280	6/280	2,1
all	RMMCH	353	1/353	0,3
all	KH	333	6/333	1,8
1	CHBAH	79	3/79	3,8
1	RMMCH	115	1/115	0,9
1	KH	113	2/113	1,8
2	CHBAH	81	2/81	2,5
2	RMMCH	120	0/120	0,0
2	KH	117	0/117	0,0
3	CHBAH	120	1/120	0,8
3	RMMCH	118	0/118	0,0
3	KH	103	4/103	3,9

KEY: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'parts cut off'* was one of the least common errors in the study and was identified in less than 4% of radiographs in all 3 hospitals throughout all 3 phases of the study. Chris Hani Baragwanath Academic Hospital (2.1%) and KH (1.8%) both had a total of 6 cases which demonstrated the error '*parts cut off',* The most number or radiographs with the error *'parts cut off'* were identified at CHBAH in phase 1 (3.8%, 3/79), and at KH in phase 3 (3.9%, (4/103). RMMCH only had this error identified on a single radiograph in phase 1 (0.3%; 1/353).

The number of radiographs with the quality error '*parts cut off*' at each centre, expressed as a proportion of the total number of radiographs reviewed during each phase, is shown in Figure 4.7.

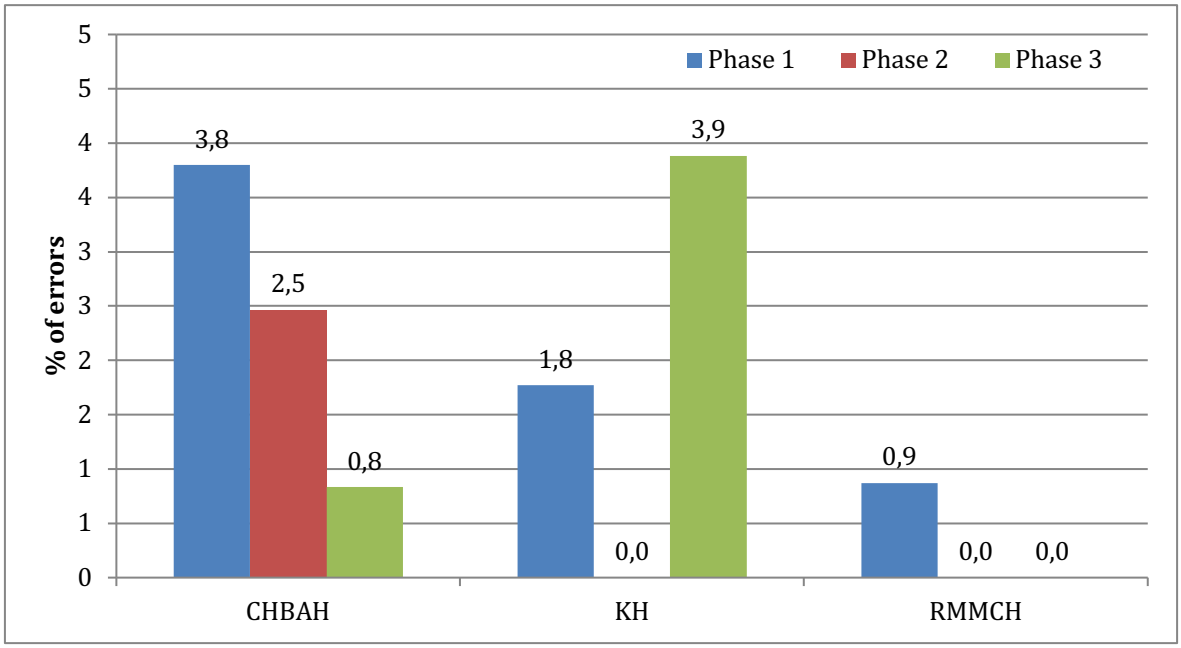


Figure 4. 7 Proportional representation of the quality error *'parts cut off'* at each centre during each phase of the study

The proportion of the '*parts cut off*' error was significantly higher in KH in phase 3 as compared to phase 2 (p=0.047). There was no statistically significant difference in this error rate between phases for CHBAH and RMMCH. KH achieved zero '*parts cut off*' errors in phase 2 and RMMCH achieved this in both phases 2 and 3. Within Phase 3, the proportional percentage of '*parts cut off*' errors was significantly higher in KH compared to RMMCH (p=0.046).

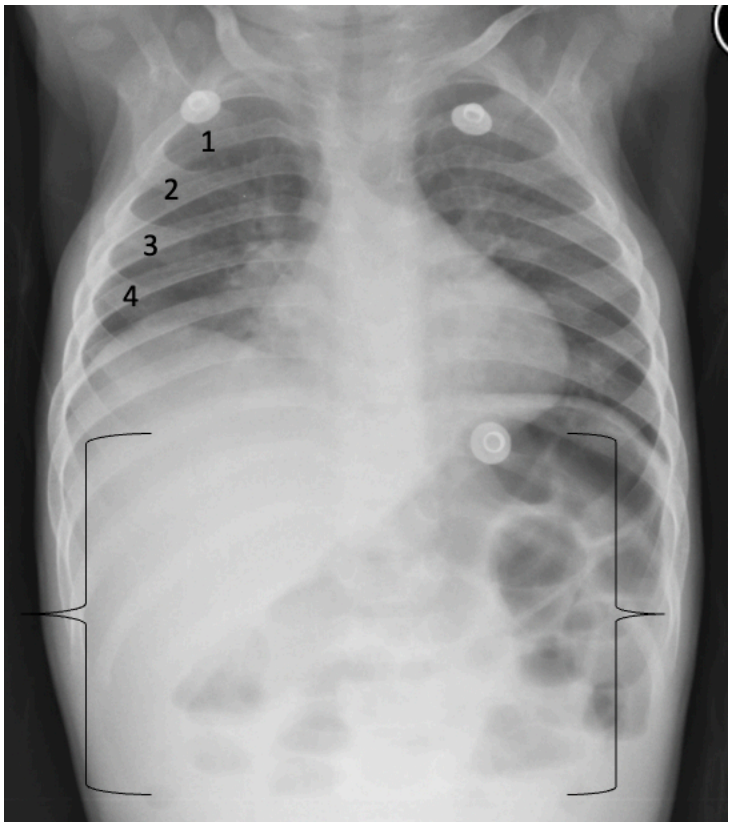


Figure 4. 8 The radiograph demonstrates several image quality errors including 'poor collimation' (brackets) and 'under-inspiration' as only the 4th anterior rib is seen above right hemi-diaphragm

4.5.2 Variable (2) – Under-inspiration

The number of radiographs with the quality error '*under-inspiration'* overall at each centre during each phase and expressed as a percentage of the total number of radiographs reviewed during each phase, is shown in Table 4.17.

Table 4. 17 The number and proportion of radiographs with the quality error '*under-inspiration'* overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with *'under-inspiration'*	
			n	%
Overall		966	187/966	19,4
1	all	307	54/307	17,6
2	all	318	67/318	21,1
3	all	341	66/234	19,4
all	CHBAH	280	65/280	23,2
all	RMMCH	353	54/353	15,3
all	KH	333	68/333	20,4
1	CHBAH	79	12/79	15,2
1	RMMCH	115	14/115	12,2
1	KH	113	28/113	24,8
2	CHBAH	81	27/81	33,3
2	RMMCH	120	21/120	17,5
2	KH	117	19/117	16,2
3	CHBAH	120	26/120	21,7
3	RMMCH	118	19/118	16,1
3	KH	103	21/103	20,4

KEY: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

Overall the error '*under-inspiration'* was identified in a total of 187 (19.4%) radiographs. The error was most commonly identified in phase 2 where 67/318 radiographs (21.1%) demonstrated the error. The error was most prevalent at CHBAH where it was identified in 23.2% (65/280) of all the radiographs.

The proportion of the error '*under-inspiration'* at each centre and during each phase is shown in Figure 4.9.

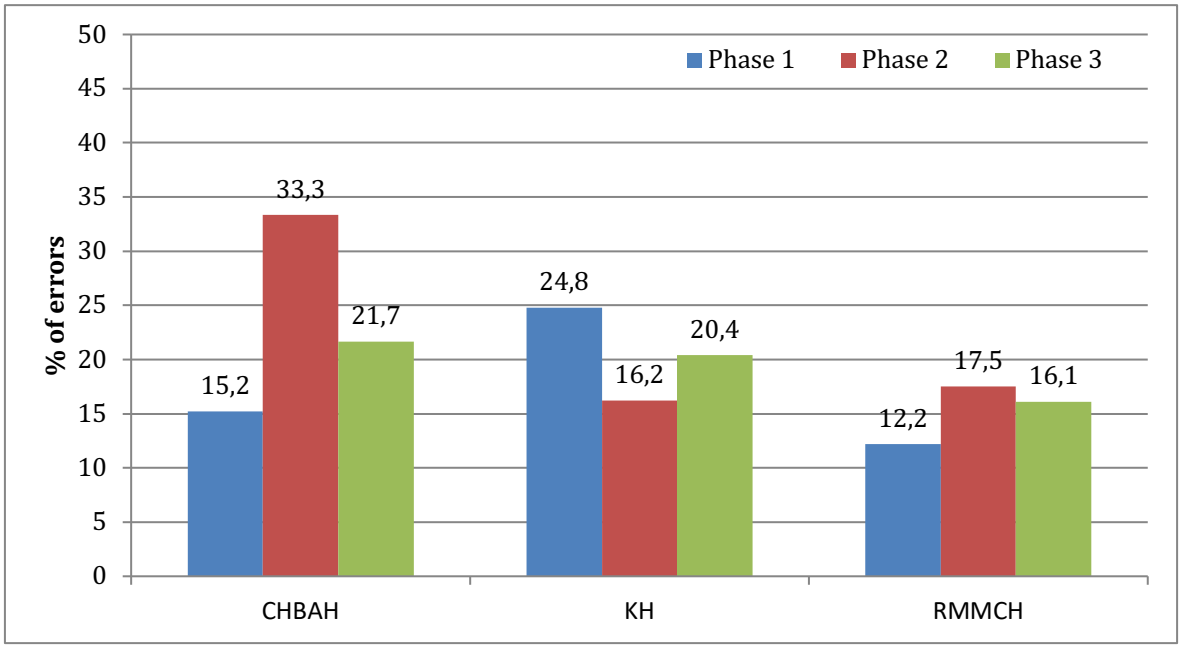


Figure 4. 9 Proportion of the quality error '*under-inspiration*' at each centre during each phase of the study.

Within Phase 1, the proportional of the '*under-inspiration*' error was significantly higher at KH compared to RMMCH. Within phase 1, the proportional of the '*under-inspiration*' error was highest at KH, where it was identified in 28 out of the 113 (24.8%) radiographs. RMMCH had the lowest proportion of the '*under-inspiration*' error (12.2%) in phase 1. Within Phase 2, the proportional of the '*under-inspiration*' error was significantly higher at CHBAH compared to KH and RMMCH. For CHBAH, the percentage of the '*under-inspiration*' error was significantly higher in phase 2 (p=0097) compared to phase 1. In phase 2 at CHBAH the '*under-inspiration*' error was as identified in one third of the radiographs (33.3%) – more than double the error rate in phase 1 (15.2%). RMMCH also demonstrated an increase in the proportion of the '*under-inspiration*' error in phase 2 (17.5%) compared to phase 1 (12.2%). There was a steady increase in the proportion of the '*under-inspiration*' error at RMMCH. For KH the proportion of the '*under-inspiration*' error decreased (from 24.8% to 16.2%) from phase 1 to phase 2, and increased again in phase 3 (20.4%). There was no significant change in the proportion of the '*under-inspiration*' error at KH and RMMCH between phases.

Figure 4.8 demonstrates an under-inspired chest radiograph.

4.5.3 Variable (3) – Rotation

The number of radiographs with the quality error '*rotation'* overall at each centre during each phase, and expressed as a percentage of the total number of radiographs reviewed during each phase is shown in Table 4.18

Table 4. 18 The number of radiographs with the quality error '*rotation'* overall at each centre and during each phase

Phase	Centre	Total number of cases	Cases with *'rotation'*	
			n	%
Overall		966	335/966	34,7
1	all	307	109/307	35,5
2	all	318	131/318	41,2
3	all	341	95/341	27,9
all	CHBAH	280	137/280	48,9
all	KH	333	116/333	34,8
all	RMMCH	353	82/353	23,2
1	CHBAH	79	39/79	49,4
1	KH	113	45/113	39,8
1	RMMCH	115	25/115	21,7
2	CHBAH	81	57/81	70,4
2	KH	117	44/117	37,6
2	RMMCH	120	30/120	25,0
3	CHBAH	120	41/120	34,2
3	KH	103	27/103	26,2
3	RMMCH	118	27/118	22,9

KEY: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

Rotation was the second most common error identified throughout the study with a total of 335/966 (34.7%) radiographs demonstrating this error. For CHBAH, the proportion of '*rotation'* was highest in phase 2 where 57/81 (70.2%) of the radiographs demonstrated the error; the error was identified less commonly in phase 3 (41/120, 34.2%).

Figure 4.10 below compares the proportion of '*rotation'* errors between the 3 hospitals and phases.

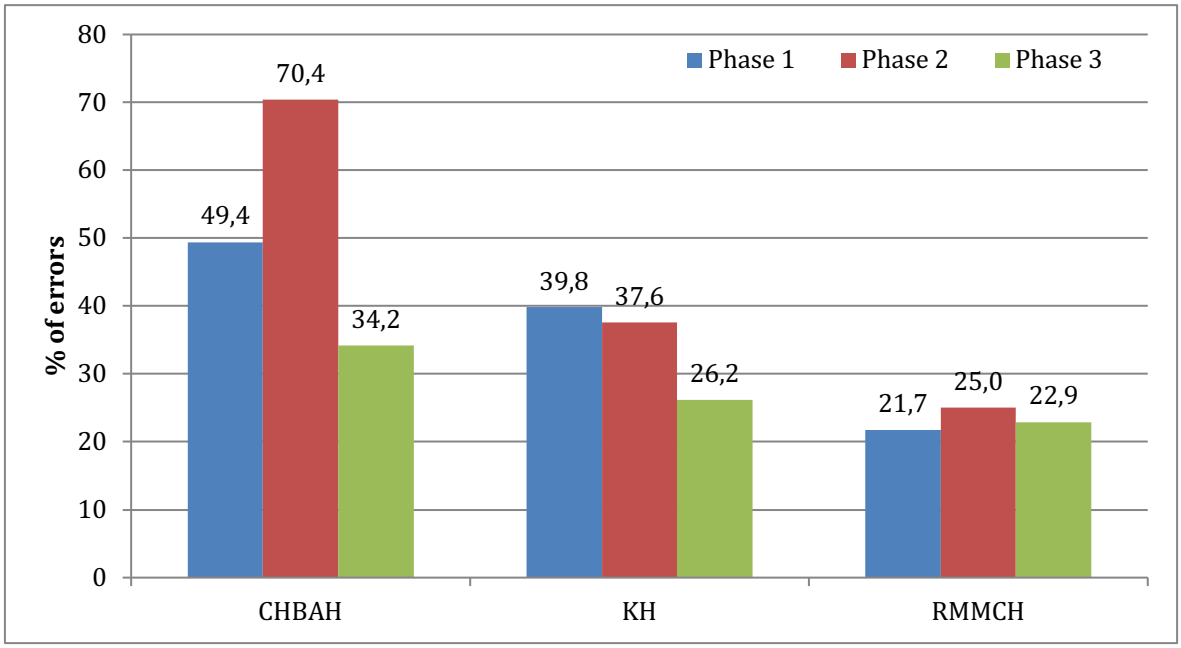


Figure 4. 10 Proportion of the quality error '*rotation'* at each centre during each phase of the study.

In phase 1, the proportion of *'rotation'* at CHBAH (49.4%) and KH (39.8%) was higher than at RMMCH (21.7%). In Phase 2, CHBAH and RMMCH had an increase in the proportion of errors, which was statistically significant at CHBAH (p=0.0096). At KH there was a steady decline in the error rate, which was statistically significant between phases 1 and 3 (p=0.043).

Figure 4.11 below demonstrates an example of a rotated radiograph.

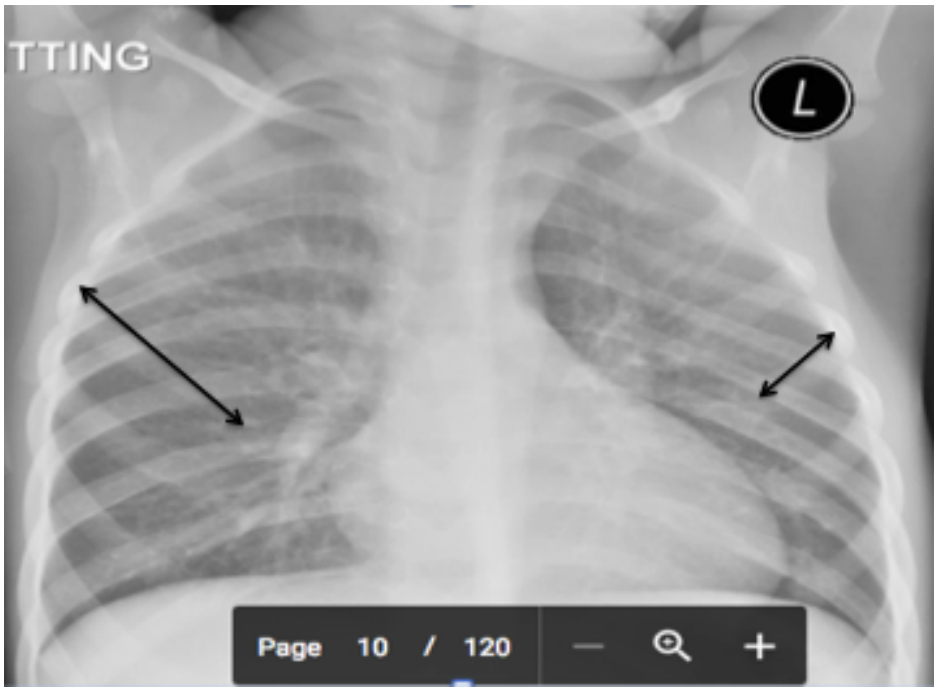


Figure 4. 11 The chest radiograph demonstrates the quality error of 'rotation'; there is asymmetry of the lengths of the anterior ribs (see arrows) with the right ribs being longer than the left, indicating that the patient is rotated to the left

4.5.4 Variable (4) – Scapula in the way

The number of radiographs with the quality error '*scapula in the way'* overall at each centre during each phase, and expressed as a percentage of the total number of radiographs reviewed during each phase, is shown in Table 4.19

Table 4. 19 The number of radiographs with the quality error '*scapula in the way'* overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with '*scapula in the way'*	
			n	%
Overall		966	374/966	38,7
1	all	307	132/307	43,0
2	all	318	132/318	41,5
3	all	341	110/341	32,3
all	CHBAH	280	111/280	39,6
all	KH	333	150/333	45,0
all	RMMCH	353	113/353	32,0
1	CHBAH	79	35/79	44,3
1	KH	113	58/113	51,3
1	RMMCH	115	39/115	33,9
2	CHBAH	81	32/81	39,5
2	KH	117	56/117	47,9
2	RMMCH	120	44/120	36,7
3	CHBAH	120	44/120	36,7
3	KH	103	36/103	35,0
3	RMMCH	118	30/118	25,4

KEY: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *' scapula in the way'* was the most common error identified throughout the study, a total of 374/966 (38.7%) radiographs demonstrated this error. At KH 45% of radiographs reviewed demonstrated this error; at CHBAH the error was identified in 39.6% (111/280); and at RMMCH it was in 32% (113/353) of the radiographs.

Figure 4.12 below compares the proportion of '*scapula in the way'* errors between the 3 hospitals and phases.

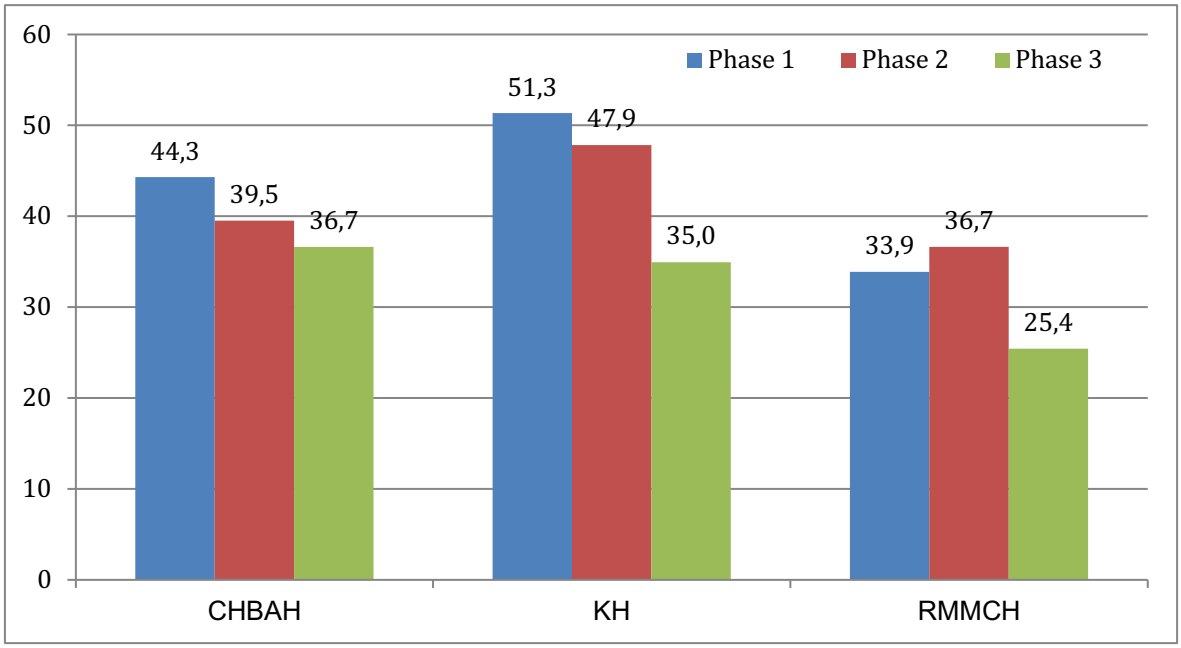


Figure 4. 12 Proportion of the quality error 'scapula in the way' at each centre during each phase of the study.

In phase 1, the proportion of '*scapula in the way'* errors at KH (51.3%, 58/113) was higher than at RMMCH (33.9%, 39/115) and CHBAH (39.5%, 39/115). There was a steady decrease in the proportion of *'scapula in the way'* over the three phases at CHBAH and KH, however, the change was not statistically significant. For KH, the proportion of errors was significantly lower (p=0.019) in phase 3 (35%) compared to phase 1. RMMCH had a mild increase in the proportion of '*scapula in the way'* errors in phase 2 (33.9% in phase 1 to 36.7% in phase 2), and there was a decrease in the proportional error rate in phase 3 (25.4%). However, the difference in the error rate between phases was not statistically significant. The proportion of '*scapula in the way'* errors achieved (25.4%, 30/118)) was at the RMMCH in phase 3.

Figure 4.13 below demonstrates an example of a radiograph with the scapula projecting over the left lung.

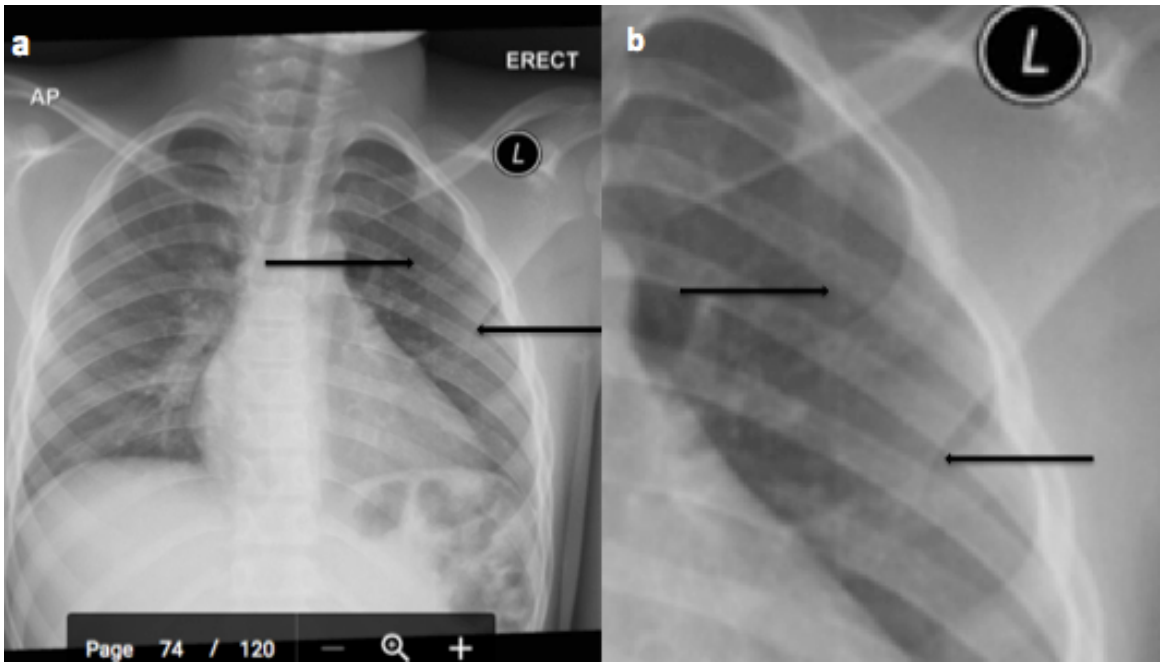


Figure 4. 13 (a and b). Chest radiograph demonstrating a routine projection (a) and a magnified view (b) of the left scapula (see arrows) projecting over more than 1cm of the peripheral aspect of the radiograph. This can lead to the misinterpretation, including mimicking the presence of a pneumothorax.

4.5.5 Variable (5) – Kyphotic/lordotic

The number of radiographs with the quality error '*patient kyphosis/lordosis'* overall at each centre during each phase and expressed as a percentage of the total number of radiographs reviewed during each phase, is shown in Table 4.20.

Table 4. 20 The number of radiographs with the quality error '*patient kyphosis/lordosis'* overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with '*patient kyphosis/lordosis'*	
			n	%
Overall		966	88/966	9,1
1	all	307	24/307	7,8
2	all	318	41/318	12,9
3	all	341	23/341	6,7
all	CHBAH	280	40/280	14,3
all	RMMCH	353	27/353	7,6
all	KH	333	21/333	6,3
1	CHBAH	79	9/79	11,4
1	RMMCH	115	9/115	7,8
1	KH	113	6/113	5,3
2	CHBAH	81	21/81	25,9
2	RMMCH	120	9/120	7,5
2	KH	117	11/117	9,4
3	CHBAH	120	10/120	8,3
3	RMMCH	118	9/118	7,6
3	KH	103	4/103	3,9

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'patient kyphosis/lordosis'* was identified in 9.1% (88/966) of all the radiographs reviewed. The highest number of radiographs with the error was identified during phase 2 (12.9%, 41/318). Overall the error rate was highest at CHBAH (14.3%, 40/280) and lowest at KH (6.3%, 21/333).

The proportion of the error *'patient kyphosis/lordosis'* at each hospital and during each phase is shown in Figure 4.14 below.

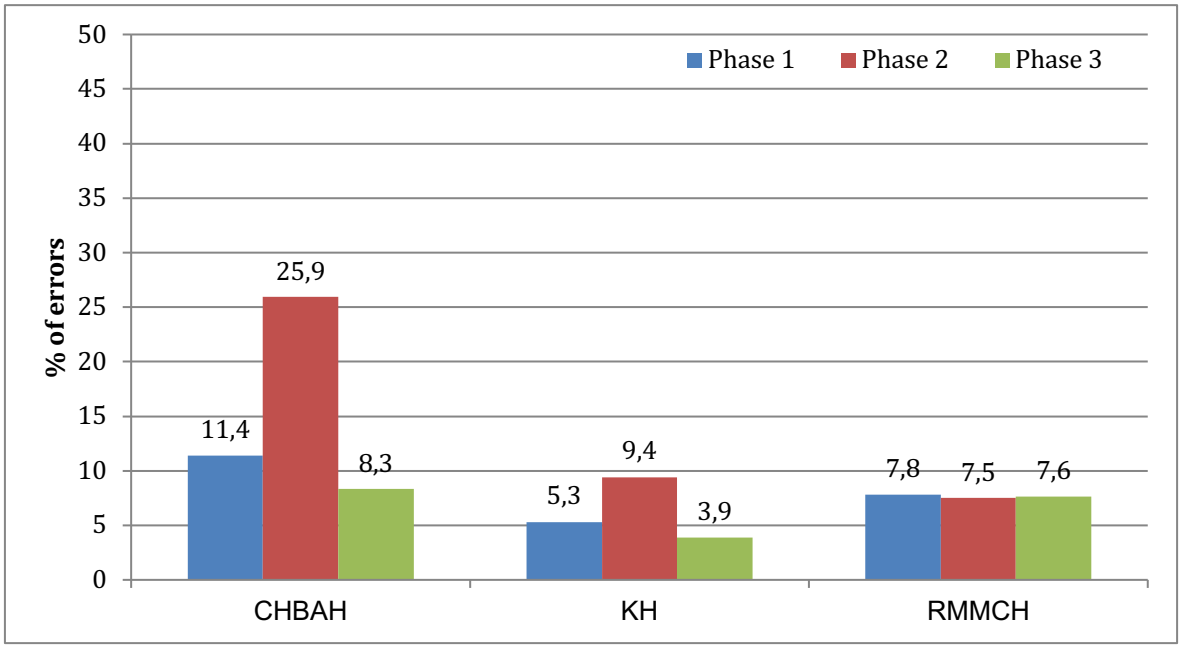


Figure 4. 14 Proportion of the quality error *'patient kyphosis/lordosis'* at each centre, during each phase of the study.

Within phase 2, the proportion of errors was significantly higher at CHBAH compared to RMMCH (p=0.0005) and KH (p=0.0029). For CHBAH there was a statistically significant increase in the proportional percentage error rate between phases 1 and 2 (p=0.025) and a statistically significant decrease (improvement) in the error rate between phases 2 and 3 (p=0.0012). At KH there was a mild increase in the error rate in phase 2 (to 9.4%;11/117 from 5.3%; 6/113) compared to phase 1. The lowest error rate was at KH in stage 3 (3.9%, 4/103). There was no statistically significant change in the proportion of '*patient kyphosis/lordosis'* between phases at RMMCH and KH.

Figure 4.15 below demonstrates an example of a lordotic chest radiograph.

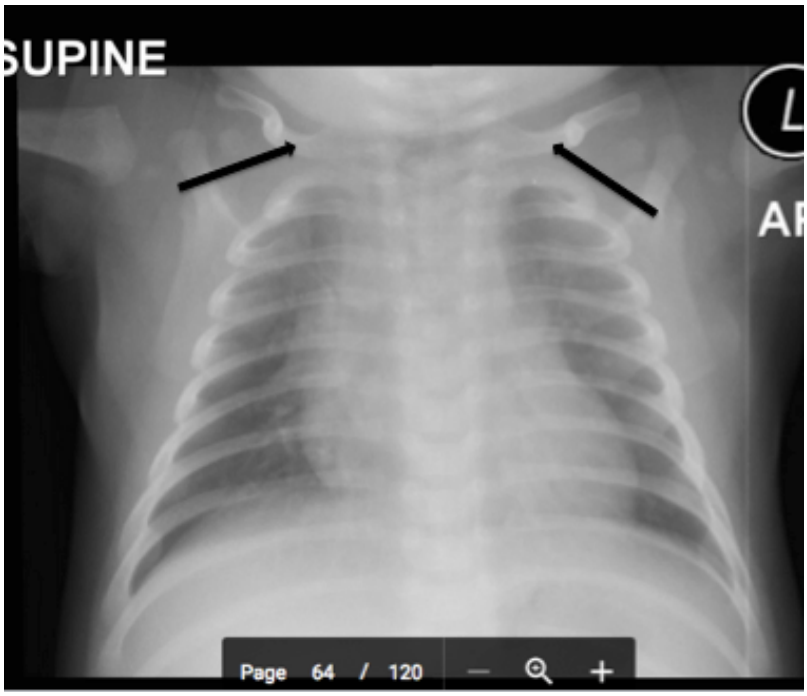


Figure 4. 15 Chest radiograph demonstrating a lordotic view with cranial positioning of the clavicles at the level of the C7/T1 (see arrows) vertebral bodies and horizontal ribs

4.5.6 Variable (6) – Artefact/foreign body

The number of radiographs with the quality error '*artefact/foreign body'* overall at each centre during each phase and expressed as a percentage of the total number of radiographs reviewed during each phase, is shown in Table 4.21.

Table 4. 21 The number of radiographs with the quality error '*artefact/foreign body'* overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with '*artefact/foreign body'*	
			n	%
Overall		966	98/966	10,1
1	all	307	21/307	6,8
2	all	318	55/318	17,3
3	all	341	22/341	6,5
all	CHBAH	280	65/280	23,2
all	RMMCH	353	12/353	3,4
all	KH	333	21/333	6,3
1	CHBAH	79	7/79	8,9
1	RMMCH	115	6/115	5,2
1	KH	113	8/113	7,1
2	CHBAH	81	45/81	55,6
2	RMMCH	120	4/120	3,3
2	KH	117	6/117	5,1
3	CHBAH	120	13/120	10,8
3	RMMCH	118	2/118	1,7
3	KH	103	7/103	6,8

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'artefact/foreign body'* was identified in 10.1% (98/966) of all the radiographs reviewed. Overall the error rate was highest at CHBAH (23.2%, 65/280) and lowest at RMMCH (3.4%, 12/353). The highest proportion of radiographs demonstrating '*artefact/foreign body'* was during phase 2 (17.3%, 55/318).

The proportion of the error '*artefact/foreign body'* at each hospital and during each phase is shown in Figure 4.16.

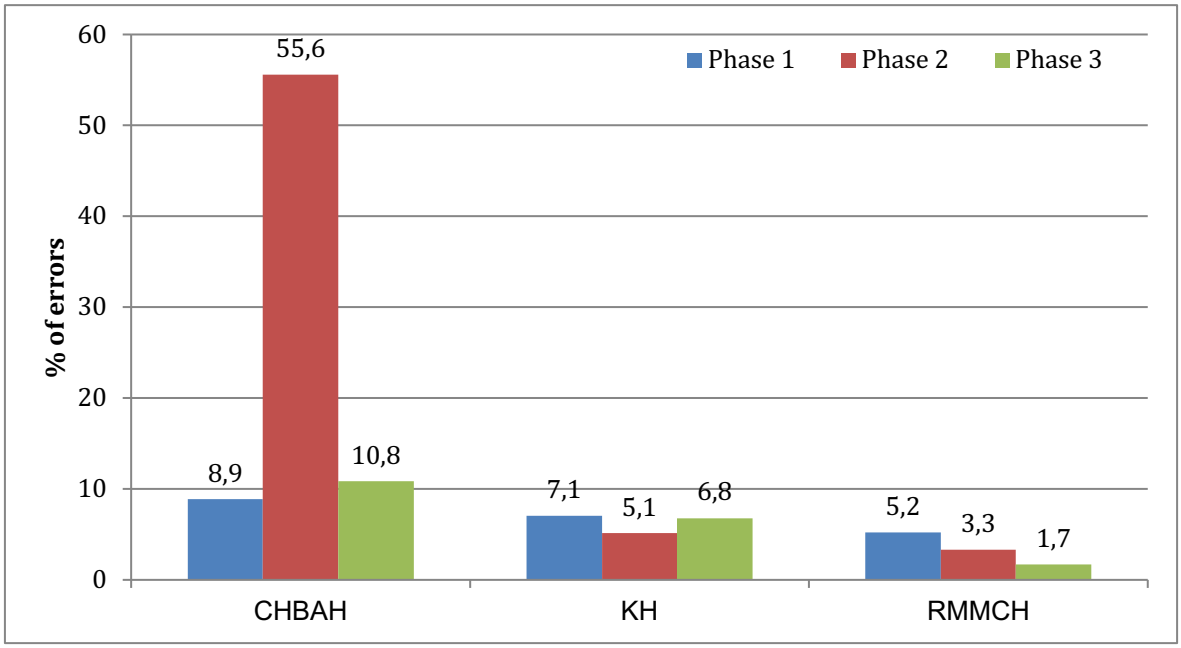


Figure 4. 16 Proportional percentage of the quality error *'artefact/foreign body'* at each centre, during each phase of the study

Within phase 2, the proportion of '*artefact/foreign body'* errors was significantly higher for CHBAH compared to KH (<0.0001) and RMMCH (<0.0001). There was also a statistically significant increase in the proportion of this error at CHBAH in phase 2 (p<0.0001), and a statistically significant decrease in the error percentage (p<0.0001) between phases 2 and 3. There was a steady decline in the proportional percentage of errors at RMMCH in the three phases. This, however, was not statistically significant. At KH there was a small decrease in the proportional percentage error in phase 2. RMMCH had the lowest proportional percentage in phase 3 where only 2 out of 118 (1.7%) radiographs had artifacts or foreign bodies identified. Common foreign bodies included the presence of tubing and electrodes on the radiograph. There were also traditional beads around the necks of patients. This is commonly worn to ward off 'evil spirits' and cannot be removed in fear of inciting anger from the ancestors (Figure 4.17). Common artifacts included linear artifacts from detectors Figure 4.17) and overlying bedding/clothing.

Figure 4.17 The radiographs below demonstrate various artefacts identified on the radiographs included in the study.

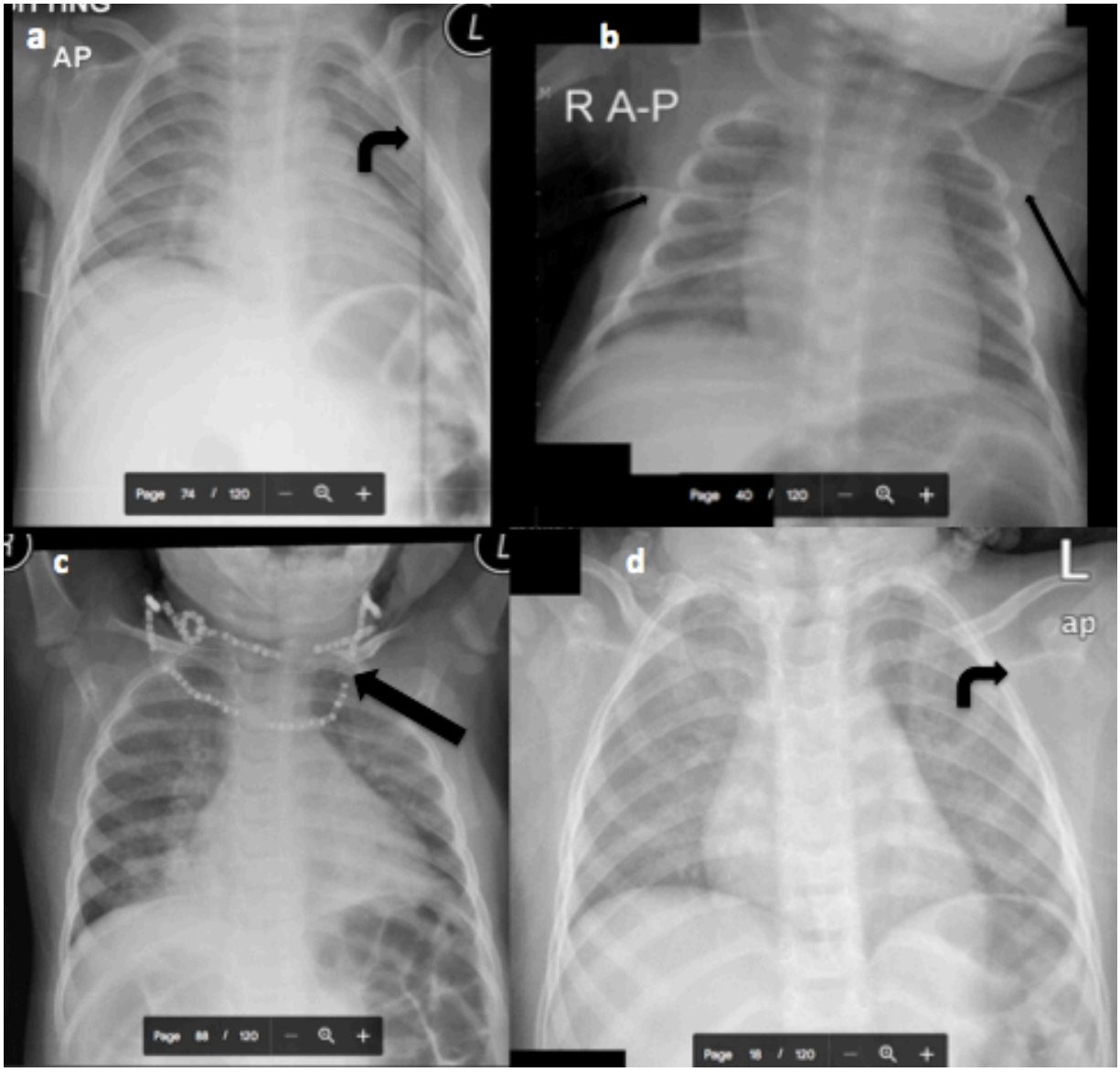


Figure 4. 17 (a,b,c and d). Different artefacts identified on chest radiographs reviewed in the study; Images (a) demonstrates linear artefact from the detectors used (curved arrow top row). Image (b) demonstrates artefact from the patient's bedding/clothing (thin arrow) and (c) shows artefact from beads hanging around the patient's neck (thick arrow). These are often worn to ward off 'evil'.
(d) Demonstrating another example of linear artefact likely arising from the detector (curved arrow bottom row).

4.5.7 Variable (7) – Central vessels not well seen

The number of radiographs with the quality error *'central vessels not well seen'* overall at each centre during each phase and expressed as a percentage of the total number of radiographs reviewed during each phase is shown in Table 4.22.

Table 4. 22 The number of radiographs with the quality error *'central vessels not well seen'* overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with *'central vessels not well seen'*	
			n	%
Overall		966	64/966	6,6
1	all	307	7/307	2,3
2	all	318	49/318	15,4
3	all	341	8/341	2,3
all	CHBAH	280	53/280	18,9
all	RMMCH	353	4/353	1,1
all	KH	333	7/333	2,1
1	CHBAH	79	4/79	5,1
1	RMMCH	115	2/115	1,7
1	KH	113	1/113	0,9
2	CHBAH	81	44/81	54,3
2	RMMCH	120	1/120	0,8
2	KH	117	4/117	3,4
3	CHBAH	120	5/120	4,2
3	RMMCH	118	1/118	0,8
3	KH	103	2/103	1,9

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'central vessels not well seen'* was the third least common error and was identified in 6.6% (64/966) of all the radiographs reviewed. Overall the error rate was highest at CHBAH (18.9%, 53/280) and lowest at RMMCH (1.1%, 4/353). The highest number of radiographs demonstrating the error overall were identified in phase 2 (15.4%, 49/318) and the lowest in phase 3 (2.3%, 8/341).

The proportion of the error *'central vessels not well seen'* at each centre and during each phase is shown in Figure 4.18.

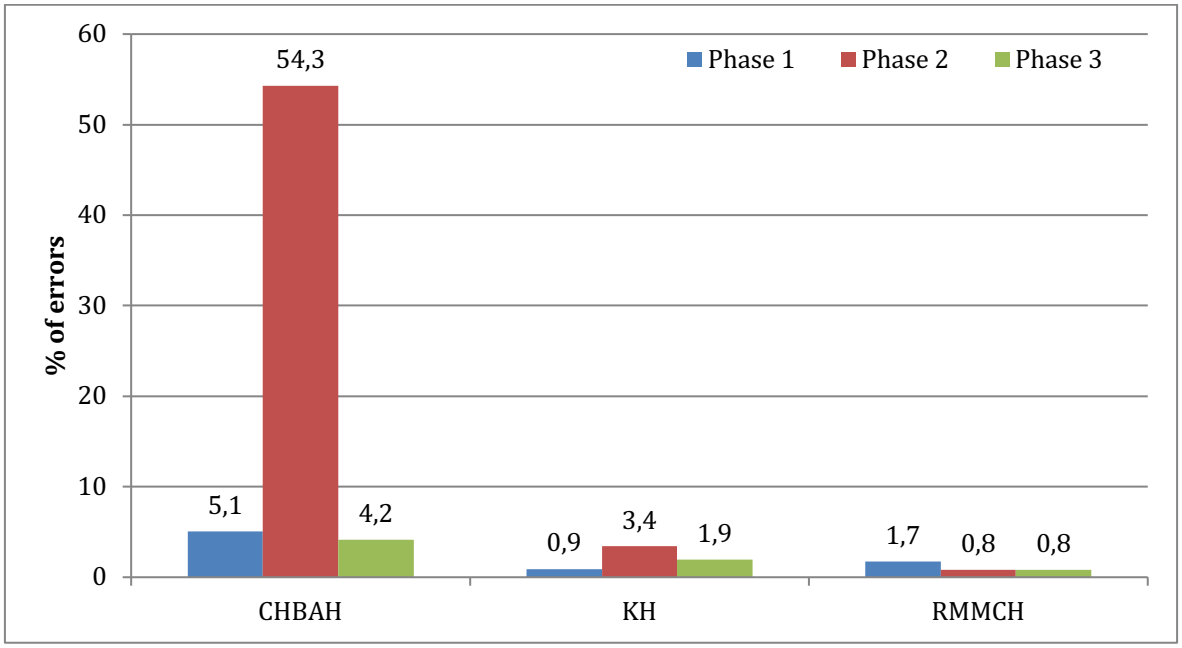


Figure 4. 18 Proportion of the quality error 'central vessels not well seen' at each centre during each phase of the study.

Within phase 2, the proportion of *'central vessels not well seen'* was significantly higher for CHBAH than for KH ($p<0.0001$) and RMMCH ($p<0.0001$). This was mostly due to poor exposure of the radiographs resulting in challenges differentiating anatomical structures. There was a statistically significant increase in the proportion of this error at CHBAH in phase 2 ($p<0.0001$,) and a statistically significant decrease in the error percentage between phases 2 and 3 ($p<0.0001$). The proportional error at RMMCH was very low in all 3 phases, ranging from 1.7% in phase 1 to 0.8% in phases 2 and 3. At KH there was a small increase in the error percentage in phase 2 (3.4%) compared to phases 1 (0.9%) and 3 (1.9%). These changes were not statistically significant ($p=0.37$ and $p=0.69$, respectively).

Figure 4.19 below is an example of a poorly exposed chest radiograph with the *'central vessels not well seen'* .

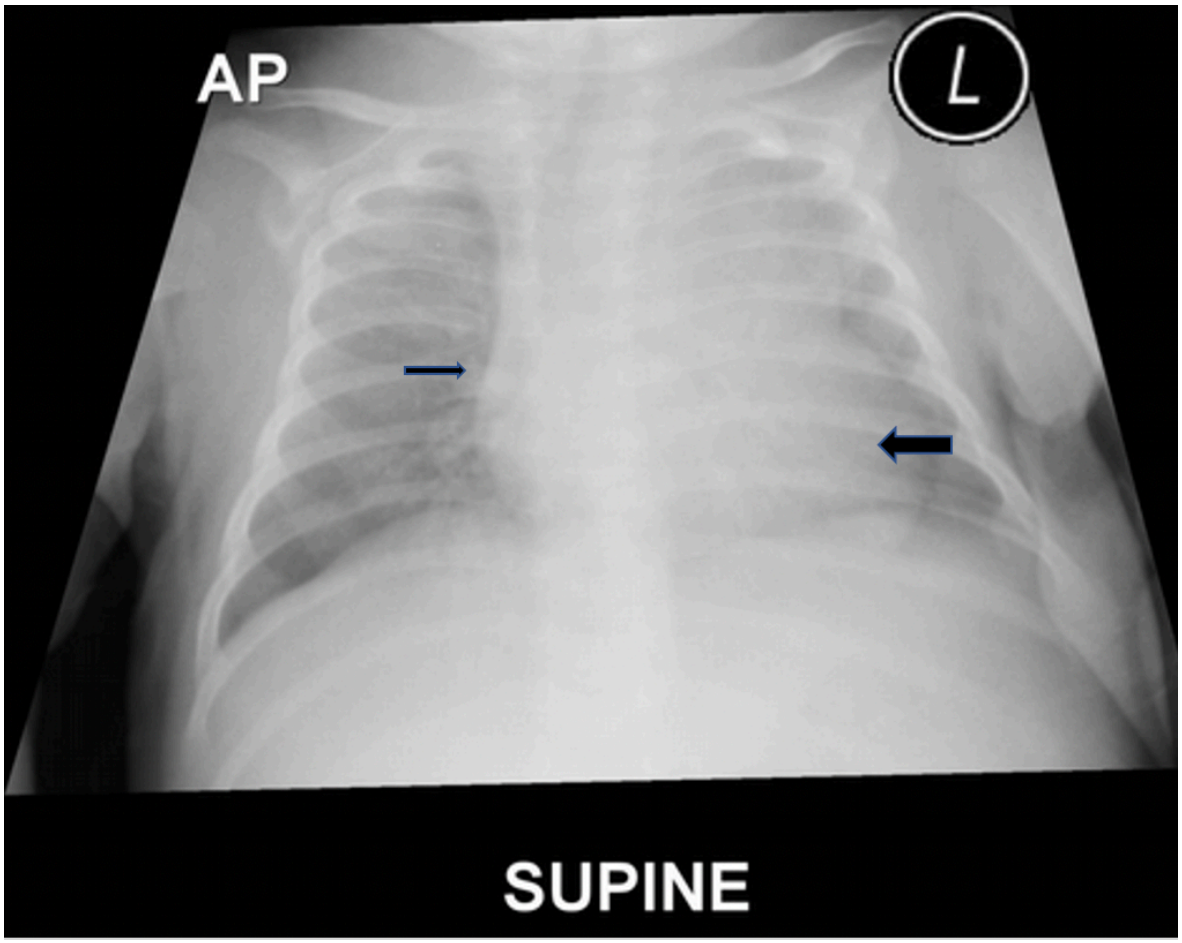


Figure 4. 19 Chest radiograph demonstrating a poorly exposed film where the central (thin arrow) including the vessels behind the heart (thick arrow) are not well visualised.

4.5.8 Variable (8) – Peripheral vessels not well seen

The number of radiographs with the quality error *'peripheral vessels not well seen'* overall at each centre during each phase and expressed as a percentage of the total number of radiographs reviewed during each phase is shown in Table 4.23.

Table 4. 23 The number of radiographs with the quality error *'peripheral vessels not well seen'* overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with *'peripheral vessels not well seen'*	
			n	%
Overall		966	158/966	16,4
1	all	307	35/307	11,4
2	all	318	101/318	31,8
3	all	341	22/341	6,5
all	CHBAH	280	81/280	28,9
all	RMMCH	353	55/353	15,6
all	KH	333	22/333	6,6
1	CHBAH	79	11/79	13,9
1	RMMCH	115	18/115	15,7
1	KH	113	6/113	5,3
2	CHBAH	81	58/81	71,6
2	RMMCH	120	32/120	26,7
2	KH	117	11/117	9,4
3	CHBAH	120	12/120	10,0
3	RMMCH	118	5/118	4,2
3	KH	103	5/103	4,9

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'peripheral vessels not well seen'* was identified in 16.4% (158/966) of all the radiographs reviewed. Overall the error rate was highest at CHBAH (28.9%, 81/280) and lowest at KH (6.6%, 22/333). The highest number of radiographs demonstrating the error overall were identified in phase 2 (31.8%, 101/318) and the lowest in phase 3 (6.5%, 22/341).

The proportion of the error *'peripheral vessels not well seen'* at each centre and during each phase is shown in Figure 4.20.

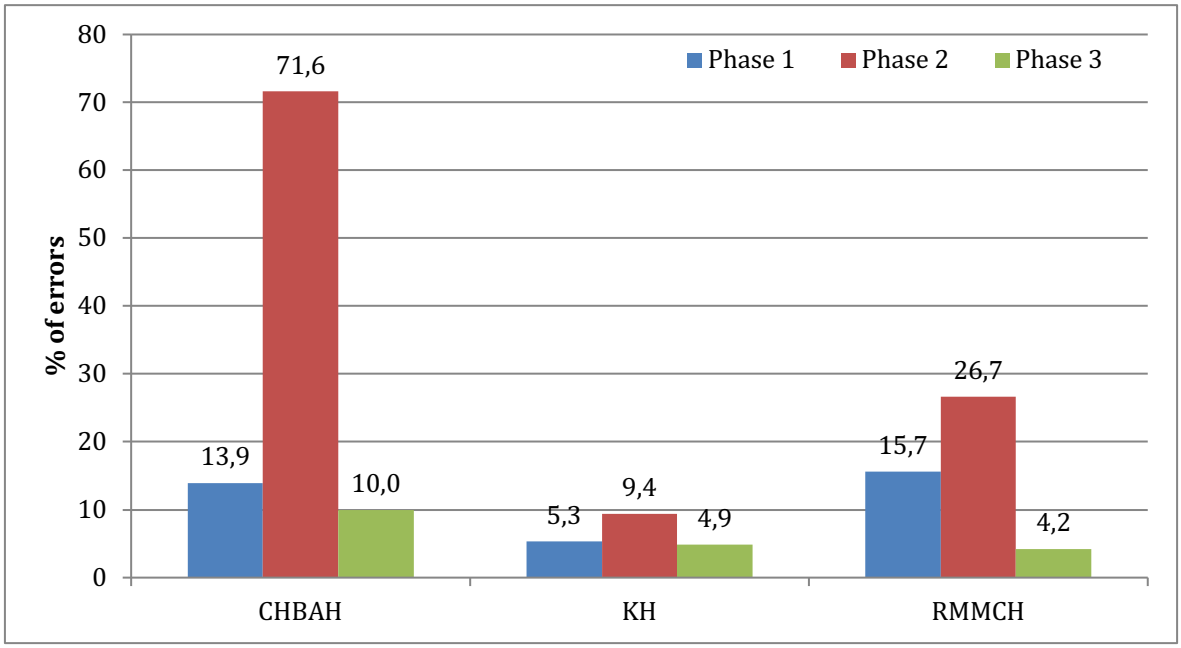


Figure 4. 20 Proportion of the quality error 'peripheral vessels not well seen' at each centre during each phase of the study.

In phase 1, the proportion of *'peripheral vessels not well seen'* was significantly higher at RMMCH compared to KH (p= 0.016). In phase 2, the proportion of this error decreased in the order CHBAH > RMMCH > KH. All of the centres demonstrated an increase in the proportion of the error in phase 2. CHBAH had the highest proportion of the error *'peripheral vessels not well seen'* in phase 2, which was identified in 58 out of the 81 radiographs reviewed (71.6%). For CHBAH the proportion of these errors was significantly higher in phase 2 compared to phases 1 and 3; there was a statistically significant increase from phase 1 to 2 ($p<0.0001$) and a statistically significant decrease in the error percentage from phases 2 to 3 ($p<0.0001$). This was mostly due to poor exposure of the radiographs resulting in challenges differentiating anatomy. For RMMCH there was a statistically significant improvement in the error rate between phases 1 and 3 ($p=0.0039$) and between phases 2 and 3 ($p<0.0001$). The lowest error rate was at RMMCH in phase 3 (4.2%, 5/118). There was no significant difference in the proportion of the error at KH; the overall error rate at KH was low, ranging between 4.9% (5/113) in phase 3 to 9.4% (11/117) in phase 2.

4.5.9 Variable (9) – Poor collimation

The number of radiographs with the quality error *'poor collimation'* overall, at each centre during each phase and expressed as a percentage of the total number of radiographs reviewed during each phase is shown in Table 4.24.

Table 4. 24 The number of radiographs with the quality error *'poor collimation'* overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with *'poor collimation'*	
			n	%
Overall		966	214/966	22,2
1	all	307	83/307	27,0
2	all	318	91/318	28,6
3	all	341	40/341	11,7
all	CHBAH	280	76/280	27,1
all	RMMCH	353	21/353	5,9
all	KH	333	117/333	35,1
1	CHBAH	79	25/79	31,6
1	RMMCH	115	7/115	6,1
1	KH	113	51/113	45,1
2	CHBAH	81	29/81	35,8
2	RMMCH	120	12/120	10,0
2	KH	117	50/117	42,7
3	CHBAH	120	22/120	18,3
3	RMMCH	118	2/118	1,7

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

Poor collimation was the third most common error identified throughout the study and was identified in 22.2% (214/966) of all the radiographs reviewed. Overall the error rate was highest at KH (35.1%, 117/280) and lowest at RMMCH (5.9%, 21/353). The highest number of radiographs demonstrating *'poor collimation'* overall were identified in phase 2 (28.6%, 91/318) and lowest in phase 3 (11.1%, 40/341).

The proportion of the error *'poor collimation'* at each centre and during each phase is shown in Figure 4.21.

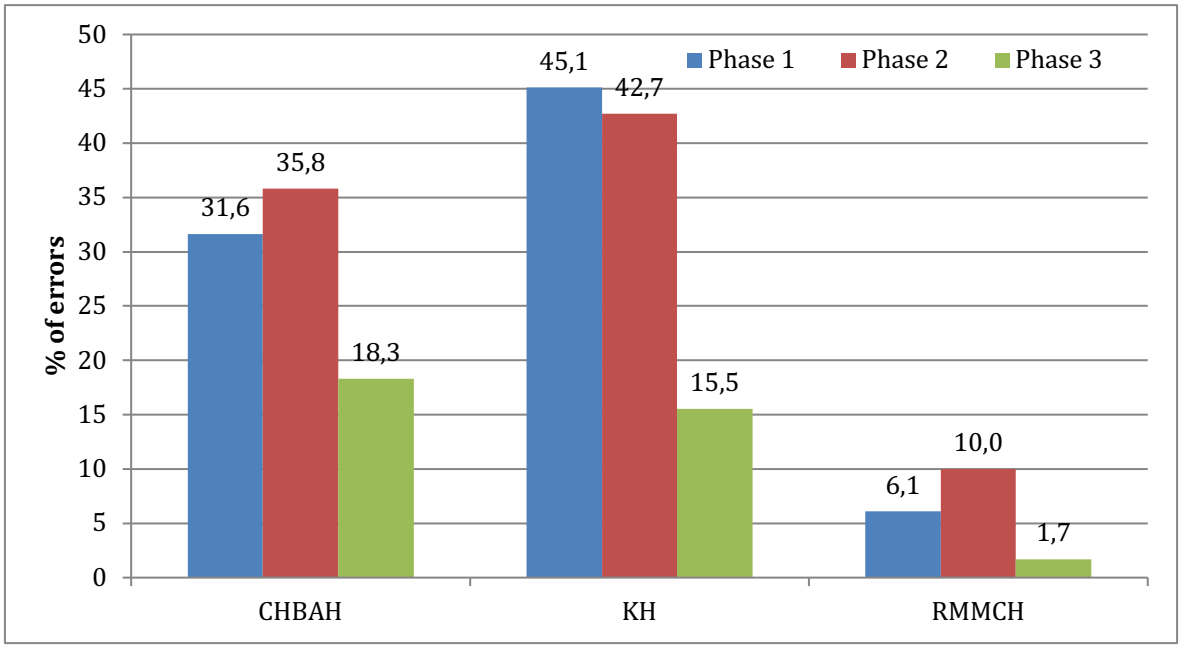


Figure 4. 21 Proportion of the quality error *'poor collimation'* at each centre during each phase of the study.

KH had the highest proportion of *'poor collimation'* in phase 1 (45.1%, 51/113) and phase 2 (42.7%, 50/117); the highest proportion of the error in phase 3 was found at CHBAH (18.3%, 22/120). There was a statistically significant improvement in the error rate at CHBAH between phases 1 and 3 (p=0.040) and between phases 2 and 3 (p=0.0078). There was continuous improvement with a decline of the proportion of *'poor collimation'* errors in the different phases at KH; the improvement was statistically significant between phases 1 and 3 (p<0.0001) and between phases 2 and 3 (p<0.0001)). There was a statistically significant improvement in the error proportional percentage at RMMCH between phases 2 and 3 (p=0.011).

Figure 4.22 below demonstrates examples of poorly collimated radiographs.

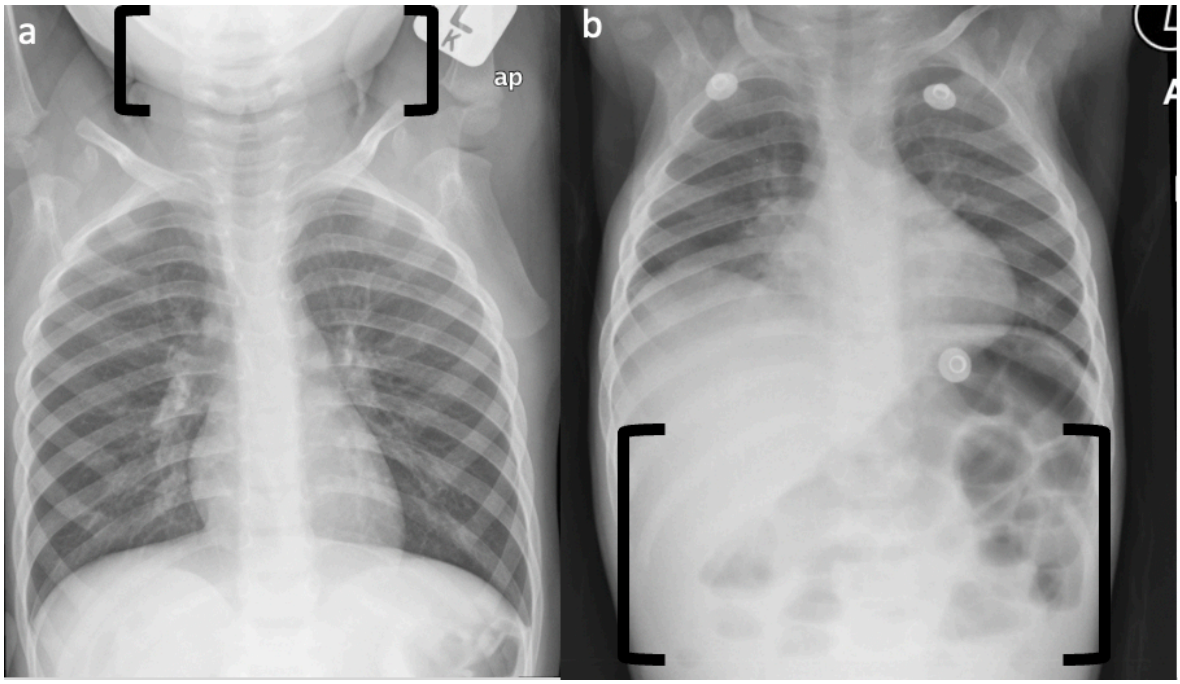


Figure 4. 22 (a and b). Chest radiographs demonstrating poor collimation with inappropriate inclusion of the upper neck (short brackets) and head in (a) and the abdomen in (b) (long brackets). Radiograph (b) also demonstrates under-inspiration with only 4 anterior ribs seen above the right hemidiaphragm.

4.5.10 Variable (10) – Trachea and bronchi not clearly seen

The number of radiographs with the quality error *'trachea and bronchi not clearly seen'* overall, at each centre during each phase, and expressed as a percentage of the total number of radiographs reviewed during each phase, is shown in Table 4.25.

Table 4. 25 The number of radiographs with the quality error *'trachea and bronchi not clearly seen'* overall, *at* each centre and during each phase

Phase	Centre	Total number of cases	Cases with *'trachea and bronchi not clearly seen'*	
			n	%
Overall		966	189/966	19,6
1	all	307	62/307	20,2
2	all	318	87/318	27,4
3	all	341	40/341	11,7
all	CHBAH	280	87/280	31,1
all	RMMCH	353	43/353	12,2
all	KH	333	59/333	17,7
1	CHBAH	79	20/79	25,3
1	RMMCH	115	16/115	13,9
1	KH	113	26/113	23,0
2	CHBAH	81	58/81	71,6
2	RMMCH	120	14/120	11,7
2	KH	117	15/117	12,8
3	CHBAH	120	9/120	7,5
3	RMMCH	118	13/118	11,0
3	KH	103	18/103	17,5

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'trachea and bronchi not clearly seen'* was identified in 19.6% (189/966) of all the radiographs reviewed. Overall the error rate was highest at CHBAH (31.1%, 87/280) and lowest at RMMCH (12.2%, 43/353). The highest number of radiographs demonstrating the error overall were identified in phase 2 (27.4%, 87/318) and the lowest in phase 3 (11.7%, 40/341).

The proportion of the error *'trachea and bronchi not clearly seen'* at each centre and during each phase, is shown in Figure 4.23.

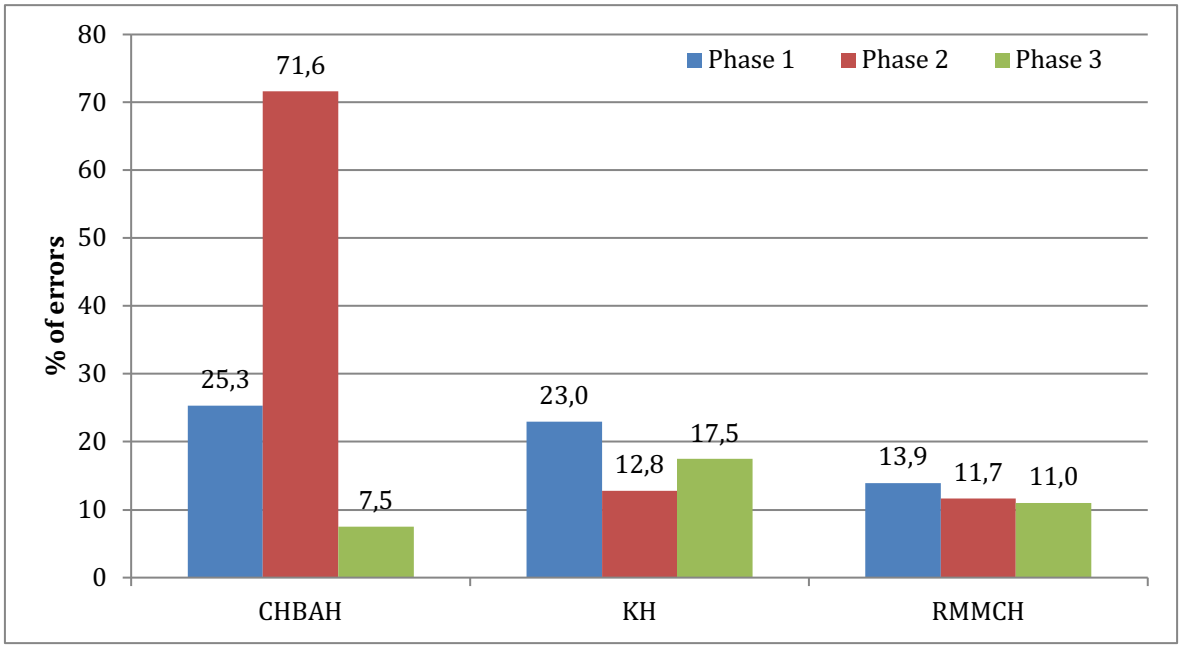


Figure 4. 23 Proportion of the quality error '*trachea and bronchi not clearly seen'* at each centre during each phase of the study.

In phase 2, the proportion of *'trachea and bronchi not clearly seen'* error was significantly higher for CHBAH compared to KH (p <0.0001) and RMMCH (p <0.0001). In phase 3 the percentage of errors was significantly higher for KH compared to CHBAH (p=0.025).

At CHBAH, the proportion of *'trachea and bronchi not clearly seen'* decreased in the order Phase 2 > 1 > 3. The lowest proportional error percentage at CHBAH was in phase 3 where it was identified in 7.5% (9/120) of the radiographs. The differences in the proportion of errors at CHBAH was significant between all three different phases. At RMMCH there was continuous improvement with a decrease of the proportion of the *'trachea and bronchi not clearly seen'* errors in the different phases. The improvement, however, was not statistically significant. There was no significant change in the proportion of the error at KH.

4.5.11 Variable (11) – Vessels behind heart not well seen

The number of radiographs with the quality error *'vessels behind heart not well seen'* overall, at each centre during each phase, and expressed as a percentage of the total number of radiographs reviewed during each phase is shown in Table 4.26.

Table 4. 26 The number of radiographs with the quality error 'vessels behind heart not well seen' overall, at each centre and during each phase

Phase	Centre	Total number of cases	Cases with *'vessels behind heart not well seen'*	
			n	%
Overall		966	97/966	10,0
1	all	307	17/307	5,5
2	all	318	64/318	20,1
3	all	341	16/341	4,7
all	CHBAH	280	79/280	28,2
all	RMMCH	353	4/353	1,1
all	KH	333	14/333	4,2
1	CHBAH	79	15/79	19,0
1	RMMCH	115	1/115	0,9
1	KH	113	1/113	0,9
2	CHBAH	81	54/81	66,7
2	RMMCH	120	2/120	1,7
2	KH	117	8/117	6,8
3	CHBAH	120	10/120	8,3
3	RMMCH	118	1/118	0,8
3	KH	103	5/103	4,9

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'vessels behind heart not well seen'* was identified in 10% (97/966) of all the radiographs reviewed. Overall, the error rate was highest at CHBAH (28.2%, 79/280) and lowest at RMMCH (1.1%, 4/353). The highest number of radiographs demonstrating the error overall were identified in phase 2 (20.1%, 64/318) and the lowest in phase 3 (4.7%, 16/341).

The proportion of the error *'vessels behind heart not well seen'* at each centre and during each phase, is shown in Figure 4.24.

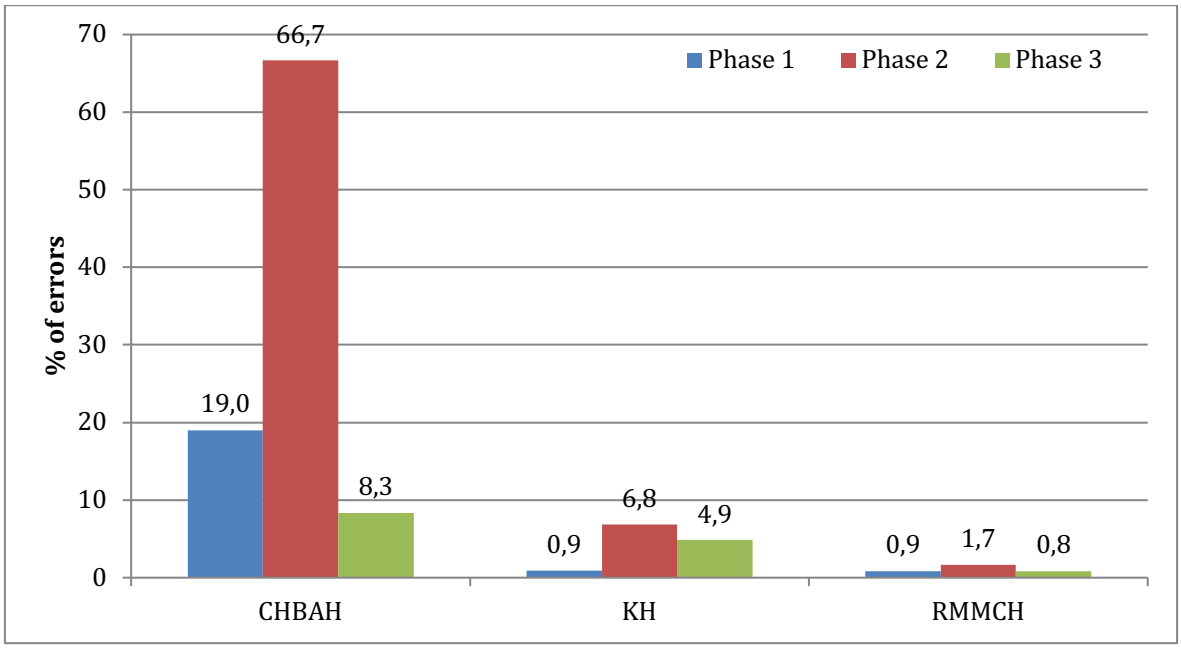


Figure 4. 24 Proportion of the quality error *'vessels behind heart not well seen'* at each centre during each phase of the study

In phases 1 and 2, the proportion of *'vessels behind heart not well seen'* was significantly higher for CHBAH and KH compared to RMMCH ($p<0.0001$). In phase 3, the proportion of this error was significantly higher for CHBAH than for RMMCH ($p=0.010$).

For CHBAH, the proportion of the *'vessels behind heart not well seen'* error decreased in the order phase 2 > 1 > 3. The lowest proportion of the error was found at RMMCH and KH in phase 1 where both hospitals had an error percentage of 0.9%. RMMCH had the lowest proportion of the error in phase 3 (0.8%, 1/118).

The proportion of the error *'vessels behind heart not well seen'* was lower at RMMCH and KH throughout all three phases compared to CHBAH. There were statistically significant differences in the proportion of this error at CHBAH between phases 1 and 2 ($p<0.0001$), phases 2 and 3 ($p<0.0001$) and phases 1 and 3 ($p=0.031$). There was a statistically significant increase in the proportion of the

error at KH between phases 1 and 2 (p=0.036), where the error rate increased from 0.9% (1/113) to 6.8% (8/117). The error rate at RMMCH was very low, ranging between 0.8% (1/118) in phase 3 to 1.7% (2/120) in phase 2.

4.5.12 Variable (12) – Wrong or no L/R markers

The number of radiographs with the quality error *'wrong or no L/R markers'* overall, at each centre during each phase, and expressed as a percentage of the total number of radiographs reviewed during each phase, is shown in Table 4.27.

Table 4. 27 The number of radiographs with the quality error *'wrong or no L/R markers'* overall, at **each centre and during each phase**

Phase	Centre	Total number of cases	Cases with *'wrong or no L/R markers'*	
			n	%
Overall		966	16/996	1,7
1	all	307	9/307	2,9
2	all	318	6/318	1,9
3	all	341	1/341	0,3
all	CHBAH	280	10/280	3,6
all	RMMCH	353	6/353	1,7
all	KH	333	0/333	0,0
1	CHBAH	79	5/79	6,3
1	RMMCH	115	4/115	3,5
1	KH	113	0/113	0,0
2	CHBAH	81	4/81	4,9
2	KH	117	0/117	0,0
2	RMMCH	120	2/120	1,7
3	CHBAH	120	1/120	0,8
3	RMMCH	118	0/118	0,0
3	KH	103	0/103	0,0

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

The error *'wrong or no L/R markers'* was the second least common error and was identified in 1.7% (16/966) of all the radiographs reviewed. Overall the error rate was highest at CHBAH (3.6%, 10/280), followed by RMMCH (1.7%, 6/353). KH

maintained a zero error rate throughout all three phases as did RMMCH in phase 3. The highest number of radiographs demonstrating the error overall were identified in phase 1 (2.9%, 9/307) and the lowest in phase 3 (0.3%, 1/341).

The proportion of the error '*wrong or no L/R markers'* at each hospital and during each phase is shown in Figure 4.25.

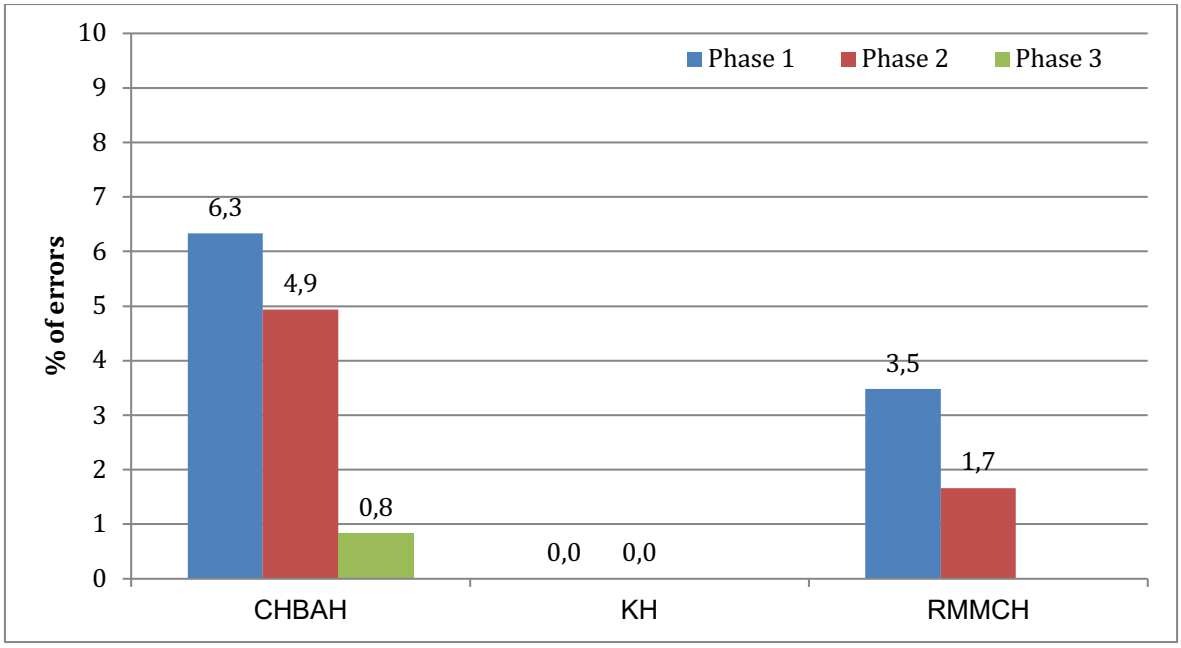


Figure 4. 25 Proportion of the quality error '*wrong or no L/R markers'* at each centre during each phase of the study

In phases 1 and 2, the percentage of 'wrong or no L/R markers' errors was significantly higher for CHBAH compared to KH (p=0.011 and p=0,027, respectively).

CHBAH had the highest proportion of this error throughout all phases. The highest error percentage was in phase 1 (6.3%, 5/79). There was a steady improvement and decrease in the error percentage at CHBAH. There was a statistically significant improvement of the proportion of this error at CHBAH between phases 1 and 3 (p=0.037). There was a steady improvement and decrease in the proportion of the 'wrong or no L/R markers' error at RMMCH, however, the change

was not statistically significant (between phases 1 and 2 (p=0,44) and phases 2 and 3 (p=0,49)).

4.6. Social media engagement

There was minimal interaction and engagement with the social media platforms. There was no significant benefit demonstrated from the intervention. The poor engagement was a major failure of the research as the assessment of the effect of the social media intervention on quality was not possible. Interaction with the social media platforms is recorded below.

4.6.1 Twitter

The Twitter handle was @Quality_Xray (Figure 4.26). There were a total of 17 Twitter followers from June to September 2014. The number of followers increased to 18 in October, 19 in November and then decreased to 18 followers by December of the same year (Figures 4.27 and 4.28).



Figure 4. 26 Quality_Xray Twitter profile picture



Figure 4. 27 Demonstrates the number of Twitter followers gained in the first month of the study, and the most popular links based on the number of clicks for each link.



Figure 4. 28 Demonstrates the number of Twitter followers and the brief increase of the number in November 2014

Table 4.28 summarises the categories of followers on Twitter, and Table 4.29 summarises the demographics of the radiographers from each hospital that followed the study on Twitter.

Table 4. 28 Twitter followers

	Centres	Twitter followers n=19 (%)	As a percent of the number of radiographers at the hospitals included in the study
Radiographers from the 3 hospitals included in the study	**Total radiographers**	6/19 (31.6%)	6/88 (6.8%)
	CHBAH (n=64)	**1/19 (5.3%)**	**1/64 (1.6%)**
	KH (n=11)	**4/19 (21.1%)**	**4/11 (36.4%)**
	RMMCH (n=13)	**1/19 (5.3%)**	**1/13 (7.7%)**
Social media assistant		1/19 (5.3%)	
Teaching Platforms		2/19 (10.5%)	
Organisations		2/19 (10.5%)	
Managing Director Medical Company		1/19 (5.3%)	
Other		7	
TOTAL Total Radiographers		19 **6/19 (31.6%)**	**6/88 (7%)**

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

Table 4. 29 Demographics of Twitter followers from the 3 hospitals included in the study

Twitter followers at each hospital included in the study	Radiographers	Gender	Age (years)
CHBAH	1	M	30*
KH	1	M	35
	2	F	23
	3	F	32
	4	F	32
Average age			30.5
RMMCH	1	F	41

**Estimate as no demographic information provided by head of radiography*

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

There were a total six radiographers from the three hospitals following the study on Twitter. There was one radiographer was from CHBAH and RMMCH and four were from KH. Two accounts were from companies (10.5%), one was a managing director of a company, two were radiology related educational accounts. We were not able to determine the origin of eight of the followers and one account was of the radiology registrar (social media assistant) who was assisting with the social media aspect of the study. The average age of the radiographers from the three hospitals who engaged on Twitter was less than 36 years, the oldest was 41,8 years and the youngest 23.3 years old.

There were a total of 61 Tweets sent out during the study (26 May to 30 December 2021). The only tweet that received a retweet was one that was posted on the 26 May 2014, the week before the official launch of the study. The retweet was of the posting of the link to a video on quality assurance of paediatric chest X-rays, and it was retweeted by an online radiology teaching platform (Figure 4.29). This tweet also received a single like. The video was posted after the site visits to the different hospitals had been completed, and it consisted of the same material from

the tutorial that was given on the importance of good quality radiographs and the impact of quality errors on diagnosis. The video can be accessed on the following link: https://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwj2qI_FnuLyAhVDZcAKHfxzCkIQFnoECAMQAQ&url=https%3A%2F%2Fwww.youtube.com%2Fchannel%2FUCfMGzD_YxlIYxvcM7ZYzOWw&usg=AOvVaw2L2rkHzTTBnYmxKOXM147g .

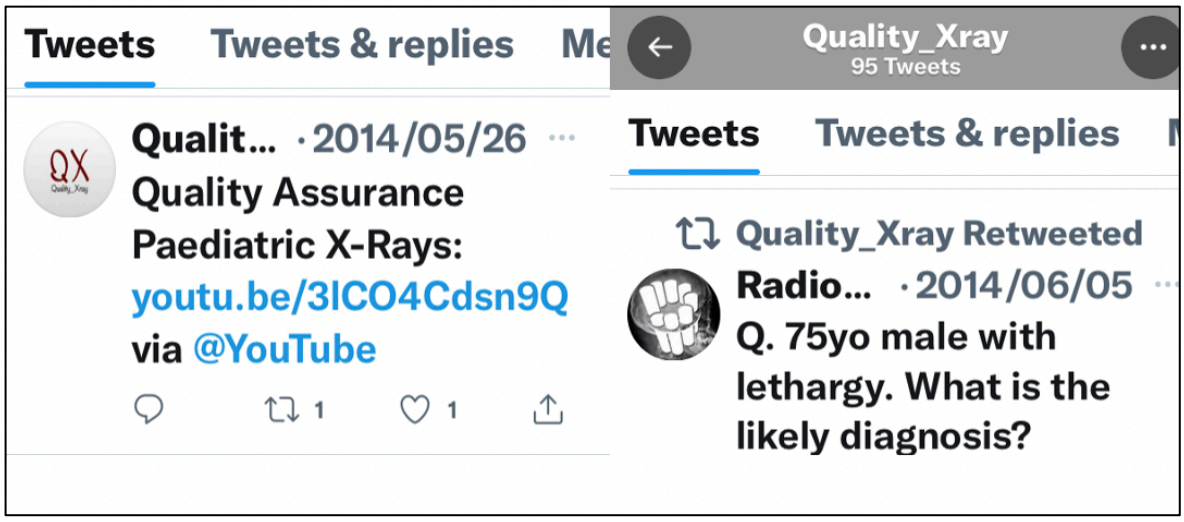


Figure 4. 29 Demonstrates the retweet of the link to the YouTube video on quality assurance of paediatric chest radiographs

Table 4.30 highlights the activity and engagement on Twitter. There were three clicks on the Twitter profile in June 2014, and three new mentions between 26 May and 30 June. There were no more clicks or mentions during the rest of the study. There was a single comment made on 24 July 2014 where a radiographer from RMMCH asked a question regarding the exposure factors of the radiograph used in the post (Figure 4.30).

Table 4. 30 Activity on Twitter

Activity markers	Number of tweets	Date of tweet in (2014)
Total	61	
Number of 'likes'	1	26 May
Clicks on Twitter profile	3	26 May–30 June
Mentions on Twitter profile	3	
Number of 'retweets'	1	26 May
Comment	1	24 July



Figure 4. 30 Demonstrates a comment from a radiographer on a tweet

4.6.2 Facebook

The Quality Xray Facebook page had a total of 37 friends/followers (https://www.facebook.com/profile.php?id=100008361120160). Thirteen (35.1%) of the Facebook friends were radiographers, eight were from the three

participating hospitals (9.1% of radiographers in the study). Of the 13 radiographer Facebook friends one (2.7%) was from CHBAH, five (13.5%) were from RMMCH and two (5.4%) were from KH (Table 4.31). The original Facebook page was kept open throughout the study and engagement was mostly on this platform, with 1.6% radiographers from CHBAH, 38% (5/13) from RMMCH and 18.2% (2/11) were from KH and who all signed on to this platform. The average age of the radiographers from the three centres who engaged with Facebook was 30.5 years, the oldest was 41.8 years and the youngest 22.7 years (Table 4.28).

Table 4. 31 Facebook friends

<table>
<tr><th></th><th>Facebook Friends (n=37)</th><th colspan="3">Radiographers from the hospitals included in the study using the Facebook page</th></tr>
<tr><td>Identified themselves as Radiographers</td><td>13/37 (35.1%)</td><td colspan="3"></td></tr>
<tr><td rowspan="3">Radiographers from the hospitals included in the study using the Facebook page</td><td rowspan="3">8/37 (21.6%)</td><td>CHBAH (N=64)</td><td>1/37 (2.7%)</td><td>1/64 (1.6%)</td></tr>
<tr><td>RMMCH (n=13)</td><td>5/37 (13.5%)</td><td>5/13 (38.5%)</td></tr>
<tr><td>KH (n=11)</td><td>2/37 (5.4%)</td><td>2/11 (18.2%)</td></tr>
<tr><td>Healthcare Workers</td><td>6/37 (16.2%)</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Social Media Assistant</td><td>1/37 (2.7%)</td></tr>
<tr><td>Other</td><td>9/37 (24.3%)</td></tr>
<tr><td>Total</td><td>37</td><td>88</td><td colspan="2">8 (9.1% of total radiographers in the study)</td></tr>
</table>

Key: CHBAH = Chris Hani Baragwanath Academic Hospital; RMMCH = Rahima Moosa Mother and Child Hospital; KH = Khayelitsha Hospital

Table 4.32 summarises the demographics of the radiographers from each hospital who were friends on the Facebook page.

Table 4. 32 Demographics of Facebook friends from the 3 participating hospitals

Facebook friends at each centre	Number of Radiographers	Gender	Age (years)	Average age
CHBAH	1	M	30*	30
KH	1	F	32.25	29.92
	2	F	27.58	
RMMCH	1	F	39.92	31.75
	2	F	30.83	
	3	F	41.83	
	4	F	22.67	
	5	F	23.5	

**Estimate as no demographic information provided by chief radiographer*

Table 4.33 summarises the activity on the Facebook pages.

Table 4. 33 Activity on Facebook

Activity markers	Numbers	Date of post in (2014)
Total number of Facebook posts	48	
Number of 'likes'	3	2 October 22 October 1 December
Number of comments	3	2 October 17 November
Number of comments providing insights	1	2 October
Number of 'shares'	1	25 September

Between 1 June and 31 December 2014, a total of 48 posts were posted on Facebook from Hootesuite. These included quizzes and answers to identify the error on the radiograph, as well as tips on good practice (Figure 4.31).

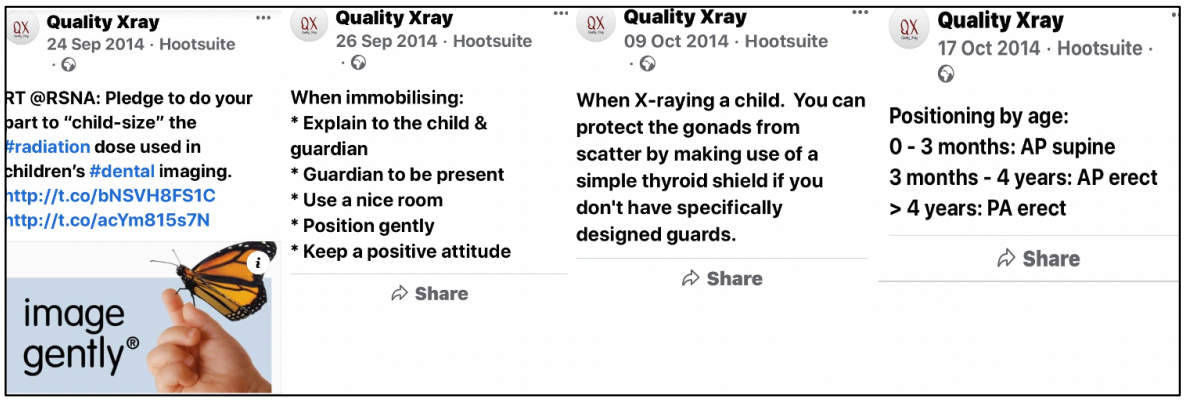


Figure 4. 31 Snapshots of tips on good practice that were posted on the Facebook page

A single post on the Facebook page was shared. It was posted on the 25 September 2014 (Figure 4.32).



Figure 4. 32 Facebook post that was shared

There were two posts that were posted on the 2 October and 17 November received comments (three comments in total) (Figures 4.33 and 4.34). Only one comment provided insight and a recommendation (Figure 4.35).

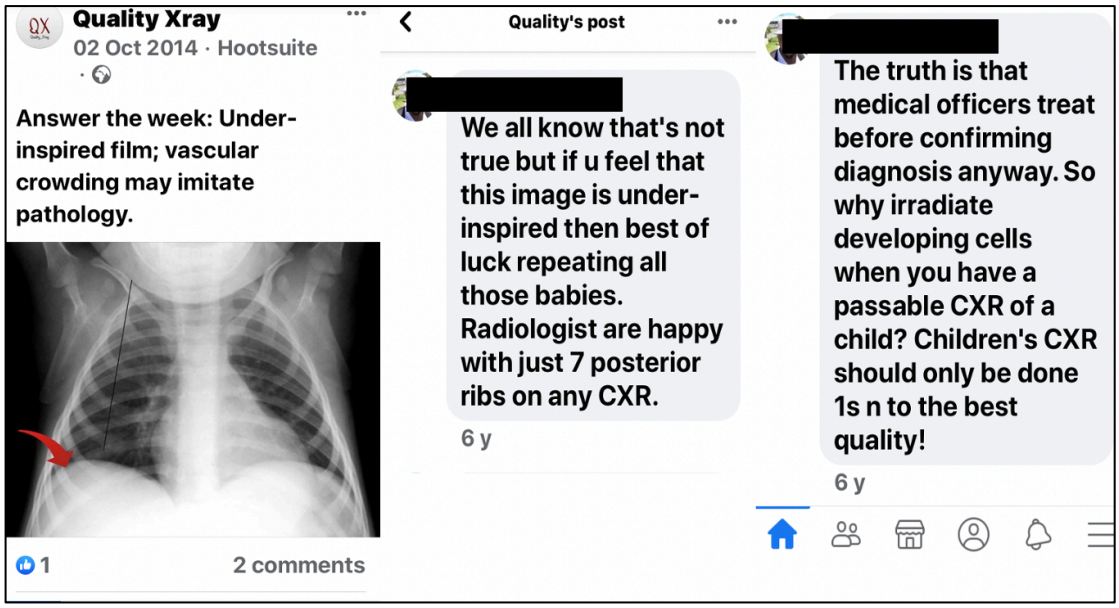


Figure 4. 33 Post from Facebook that received 2 comments from the same individual



Figure 4. 34 Post from Facebook that received a comment

There were three posts were made on 2 October, 22 October and 1 December and each received a single ‘like’ (Figure 4.34).

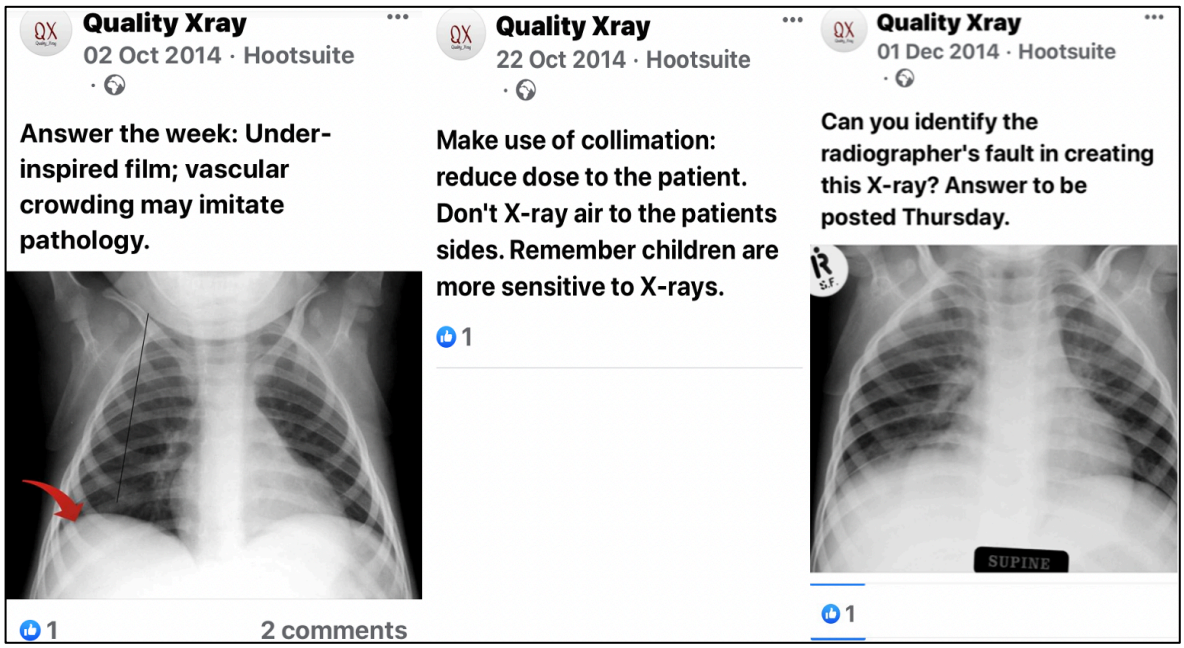


Figure 4. 35 Facebook posts that received 'likes'

After the private Facebook pages were created for the individual hospitals on 16 September 2014, three out of the thirteen (27.3%) radiographers from RMMCH joined the group. On the RMMCH Facebook page (Quality_Xray RMMCH), four Facebook posts were viewed in October and two in November, all by a single person. No other radiographers from KH or RMMCH joined the private Facebook groups despite sending several invitations via individual email addresses.

CHAPTER 5: Discussion

5.1 Introduction

Our study is unique in several ways. Firstly, it focused on the assessment of the quality of paediatric chest radiographs sourced from three geophysically separated South African hospitals of different healthcare service levels and resource profiles (personnel and equipment). Secondly, a standardised minimum level of radiologist training was used for the performance of the quality assessment using a standardised recording tick sheet with standardised definitions of radiographic error. Providing the images in JPEG rather than DICOM format resulted in standardisation of the viewing parameters. Thirdly, a further novel initiative was the use of the social media platforms Facebook and Twitter as education and communication tools (195) that intended to improve the quality of the paediatric radiographs remotely at the different centres.

Our results showed that the only hospital to demonstrate minimal, sustained, but non-significant improvement in the overall quality score of radiographs throughout the different phases of the study, was RMMCH.
There was, however, statistically significant improvement (i.e. a decrease) in the median quality score between phase 1 and 3 for CBAH and KH while RMMCH maintained the lowest median quality score throughout the study. The general standard of chest radiography at RMMCH was high. Both KH and CHBAH demonstrated a decline in the quality of the radiographers in phase 2 with an improvement in phase 3. Phase 3 demonstrated the highest proportion of radiographs with a perfect score and the highest proportion of 'high quality' radiographs for all three hospitals.

Most of the radiographs (72.8%) reviewed in the study were of 'diagnostic quality' (i.e. $\leq$4 errors) with 18.9% of all the radiographs reviewed receiving a 'perfect' score (i.e. no errors) (Table 4.10). A quarter of the radiographs were of poor

diagnostic quality which is not acceptable for clinical practice. At KH there was sustained quality improvement over the 3 phases of the study for quality factors *(3) patient rotation* and *(4) scapula in the way*. The improvement was significant for both factors between phases 1 and 3 with p-values of 0.043 and 0.019, respectively. At CHBAH sustained, but not significant improvement was noted for factors *(1) absent body parts in FOV* and *(4) scapula in the way*. At RMMCH sustained, but not significant improvement was noted for quality factors *(6) artefact/foreign body, (7) central vessel visualisation,* and *(10) trachea and bronchi visualisation*. The most common radiographic errors were mainly those related to patient positioning and included *(4) scapula in the way (38.7%), (3) patient rotation (34.7%), (9) poor collimation (22.2%)* and *(2) under-inspiration (19.2%).*

The engagement with social media was low throughout phases 2 and 3 after the site visits. The radiographers from RMMCH and KH interacted with the social media, however, less than 50% of the radiographers involved in the study participated. This was a significant weak point of the study as the success of the study depended on engagement. There was no significant benefit demonstrated from the social media intervention.

The preceding chapters mentioned the objectives of the study, presented a literature review, described the research methodology and data analysis, and reported the findings. The findings, including the limitations, future applications and conclusions established on the findings of the study are discussed in this chapter.

5.2 Results in context

5.2.1 Inter-rater analysis

A total of 124 radiographs were removed from the initial 1080 that were selected for the study, resulting in a final sample of 966 radiographs which were used for further analysis. The radiographs that were removed included lateral radiographs

(3), portable radiographs (116) or those that had duplicated identification numbers (5). We had defined that the inter-rater results were “closely similar if the difference in the frequency between all reviewers was less than 2%, relatively similar if the difference is less than 5%, and discrepant if more than 5%” (192).

We found that the inter-rater agreement was poor for most of the factors among all reviewers (including the PI). Inter-rater analysis found large discrepancies in the inter-rater agreement for factors *(4) scapula in the way (* κ scores of 0.36)*, (9) poor collimation (*κ scores of 0.47) and *(10) trachea and bronchi not clearly seen (*κ scores of 0.49)*.* There was moderate agreement between raters for factors *(5) kyphotic/lordotic (*κ scores of 0.54) and *(8) peripheral vessels not well seen (*κ scores of 0.63)*.* There was relative similarity for factors *(6) artefact/foreign body (*κ scores of 0.86)*, (7) central vessel visualisation (* κ scores of 0.86) and factor *(11) post cardiac vessel visualisation (*κ scores of 0.78).

The strongest agreement with κ scores greater than 0.95 among all reviewers and between each of the reviewer pairs were factors *(1) absent patient body parts from FOV (*κ scores of 0.96) and *(12) absent or wrong image orientation marking (*κ scores of 0.98). Factor *(3) rotation*, had the least agreement (κ score of 0.36) among the 3 reviewers with very low κ scores suggesting almost no agreement. The κ score between reviewers 1 and 3 was 0.00 between reviewers 2 and 3 was 0.06. The factor (2*) under inspired films,* also demonstrated low agreement with a κ score of 0.32 among the reviewer. There was no agreement at all between reviewers 1 and 3 with a κ score of 0.0 and reviewers 2 and 3 (κ scores of 0.09). The marked interobserver variability in these 2 factors was also demonstrated in a study by Tauschner et al., where there was strong overall interobserver agreement with a mean Cohen’s Kappa score of 0.79, but the interobserver agreement was low for *(a) performed at peak of inspiration* (κ =0.39) and (*b) no rotation in the horizontal or vertical plane* (κ = 0.39) (5).

The marked variability amongst the reviewers suggests a high level of subjectivity in the assessment of quality factors for paediatric chest radiographs and may infer that the current guidelines (5,196) need to be modified in order to increase objectivity and practical application (5,197). It is easy to identify quality factors

such as ‘cut-off’, ‘absent/wrong image marker’ or the visibility of a ‘foreign body’ on the radiograph (198), however, not all quality factors are that straightforward (198). It would be beneficial to modify and validate the quality assessment criteria (196) to ensure more reliable and consistent assessment, leading to a reduction of the subjective interpretation of the quality of an image (16,198,199).

A second option to consider would be the identification of quality factors that have the most significant effect on the accuracy of diagnosing pathology and the clinical outcome of the patient, and the creation of a new quality assessment tool for identifying these factors (192). These factors will need to be strictly defined to reduce subjectivity and to ensure greater objectivity (192,196). One of the quality factors that greatly affects diagnosis is under-inspiration, which results in crowding of the bronchovascular markings and increased density of the lungs. This can easily be misinterpreted as pathology such as infection, atelectasis or hilar fullness mimicking lymphadenopathy (192). Another factor that can lead to misdiagnosis of pathology is rotation, which can cause differential density of the lungs and on a supine radiograph this may mimic a unilateral pleural effusion (192).

Contrary to other studies, the differences in error detection by the reviewers could not be attributed to different speciality training (200) as all the reviewers in this study were trained at the same university. The poor agreement may have been influenced by differences, between the reviewers, in the number of years of clinical experience they had post qualification. However, quality assessment of chest radiographs should form part of routine, daily practice by both qualified radiologists and radiographers, irrespective of the level of experience. The interpretation of the quality of a radiograph should be established during basic specialty training, and should therefore not be considered as a factor that can influence the reliability of the evaluation of the quality of a radiograph.

It is important to consider rater fatigue (201) in this study as the reviewers had to assess a total of 1077 of radiographs. Rater fatigue affects individuals differently and this could potentially account for some of the variability observed in our research. Effort was made to reduce rater fatigue by having the radiographs assessed by the reviewers at 3 separate time intervals. Another factor that could account for variability in our results is the leniency and willingness to overlook

radiographic errors by radiologists (and clinicians) when diagnostic accuracy is not significantly affected. Whaley et al. demonstrated this phenomenon in 2013 in a study which contrasted and compared the results of QA performed on chest radiographs by radiologists and technologists. Similarly, Whaley et al. showed poor inter-reader agreement amongst the radiologists and radiographers. The variability was greater when comparing the results between the radiologists and technologists (198). The authors resolved that radiologists demonstrated greater subjectivity in the evaluation of radiographs of inferior quality when making a diagnosis was still possible (198,202). This was also confirmed in similar studies by Dunn and Rogers and Kjelle et al. and Mount (2016). that showed that radiologists were inclined to keep more images that had quality errors compared to radiographers (16,75,203). Attempts to avoid this bias were made by providing a QA data capturing tick sheet that was hosted on REDCap, which enabled the reviewer to record the presence and absence of individual radiographic error, irrespective of the presence of pathology on the radiograph.

The option to retrain the reviewers before having them reassess the radiographs (196) was considered as training has been shown to increase inter-rater reliability (199,204), while other studies recommend more formal training only for the less experienced (204). A suggestion to have the reviewers assess the radiographs by consensus to create a platform for discussion and increased accuracy in assessment (200) was considered after review of the study by Bender et al. This study also demonstrated poor inter-rater agreement between radiologists using the Radpeer system, which is central to the peer review process of several radiology centres (197). Both options would have proved challenging as the reviewers were geographically separated and the study included a very large number of radiographs.

5.2.1.1 Conclusion

Although there was marked inter-rater variability on several quality factors after considerable consideration, it was decided to use the majority decision of the 3 reviewers in further analysis for the study, as our study design fit the independent, necessary and sufficient conditions for simple majority decision. The individual or group decision was universally decisive. Each reviewer decision was treated the

same regarding the influence a decision made on the outcome, anonymity was ensured, the group decision did not favour any alternative outcome, and the final decision responded to changes in individual preferences in a ‘positive’ way (205).

5.2.2 Quality analysis of radiographs

The prevalence of each error was assessed at all 3 centres in all 3 phases of the study. The lower the quality score, the better the quality of the radiograph. We created subcategories for further classification of the results as according to Hlabangana et al. Radiographs with 5 or more errors were characterised as ‘poorly diagnostic’. Those with 4 or less errors (but not perfect) were placed in the ‘diagnostic’ category, and those with no errors were categorised as ‘perfect’ (2).

Of the 966 radiographs reviewed nearly one fifth (18.9%; n=183) of the radiographs were ‘perfect’ and did not have any errors. This was higher than the study by Hlabangana et al. in a similar clinical setting that reviewed the quality of 438 paediatric chest radiographs, and which only demonstrated 1.6% (2) ‘perfect’ radiographs. The highest percentage of these were identified in phase 3 where 26.4% (90/341) fell into this category (Table 4.10), which may be considered one success of this remote quality assurance project. RMMCH had the highest number of ‘perfect’ radiographs overall, with 105/353 (29.7%) of the radiographs that have no quality errors (Table 4.13), and these likely reflect the make-up of the radiographer group who were dedicated paediatric radiographers in a stand-alone ‘mother and child’ hospital.

Overall, the majority (72.8%) of the radiographs included in this study were of ‘diagnostic’ quality (i.e. 1–4 errors). In a study by Hlabangana et al. in a similar clinical setting, 59.4 % of the radiographs were ‘diagnostic’. Phase 1 had the highest percentage of ‘diagnostic’ quality radiographs (78.8%). This was followed by phase 3 (71.6%). Phase 2 had the lowest number of diagnostically accurate radiographs overall (68.2%). At CHBAH and RMMCH there was no significant difference between phases 1 and 3 of the study for radiographs that were characterised as “high quality’ (0-4 errors) or ‘diagnostically quality’ (1-4 errors).

Conversely there was statistically significant improvement at KH in the 'diagnostically quality' (1-4 errors) radiographs between phases 1 and 3 ($p = 0.0019$).

We had hoped to see progressive improvement in the overall quality factor of the radiographs taken at each centre after introducing interventions via social media in phase 2 of the study, with either sustained or continued improvement in phase 3. However, due to the poor interaction and engagement with the social media platforms, which was integral to the success of the study, it was found that the overall quality of the chest radiographs was only sustained and slightly improved at RMMCH, which demonstrated a stable mean quality score across all 3 phases. KH demonstrated a stable mean quality score in phases 1 and 2 with an improved mean quality score in phase 3. No sustained improvement in the mean quality score was observed at CHBAH in the phases after the intervention (Figure 4.2). Continued improvement is often difficult to sustain: Alexander et al. in a paper on lessons learned from quality improvement research note that improvement changes often have short half-lives, with most organisations reverting back to previous established routines and norms once interventions have been completed (206).

The RMMCH is a mother and child hospital. At the time of the study it was one of the few public sector hospitals to have a dedicated paediatric radiologist. The overall quality of the radiographs at the hospital was high.

During phase 2 CHBAH the quality factors related to exposure were high with more that 50% of patients demonstrating related errors in the quality factors (7) *central vessels not seen*, (8) *peripheral vessels no well seen*, (10) *trachea and bronchi not clearly seen* and (11) *vessels behind the heart not well seen.* Improving exposure factors used during plain film radiography is a critical component of dose optimisation. A study by Hayre in the United Kingdom in 2016 demonstrated that only some of the radiographers changed the preset exposure factors to suit each individual patient (19). Others only used the pre-set exposures on the X-ray machine which may result in 'under' or 'over' exposure of the patient depending on individual patient parameters (14,19). While specific exposure

factors were not measured in this study, the high percentage of radiographs with exposure related errors indicates that the appropriate exposure factors were not employed (19). Moolman et al. conducted a survey in South Africa to assess radiographer knowledge on paediatric dose protocols. The study highlighted a lack of knowledge on appropriate doses for children and a need for more training in this regard (56). Moolman et al. highlighted that many (49%) of the radiographers that had been trained on digital radiography systems had not been adequately trained on paediatric protocols (56).

At CHBAH the improvement between phases 2 and 3 could partly be attributed to, the services of a consultant radiologist with an interest in paediatric imaging and who was allocated to the paediatric imaging department for most of the week (i.e. at least 2–3 days out of 5) as from August 2014 (the third month of the study). Having an on-site radiologist provides not only some senior oversight, which on its own may bring about short term change, but also an ongoing parallel quality improvement effort. Radiographs are often rejected for diagnostic interpretation and repeat radiographs are then indicated at the instruction of the paediatric radiologist.

Another way to view the results is that all 3 hospitals had the highest proportions of radiographs with perfect scores and high quality radiographs in phase 3. Also, the lowest proportion of radiographs with any error and poor quality radiographs were in phase 3, suggesting that the intervention had some influence over the study period.

The most common error types were factors (*4) scapula was in the way* (38.7%), (*3) patient rotation* (34.7%), and *(9) poor collimation* (22.2%) (Figure 4.1). Poor collimation (inappropriate field size) and patient rotation, errors relating to poor/inadequate patient positioning were found to be the most common errors in paediatric imaging in several international studies (2,5,17,77,207–209). A study by Rochmayanti et al. (2023) demonstrated that the most frequent reasons for rejecting radiographs were due to patient positioning (31%), which included patient rotation and poor collimation (24). Adequate patient positioning and immobilization are more challenging in younger patients, due to communication barriers, patient

anxiety and poor cooperation (2,5,24). Morrison et al. revealed in a survey of 463 radiographers that the risk of the decreased patient cooperation encouraged radiographers to increase the field of view in infants and children to ensure the inclusion of the necessary structures and anatomy (210,211). Alsleem et al. performed a survey of 376 radiographers from Saudi Arabia and Australia to assess knowledge and perception of optimising image quality in paediatric digital radiography. A significant finding from both countries was that the majority of radiographers had not received formal training in paediatric DR examinations, and almost 75% of the radiographers believed that they were not required to adjust collimation when using digital radiography, as post processing enabled them to crop images to assimilate correct field of view (62).

There is a widespread need in both LMICs and HICs for continuous and sustainable training and education in paediatric DR to ensure adequate knowledge on image quality, exposure factors and techniques for imaging children (210). Such an endeavor needs the collaborative efforts between service providers, training institutions, paediatric radiology committees and organisations and radiologists (210).

The least commonly identified errors were *(1) absent body parts in FOV* (1.4%) and *(12) absent or wrong image orientation marking* (1.7%). Similar to our findings studies by Tschauner et al. and Hlabangana et al. demonstrated that less than 5% of the included radiographs did not include diagnostically necessary structures (2,5).

5.2.2.1 Conclusion

The only centre to demonstrate continuous improvement in the overall quality of radiographs was RMMCH. Statistically significant improvement (decrease) in the median quality score between phase 1 and 3 was observed at CHBAH and KH, while RMMCH maintained the lowest median quality score throughout the study. Phase 3 also demonstrated the highest proportion of radiographs with a perfect score and the highest proportion of ‘high quality’ radiographs for all 3 hospitals.

While image quality overall was of ‘diagnostic’ quality, quality improvement of most of the quality factors was not sustained over the 3 phases of the study. The higher quality shown consistently at the only stand-alone mother and child hospital, RMMCH, that has dedicated paediatric radiographers and on-site paediatric radiologists’ interpretation, supports this type of service provision, but are unrealistic regarding provision of care for children throughout South Africa. However, dedicated paediatric radiography units with paediatric radiologist oversight are recommended for all sites imaging children.

The improvements in chest radiography cannot be attributed to the interaction with social media platforms as engagement was poor at all 3 centres.

5.2.3 Social media engagement

Overall engagement with social media platforms was very low. There are several possible reasons for this, including aspects relating to the study design and the socioeconomic reality of South Africa.

Although using social media as communication and educational tools among a group of professionals has many advantages, the next section will try to explain why this was not successful in our study and will attempt to extract any lessons that can be learnt from this exercise.

5.2.3.1 Study design

The ultimate goal of the study was to show that radiographic quality improvement could be achieved through a mechanism limiting the physical visiting of geographically distant institutions for performing QA, and to assess the effectiveness of remote communication on social media to educate and improve the quality of paediatric chest radiographs in South Africa. Hence, only a single visit was made to each of the radiology departments for introducing the study to the radiographers. One can argue that the poor interaction with the social media

platforms could have been partly due to insufficient training in and reinforcement of the social media networks that were used (212,213). However, attempts to mitigate against this were made by identifying radiographers (superusers) who indicated that they were familiar with Facebook and Twitter for assisting individuals experiencing challenges on the platforms. The identification of superusers was also an attempt to foster ownership of the study by the radiographers in an attempt to seamlessly drive the use of the platforms (155,213–215), and to make usage seem less forced (155). A study by Guerra et al. in 2022 surveyed 285 health professionals from 35 different countries revealed that most of the health professionals interacting with social media did so passively and hardly actively engaged or contributed original content to the platforms they engaged on (146). Research by Dixon-Woods et al. highlighted that important factors influencing the success of QI endeavours include initiatives that are locally owned, locally designed, locally driven and locally customised (216). Those which are enforced by peers rather than external (and/or higher) forces and authority, tend to have greater success and sustainability (216). Top-down mHealth initiatives appears to often experience challenges with sustainability and adaptability (109).

Another challenge that could have limited uptake and interaction with the social media was the wide range in the ages of the radiographer population: 19–64 years. Effort was made to make the posts and content on social media educational, interesting, interactive and relevant to daily practice (120). This is supported by a study by Kauffman et al. that looked into which Facebook posts yielded the best response in radiology education. The study highlighted that posts that were posted 'just for fun' and quizzes yielded the best responses. There was greater engagement with instructional videos when compared to case images (217). There was, however, no specific effort to produce age-specific or age-relatable messaging (120). As shown by the Pew review, age is strongly related to social media usage, with younger people (the 18–29-year age group) more likely to interact with social networking sites (100,111). The majority of Internet users are students (97), the average age of radiographers who signed onto the social media platforms to be between 30 and 32 years. Focus on the younger radiographers may have yielded improved interaction and better results (206). McCool et al. and Rowland et al. in a review of mHealth initiatives highlighted that the decrease

in desired compliance and outcomes of such initiatives could partly be attributed to a lack of research on the utility of these apps in different population groups (107,108).

Cheston et al. (2013) cited the demand on time as a possible challenge for using social media as an educational/teaching tool (139). Time definitely posed a challenge at the centres in this study, due to large workloads and limited human resources.
Participants did not have much time during working hours to engage with the social networking platforms. Despite attempts to keep the Facebook posts and tweets short, interesting and relevant, there was very little participation or interaction on the social networking sites.

The study focused solely on paediatric frontal chest radiographs in departments that image the whole body of both adults and children. Therefore, focus on the frontal chest examination only may have reduced the radiographer's perceived value and relevance of the study with regard to the overall QA and QI requirements of the radiology departments overall.

5.2.3.2 Social issues surrounding the lack of interaction

Despite the initial perceived participant interest demonstrated in the study, several socioeconomic factors were identified as possible barriers to engagement. This highlights the need to consider deeper and broader thought to be factored into study design and for the control of external factors such as costs (both known and hidden) (109), other than the QI intervention that can influence the results and change quality outcomes (206).

At the time of the study (2014) (and currently in 2024) Facebook and Twitter were touted as the most popular social media platforms used in education and communication internationally (146,151,155,213), however, due to associated high data usage requirements (especially for Facebook) and the local technological and economic landscape in South Africa at the time, they may not have been ideal for the radiography population included in the study. Dixon-Woods et al. suggested

that the ‘plug and play’ notion of QI initiatives working, as well as in the environment that they were designed, is misguided and short-sighted. They stressed that the contextual characteristics that made it work in the first place would need to be replicated and equally available. This is often not the case (216) and was not the case in our study. Knowledge of and attention to the social and cultural context is imperative for QI interventions to work (109,206,216,218).

The cost of data was and is still high in South Africa with most South Africans not having access to free Wi-Fi where they reside or where they are employed. It is suggested that more affordable, low data demanding and freely downloadable social media instant mobile messaging apps such as WhatsApp (96,108,219) (the number one messaging app in several LMICs) (96) and Telegram may have been more accessible and relevant to the radiographers participating in the study (100). These apps enable communication with voice, video and text. Further advantages of these apps are the ability to easily upload multi-media and share links to other social media platforms (219). A survey conducted in Saudi Arabia in in 2017 assessed the utility of using social media platforms in radiation-safety education among radiographers. The study revealed that the most commonly used social media platform among the 159 participants was WhatsApp (96.2%); 60.4% used Twitter and 46.5 % used Facebook (117). A study performed in the Nordic area by Pendersen et al. in 2024 demonstrated a preference for Facebook with 93% of respondents using the platform (141). This study further highlighted that a few radiographers used social media to create educational content and the need for guidelines to assist with maintaining professional boundaries and ethics (141).

Our study did not review the cost or potential costs of the intervention for the individual participants – a downfall of many QI studies. A review of the effectiveness of QI studies by Alexander et al. demonstrated that only 12% of studies reviewed costs or potential costs prior to performing the study (206).

There was limited access to the Internet and none of the hospitals included in the study had access to free Wi-Fi or available computers with access to the Internet. At the time of the study (and currently in 2024), this was (and is) the general experience in most public and private hospitals in South Africa. A review by McCool et al. on mHealth initiatives in LMICs, confirms that often the decreased

interaction and success of such initiatives in this setting is the lack of technical resources required to implement and sustain programs (108). The radiographers would have had to use personally purchased data for interacting with the social media platforms, thus creating a limiting factor to the frequency and depth of interaction with the platforms. This could have been mitigated against by providing data for the radiographers involved in the study or establishing Wi-Fi access in radiology departments at each of the hospitals but this was not anticipated at the planning stage. Data bundles as prizes for correct answers to the quizzes on Facebook and Twitter could have potentially increased and or encouraged participation. On Facebook there are paid options available to promote a page to participants.

Research by Mahlalela et al. on mobile phone intervention in post-rape service delivery, also highlighted this point and concluded that individuals interacted more readily with technology-based platforms that were affordable, easily accessible and familiar (220). Health workers in research by Hampshire et al. on mHealth in Africa reported that the costs related to the purchasing of data utilised a significant percentage of monthly income, often resulting in personal sacrifices (109). The above findings have been further supported by the research by Perrin et al. from the Pew research centre in Washington DC, which identified that people who live in urban and developed communities and households with a higher income, were more likely to use social media (111) and mHealth initiatives (108).

The hospitals included in the study are located in the lower income areas and townships in South Africa: KH and CHBAH are both located in townships and informal settlements, and RMMCH is situated in mainly in the Westbury (west of Johannesburg, South Africa) area, and services low-income clients.
The average monthly household income in South Africa is $180 and in the rural communities this decreases to about $55 (170). The average monthly amount used on data in lower income and rural communities ranges between $5–14, thus when compared to the average monthly income, this amount is relatively high (165,167,170). A study published in 2020 compared the cost of 1 gigabyte (GB) of data in different countries (cheapest to the most expensive) ranked South Africa as 115th out of 155 countries. One GB of data cost $4.30 in South Africa,

compared to India (ranked 1st) where 1GB of data costs $0.09. The country with the most expensive price for 1GB of data was Malawi at a price of R27.41 (221). A study in 2023 revealed that the cost of 1GB of data had decreased to $1.18 with South Africa ranking 149/237 (222).The cost of data in South Africa is more expensive than in several African countries, and cheaper than some HICs such as Canada or the United States. What this comparison fails to highlight is that the cost of data per megabyte is highest for the poor, who cannot afford bulk data packages and are therefore limited to the more expensive usage-based billing options (223).

Due to the informal economy usage-based billing is more common in low-income environments in South Africa (150,167) with users purchasing data when needed and opting for pre-paid or pay-as-you-go options rather than mobile data contracts (150,165,167,170). Such practices would obviously not foster or encourage communities with limited resources and constrained disposable income to voluntarily engage deeply with educational content, even if it was beneficial (167). There are several barriers to purchasing mobile contract plans, which include the need to provide proof of residence (this is very difficult in townships and informal settlements) and a reliable source of income supported with bank statements – requirements which exclude several individuals such as informal workers and students (167). Internet for mobile phones can be purchased in time-restricted data bundles or as airtime. Table 5.1 provides a summary of a few of the lower-level data plan options that were available in 2015–16 close to the period when the study was conducted. In 2014 the main mobile network operators in South Africa were “Vodacom (39.3%), MTN (35.1%), Cell-C (22.7%), Telkom (2.3%)” (224) and Virgin (0.6%).

Table 5. 1 Data Plans from mobile operators in South Africa

Operator	Plan 1	Plan 2	Plan 3	Plan 4
MTN	5MB	20MB	50MB	300MB
cost	R4	R12	R25	R85
lasts	1-day	1-day	3-days	5-days
Vodacom	20MB	100MB	250MB	250MB
costs	R5	R10	R20	R60
lasts	1-day	1-day	1-day	1-month
Cell-C	20MB	100MB	100MB	300MB
costs	R3	R13	R25	R60
lasts	1-day	1-day	1-month	1-month
Telkom	25MB	50MB	100MB	250MB
costs	R8	R15	R29	R39
lasts	1-month	1-month	1-month	1-month

(167)

Users in lower income brackets are often more aware of the data consumption patterns of phone apps, preferring to use Wi-Fi connections when available (167). They also incorporate several data maximising practices such as switching off data when not in use (150); the use of several sim cards or the purchasing of multiple starter packs to maximise on the operator dependent specials such as free air-time (165); and using data at night when it is cheaper (225). Research, however, has shown that the mean daily usage of data exceeds that of Wi-Fi use and this is as a result of the lack of access to public Wi-Fi (167). Poor network connectivity as well as uneven network coverage are further challenges that users in resource-restrained communities experience (108,160,161,167,170), because establishing telecommunication access in rural or informal settlements is neither easy or profitable (170). The choice of apps used is very limited with data mainly used for sending messages, entertainment and hustling for additional income generation (167,170). Google Play Store and Chrome, Facebook (for personal use) and WhatsApp are the most popular data consuming applications used (167). It has also appeared that the uptake of mHealth initiatives is lower in LMICs

compared to developed countries with barriers to implementation, including resource and technical limitations (108).

5.2.3.3. Conclusion

There was low engagement with the social media platforms in our study, but our results highlighted that most of those who joined the Facebook page and Twitter accounts were younger, and more radiographers interacted with Facebook.

5.3 Limitations of this study

5.3.1 Introduction

There were several limitations due to a number of factors, such as those related to the use of JPEG instead of DICOM images; the inclusion of radiographs that were taken by student radiographers; the lack of familiarity using social media platforms as educational tools; and socioeconomic factors.

5.3.2 Inter-rater analysis

The PI did not have access to secure, technologically advanced, online data-sharing platforms that are readily available in the high-income countries (HICs) (e.g. Ambra® or Life Image). This limitation resulted in radiographs that had to be manually selected, anonymised, captured and shared on REDCap with the reviewers in JPEG format, rather than DICOM format, which is more commonly used on PACS® stations by radiologists. The reviewers therefore were not able to manipulate or optimise the images to improve visualisation of structures. Visibility of quality factors related to exposure, such as *(8) Peripheral vessels not well seen, (10) Trachea and bronchi not well seen*, and *(11) Vessels behind heart not well seen* were potentially compromised by the inability of the reviewers to enlarge and

adjust the brightness, contrast and resolution of the images. However, it is necessary to state that the standardised JPEG format allowed for each reviewer to view the images as presented for interpretation by the technologist, with the same resolution and contrast, enabling standardised inter-rater assessment. Access to only JPEG images of radiographs for both diagnosis and QA reflects the typical scenario of volunteer and informal teleradiology efforts in resource-limited, underserved regions in Africa (226).

5.3.3 Quality assurance

There were a number of limitations related to QA. The first limitation was that there was no analysis of the reject films, as such films were not available for the study. Quality assurance of these films would have strengthened the study, as reject analysis is a good method for the QA of radiographic technique (18,74,75,78,227). The current data set of images therefore represents images that were considered acceptable by the radiographers and presented for diagnostic interpretation, i.e. they were not discarded and some may represent repeat radiographs after the initial radiograph was discarded. The quality improvement effort can therefore be assessed on our set of radiographs as it represents the radiographers' final effort, and it includes self-assessment of the work as adequate for presentation to radiologists for reporting.

Another limiting factor (although insisted upon by the research protocol assessor panel) was the inclusion of all the radiographers from the 3 centres in the study, without focusing on those working specifically in the paediatric department. Although this was not a major limitation at the smaller hospitals (i.e. RMMCH and KH) as all the radiographers were equally exposed to patients imaged in the department, it was a major limiting factor for a large centre such as CHBAH, where 2–3 student radiographers rotated through the department on a monthly basis. This was compounded by the absence of radiographer identifiers on the radiographs, resulting in films taken by student radiographers being included in the study even though they were not in fact participants in the quality intervention. However, this represents a real scenario which should be considered in quality

assessment and improvement efforts, and where senior radiographers should be responsible for training and evaluating the work of student radiographers in providing diagnostic quality images for patient care.

5.3.4 Social media

The primary limitation of the study was the poor engagement with the social media platforms with less than half of the radiographers engaging with the content. Interaction with the social media platforms was key and fundamental to the success of the study and could be the reason there was no demonstrated benefit from the interaction. The lack of engagement was a potential bias in the study.

The radiographers at all of the sites had heard of Facebook and Twitter but not all of the users were very familiar with or active on the platforms. We attempted to mitigate against this by giving a PowerPoint presentation on the social media platforms, which included a demonstration on how to create personal accounts. The social media assistant also assisted several radiographers to create personal accounts and/or to link to the study Facebook page and Twitter handle. Further efforts to support radiographers who had less experience on the social media platforms included the identification and appointment of 'superusers' at each of the hospitals to provide further assistance during the course of the study. We do concede that frequent visits by the PI could have addressed the matter by encouraging greater participation. However, this would have been contrary to the study goals and design which focused on remote communication and education. A pilot study to assess the environment and social media readiness at each of the sites could have assisted in creating a more locally relevant study design.

English was the only medium of communication used in the study and this could have created a limitation for interaction for the multilingual participants. Research has shown that careful consideration of the language(s) used (114,149,228), methods of communication and the specific timing of the communication should be made in mHealth, as they could pose a logistical challenge to the uptake and interaction with social media (114,149). English was chosen as the language for

communication as it is the language of instruction at universities. It was the language the PI was most comfortable with, and research has shown that individuals who are able to read and speak English demonstrate greater participation in mobile activities (111). There are 11 official languages in South Africa, and it would have proved to be challenging to attempt to communicate with all of the radiographers in their mother tongue. However, communication in a more language concordant manner (228) could potentially have increased uptake and interaction.

5.4 Future applications

5.4.1 Use of social media as communication and educational tools

In 2014 when the study was conducted there was little to no research on the use of social media as communication and education tools in radiography, and specifically in quality assurance in radiography. There has been rapid growth in the use of online platforms including social media in the past 4 years due to the Covid-19 pandemic, which resulted in the closure of universities, the termination of in-person lectures and tutorials, and the rapid transition to remote and online learning worldwide (225,229).

Prior to the pandemic, cell phone use amongst the youth was increasing rapidly across Africa, the use and utility in the context of education (175,230) and the formation-supportive microcommunities and peer-assisted learning (PAL) that facilitated sharing of information and course material (231). This has exploded in the last 2 years.

Future research using social media platforms as communication and education tools should undertake a thorough needs analysis. Researchers need do their due diligence to identify the potential gaps, the causes of the gaps and the potential solutions. A need analysis will also assess the readiness of the study environment for such an intervention.

Support from management is paramount for the success of quality improvement initiatives. Support should not only involve obtaining permission to perform the research but should also include clear demonstration of the value of the interventions to ensure buy-in by management and those working on the ground. This will introduce shared value and understanding of the benefit of the study which will increase the possibility of the success of the interventions.

A further step to ensure better cooperation is the inclusion of management and the workers on the ground in the co-design of the project. Brainstorming with all relevant and important stakeholders will assist in performing a thorough environmental analysis and identify potential bottle necks and barriers to the success of the study. Co- design with the actual people who will be involved in the study will foster co-ownership further establishing a foundation for greater success.

A thorough cost- benefit analysis should also be performed to help identify the best social media platform to use and to determine the actual feasibility of the project. This will help identify platforms which are familiar and frequently used by the study participants. Therefore, avoiding the ‘top-down’ approach and fostering a ‘bottom-up’ approach which has been shown to result in greater success and sustainability.

This study recommends that future research focuses on the introduction and incorporation of social networking sites in the learning process of undergraduate and postgraduate radiography students, and to assess the acceptance of different methods of social media mediated virtual learning. Introduction of these platforms may have greater uptake in the younger students, as research has shown that mature diagnostic radiography students often lack familiarity with technology and have a greater preference to in-person teaching (229) as also suggested by our findings. Quantitative and qualitative feedback on student and lecturer preferences, perceptions of, interaction with, and attitudes towards the use of the various social media platforms, would provide insight to lecturers to increase agility in the adaptation of teaching methods (138,151,155,213,225,232). Research by Elliot et al. in the United Kingdom assessed the effectiveness of the use of PowerPoint presentations for remote learning in radiography during the Covid

pandemic. The research highlighted the challenges students had in transitioning to this format of learning and raised concerns that although students were passing the assessments, deep learning and understanding of the important concepts were not necessarily achieved (229). There were students in this cohort that experienced challenges with Internet access and connectivity as well as difficulty balancing the studies with household demands and responsibilities. This would also be true in South Africa. These challenges were captured in a study by Mulla et al. in 2023. The study highlighted the technical challenges of both students and educators related to the transition form in person to online teaching in radiography in a South African teaching institution. Additional socio-economic challenges such as the inequality in infrastructure such as computers, smart phones and other devices, unreliable electricity supply and the high cost of data were mentioned in the study (158,225). The study revealed that many students were not able to attend online lectures live, preferring to watch recordings at night when data costs are cheaper (225). This added additional anxiety to the learning process (225). Most teaching institutions provide internet connectivity on their campus however, several students in LMICs would need to use their own data to access the Internet at home. Universities could potentially broker deals with Internet service providers for discounted data bundle packages for their students.

Although several studies have shown the use of Facebook, Twitter and content sites such as YouTube to be beneficial (151), it is recommend that platforms such as WhatsApp and Telegram should also be used in the South African setting, as these social media tools are familiar, more affordable, less data-intensive and readily accessible to a wider demographic of students. Due to the practical nature of radiography, virtual simulation programs in isolation, as well as in conjunction with in-person practical training, need to be developed, and the effectiveness in ensuring adequate student training and competence needs to be assessed (233). Research by Lee et al. at Monash University, Australia compared the competence and confidence of students who received on-site training in Computed Tomography (CT) and those who received remote training on a simulator. Knowledge acquisition was comparable between the 2 groups, however, the group that received training under simulation expressed decreased confidence in the practical application in the clinical setting (234).

Future research needs to address the risks related to using social media as educational and communication tools and to develop guidelines to mitigate against them (139). Research to improve the metrics to measure the depth of learning and student engagement are required, as these are currently lacking (229).

It is imperative for both students, lecturers and universities/colleges to receive support as they transition from the more traditional methods of teaching to the use and incorporation of social networking sites and other electronic platforms. There is variation in the extent and penetration of engagement with social media among the population, and both lecturers and students would need to be assisted in identifying relevant content and the best method/platform to transfer and share knowledge (120)(155). Although students may be familiar with social networking sites on a social level, they may not intuitively know how to engage with and use social networking platforms in the educational environment. There is a need to assist and demonstrate to both students and lecturers how to engage and maximise the use of social media mediated peer-related learning to ensure that they fully benefit from these new educational tools (155,229).

5.4.2 Quality assurance

Efforts to achieve greater reliability and objectivity in image quality assessment could include the digitization of the quality assessment process, with the inclusion of the use of artificial intelligence (AI) (8–10), including its use in reject/repeat applications (24). Ultra-modern X-ray machines are to ensure the generation of high quality radiographs, due to embedded software that has built-in capability to automatically capture repeat images while discarding those compromised by motion artefact (9,24). In paediatric imaging, however, this may not be acceptable routine practice as interpreting radiologists want to avoid repeat exposure of children to radiation and are therefore more lenient and likely to accept some radiographic errors. There is the need for the development of uniform chest radiography protocols that technologists should refer to when acquiring

radiographs. Display stations in the X-ray and reporting rooms should be calibrated to ensure that all staff members in the radiology department are able to see the same rendered image (235). Medical physicists play a key role in improving the efficiency of imaging departmental operations by automating imaging algorithms that function as substitutes for human observation (236). Lin et al. developed an application that spontaneously segregates digital chest radiographs to assess 10 physical attributes that relate to10 characteristics associated with image quality (237). We understand the challenge of implementing these measures in the African healthcare setting where countries with limited resources are pressured to increase patient throughput while being expected to decrease service and maintenance costs. These technological developments and advances, however, do represent potential alternatives to human intervention for remote and understaffed regions.

'Institutional compliance' poses another challenge in meeting radiographic quality requitements (238). Even with requisite accreditation by internationally recognized QA organisations, institutional conformity is not guaranteed to the stipulated QA protocols. Our recommendation is to perform scheduled and structured quality improvement initiatives (239), focused on identifying the quality problems that are frequently encountered while designing practical locally relevant solutions. The relevant regulatory boards should conduct unannounced audits to ensure compliance to the stipulated quality standards and guidelines. The QA training of healthcare workers should be locally relevant with a focus on 'problem-solving' methodology. This training should be presented to the entire staff compliment, irrespective of individual specialty or tenure (240). However, our findings of higher radiographic quality of paediatric chest radiographs at the dedicated mother and child hospital through all phases of this study, speak to the role of subspecialist expertise and experience in improving quality. Lack of adherence to QA guidelines and the lack of active participation in improvement measures to improve image quality, can negatively impact patients, delaying diagnosis and management. Other undesirable outcomes include the risk of high radiation exposure and unnecessarily increased costs.

5.5 Conclusion

Our study focuses on the quality of paediatric chest radiographs obtained in radiology departments in 3 geographically separated South African hospitals with different resource profiles (personal and equipment). The 3 hospitals included in the study were CHBAH, a tertiary (level 3) hospital in Soweto, a township in Johannesburg; RMMCH a district (level 2) hospital situated in the low-income suburb of Westbury in Johannesburg – both are found in the Gauteng Province; and KH a district (level 1) hospital situated in the township and informal settlement of Khayelitsha on the outskirts of Cape Town in the Western Cape Province.

To our knowledge this study is the first to incorporate the use of the social media platforms Facebook and Twitter as quality improvement tools to remotely educate and communicate with the radiographers on the important quality factors of paediatric chest radiographs. Quality assessment of the radiographs was performed using reviewers with a similar level of postgraduate radiologist training, a standardised tick sheet and standardised viewing parameters. Quality assessment was performed before and after a number of interventions, using social media platforms, and a comparison of the quality scores from the different phases of the study was made.

The results showed that there was low engagement by the radiographers with the social media platforms overall. The social media intervention was not successful and did not have the desired impact creating a potential bias in the study. Less than 40% of the radiographers from the different centres interacted with the social media platforms. More radiographers from RMMCH chose to interact on Facebook, while more radiographers from KH opting to interact on Twitter. Younger radiographers tended to interact more than older radiographers on the social media platforms.
Image quality in the majority of radiographs reviewed was categorised as ‘diagnostic’, but only one centre (RMMCH – the only dedicated ‘mother and child’ hospital) demonstrated continuous improvement in the overall quality of radiographs. CHBAH and KH demonstrated statistically significant improvement

(decrease) in the median quality score between phases 1 and 3. Phase 3 also demonstrated the highest proportion of radiographs with a perfect score, and the highest proportion of ‘high quality’ radiographs for all 3 hospitals.

Quality improvement of most of the individual quality factors was not sustained over the 3 phases of the study. Factors related to insufficient patient positioning *(4)scapula in the way, (3) patient rotation*) and *(9) inadequate collimation* were the most commonly detected quality factors, and they are reflective of the challenges in imaging children who are often unable to or unwilling to co-operate.

The higher quality shown consistently at the only stand-alone mother and child hospital (RMMCH), which had dedicated paediatric radiographers and on-site paediatric radiologist interpretation, support recommending this type of service provision for quality improvement of paediatric radiographs in particular, but are likely unrealistic for provision of care for children throughout South Africa.

Our study outcomes did not match our hypothesis or the aspirations highlighted in the literature regarding the effectiveness of the use of social media as communication tools for quality assessment and improvement for remote settings. The study in many respects was ahead of its time, as failings were not due to the platforms themselves, but by the lack of readiness for usage on the part of the PI, the socio-environmental settings and the study population. In many respects, IT infrastructure development in South African public hospitals, which is a major barrier to uptake, has not progressed beyond what was available in 2014 when the study was conducted. There is still no free Wi-Fi access available in public hospitals, mobile data costs remain high for the intended users and socio-economic and infrastructure stability cannot be predicted in the South African climate. We hope to publish the findings of our study to highlight these challenges and the lessons learned in an article entitled, "Challenges of using social media in Radiography in LMICs- Experience of selected centres in South Africa".

This research is relevant today even though social media has been used more in education, especially during and after the Covid -19 pandemic. The most effective

use of social media and which platforms to use are still being debated and explored.

Staffing shortages are constant challenge with several centres not having X-rays reported and only reviewed by the referring clinician. Ensuring good quality imaging is therefore paramount and in geographically separated resource constrained environments where this task falls on radiographers - novel methods are required to fill human and expertise gaps.

Further research is required on how to successfully repurpose these social networking sites into effective educational tools, specifically for quality assessment and quality intervention in paediatric radiography. The Covid-19 pandemic has created an environment ripe with opportunities for the development of locally relevant and sustainable digital scholarship in medical education.

Appendix A: QA Tick-sheet

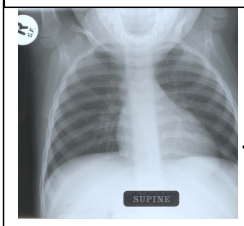
QA Tick-sheet: Data Collection: Quality Assessment [QA] of Frontal Chest Radiographs

Date:	**Patient code**	**Reviewer name:**

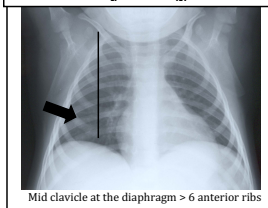
Instructions: Please circle **Yes (Y) or No (N)** for each section

DOB:

1. Parts Cut-off
Y **N**

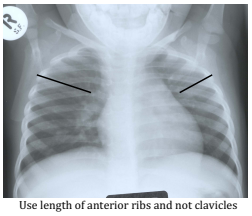


2. Under Inspired (< 6 ant ribs)



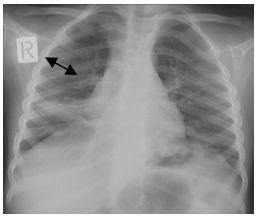
Mid clavicle at the diaphragm > 6 anterior ribs

3. Rotated
Y **N**

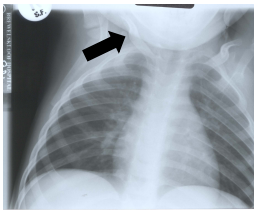


Use length of anterior ribs and not clavicles

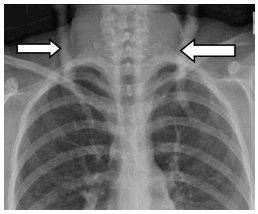
4. Scapula in the way (> 1 cm)
Y **N**



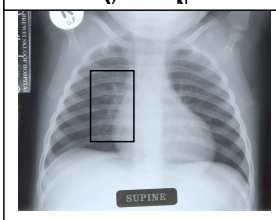
5. Kyphotic or lordotic?
Y **N**



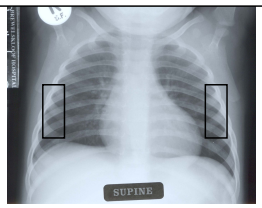
6. Artifact / Foreign body
Y **N**



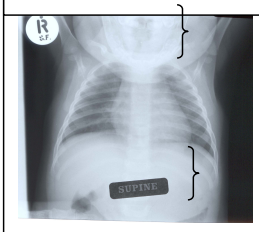
7. Central vessels not well seen



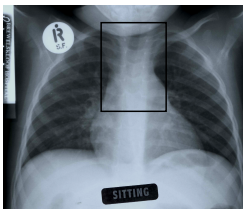
8. Peripheral vessels not well seen
Y **N**



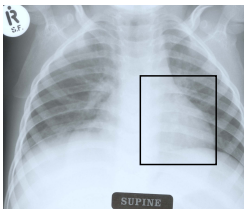
9. Poor collimation
Y **N**



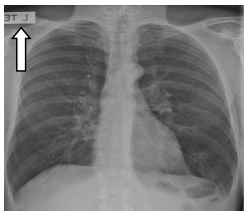
10. Trachea and bronchi not clearly seen
Y **N**



11. Vessels behind heart not well seen
Y N



12. Wrong (no) Left/Right marker
Y **N**



Appendix B: Ethics Clearance Certificate

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M130665

NAME: (Principal Investigator)	Dr Linda Tebogo Hlabangana
DEPARTMENT:	Radiology Charlotte Maxeke Johannesburg Academic
PROJECT TITLE:	Novel Mechanisms for Maintaining Paediatric Chest X-Ray Quality Assurance (AQ) and Implementing Quality Improvement (QI) in a Developing Country
DATE CONSIDERED:	28/06/2013
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Prof S Andronikou
APPROVED BY:	Professor PE Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 30/10/2013

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature M130665Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

Appendix C: Comparison of the proportional percentages of errors and the p-values between phases and hospitals for each phase for the different variables

Table C. 1 Comparison of the median quality scores between hospitals during each phase for each of the 3 hospitals

Phase	Median quality score (%)			p-value for between-group test		
	CHBAH	RHMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	16,7	8,3	16,7	0,40	<0.0001 r=0.36	<0.0001 r=0.36
2	50,0	8,3	16,7	<0.0001 r=0.60	<0.0001 r=0.67	0.0098 r=0.17
3	8,3	8,3	8,3	0,27	<0.0001 r=0.30	0.0026 r=0.20

Table C. 2 Comparison of the median quality scores during each phase for each of the 3 hospitals

Hospital	Median quality score (%)			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	16,7	50,0	8,3	<0.0001 r=0.55	0.0011 r=0.23	<0.0001 r=0.65
RHMMCH	8,3	8,3	8,3	0,062	0,065	0.063
KH	16,7	16,7	8,3	0,11	<0.0001 r=0.28	0.0038 r=0.20

Table C. 3 Comparison of the proportional percentages of errors and the p-values between hospitals for each phase for the variable *'parts cut off'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	3,8 (3/79)	0,9 (1/115)	1,8 (2/113)	0,4	0,31	0,62
2	2,5 (2/81)	0,0 (0/120)	0,0 (0/117)	0,17	0,16	>0.99
3	0,8 (1/120)	0,0 (0/118)_	3,9 (4/103)	0,18	>0.99	0.046 phi=0.15

Table C. 4 Comparison of proportional percentages of errors and the p-values between phases for the variable *'parts cut off'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	3,8 (3/79)	2,5 (2/81)	0,8 (1/120)	0,68	0,30	0,57
RMMCH	0,9 (1/115)	0,0 (0/120)	0,0 (0/118)_	0,49	0,49	>0.99
KH	1,8 (2/113)	0,0 (0/117)	3,9 (4/103)	0,24	0,43	0.047 phi=0.15

Table C. 5 Comparison of proportional percentages of errors and the p-values between hospitals for each phase for the variable *'under-inspiration'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	15,2 (12/79)	12,2 (14/115)	24,8 (28/113	0,15	0,67	0.017 phi=0.16
2	33,3 (27/81)	17,5 (21/120)	16,2 (19/117)	0.0062 phi=0.20	0.012 phi=0.18	0,86
3	21,7 (26.120)	16,2 (19/117)	20,4 (21/103)	0,87	0,32	0,48

Table C. 6 Comparison of proportional percentages of errors and the p-values between phases for the variable *'under-inspiration'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	15,2 (12/79)	33,3 (27/81)	21,7 (26.120)	0.0097 phi=0.21	0,27	0,074
RMMCH	12,2 (14/115)	17,5 (21/120)	16,1 (19/118)	0,28	0,45	0,86
KH	24,8 (28/113)	16,2 (19/117)	20,4 (21/103)	0,14	0,52	0,49

Table C. 7 Comparison of proportional percentages of errors and the p-values between hospitals for each phase for the variable *'rotation'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	49,4 (39/79)	21,7 (25/115)	39,8 (45/113)	0,24	<0.0001 phi=0.29	0.040 phi=0.20
2	70,4 (57/81)	25,0 (20/120	37,6 (44/117)	<0.0001 phi=0.32	<0.0001 phi=0.44	0.049 phi=0.14
3	34,2 (41/120)	22,9 (27/118)	26,2 (27/103)	0,24	0,063	0,64

Table C. 8 Comparison of proportional percentages of errors and the p-values between phases for the variable *'rotation'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	49,4 (39/79)	70,4 (57/81)	34,2 (41/120)	0.0096 phi=0.21	0.039 phi=0.15	<0.0001 phi=0.35
RMMCH	21,7 (25/115)	25,0 (20/120)	22,9 (27/118)	0,64	0,88	0,76
KH	39,8 (45/113)	37,6 (44/117)	26,2 (27/103)	0,79	0.043 phi=0.14	0,083

Table C. 9 Comparison of percentages of errors and the p-values between hospitals for each phase for the variable *'scapula in the way'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	44,3 (35/79)	33,9 (39/115)	51,3 (59/113)	0,38	0,18	0.011 phi=0.18
2	39,5 (32/81)	36,7 (44/120)	47,9 (56/117)	0,31	0,77	0,089
3	36,7 (44/120)	25,4 (30/118)	35,0 (36/103)	0,89	0,069	0,14

Table C. 10 Comparison of percentages of errors and the p-values between phases for the variable *'scapula in the way'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	44,3 (35/79)	39,5 (32/81)	36,7 (44/120)	0,63	0,30	0,77
RMMCH	33,9 (39/115)	36,7 (44/120)	25,4 (30/118)	0,68	0,20	0,069
KH	51,3 (59/113)	47,9 (56/117)	35,0 (36/103)	0,69	0.019 phi=0.17	0,057

Table C. 11 Comparison of proportional percentage of errors and the p-values between hospitals for each phase for the variable error *'patient kyphosis/lordosis'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	11,4 (9/79)	7,8 (9/115)	5,3 (6/113)	0,17	0,45	0,59
2	25,9 (21/81)	7, 5 (9/120)	9,4 (11/117)	0.0029 phi=0.22	0.0005 phi=0.25	0,65
3	8,3 (10/120)	7,6 (9/118)	3,9 (4/103)	0,27	>0.99	0,27

Table C. 12 Comparison of proportional percentage of errors and the p-values between phases for the variable *'patient kyphosis/lordosis'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	11,4 (9/79)	25,9 (21/81)	8,3 (10/120)	0.025 phi=0.18	0,47	0.0012 phi=0.24
RMMCH	7,8 (9/115)	7, 5 (9/120)	7,6 (9/118)	>0.99	>0.99	>0.99
KH	5,3 (6/113)	9,4 (11/117)	3,9 (4/103)	0,31	0,75	0,12

Table C. 13 Comparison of proportional percentages of errors and the p-values between hospitals for each phase for the variable error *'artefact/foreign body'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	8,9 (7/79)	5,2 (6/117)	7,1 (8/113)	0,78	0,39	0,59
2	55,6 (45/81)	3,3 (4/120)	5,1 (6/117)	<0.0001 phi=0.56	<0.0001 phi=0.60	0,54
3	10,8 (13/120)	1,7 (2/118)	6,8 (7/103)	0,35	0.0058 phi=0.19	0,086

Table C. 14 Comparison of proportional percentages of errors and the p-values between phases for the variable *'artefact/foreign body'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	8,9 (7/79)	55,6 (45/81)	10,8 (13/120)	<0.0001 phi=0.49	0,81	<0.0001 phi=0.48
RMMCH	5,2 (6/117)	3,3 (4/120)	1,7 (2/118)	0,53	0,17	0,68
KH	7,1 (8/113)	5,1 (6/117)	6,8 (7/103)	0,59	>0.99	0,78

Table C. 15 Comparison of percentages of errors and the p-values between hospitals for each phase for the error *'central vessels not well'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	5,1 (4/79)	1,7 (2/115)	0,9 (1/113)	0,16	0,23	>0.99
2	54,3 (44/81)	0,8 (1/120)	3,4 (4/117)	<0.0001 phi=0.58	<0.0001 phi=0.63	0,21
3	4,2 (5/120)	0,8 (1/118)	1,9 (2/103)	0,45	0,21	0,60

Table C. 16 Comparison of percentages of errors and the p-values between phases for the error 'central vessels not well seen'

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	5,1 (4/79)	54,3 (44/81)	4,2 (5/120)	<0.0001 phi=0.54	0,74	<0.0001 phi=0.57
RMMCH	1,7 (2/115)	0,8 (1/120)	0,8 (1/118)	0,62	0,62	>0.99
KH	0,9 (1/113)	3,4 (4/117)	1,9 (2/103)	0,37	0,61	0,69

Table C. 17 Comparison of proportional percentage of errors and the p-values between hospitals for each phase for the variable 'peripheral vessels not well seen'

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	13,9 (11/79)	15,7 (18/115)	5,3 (5/113)	0,068	0,84	0.016 phi=0.16
2	71,6 (58/81)	26,7 (32/120)	9,4 (11/117)	<0.0001 phi=0.64	<0.0001 phi=0.44	0.0007 phi=0.22
3	10,0 (12/120)	4,2 (5/118)	4,9 (5/103)	0,21	0,13	>0.99

Table C. 18 Comparison of proportional percentage of errors and the p-values between phases for the variable *'peripheral vessels not well seen'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	13,9 (11/79)	71,6 (58/81)	10,0 (12/120)	<0.0001 phi=0.58	0,50	<0.0001 phi=0.63
RMMCH	15,7 (18/115)	26,7 (32/120)	4,2 (5/118)	0,055	0.0039 phi=0.19	<0.0001 phi=0.31
KH	5,3 (5/113)	9,4 (11/117)	4,9 (5/103)	0,31	>0.99	0,30

Table C. 19 Comparison of proportional percentage of errors and the p-values between hospitals for each phase for the error *'poor collimation'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	31,6 (25/79)	6,1 (7/115)	45,1 (51/113)	0,072	<0.0001 phi=0.34	<0.0001 phi=0.45
2	35,8 (29/81)	10,0 (12/120)	42,7 (50/117)	0,38	<0.0001 phi=0.31	<0.0001 phi=0.37
3	18,3 (22/120)	1,7 (2/118)	15,5 16/103)	0,60	<0.0001 phi=0.28	0.0003 phi=0.25

Table C. 20 Comparison of pproportional percentage of errors and the p-values between phases for the error *'poor collimation'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	31,6 (25/79)	35,8 (29/81)	18,3 (22/120)	0,62	0.040 phi=0.15	0.0078 phi=0.20
RMMCH	6,1 (7/115)	10,0 (12/120)	1,7 (2/118)	0,34	0,099	0.011 phi=0.18
KH	45,1 (51/113)	42,7 (50/117)	15,5 16/103)	0,79	<0.0001 phi=0.31	<0.0001 phi=0.30

Table C. 21 Comparison of proportional percentage of errors and the p-values between hospitals for each phase for the variable *'trachea and bronchi not clearly seen'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	25,3 (20/79)	13,9 (16/115)	23,0 (26/113)	0,74	0,060	0,089
2	71,6 (58/81)	11,7 (14/120)	12,8 (15/117)	<0.0001 phi=0.60	<0.0001 phi=0.61	0,84
3	7,5 (9/120)	11,0 (13/118)	17,5 (18/103)	0.025 phi=0.15	0,38	0,18

Table C. 22 Comparison of proportional percentage of errors and the p-values between phases for the variable *'trachea and bronchi not clearly seen'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	25,3 (20/79)	71,6 (58/81)	7,5 (9/120)	<0.0001 phi=0.46	0.0008 phi=0.25	<0.0001 phi=0.67
RMMCH	13,9 (16/115)	11,7 (14/120)	11,0 (13/118)	0,70	0,56	>0.99
KH	23,0 (26/113)	12,8 (15/117)	17,5 (18/103)	0,057	0,40	0,35

Table C. 23 Comparison of proportional percentage of errors and the p-values between hospitals for each phase for the variable *'vessels behind heart not well seen'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	19,0 (15/79)	0,9 (1/115)	0,9 (1/113)	<0.0001 phi=0.32	<0.0001 phi=0.32	>0.99
2	66,7 (54/81)	1,7 (2/120)	6,8 (8/117)	<0.0001 phi=0.63	<0.0001 phi=0.71	0,057
3	8,3 (10/120)	0,8 (1/118)	4,9 (5/103)	0,43	0.010 phi=0.18	0,10

Table C. 24 Comparison of proportional percentage of errors and the p-values between phases for the variable *'vessels behind heart not well seen'*

Hospital	% of cases with errors			p-value for between-group test		
	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	19,0 (15/79)	66,7 (54/81)	8,3 (10/120)	<0.0001 phi=0.48	0.031 phi=0.15	<0.0001 phi=0.61
RMMCH	0,9 (1/115)	1,7 (2/120)	0,8 (1/118)	>0.99	>0.99	>0.99
KH	0,9 (1/113)	6,8 (8/117)	4,9 (5/103)	0.036 phi=0.15	0,11	0,58

Table C. 25 Comparison of the proportional percentage of errors and the p-values between hospitals for each phase for the variable *'wrong or no L/R markers'*

Phase	% of cases with errors			p-value for between-group test		
	CHBAH	RMMCH	KH	CHBAH vs KH	CHBAH vs RMMCH	KH vs RMMCH
1	6,3 (5/79)	3,5 (4/115)	0,0 (0/113)	0.011 phi=0.19	0,49	0,12
2	4,9 (4/81)	1,7 (2/120)	0,0 (0/117)	0.027 phi=0.17	0,22	0,50
3	0,8 (1/120)	0,0 (0/118)	0,0 (0/103)	>0.99	>0.99	>0.99

Table C. 26 Comparison of the proportional percentage of errors and the p-values between phases for the variable *'wrong or no L/R markers'*

	Phase 1	Phase 2	Phase 3	Phase 1 vs 2	Phase 1 vs 3	Phase 2 vs 3
CHBAH	6,3 (5/79)	4,9 (4/81)	0,8 (1/120)	0,74	0.037 phi=0.16	0,16
RMMCH	3,5 (4/115)	1,7 (2/120)	0,0	0,44	0,058	0,49
KH	0,0	0,0	0,0	>0.99	>0.99	>0.99

Appendix D: Student's contribution to articles and agreement of co-authors

Appendix D. Student's contribution to articles and agreement of co-authors

Appendix D. 1

I, Linda Tebogo Hlabangana, student number 9600983m declare that this Thesis is my own work and that I contributed adequately towards research findings published in the article(s) stated below which are included in my Thesis.

Signature of Student.....**Date**.....

Name of Primary Supervisor.....Savvas Andronikou

Signature of Primary Supervisor .....**Date**.....30 March 2024

Agreement by co-authors: By signing this declaration, the co-authors listed below agree to the use of the article by the student as part of his/her Thesis In cases where the student is not the 1st author of a published article, the primary supervisor must explain (under comments) why the student is entitled to use the paper for his/her degree purposes.

Article 1: Title: Short-term impact of pictorial posters and a crash course on radiographic errors for improving the quality of paediatric chest radiographs in an unsupervised unit - a pilot study for quality-assurance outreach.
Journal name, year, volume and pages: Pediatr Radiol. 2015 Feb;45(2):158-65.

Author	Name	Signature	Date
1st author	Hlabangana LT		
2nd author	Andronikou S		30/03/2024

Appendix D. 2 Student's contribution to articles and agreement of co-authors

I, Linda Tebogo Hlabangana, student number 9600983m declare that this Thesis is my own work and that I contributed adequately towards research findings published in the article(s) stated below which are included in my Thesis.

Signature of Student.....**Date**.....

Name of Primary Supervisor.....Savvas Andronikou

Signature of Primary Supervisor .....**Date**.....30 March 2024

Agreement by co-authors: By signing this declaration, the co-authors listed below agree to the use of the article by the student as part of his/her Thesis In cases where the student is not the 1st author of a published article, the primary supervisor must explain (under comments) why the student is entitled to use the paper for his/her degree purposes.

Article 2: Title: Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays
Journal name, year, volume and pages: J Med Imaging Radiat Sci. 2021 Sep;52(3):427-434.

Author	Name	Signature	Date
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2nd author	Elsingergy M,		
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4th author	Boschoff PE		
5th author	Goodier M		
6th author	Bove M		
7th author	Andronikou S		30/03/2024

Author	Name	Signature	Date
1st author	Hlabangana L T		30/03/2024
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Author	Name	Signature	Date
1st author	Hlabangana L T		30/03/2024
2nd author	Elsingergy M,		
3rd author	Ahmed A		
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5th author	Goodier M		30/3/2024
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Appendix D. 3 Student's contribution to articles and agreement of co-authors

I, Linda Tebogo Hlabangana, student number 9600983m declare that this Thesis is my own work and that I contributed adequately towards research findings published in the article(s) stated below which are included in my Thesis.

Signature of Student.....**Date**.....30/03/2024

Name of Primary Supervisor.....Savvas Andronikou

Signature of Primary Supervisor .....**Date**.....30 March 2024

Agreement by co-authors: By signing this declaration, the co-authors listed below agree to the use of the article by the student as part of his/her Thesis In cases where the student is not the 1st author of a published article, the primary supervisor must explain (under comments) why the student is entitled to use the paper for his/her degree purposes.

Article 3: Title: Response to the letter to the editor re: Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays
Journal name, year, volume and pages: J Med Imaging and Radiat Sci. 2021 Dec 1;52(4):659-60.

Author	Name	Signature	Date
1st author	Elsingergy M,		30/03/2024
2nd author	Kidd M		
3rd author	Hlabangana L T		30/03/2024
4th author	Andronikou S		30/03/2024

Comments by Primary Supervisor : This paper reflects the content of Dr Hlabangana's PhD

Appendix D. 4 Student's contribution to articles and agreement of co-authors

I, Linda Tebogo Hlabangana, student number 9600983m declare that this Thesis is my own work and that I contributed adequately towards research findings published in the article(s) stated below which are included in my Thesis.

Signature of Student.....**Date**.....30/03/2024

Name of Primary Supervisor.....Savvas Andronikou

Signature of Primary Supervisor .....**Date**.....30 March 2024

Agreement by co-authors: By signing this declaration, the co-authors listed below agree to the use of the article by the student as part of his/her Thesis In cases where the student is not the 1st author of a published article, the primary supervisor must explain (under comments) why the student is entitled to use the paper for his/her degree purposes.

Article 4: Title: Response to the letter to the editor re: Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays
Journal name, year, volume and pages: J Med Imaging and Radiat Sci. 2021 Dec 1;52(4):659-60.

Author	Name	Signature	Date
1st author	Hlabangana L T		30/03/2024
2nd author	Andronikou S		30/03/2024
3rd author	Maré I A		31/03/2024
4th author	Maré W T		31/03/2024

Appendix E: Plagiarism declaration

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I LINDA TEBOGO HLABANGANA (Student number: 9600983M) am a student registered for the degree of Doctor of Philosophy in Diagnostic Radiology in the academic year 2023.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

Signature: _____ Date: 31/3/2024

1

Appendix F: Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays.

The following is the article as it appeared in the Journal of Medical Imaging and Radiation Sciences in May 2021.



Journal of Medical Imaging and Radiation Sciences xxx (xxxx) xxx



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Research Article

Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays

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ABSTRACT

Purpose: The goal of the study is to determine the inter-rater agreement on multiple factors that were utilized to evaluate the quality of pediatric chest X-ray exams from different levels of healthcare provision in an African setting.

Methods: The image quality of pediatric chest X-rays from 3 South African medical centers of varying level of healthcare service were retrospectively assessed by 3 raters for 12 quality factors including: (1) absent body parts; (2) under inspiration; (3) patient rotation; (4) scapula in the way; (5) patient kyphosis/lordosis; (6) artefact/foreign body; (7) central vessel visualization; (8) peripheral vessels visualization; (9) poor collimation; and (10) trachea and bronchi visualization; (11) postcardiac vessel visualization; and (12) absent or wrong image orientation. Analysis was performed using the Brennan—Prediger coefficient of agreement for inter-rater reliability and Cochran's Q statistic and McNemar's test for inter-rater bias.

Results: 1077 X-rays were reviewed. The least difference between observers in the frequency of the errors was noticed for factors (1) absent body parts and (12) absent or wrong image orientation with almost perfect agreement between raters. κ score for these two factors among all raters and between each pair of raters was more than 0.95 with no significant inter-rater bias.

Conversely, there was poor agreement for the remaining factors with the least agreed on being factor (3) patient rotation with a κ score of 0.23. This was followed by factors (2) under inspiration (κ score of 0.32) and factors (4) scapula in the way (κ score of 0.35) respectively. There was significant inter-rater bias for all these three factors.

Conclusion: Many of the factors used to assess the quality of a chest X-ray in children demonstrate poor reliability despite mitigation against variations in training, standard quality definitions and level of healthcare service provision. New definitions, objective measures and recording tools for assessing pediatric chest radiographic quality are required.

RÉSUMÉ

Objectif : Cette étude a pour but de déterminer le degré de concordance entre les différents facteurs utilisés pour évaluer la qualité des

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Ethical approval: Requirements for informed consent was waived for all study participants. The Human Research and Ethics Committees of the Faculty of Health Sciences at the University of the Witwatersrand approved the study.
Contributors: All authors contributed to the conception or design of the work, the acquisition, analysis, or interpretation of the data. All authors were involved in drafting and commenting on the paper and have approved the final version.
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radiographies pulmonaires pédiatriques réalisées à différents niveaux de soins de santé dans un contexte africain.

Méthodologie : La qualité d'image des radiographies pulmonaires pédiatriques de trois centres médicaux sud-africains de différents niveaux de services de soins de santé a été évaluée rétrospectivement par trois évaluateurs pour 12 facteurs de qualité, notamment: (1) absence de parties du corps; (2) inspiration insuffisante; (3) rotation du patient; (4) omoplate gênante; (5) cyphose/lordose du patient; (6) artefact/corps étranger; (7) visualisation des vaisseaux centraux; (8) visualisation des vaisseaux périphériques; (9) mauvaise collimation; (10) visualisation de la trachée et des bronches; (11) visualisation des vaisseaux post-cardiaque; et (12) absence ou mauvaise orientation de l'image. L'analyse a été effectuée en utilisant le coefficient de concordance de Brennan-Prediger pour la fiabilité inter-juges et la statistique Q de Cochran et le test de McNemar pour le biais inter-juges.

Résultats : 1077 radiographies ont été examinées. La plus faible différence entre les observateurs dans la fréquence des erreurs a été notée pour les facteurs (1) absence de parties du corps et (12) absence ou mauvaise orientation de l'image, avec un accord presque parfait entre les juges. Le score κ pour ces deux facteurs entre tous les évaluateurs et entre chaque paire d'évaluateurs était supérieur à 0,95, sans biais inter-juges significatif. En revanche, la concordance était faible pour les autres facteurs, le facteur (3) rotation du patient étant le moins bien accepté avec un score κ de 0,23. Il était suivi par les facteurs (2) inspiration insuffisante (score κ de 0,32) et (4) omoplate gênante (score κ de 0,35) respectivement. Il y avait un biais inter-juges significatif pour ces trois facteurs.

Conclusion : Plusieurs des facteurs utilisés pour évaluer la qualité d'une radiographie pulmonaire chez les enfants démontrent une faible fiabilité malgré l'atténuation des variations dans la formation, les définitions de qualité standard et le niveau de prestation des services de santé. Il est nécessaire de mettre au point de nouvelles définitions, des mesures objectives et des outils d'enregistrement pour évaluer la qualité des radiographies pulmonaires pédiatriques.

Keywords: Quality assurance; Children; Chest; X-rays; Radiographs

Introduction

Assessment of the quality of radiological exams should be an integral part of routine inspection protocols to ensure that the optium health care service is delivered to the patients [1,2]. This is particularly releveant to conventional pediatric radiographs, which often have several constraints jeopardizing their quality such as poor patient cooperation and frequent technical limitations [1].

Chest radiography is the most common diagnostic modality used for evaluation of cardiothoracic and respiratory diseases [3]. Optimization of image quality of the performed exams is necessary to ensure accurate radiological interpretation and to avoid any inappropriate management [4]. This requires the technologists performing these exams to have a minimum set of skills and experience to consistently ensure that the generated X ray images align with the established quality standards [5].

When performing chest radiography on pediatric patients specifically, there are a number of important factors that a radiographer needs to ensure are optimised in order to obtain a good quality radiograph [6]. One of these factors is limiting patient rotation, which can be in the horizontal plane or vertical plane, resulting in differential density of the hemithoraces or a lordotic or kyphotic X-ray respectively, with distortion of normal anatomy [2]. Collimation is the restriction of the field-size to only the area of interest [7]. Good collimation requires the patient to remain still with accurate positioning which can be challenging with children. Precise collimation reduces 'scatter' radiation resulting in image processing accuracy and improved contrast and resolution [7]–[9]. It should be noted, however, that excessive collimation can lead to cut-off of anatomic structures, which is a significant radiographic error in itself.

For standard anterior posterior (AP) radiographs, the technologist attempts to catch the picture at full inspiration which is represented by an adequate number of rib ends visualised above the mid-diaphragm (6 anterior ribs). Full inspiration is required because the lung volume of a chest radiograph is an important part of the search for pathology such as air-trapping or volume loss [10]. Under-inspired radiographs may give misleading findings that simulate disease pathologies. For example, normal lungs may appear opaque giving a false interpretation of pneumonia which can misdirect patient management. Similarly a normal sized heart may appear enlarged raising suspicion for congenital heart diseases and heart failure [10]. The duration of exposure and the power of the beam (determined by the kilovolts–kVp) both affect penetration. A poorly penetrated film looks diffusely light/white and soft tissue structures, especially those behind the heart, are obscured. Features such as lung markings are poorly seen when a film is over-penetrated as the film looks diffusely dark [10].

The presence of artefacts and foreign bodies can compromise diagnostic interpretation of X ray exams. This is particularly common in radiographs performed in pediatric wards where overlying patient medical or personal equipment may obscure the image. Sometimes patient normal anatomical structures serve as artefacts themselves affecting the quality of the generated image. Dressed hair artefacts (e.g. braids) may show translucent lines descending along side the trachea which could raise suspicion for a possible mediastinal air leak [11]. Baby skin folds may appear as curvilinear white lines mimicking the lung edge.

The above determinants of the quality of a radiograph are assessed subjectively and are therefore open to individual interpretation. The main goal of the study is to determine the agreement between raters for each of the different factors that

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are used to assess quality of pediatric chest X-ray exams from different levels of healthcare provision in an African setting.

Methods

Study design and exam selection

This multicenter retrospective cohort was approved by Human Research and Ethics Committees of the Faculty of Health Sciences at the University of the Witwatersrand. Requirement for patient's informed consent was waived. Pediatric chest X-ray images were collected from three sites differing in geographic location and service level in South Africa. These three institutions included a tertiary referral health care center providing all radiology modalities with a subspecialized pediatric section that have dedicated pediatric radiologists and technologists, a regional Mother-Child hospital providing all radiologic modalities except MRI with dedicated pediatric technologists, and a local hospital only providing plain radiography without dedicated pediatric radiologists or technologists. Three sets of 120 consecutive pediatric chest X-ray examinations were collected from each of the three institutions at three different time points giving a total set of 1080 exams. Chest X-ray examinations were excluded when there was only a lateral radiograph for review. Each X-ray was assessed by a group of 3 certified radiologists, including 1 subspecialized pediatric radiologist, all of whom had received their specialty training from the same institution. Raters reviewed the exams independently and were blinded to each other's scoring. All X-ray exams evaluated in this study were captured and stored in JPEG format which precluded image windowing, providing for standardized viewing parameters, and any patient identifier was removed. Steps of exams selection, review, exclusion, and analysis are depicted in Figure 1.

Data collection

For each exam reviewed, the raters were asked to comment with a "yes" or "no" answer for the presence of one of 12 different quality factors / radiographic faults. These 12 factors (Figure 2) included the following; *(1) if parts of the patient were cut off from the field of view (FOV); (2) If the film was under inspired (less than 6 anterior ribs shown); (3) if patient was rotated; (4) if the scapula was in the way; (5) if the patient was kyphotic or lordotic; (6) if there was artefact or a foreign body on the X-ray; (7) if the central or (8) the peripheral vessels were not visible; (9) if there was poor collimation; (10) if the trachea and bronchi were not visible; (11) if the vessels behind the-heart were not visible; and (12) and if there was absent or wrong image orientation marking*. These 12 factors were compiled into a quality assurance data collection tool for chest radiographs in children based on international quality assurance sources, including the European Commission guidelines for pediatric radiographs, and was designed and published by Hlabangana and Andronikou, 2015 [12]. No rater was asked to provide a medical diagnosis for any of the radiographs reviewed. All raters' data along with de-identified images were stored on an online web-based tool designed specifically for research data management called REDCap® (Vanderbilt University, Nashville, TN).

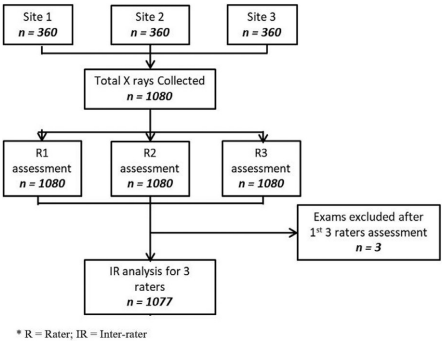

Figure 1. Flowchart showing steps for X-ray exam selection, review, exclusion and analysis.

Statistical analysis

For each quality factor, Brennan-–Prediger coefficient of agreement for more than *two raters (κBP)* was utilized to assess the inter-rater reliability between all raters while Brennan-–Prediger coefficient of agreement for two raters ($\kappa 2$) was utilized to assess the inter-rater reliability between pairs of raters [12]. Inter-rater bias among the three raters was determined using Cochran's Q statistic; McNemar's test was used to determine inter-rater bias among pairs of raters. Data analysis was carried out using SAS® v9.4 (North Carolina State University, Raleigh, NC). The 5% significance level was used.

Results

From the 1080 X-rays available, 3 were removed because only lateral views were available, leaving a total of 1077 X-rays for review. Inter-rater reliability analysis between all 3 raters and each pair of raters was done on these 1077 exams.

Table 1 summarizes the detailed results of the frequency (in percentage) of the error in each of the 12 quality factors as assessed by each rater for the 1077 exams that were reviewed by the 3 raters (after excluding the 3 lateral X-rays). We defined that the inter-rater results are closely similar if the difference in the frequency between all raters was less than 2%, relatively similar if the difference is less than 5%, and discrepant if more than 5%. Our results show that there were close similarities between the 3 raters in the frequency of the errors for quality factor *(1) absent patient body parts from FOV* and *(12) absent or wrong image orientation marking*. There were relatively close similarities for factor *(7) central vessel visualization* and factor *(11) post cardiac vessel visualization*. However, there were significant discrepancies between the 3 raters in the frequency of the errors for the remaining quality factors *(2) under inspiration, (3) patient rotation, (4) scapula in the way, (5) patient kyphosis/lordosis, (6)*

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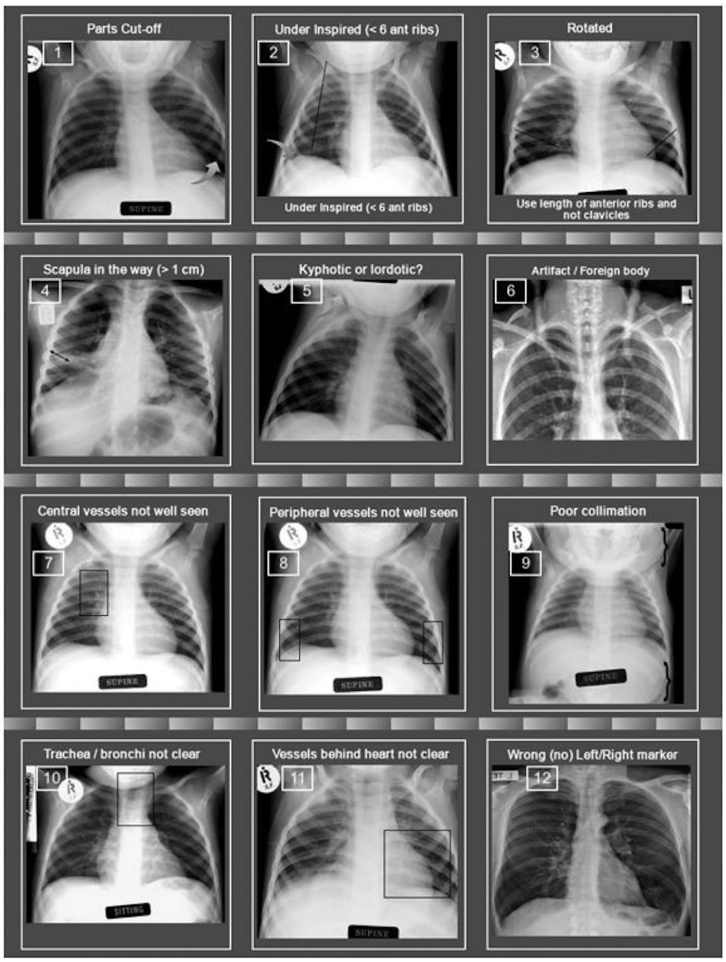

Figure 2. Compilation of the 12 radiographic errors for pediatric frontal chest radiographs numbered from 1 to 12 as sent to the reviewers for performing the quality assessment in this project.

artefact/foreign body, (8) peripheral vessels visualization, (9) poor collimation, and (10) trachea and bronchi visualization.

Table 2 shows the Brennan–Prediger coefficient of agreement between the 3 raters for the 1077 X-ray exams reviewed. There was substantial (or better) agreement ($\geq$ 0.70) between all raters as well as between each pair of raters–bold black in Table 3–for factors *(1) absent body parts from FOV, (6) artefact/foreign body, (7) central vessel visualization, (11) post cardiac vessel visualization and (12) absent or wrong image orientation marking*. Within these quality factors, only factors *(1) absent body parts from FOV* and *(12) absent or wrong image orientation marking* had no significant inter-rater bias. For factors *(6) artefact/foreign body and (7) central vessel visualization*, there was significant inter-rater bias between all pairs of raters. For factor *(11) post cardiac vessel visualization*, there was unbiased (substantial) agreement between raters 2 and 3 only (Table 3).

Conversely, there was poor agreement (<0.70) between all raters as well as between each pair of raters on many of the quality factors including factors *(2) under inspiration, (3) patient rotation, (4) scapula on the way, (5) patient kyphosis/lordosis, (9) poor collimation, and (10) trachea and bronchi visualization* (Table 2). Within these quality factors, factors *(2) under inspiration, (3) patient rotation, (4) scapula on the way* and *(10) trachea*

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Table 1
Percentage of cases with errors identified by each of the raters for a total of 1077 radiographs.

Quality factor	% Error identified		
	Rater 1	Rater 2	Rater 3
1. Parts cut off	1.7	2.0	2.3
2. Under Inspired (< 6 ant ribs)	2.2	19.9	52.0
3. Rotated	28.2	31.3	75.2
4. Scapula in the way (> 1 cm)	29.6	35.1	59.2
5. Kyphotic or lordotic?	21.1	14.7	13.3
6. Artefact / Foreign body	10.0	19.5	17.2
7. Central vessels not well seen	13.7	11.3	8.9
8. Peripheral vessels not well seen	28.7	26.6	9.9
9. Poor collimation	35.7	33.9	9.2
10. Trachea and bronchi not clearly seen	17.7	43.1	26.9
11. Vessels behind heart not well seen	14.2	18.9	18.2
12. Wrong (or no) Left/Right marker	1.8	2.0	2.1

and bronchi visualization showed significant inter-rater bias between all pairs of raters. For factor *(5) patient kyphosis/lordosis*, there was unbiased (but only moderate) agreement between raters 2 and 3 while for factor *(9) poor collimation*, there was unbiased (but only moderate) agreement between raters 1 and 2 (Table 3).

Discussion

This study is unique in that it focuses on the quality of chest radiographs in children obtained in three different African healthcare service levels of wide geographic separation, and that the quality assessment was performed using a standardized minimum level of radiologist training, standardized recording sheet with standardized definitions of radiographic error as well as standardized viewing parameters, as the images were provided as JPEG rather than DICOM format.

In our study, we found that agreement between raters was poor for the majority of the quality factors evaluated. The only two factors that had almost perfect agreement with no significant inter-rater bias were factors *(1) absent body parts in FOV* and *(12) absent or wrong image orientation marking* with κ scores exceeding 0.95 among all raters and between each pair of raters. In contrast, the factor agreed on the least (κ score of 0.23) among all raters was factor *(3) patient rotation*, with very low κ scores of 0.03 between raters 1 and 3 and 0.09 between raters 2 and 3 suggesting almost no agreement. Another factor where there was low agreement was factor (2*) under inspired films - less than 6 anterior ribs shown,* with a κ score of 0.32 in overall agreement and no agreement at all between raters 1 and 3–κ score of 0. Factor *(4) if the scapula was in the way,* also had a low overall κ score of 0.35 in keeping with poor agreement.

The marked variability amongst the raters, under standardized viewing and interpreting conditions, suggests that the assessment of quality factors for pediatric chest X-rays is highly subjective and that the current definitions need to be modified to provide more practical and objective assessment of the image quality [13,14]; especially for quality factors that demonstrated most inter-rater variabilities, such as under inspiration and patient rotation. Not all quality factors are as obvious as "cut-off" of portion of the anatomy, presence of a "foreign body" on the film [15], or " absent or wrong image marker", therefore validation of the quality assessment criteria would be ideal

Table 2
Brennan—Prediger coefficient of agreement between the 3 raters for a total of 1077 radiographs.

Quality factor	Brennan—Prediger coefficient of agreement							
	Overall		Rater 1 vs. 2		Rater 1 vs. 3		Rater 2 vs. 3	
	Coefficient	95% confidence interval	Coefficient	95% confidence interval	Coefficient	95% confidence interval	Coefficient	95% confidence interval
1. Parts cut off	**0.96**	*(0.95–0.97)*	**0.96**	*(0.94–0.98)*	**0.96**	*(0.94–0.98)*	**0.96**	*(0.94–0.97)*
2. Under Inspired (< 6 ant ribs)	0.32	*(0.00–0.96)*	0.64	*(0.59–0.69)*	0.00	*(0.00–0.06)*	0.33	*(0.27–0.39)*
3. Rotated	0.23	*(0.00–0.92)*	0.58	*(0.53–0.63)*	0.03	*(0.00–0.09)*	0.09	*(0.03–0.15)*
4. Scapula in the way (> 1 cm)	0.35	*(0.02–0.68)*	0.51	*(0.46–0.56)*	0.23	*(0.17–0.29)*	0.32	*(0.26–0.38)*
5. Kyphotic or lordotic?	0.51	*(0.34–0.68)*	0.58	*(0.53–0.63)*	0.43	*(0.38–0.48)*	0.52	*(0.47–0.57)*
6. Artefact / Foreign body	**0.81**	*(0.67–0.95)*	**0.75**	*(0.71–0.79)*	**0.80**	*(0.76–0.84)*	**0.88**	*(0.85–0.91)*
7. Central vessels not well seen	**0.83**	*(0.80–0.86)*	**0.83**	*(0.80–0.86)*	**0.83**	*(0.80–0.86)*	**0.83**	*(0.80–0.86)*
8. Peripheral vessels not well seen	0.62	*(0.49–0.75)*	0.68	*(0.64–0.72)*	0.57	*(0.52–0.62)*	0.61	*(0.56–0.66)*
9. Poor collimation	0.47	*(0.35–0.59)*	0.52	*(0.47–0.57)*	0.43	*(0.38–0.48)*	0.45	*(0.40–0.50)*
10. Trachea and bronchi not well seen	0.48	*(0.21–0.75)*	0.41	*(0.36–0.46)*	0.62	*(0.57–0.67)*	0.41	*(0.36–0.46)*
11. Vessels behind heart not well seen	**0.76**	*(0.68–0.84)*	**0.79**	*(0.75–0.83)*	**0.77**	*(0.73–0.81)*	**0.73**	*(0.69–0.77)*
12. Wrong (or no) Left/Right marker	**0.97**	*(0.94–1.00)*	**0.97**	*(0.95–0.98)*	**0.96**	*(0.94–0.98)*	**0.98**	*(0.97–0.99)*

KEY:.
0.00–0.19 Slight agreement.
0.20– 0.39 Fair agreement.
0.40–0.59 Moderate agreement.
0.60–0.79 Substantial agreement.
0.80–0.99 Almost perfect agreement.

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Table 3
P-value for inter-rater bias between the 3 raters for 1077 radiographs.

Quality factor	*p*-value for inter-rater bias			
	Cochran's *Q* test	McNemar's test		
	Overall	Rater 1 vs. 2	Rater 1 vs. 3	Rater 2 vs. 3
1. Parts cut off	0.32	0.39	0.13	0.53
2. Under Inspired (< 6 ant ribs)	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
3. Rotated	**<0.0001**	**0.029**	**<0.0001**	**<0.0001**
4. Scapula in the way (> 1 cm)	**<0.0001**	**0.0003**	**<0.0001**	**<0.0001**
5. Kyphotic or lordotic?	**<0.0001**	**<0.0001**	**<0.0001**	0.35
6. Artefact / Foreign body	**<0.0001**	**<0.0001**	**<0.0001**	**0.0023**
7. Central vessels not well seen	**<0.0001**	**0.0073**	**<0.0001**	**0.0023**
8. Peripheral vessels not well seen	**<0.0001**	0.082	**<0.0001**	**<0.0001**
9. Poor collimation	**<0.0001**	0.23	**<0.0001**	**<0.0001**
10. Trachea and bronchi not clearly seen	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
11. Vessels behind heart not well seen	**<0.0001**	**<0.0001**	**<0.0001**	0.56
12. Wrong (or no) Left/Right marker	0.59	0.49	0.39	0.74

P value < 0.05 is considered statistically significant.

[13] as this would reduce subjective interpretation and lead to a more reliable, uniform and consistent assessment of the image quality [15,16]. Another option to consider would be to create a new quality assessment tool by identifying quality factors that have the greatest impact on diagnostic accuracy and clinical outcomes, ensuring that these factors are strictly defined to obtain a more objective assessment [13]. Good examples of quality factors that affect diagnosis are under inspired radiographs which result in lung hyper density that can be mistaken for pathology such as infection or atelectasis or when rotation causes differential density of the two hemi thoraces and mimics unilateral effusion on a supine pediatric radiograph.

In contrast to prior studies, the inconsistency in error identification could not be explained by differences in the reviewer specialty training [17] as all the raters in this study had received specialist training in the same program at the same university. Nor could it be explained by the presence of 3 sites with different levels of health care as the three raters had to review all the X rays obtained from each site. The poor agreement could be affected by variations in years of clinical experience between the raters, but considering that chest X-ray quality should be assessable by qualified radiologists and technologists at all levels of experience, interpretation of evaluation criteria should not depend on experience beyond speciality training and should not feature as a factor influencing reliability of evaluation.

Rater fatigue [18] is an important factor that has to be taken into consideration in this research especially since our raters were required to evaluate a large sample of radiographs. Rater fatigue affects each individual differently and could be responsible for some of the variability noticed in our study as the raters had to check the quality of 1077 X ray exams. We attempted to minimize rater fatigue by asking our reviewers to evaluate the radiographs collected at three different time intervals. Another important point that accounts for quality assurance (QA) variability is the leniency of physicians to the presence of radiographic error as long as the main medical diagnosis of the exam is not compromised. This phenomenon was highlighted in a 2013 study conducted by Whaley et al. which compared the results of QA performed by radiologists and radiographic technologists on chest radiographs. Similar to our findings Whaley et al. demonstrated poor inter-reader agreement within each of the two groups and an even greater variability between radiologists and technologists. They concluded that radiologists were more subjective when they evaluated studies with inferior quality, as their judgement was influenced by their ability to interpret the radiographs for diagnostic purposes, based on the indication provided, rather than the objective assessment of the quality of the image [15]. We attempted to mitigate against this phenomenon by providing a QA data recording tool for documenting the presence of each type of radiographic fault individually, irrespective of the diagnostic value of the radiograph. The radiologists were not required to make a diagnosis or comment on the diagnostic nature of the radiograph.

In an effort to achieve a more reliable and objective assessment of image quality, extensive investment could be made to digitize the quality assessment process. State-of-the-art X-ray machines come with software that can automatically capture repeat views and eliminate those that are affected by motion artefacts to ensure high quality of the generated films. This may not be an acceptable routine in pediatric X-ray practice where interpreting radiologists often accept some radiographic errors in order to avoid repeat radiation exposure to a child. Uniform chest radiography protocols should be developed for technologists to follow when operating X ray machines. All acquisition display stations should be calibrated to make sure that every member of the radiology staff (including physicians, technicians, and physicists) is able to see the same rendering of the image [19]. Medical physicists are key in developing automated imaging algorithms that act as surrogates for human observers to improve the overall efficiency of the imaging operation [20]. Lin et al. developed software that automatically decomposes and segments digital chest radiographs to determine ten physical elements that correspond to ten distinct perceptual char-

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acteristics related to image quality. The software constructs regions of interest (ROIs) by automatically detecting prominent anatomic landmarks and uses Laplacian pyramid decomposition (LPD) of the displayed image within the ROIs to calculate specifically defined physical quantities [21]. We understand that these measures can be difficult to implement in many of the African health care settings given the current socio-economical context where many of the African countries are under pressure to increase productivity while reducing service and maintenance costs for rational use of already limited and scarce medical resources.

Another possible challenge in meeting radiographic quality control is "institutional compliance" [22]. It seems that, even with institutional accreditation by internationally recognized QA agencies, compliance to the structured QA protocols cannot be guaranteed. We recommend performing systematic and structured quality improvement programs [23] focused on identifying commonly encountered quality problems and outlining practical and effective methods to confirm their resolution. Random unexpected audits should be conducted by designated regulatory boards to make sure that approved quality control guidelines are followed. Similarly, QA training of healthcare providers should follow a "problem-solving" methodology with the same level of training delivered to all staff members regardless of their specialization or years of experience [24]. Absence of active engagement in quality improvement can impact patients and health providers with serious unnecessary consequences such as the risk of exposure to excessive radiation, diagnostic errors, or exam repetition due to poor visualization with the addition of needless costs.

We recognize one important limitation in our study. Because of the limited availability of advanced online secure data sharing platforms typically found in the developed world (e.g. Ambra® or Life Image ®), X ray images were anonymized, captured, and shared across the sites in JPEG format (instead of DICOM format commonly used by radiologists in PACS® stations). This limited the raters' ability to window, magnify, and optimize the images' brightness, contrast, and resolution. The limited access to updated technology could be a confounding factor for inter-rater reliability particularly for quality factors *(8) Peripheral vessels, (10) Trachea and bronchi*, and *(11) Vessels behind heart* where the visibility of these structures could be compromised by this limitation further aggravating subjective rater judgement. However, it is important to note that, with JPEG image format, each observer viewed each X-ray with the same brightness, contrast and resolution hence providing a standardized format allowing for inter-reader assessment. Having JPEG versions of the imaging only for both diagnostic interpretation and quality assurance also reflects the typical scenario of informal tele-reading followed by many African practice settings and humanitarian agencies such as the tele-reading platform for the World Federation of Pediatric Imaging volunteer tele-reading service and the tele-reading platform for Medecins Sans Frontiers [personal communication, Savvas Andronikou who acts as tele-reader on both platforms].

Conclusion

Our results show that many of the quality factors used to assess the quality of a chest X-ray in children have poor reliability, reflecting the subjectivity in quality assessment, despite efforts to mitigate against lack of standardization and despite inclusion of both basic and specialized centers. New definitions of objective measures for assessing pediatric chest radiographic quality are required. Once these have been developed, validated and standardized across multiple environments internationally (in both developed and developing countries) they can be applied using technologically updated tools including deep learning algorithms. The impact on clinical interpretation was not assessed in this paper and is often not assessed when performing quality assurance. We believe that any new standards in quality assessment need to be translated into clinical interpretive radiology practice by re-educating radiologists on what is acceptable for accurate diagnosis and what is not.

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Appendix G: Response to the letter to the editor re: Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays.

The following is the a response to the letter to the editor re: **Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays** as it appeared in the Journal of Medical Imaging and Radiation Sciences in September 2021.

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Letter to the Editor

Response to the letter to the editor re: Inter-rater reliability in quality assurance (QA) of pediatric chest X-rays

Dear editors,

We would like to thank Dr. Siamak Sabour for his interest in our work and for taking the time to review our paper and express his concerns. We also would like to thank you for giving us the opportunity to clarify aspects of our statistical analysis section in relation to issues raised in Dr. Sabour's letter.

Dr. Sabour raised potential concerns regarding the utility of κ score to assess agreement between qualitative variables. In his letter, a hypothetical example is presented in a table format, where the correspondence of the "A" outcome was similar and good for both (a) and (b) situations (94% agreement for case (a) and 90% agreement for case (b)). However, the correspondence of the "B" outcome was different (50% agreement for case (a) and 90% agreement for case (b)). These results show that kappa was clearly penalized for "low" agreement for the B outcome in case (a). This should be highlighted as a statistical limitation if one takes into consideration that the 50% correspondence for case (a) would be an unreliable estimate due to small numbers. But this does not mean that it should not be reported at all, because it does indicate a possible issue with poor correspondence. Our suggestion would be; therefore, to report the lower kappa, but also report the Brennan-Prediger coefficient (0.8) or the Randolph free-marginal kappa (0.8). In this example these two gave the same result.

We agree with Dr. Sabour's statements that κ score depends on the prevalence in each category and that Fleiss Kappa has strength in its ability to assess inter-rater agreement between more than two raters compared to Cohen's Kappa which can only assess inter-rater reliability between two raters. We do; however, partially disagree with his statement that κ score of the two tests would differ if they were applied to the same dataset. If Fleiss kappa was applied to two raters, it would give the same results as the Cohen's kappa. For case (a) described in Dr. Sabour's letter, the Fleiss kappa=0.44. Furthermore, even when applied to more than two raters, the Fleiss kappa would also have the same problem when there are few outcomes for one of the categories. In the data reported in our paper, for example, the "Parts cut off" gives a Fleiss kappa=0.48, and this was low due only about 50% agreement for "yes" cases, but the latter is again an unreliable estimate due to small numbers. Thus, the Brennan-Prediger coefficient and/or Randolph free-marginal kappa should be reported as well (both =0.96).

Table 1
Inter-rater agreement between the three raters for the 10 factors used to assess the quality of pediatric chest X-rays.

Quality Factor	Fleiss Kappa	Randolph Kappa	Brennan-Prediger coefficient
1.Parts cut off	0.48	0.96	0.96
2.Under Inspired (< 6 ant ribs)	0.09	0.32	0.32
3.Rotated	0.22	0.23	0.23
4.Scapula in the way (> 1 cm)	0.33	0.35	0.35
5.Kyphotic or lordotic?	0.10	0.51	0.51
6.Artefact / Foreign body	0.64	0.81	0.81
7.Central vessels not well seen	0.57	0.83	0.83
8.Peripheral vessels not well seen	0.44	0.62	0.62
9.Poor collimation	0.31	0.46	0.47
10.Trachea and bronchi not clearly seen	0.37	0.48	0.48
11.Vessels behind heart not well seen	0.58	0.76	0.76
12.Wrong (or no) Left/Right marker	0.60	0.97	0.97

In summary, when there is low occurrence for one of the categories, one needs to be careful in the reporting, because the results are unreliable (both for standard kappa and free-marginal kappa). The standard kappa is probably too sensitive for discrepancies in the low occurring outcomes, which are unreliable estimates due to small numbers. On the other hand, one should also not just report the free-marginal kappa, because this might be hiding possible discrepancies in the low occurring category[1]. Our suggestion would be to report both and clearly state the limitations of the small numbers.

We calculated the Fleiss Kappa (Table 1) to assess the inter-rater agreement between the three raters for the 10 quality assurance factors used in our original paper[2]. While the statistical

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concerns raised by Dr. Sabour are regarded and should be considered, our results still highlight that inter-rater agreement for assessment of pediatric chest X-ray quality is suboptimal and efforts should be made to improve the reliability of reporting, by implementing objective measures in quality assessment.

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Appendix H: Short-term impact of pictorial posters and a crash course on radiographic errors for improving the quality of paediatric chest radiographs in an unsupervised unit - a pilot study for quality-assurance outreach.

The following is the article as it appeared in Pediatric Radiology in August 2014.

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ORIGINAL ARTICLE

Short-term impact of pictorial posters and a crash course on radiographic errors for improving the quality of paediatric chest radiographs in an unsupervised unit — a pilot study for quality-assurance outreach

Linda Tebogo Hlabangana · Savvas Andronikou

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Abstract
Background Chest radiography is the most commonly performed diagnostic X-ray examination. The radiation dose to the patient for this examination is relatively low but because of its frequent use, the contribution to the collective dose is considerable. Optimized image quality not only allows for more accurate diagnosis but also supports radiation protection, which is particularly important in children.
Objective To determine whether the introduction of a poster of technical errors in paediatric radiography accompanied by a short lecture (crash course) for radiographers on common errors can sustainably decrease the number and rate of these errors in an unsupervised radiology department (without a paediatric-trained radiologist or paediatric-trained radiography personnel).
Materials and methods We conducted a pilot study for quality-assurance outreach, with retrospective and prospective components, in the paediatric radiology department of a teaching hospital. The technical errors in frontal chest radiographs performed in the unit were assessed by quality-assurance analysis using a customized tick-sheet. The review was performed before and after an intervention that involved a half-hour crash course and poster displays in the department. We compared the rate of technical errors made before and after the intervention.
Results There was statistically significant improvement in quality of radiographs ($P<0.0083$) performed immediately after the intervention. There was a statistically significant decline in the quality of radiographs performed >2 months after the intervention.
Conclusion A simple intervention of a crash course and poster placement resulted in improved quality of paediatric chest radiographs. A decline in quality after 2 months suggests the need to repeat this or another type of intervention regularly.

Keywords Quality assurance · Paediatric · Chest radiography

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Introduction

Chest radiography is the most commonly performed diagnostic X-ray examination [1–4]. The radiation dose to the patient for this examination is relatively low but because of its frequent use, the contribution to the collective dose is considerable [1–4]. Optimized image quality allows for more accurate diagnosis [4] and also supports radiation protection, particularly in children because of the radiosensitivity of immature organs. Technical considerations such as rotation and under- or over-penetration of the film still merit attention because they are more likely to be unsatisfactory in paediatric radiology [1]. These types of errors contribute to diagnostic difficulty and to an increased dose caused by the requirement for repeat imaging.

We conducted a pilot study for quality-assurance outreach to determine whether the introduction of a poster with images of the most common radiographic technical errors for paediatric frontal chest radiographs accompanied by a crash course on those errors would improve the quality of chest radiographs. The pilot study occurred in an unsupervised radiology department, which is to say there are radiologists stationed at the hospital where the study was performed but the paediatric department is often without radiologist supervision as a result of staff shortages (up to 3–4 days out of 5 days a week).

Because of this and the absence of a paediatric-trained radiologist or radiography personnel specifically trained in paediatric imaging, the unit is classified as an unsupervised radiology department [3]. The absence of a radiologist and paediatric-trained radiographers is the norm in most of the hospitals and clinics in the public health sectors of developing countries.

Our aim was to determine whether the introduction of a poster of technical errors in paediatric radiography accompanied by a quick course on common errors can sustainably decrease the number and rate of these errors in resource-constrained units of a general hospital.

Materials and methods

We conducted a pilot study with retrospective and prospective components at one teaching hospital, which up to the time of the research had not had the services of a paediatric radiologist or paediatric-trained radiographers or technicians. Only technical errors in anteroposterior chest radiographs performed in the paediatric radiology unit were assessed by quality-assurance analysis. The radiographs were obtained on two Philips Optimus X-ray machines (HV Generator, 1997; Philips Healthcare, Best, The Netherlands). The imaging protocol for paediatric chest radiographs was written on the wall in the X-ray room and reflected the following: for children younger than 2 years: kV=53−60, mAs=1.4−2; for children ages 2–10 years: kV=66−90, mAs=2. Children were radiographed with their hands held against their heads in either erect/standing position or supine depending on their age and level of cooperation. No paediatric immobilization devices were used.

A total of 58 radiographers worked at the hospital at the beginning of the study; the radiography staff was composed of qualified senior and junior staff, as well as student radiographers. There was no consistency among either senior or junior radiography staff working in the paediatric unit because radiographers rotated through the different areas in the radiology department based on a timetable rotation.

The quality-assurance review was conducted by a single qualified radiologist (principal investigator) with regard to the technical aspects of the radiographs according to a developed quality-assurance tick-sheet (Fig. 1). The principal investigator was not blinded to the period of review. The radiographs used for the study were included sequentially (as filed and retrieved by the filing clerk) and were not preselected. The diagnostic component was not assessed. Patients with multiple X-rays (performed on separate occasions) were included in the study. Quality-assurance was not performed on rejected X-rays because review of radiographs was performed 5 months after the intervention took place and the rejected radiographs were no longer available.

Fig. 1 Quality-assurance tick-sheet used to assess the quality of the radiographs reviewed in the study ▶

Radiographic errors on each X-ray were recorded on individual tick-sheets and this information was then captured on an Excel spreadsheet (Microsoft, Redmond, WA). The errors included poor collimation, scapula in the way, parts cut off, under-inspiration, rotation, kyphotic or lordotic views, presence of artifacts (patients with unavoidable artifacts such as metallic implants and pacemakers were not excluded), inability to visualize the central or peripheral vessels and the vessels behind the heart, inability to visualize the tracheobronchial tree and absent or wrongly placed left or right markers (Fig. 1).

A poster with images of the most common radiographic errors (closely resembling the tick-sheet) was presented and explained in a 30-min talk to all radiographers working in the radiology department because there was no consistency in the radiography staff stationed in the paediatric unit. The poster (A0 size) was duplicated and placed at strategic locations in the X-ray department where paediatric radiography is performed — in front of control panel areas and at review areas. This represented an intervention, which is within acceptable quality-assurance functions of a department and also represents a simple, affordable quality-assurance solution for a developing country. Scores were calculated and types of errors categorized for the pre-poster (group 1) and post-poster period (first month post, group 2; second month post, group 3; third month onward, group 4). We compared the technical errors made before and after the intervention. The radiography staff was not aware there was an ongoing quality-assurance process or that a research project was being conducted.

The number of errors was subcategorized into “poorly diagnostic”, which represented films with five or more errors, “diagnostic”, which represented films with four or fewer errors but not perfect, and “perfect films”, which represented films with no errors. This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. Ethics approval was obtained from the Human Research Ethics Committee at the University of the Witwatersrand.

Study sample

All available paediatric anteroposterior (AP) chest radiographs (hard copies) were obtained from the filing room in the paediatric X-ray department. Most children only received AP radiographs; lateral chest radiographs were only obtained when specifically requested by a clinician or radiologist; this was because of limited resources and to limit the radiation dose to children.

Chest radiographs of children younger than 5 years were included but portable radiographs were excluded (because of specific technical differences in obtaining these). Radiographs

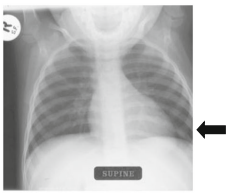
QA Tick-sheet: Data Collection: Quality Assessment [QA] of Frontal Chest Radiographs

Date: **Patient code** **Reviewer name:**

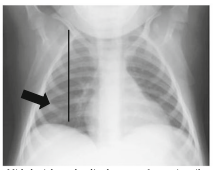
Instructions: Please circle **Yes (Y) or No (N)** for each section

DOB:

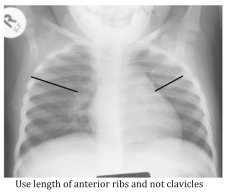
1. Parts Cut-off
Y N



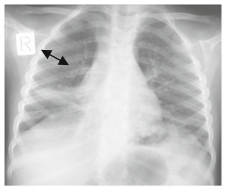
2. Under Inspired (< 6 ant ribs)
Y N


Mid clavicle at the diaphragm > 6 anterior ribs

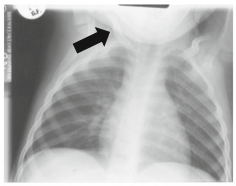
3. Rotated
Y N


Use length of anterior ribs and not clavicles

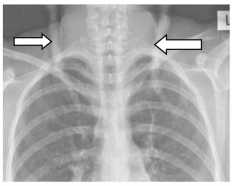
4. Scapula in the way (> 1 cm)
Y N



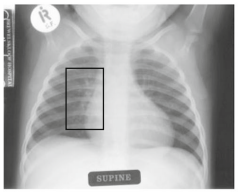
5. Kyphotic or lordotic?
Y N



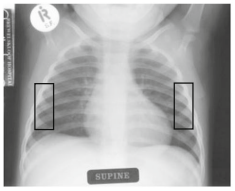
6. Artifact / Foreign body
Y N



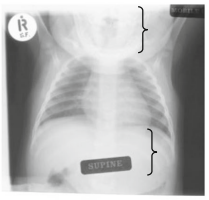
7. Central vessels not well seen
Y N



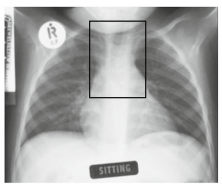
8. Peripheral vessels not well seen
Y N



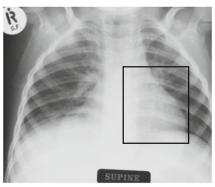
9. Poor collimation
Y N



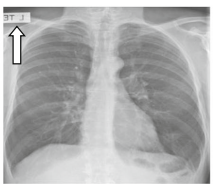
10. Trachea and bronchi not clearly seen
Y N



11. Vessels behind heart not well seen
Y N



12. Wrong (no) Left/Right marker
Y N



with no patient identification and dates of radiographic exposure were excluded from the study.

Statistical analysis

A minimum sample size of 92 radiographs per review was necessary to yield a power of 80% with a minimum difference of 15% in errors. The data were analyzed using McNamara test in comparing the proportion of errors between baseline and those during the months after the intervention. Cochran-Mantel-Haenszel statistics were used to independently assess the errors during the four review periods. The Fisher exact test was used to compare the errors between the groups.

A P-value <0.0083 was considered significant. We used the Bonferroni correction to address the problem of simultaneously comparing multiple dependent and independent statistical tests on our test data. Using the Bonferroni correction we divided the critical P-value (0.05) by the number of comparisons being made (i.e. six). In our study the P-value was calculated as follows: 0.05/6=0.0083; this modified P-value was used to determine the statistical power of the study [5].

Results

A total of 438 radiographs were included, all hard copies. The patient mean age was 10.4 months (range 1–60 months). There were 171 boys (39%) and 267 girls (61%). Of the 438 total radiographs reviewed, 137 were reviewed before the intervention (group 1), 109 were reviewed during the first month after the intervention (group 2), 100 were reviewed during the second month after the intervention (group 3), and 92 were reviewed during the third month after the intervention (group 4). The individual group demographics are summarized (Table 1). Overall and group error prevalence under specific categories of error is also summarized (Table 2).

Our scoring system demonstrated a range of scores from 0 to 12, which represents a perfect score to a maximum of nine errors for each radiograph. The total possible cumulative score of all the groups, assuming a maximum number of errors, was 12 × 438, or 5,256. The total score for the overall group, representing the actual number of errors, was 1,766. Table 3 summarizes the overall and group error prevalence as total and percentages of total possible errors and compares the prevalence of specific quantities of errors per radiograph evaluated in each group.

The majority of evaluations demonstrated more than 2 errors per film, accounting for 312 of the 438 (71.2%) radiographs evaluated in the overall group; 102 of the radiographs in group 1 (74.5%); 58 of the radiographs in group 2 (53.2%); 78 of the radiographs in group 3 (78.0%), and 74 of the radiographs in group 4 (80.4%). The group immediately after the intervention (group 2) showed an increased percentage of the number of perfect films and diagnostic films and a decrease in the percentage of poorly diagnostic radiographs.

Groups were compared with regard to their scores and the number of each type of error. There was statistically significant improvement between groups 1 and 2 (i.e. the groups before and immediately after the intervention, respectively) with regard to overall scores. There was a statistically significant deterioration in scores between the group of radiographs reviewed immediately after the intervention (group 2) and the groups of radiographs assessed during the second and third months after the intervention, i.e. between groups 2 and 3 and groups 2 and 4.

In addition there were statistically significant differences in the prevalence of specific errors. There was a statistically significant improvement between the groups before and immediately after the intervention (groups 1 and 2) with regard to the following errors: peripheral vessels not well seen (P<0.0001), tracheobronchial tree not well seen (P<0.0019) and vessels behind heart not well seen (P<0.0067). There was a statistically significant deterioration between the quality-assurance results of the group immediately after the intervention and the radiographs reviewed from the third month after the intervention (groups 2 and 4) with regard to the following errors: central vessels not well seen (P<0.0001), peripheral vessels not well seen (P<0.0001), tracheobronchial tree not well seen (P<0.0068) and vessels behind heart not well seen (P<0.0001). There was a statistically significant deterioration in the quality of radiographs between the second month after

Table 1 Summary of study demographics

	Overall	Group 1 before intervention: baseline	Group 2 first month after intervention	Group 3 second month after intervention	Group 4 third month after intervention
Number of radiographs reviewed	438	137 (31.3%)	109 (24.9%)	100 (22.8%)	92 (21.0%)
Boys	171 (39.0%)	52 (38.0%)	42 (38.5%)	39 (39.0%)	38 (41.3%)
Girls	267 (61.0%)	85 (62.0%)	67 (61.5%)	61 (61.0%)	54 (58.7%)
Mean age (months)	10.4, range 1–60 months	14.0 SD 16.1	8.8 SD 12.8	9.18 SD 14.6	8.1 SD 10.0

SD standard deviation

Table 2 Summary of the prevalence of radiographic errors as percentages of the total, for the overall study population as well as subgroups

	Overall	Group 1 before intervention: baseline	Group 2 first month after intervention	Group 3 second month after intervention	Group 4 third month after intervention
Number of radiographs x 12 possible errors = Total possible errors	438 × 12= 5,256	137 × 12=1,644	109 × 12=1,308	100 × 12=1,200	92 × 12=1,104
Cutoff	0.15% (8)	0.24% (4)	0.23% (3)	0.00% (0)	0.09% (1)
Under-inspiration	2.28% (120)	2.00% (33)	2.68% (35)	2.50% (30)	1.99% (22)
Rotation	4.33% (228)	3.59% (59)	3.75% (49)	5.17% (62)	5.25% (58)
Scapula in the way	4.24% (223)	4.74% (78)	3.44% (45)	3.92% (47)	4.80% (53)
Kyphotic/lordotic view	4.92% (259)	4.32% (71)	4.97% (65)	5.33% (64)	5.34% (59)
Artifact/foreign body	2.28% (125)	2.00% (33)	1.99% (26)	2.83% (34)	2.90% (32)
Central vessel not well seen	1.56% (82)	1.58% (26)	0.84% (11)	1.25% (15)	2.72% (30)
Peripheral vessels not well seen	2.17% (114)	3.64% (60)	0.69% (9)	1.17% (14)	2.81% (31)
Poor collimation	5.40% (284)	5.96% (98)	4.74% (62)	5.33% (64)	5.43% (60)
Tracheobronchial tree not well seen	2.62% (138)	3.16% (52)	1.61% (21)	2.58% (31)	3.08% (34)
Vessels behind heart not well seen	3.33% (175)	3.47% (57)	2.06% (27)	3.33% (40)	4.62% (51)
Wrong/no left or right marker	0.19% (10)	0.36% (6)	0.00% (0)	0.17% (2)	0.18% (2)
Total errors	33.60% (1,766)	33.88% (577)	26.99% (353)	33.58% (403)	40.13% (433)

Table 3 Summary of scores for the overall group and subgroups as well as the prevalence of specific numbers of errors per film, overall and in each group

	Overall	Group 1 before intervention: baseline	Group 2 first month after intervention	Group 3 second month after intervention	Group 4 third month after intervention
Radiographs reviewed	438	137	109	100	92
Number of errors per film	Error rate (number of radiographs)				
0 errors (perfect)	1.60% (7)	1.46% (2)	2.75% (3)	1.00% (1)	1.09% (1)
1 error	(8.22%) (36)	5.84% (8)	14.68% (16)	9.00% (9)	3.26% (3)
2 errors	18.95% (83)	18.25% (25)	29.36% (32)	12.00% (12)	15.22% (14)
3 errors	17.58% (77)	17.52% (24)	16.51% (18)	24.00% (24)	11.96%% (11)
4 errors	14.61% (64)	13.87% (19)	11.01% (12)	19.00% (19)	15.22% (14)
5 errors	1.37% (6)	16.79% (23)	12.84% (14)	8.00% (8)	16.30% (15)
6 errors	9.82% (43)	8.76% (12)	2.75% (3)	13.00% (13)	16.30% (15)
7 errors	8.68% (38)	9.49% (13)	5.50% (6)	11.00% (11)	8.70% (8)
8 errors	5.02% (22)	5.11% (7)	4.59% (5)	2.00% (2)	8.70% (8)
9 errors	1.83% (8)	2.92% (4)	0.00% (0)	1.00% (1)	3.26% (3)
5 errors or more (poorly diagnostic films)	39.04% (171)	43.07% (59)	25.69% (28)	35.00% (35)	53.26% (49)
4 errors or fewer but not perfect (diagnostic films)	59.36% (260)	55.47% (76)	71.56% (78)	64.00% (64)	45.65% (42)
0 errors (perfect films)	1.60% (7)	1.46% (2)	2.75% (3)	1.00% (1)	1.09% (1)

the intervention (group 3) and the third month (group 4) with regard to the following errors: central vessels not well seen ($P<0.0060$) and peripheral vessels not well seen ($P<0.0019$). The results of the statistical analysis comparing the different groups are summarized (Table 4) (Fig. 2).

There was statistically significant improvement between the radiographs reviewed as a baseline at the beginning of the study (group 1) and the radiographs assessed in the month immediately after the intervention (group 2) in the "poorly diagnostic" subcategory ($P=0.0001$). There was statistically significant deterioration between quality-assurance review immediately after the intervention (group 2) and the last set of radiographs assessed in the third month after the intervention (group 4) in the "poorly diagnostic" and "diagnostic" subcategories ($P=0.0001$).

Discussion

From these results, which show an initial improvement and then a progressive decline, it can be deduced that to fully benefit from a quality-assurance intervention it should be performed at least monthly. Even minor indicators of image quality need to be monitored to continuously improve it [6]. Quality assurance should therefore (ideally) be performed on a daily and continuous basis so as to improve the quality of radiography in the department.

The commonest error in our study was poor collimation, which is in keeping with findings from other international quality-assurance studies on paediatric chest radiographs [7, 8]. The next commonest errors were kyphotic/lordotic views and rotation. These three errors are related to patient positioning, which is often a challenge in the paediatric patient who is not cooperative. The least common errors were "parts cut off" and "no/wrong left or right marker," errors related to the diligence of the radiographer. From this, one can extrapolate that basic radiography at this centre is adequate and basic rules are being adhered to but more specialized paediatric training is probably necessary to decrease other technical errors specifically related to the imaging of children.

In addition, the number of errors per film improved immediately after the intervention (group 2) with a higher percentage of diagnostic (four errors or fewer) and a lower percentage of poorly diagnostic radiographs (five errors or more). This may relate to the fact that a number of radiographic errors are a product of the same problem, i.e. a moving uncooperative child may result in both cut off and poorly visualized vessels, while a radiographer may use wide collimation to avoid cutoff.

One important aspect of good radiographs in children is that they must not be at the cost of a high radiation dose [1]. Furthermore, in adult practice a poorly diagnostic radiograph may be repeated, while in a child poor-quality radiographs are often accepted to avoid the increased dose to the child from repeat exposures. As a rule, paediatric radiology emphasizes diagnostic quality over best quality [1]. There is usually a balance between dose and quality but good radiographic technique is the main factor in improving quality without the cost of increased dose [1]. Radiation protection in paediatric radiology is paramount and technique should be adapted to the size of the patient, with good collimation and use of shielding. These aspects are achieved through experienced and committed staff, which is the key to quality imaging [1], but such a staff is often not available in a resource-restricted setting, particularly in a developing country such as South Africa.

The crash course played an important part in the effectiveness of the intervention because it is clear that the poster alone was not enough to keep the quality of radiography at the high standard after the first month post intervention. The quality of radiographs after 3 months was worse than before the intervention. This could be, in part, a result of the smaller number of radiographs reviewed in the last phase of the study, (137 radiographs reviewed prior to intervention compared with 92 radiographs reviewed 3 months after the intervention). However, the progressive deterioration of quality over time supports the fact that quality assurance should be an ongoing and continuous process, because quality without regular quality assurance and quality improvement deteriorates over time.

Quality assurance in medical practice has been defined by the World Health Organization as "an organized effort by the staff operating a facility to ensure that the diagnostic images produced by the facility are of sufficiently high quality so that they constantly provide adequate diagnostic information at the lowest possible cost and the lowest possible exposure of the patients to radiation" [1]. Quality assurance is critical as a means of ensuring superior image quality and also provides

Table 4 *P*-values of statistical significance when comparing groups with regard to summated scores (i.e. total numbers of errors for each group)

	Group 1 vs. group 2 baseline vs. first month after intervention	Group 1 vs. group 3 baseline vs. second month after intervention	Group 1 vs. group 4 baseline vs. third month after intervention	Group 2 vs. group 3 first vs. second month after intervention	Group 2 vs. group 4 first vs. third month after intervention	Group 3 vs. group 4 second vs. third month after intervention
P-value	0.0001	0.6054	0.0004	0.0001	0.0001	0.0055

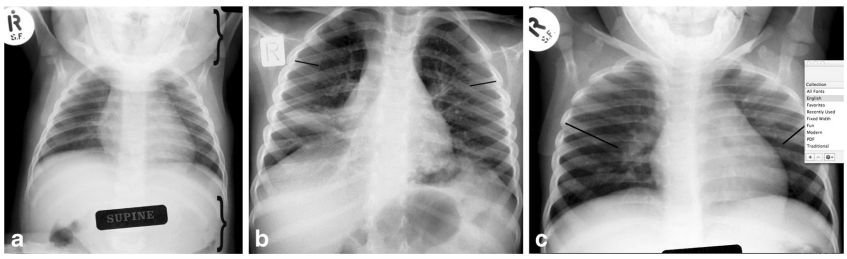


Fig. 2 Common errors seen in chest radiographs that were evaluated as part of a quality-assurance pilot program. **a** Anteroposterior (AP) chest radiograph in a 4-month-old girl demonstrates no obvious lung pathology. Technical errors include poor collimation (*black brackets*), under-inspiration and a kyphotic view. **b** AP chest radiograph in a 5-month-old girl demonstrates right middle lobe consolidation. The technical error is that the scapulae are projecting more than 1 cm over the lung fields bilaterally (*black lines*). **c** AP chest radiograph in a 6-month-old boy demonstrates no underlying lung pathology. The boy is rotated, as evidenced by the inequality of the lengths of the anterior ribs (*black lines*)

radiation protection [9]. There are two limbs in quality assurance in radiography, one that addresses quality of the diagnostic X-ray equipment and the other that reviews the quality of the radiographs performed [3, 6]. Quality assurance could be further divided into several levels, each with a different type of scientific/technical surveillance [3].

With traditional hard-copy/analogue radiography there is a penalty for poor radiographic technique, with the film turning out either too light (under-exposed) or too dark (over-exposed). Computed radiography and digital radiography have a linear relationship with film density, which has the advantage of larger latitude for error and a reduced need for repeat radiographs. The disadvantage of this is that this it can in some instances result in an increased dose to the patient, because there is no visual penalty for poor choice of settings and the latitude of the Hurter and Driffield curve, resulting in the phenomenon of radiation creep. In experienced hands, however, the use of digital radiography results in lower doses for chest radiography.

Limitations of this study and areas for improvement

The radiographs were included sequentially (as filed and retrieved by the filing clerk) and were not preselected. The study was performed during a fixed period of the year, spanning January to October, which includes all of the winter months. Children presenting for the included radiographs might reflect the age group most susceptible to infection during the winter months. In addition, younger children are more susceptible to endemic infectious diseases such as tuberculosis in our community, which may be responsible for skewing the age distribution; this, however, does represent the reality of our radiographic practice. Another limitation was that senior staff changed during the review period, which is something that needs to be factored in to programs trying to maintain quality standards. The junior radiographers (this includes student and the recently qualified radiographers) working in the paediatric department were also changing, daily and weekly. The computer system in the hospital was not working for 2 of the 4 months in the period of data collection, which limited the number of radiographs that could be traced and located for review.

One significant limitation is the bias introduced and the reliability of the findings scored by a single radiologist. At least two other readers blinded to the study methodology and review periods could have been used to reduce this bias and increase the reliability of the results. Analysis of the rejected films would have strengthened the study; this analysis was not possible because of the unavailability of these films.

Another limitation is a failure to record rejected and repeated radiographs at the time the radiographs were performed. It is possible that the crash course and posters resulted in more rejected radiographs as radiographers recognized deficiencies and thus repeated radiographs and discarded the originals. This effect was not assessed. Repeat radiographs would lead to higher-quality ratings but also increased radiation dose.

Recommendations from the study

An educational and awareness intervention is recommended monthly or at least bi-monthly for all staff rotating through a paediatric imaging department. In a developing country, this may take the form of oral, YouTube or Webinar lectures from in-house or travelling lecturers. Changing the colour or position of the poster on a monthly basis could result in continued awareness. The introduction of the use of social media platforms such as Facebook and Twitter as informational and educational tools to remind radiographers of quality-assurance practices could also be useful.

Recommended improvements to the department

The patient environment should be as welcoming and child-friendly as possible. There are many simple and inexpensive ways to do this, for example having a separate waiting area for children with suitable decorations and toys, placing pictures or murals in the X-ray room, hanging musical toys on the X-ray equipment and providing patterned lead aprons for staff and caregivers [1, 7]. The use of a patient immobilization device is suggested for hospitals with radiographers not specifically trained for paediatric examination [10].

The education of the radiographers and radiologists remains the most important factor in paediatric radiation protection [7]. All X-ray departments examining children should have a dedicated core group of staff trained in the care and imaging of children. These staff members should also function as supervisors for the training of junior staff [1]. Departments should develop standardized protocols, techniques and diagnostic pathways. They should have comparable diagnostic-quality images and use doses within published reference ranges for children [1].

Future research

We intend to correlate radiographic errors with the level of radiographer expertise and perform reject analysis. We plan to roll out the quality-assurance method to radiographic services with various resource levels in a developing country through the use of cell phones and social media platforms. We also intend to involve radiographers in the quality-assurance process and to train them in the use of the tick-sheet in the hope of creating a self-assessment culture.

Conclusion

A simple method of providing a short lecture and raising awareness through posters has been successful in improving radiographic errors in an unsupervised paediatric department. This includes the overall quantity of errors as well as the number of errors per radiograph. It is imperative to note that there is a decline within a month of the intervention, which shows a downward trend over the next few months. This is in keeping with existing teaching that quality assurance is an ongoing process and that the intervention we propose should be repeated monthly. Further research is recommended to determine whether this process can be rolled out as an outreach project in imaging departments with various resource levels to evaluate a national impact in a developing country using Internet-based tools and social media.

Conflicts of interest None

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Appendix I: Tailoring REDCap to incorporate radiographic images for an offsite quality assurance tool.

The following is the article as it appeared in the Journal of The Colleges of Medicine of South Africa 2019.

JN and WLS Lectureship 2018
Tailoring REDCap to incorporate radiographic images for an offsite quality assurance tool

ABSTRACT:

Aim: To enable X-ray images to be loaded onto Research Electronic Data Capture (REDCap) an electronic data capturing application to enable offsite image management, off-site image quality assurance with contemporaneous data collection.

Methods: Paediatric chest X-ray images were converted to pdf and linked to REDCap, a user-friendly software solution. A hyperlink connected each pdf image to a specific ticksheet which enabled the offsite reviewer to perform quality assurance on the technical quality of the X-ray.

Results: The REDCap reviewing system was found to be very convenient to the reviewers. Keeping the entire transaction electronic, from image delivery to quality assurance ticksheet completion, resulted in shorter turnaround times and reduced the chance of errors being made. The results were immediately available once the reviewers were done and the results could then be used to identify technical gaps in radiographic technique and specifically direct quality improvement efforts.

Conclusion: Leveraging off technology and the REDCap platform provided a simplified, locally relevant and sustainable solution for image management, data collection and the performing of offsite image quality. The loading and reviewing of images on REDCap could be further extrapolated for use in other scenarios such as offsite radiology reporting and in other fields where remote access to patient images would prove useful such as dermatology and opthalmology.

BACKGROUND

Organizations such as the World Health Organisation (WHO), World Federation of Paediatric Imaging(WFPI) and Medicins sans Frontieres (MSF) have been actively involved in innovations in resource limited enviroments which leverage off technology, such as telemedicine and teleradiology(1-3). By providing simplified, locally relevant and locally sustainable solutions they have facilitated the performing of radiography, the reporting on X-rays and the assessment and improvement of X-ray quality (1, 4). The quality of X-rays plays an important role in assisting radiologists and clinicians to make correct diagnoses(5), incorrect interpretation of X-rays results in incorrect diagnosis and patient mismanagement (6). This is particulary true for teleradiologists who review images remotely and are not able to immediately request repeat imaging or ensure good radiographic practice(5). Offsite quality assurance (QA) also enables identification of gaps in radiographic technique and can direct efforts for quality improvement (7).

Novel innovations continue to be required to reach a wide geographic spread of institutions by a single QA provider who must consider the varying level of expertise on the ground as well as available equipment. Innovations to simplify the QA process are required to ensure constant remote monitoring and easy feedback to geographically separated sites. Such an innovation would prove extremely useful for image management, data collection and offsite quality assurance (QA) and image interpretation. This article describes how for the first time X-ray images were linked to Research Electronic Data Capture (REDCap)(8), an electronic data capturing application to facilitate remote reviewers to securely assess the quality of the paediatric chest X-rays.

METHODOLOGY

Research electronic data capture (REDCap) a software solution created by Vanderbilt University that securely supports data collection and dissemination(8) was used in the study. The web-based application made it an ideal platform on which to conduct a multi-site study with sites and reviewers that were geographically distant from each other(8, 9).

REDCap was modified in such as way as to allow loading of individual images using the hyperlink function. The New Identifier (NEWID) function of Microsoft SQL (Structured Query language) a relational database management system (RDBMS) was used to generate globally unique identifiers (GUIDs) (10) (see figure 1) using a version 4 GUID to randomize/de-identify the images. The commands used are listed in figure 2 below. Each image was then manually inserted onto a slide, given a URL link to a record in REDCap and then converted to pdf. A small custom search-and-replace routine inside of PowerPoint was also used to make changes to the URLs, such as updating the REDCap version number within all the links. This routine is available on the public domain on the site PPTools(11).

The X-rays obtained from 3 different research sites were manually prepared in the above manner for a quality assurance study. Using REDCap's Send-It function the pdf file was securely transmitted to each reviewer. The reviewers used their personal username and password to log into the system, which gave them access only to the records specifically assigned to them (ie they could not access or view QA sheets completed by the other reviewers). Reviewers would then review the pdf image, click on the hyperlink on the image which directed them to the image's corresponding quality assurance ticksheet on REDCap where they recorded their findings (Figure 3). The records in REDCap were created into and Excel document by

uploading a comma separated values (csv) file containing the GUIDs using the import tool.

Validation was built into the QA sheet so that the reviewer would get a warning message if a field had been left blank or if a case was not completed. Custom reporting tools also allowed the data manager to monitor the progress and completion of each set of QA sheets, and at the end of each phase could send the reviewer a summary of any images that were missed or not complete. Reviewers could contact the data manager via email if they experienced any problems, and to provide feedback and suggestions about workflow and interface improvements.

ETHICS AND DATA SAFETY

Ethics approval was obtained from the Universty of Witwatersrand's Human Research Ethics Committee (ethics clearance number M130665).The recording of data was according to a numbering code that preserved patient anonymity and concealed the site where the X-ray was obtained.

RESULTS

The processing of the X-rays and the creation of the pdf documents with the imbedded hyperlink required initially significant time and effort from the study data coordinators. However, keeping the entire transaction electronic, from image delivery to QA sheet completion, resulted in shorter turnaround times for the reviewers. Electronically linking each image to its corresponding sheet also reduced the chance of errors being made (for example, the wrong QA sheet being associated to an image because of copy errors in capturing study IDs). The results were immediately available once the reviewers were done, without the need for paper case report forms (CRFs) to first be transcribed and captured electronically. By moving the logistical burden from the specialist to the study team, critical resources were conserved, while simultaneously reducing the opportunity for errors.

DISCUSSION

One of the advantages of the REDCap electronic quality assurance method used in the study is that it was convenient to the reviewers. Quality assurance could be performed on a computer and the electronic ticksheet made the process completely paperless. This reduced the number of errors and enabled the investigator to track reviewer progress. The results were immediately available enabling the institution of direct and specific quality improvement interventions. It enabled the simultaneous collection of data from 3 different reviewers on a secure platform which ensured role-based security. This facilitated real time monitoring of the integrity of the data. The platform enabled all data collected to be stored centrally and simplified the control of data sharing(8).

One of the limitations of the study was that reviewers has to deal with 2 separate windows, one being the pdf document of the X-ray image and the second being the ticksheet in a browser window, which was not the optimal solution. A recommendation to have the image and the QA sheet on the same page as seen in figure 3 was made by the reviewers.

Another limitation emerged from the way images were linked to their QA sheets; the hyperlink contained the url of the record, and this included the REDCap software version number. Since updates are published every couple of months, the hyperlinks in an image file would occasionally become outdated before a reviewer completed all the sheets. The study data managers would then generate a new image file with updated hyperlinks, but this did result in reviewers being inconvenienced.

Recommendations for future research include exploring the possibility of developing a custom plugin for REDCap to combine the image and the QA sheet onto one page. This is an attractive option, since REDCap is hosted by the University and the freeware licensing model makes it economically more viable than a bespoke software solution. Another option would be to develop a dedicated, standalone system for collaborative QA. However, the cost of software development and support could prohibit the development of a bespoke system.

The use of loading images onto REDCap function would be useful in scenarios such as radiology reporting, offsite review of dermatologic disorders, ophthalmologic examinations of the retina and several other applications where large amounts of images are to be reviewed by numerous reviewers and a reliability assessment is needed to ensure stable and consistent results.

CONCLUSIONS

Our study aimed to provide an easily accessible, repeatable means of remotely assessing the quality of chest radiographs from different centres, this was successfully achieved using the REDCap software. The results from the QA process were then used to identify technical gaps which have informed specific training and education of radiographers/technicians at the individual sites to improve the quality of the paediatric chest X-rays. The tool shows promise to be extended to be used as a training tool to inform and test radiographers/technicians on the most common technical errors encountered in their practice. The technique has been expanded to include the assessment of pathology on X-rays in subsequent research (Strasheim and Hlabangana, 2017). This may have an added benefit of being an educational tool for doctors who often are required to interpret X-rays without the assistance or opinion of a radiologist. Such a tool could also be adopted by other organisations such as WHO, WFPI and MSF.

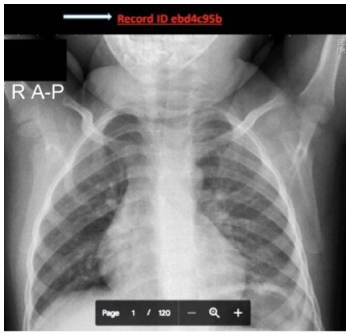

Figure 1. Image as seen on REDCap with embedded hyperlink (white arrow).

```
DECLARE @RequiredRecords INT = 100;
DECLARE @UniqueIDTable TABLE (GenID NVARCHAR(8));
WHILE (SELECT COUNT(*) FROM @UniqueIDTable) <
@RequiredRecords
BEGIN
DECLARE @AutoGenID NVARCHAR(8) = LEFT(CAST(NEWID() AS
NVARCHAR(64)), 8);
IF (SELECT COUNT(*) FROM @UniqueIDTable WHERE GenID =
@AutoGenID) = 0
INSERT INTO @UniqueIDTable SELECT @AutoGenID
END
SELECT * FROM @UniqueIDTable
```

Figure 2. Commands used on the NEWID function of Microsoft SQL to create globally unique identifiers (contributed by T Maré, private software developer).

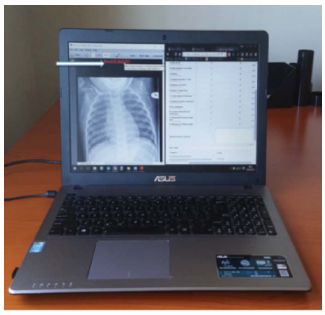

Figure 3. Photograph of the computer-based QA system, with the Xray and hyperlink (white arrow) on the left, and the REDCap ticksheet that opens when the hyperlink is clicked on the right.

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