AN INSTRUMENT TO ASSESS NEONATAL CHEST IMAGE QUALITY

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Abstract

Depending on their condition, most neonates in a neonatal intensive care unit require multiple diagnostic imaging examinations. Therefore, radiographers who perform these diagnostic imaging examinations should use optimal imaging techniques, to limit radiation dose and to ensure optimal image quality. The study wished to determine if radiographers were producing consistent optimal chest images and limiting radiation doses for neonates in a neonatal intensive care unit. A descriptive quantitative study was done by utilising a checklist compiled from literature to evaluate 450 neonatal chest images. Evaluation of the images indicates that radiographers seem unable to adhere to radiation control regulations. The authors propose including the checklist as part of a radiation safety improvement process, as it proved to be an assessment tool for identifying areas in image quality that require improvement.

Keywords: Neonatal chest, Radiographic technique, Dose optimisation, Image quality, Assessment tool

1. INTRODUCTION

Radiological procedures should deliver neonatal images of the highest possible quality for diagnostic purposes while, at the same time, keeping the radiation dose as low as possible (Sherbini, 2000). Furthermore, image quality should be standardised, because standardisation enables healthcare providers to interpret images consistently in order to formulate appropriate interventions (Vyborny, 1997). In addition, most neonates require multiple diagnostic imaging examinations during their stay in the neonatal intensive care unit (NICU), depending on underlying conditions present (Dougeni, Delis, Karatza, Kalogeropoulou, Skiadopoulos, Mantagos & Panayoitakis, 2007; Lowe, Finch, Boniface, Chaudhuri & Shekhdar, 1999). For these reasons, the International Atomic Energy Agency (IAEA), in close collaboration with the World Health Organization, gives special attention in their recommendations to the restriction of diagnostic radiological procedures on children (IAEA, 2002). In view of this restriction, if a neonatal examination is justified, the use of special lead shielding devices and correct radiographic techniques should be mandatory (Pedrosa de Azevedo, Osibote & Boechat, 2006) to limit radiation dose and ensure standardised image quality.

In a private radiology practice in the Free State, South Africa, radiologists questioned whether radiographers were producing neonatal images of standardised quality, and whether these radiographers were using optimal radiation protection during neonatal examinations. During weekly management meetings, the radiologists discussed unsatisfactory neonatal image quality areas. These unsatisfactory image quality areas are the visibility of minimum collimation on images, which restricts contrast resolution; suboptimal patient positioning, which limits diagnostic application; recording of exposure index outside of manufacturers' recommended ranges, which indicates the possibility of increased radiation dose levels; and the absence of mandatory lead shielding, which contradicts the directives of the Department of Health (RSA DoH, 1973).

The management of a New York radiology practice, similarly, identified an increase in images that showed minimum collimation, and images taken without radiation protection in place; they used a short checklist (Hellwig & Wilson, 2013). A quality improvement study at a tertiary care NICU at McMaster University Medical Center in Hamilton, Canada, evaluated images according to established radiographic principles and found areas of concern similar to those identified by the above-mentioned two practices (Loovere, Boyle, Blatz, Bowslaugh, Kereliuk & Paes, 2008). A similar study conducted in the Gauteng province of South Africa evaluated the image quality of paediatric chest images against a specific set of criteria, and identified areas of concern, which included minimum collimation and incorrectly rotated chest anatomy (Hlabangana, 2012).

2. OBJECTIVE

The primary objective of this study was to determine if radiographers working in NICUs were delivering consistent diagnostic chest image quality, without repeating the image unnecessarily and using an optimal exposure technique that limited radiation dose. A research instrument, namely, a checklist, was designed to determine the neonatal chest image quality.

3. METHODS

This was a descriptive, quantitative study of neonatal chest images produced with mobile x-ray machines in NICUs. The period of data collection was February to June 2012 at three institutions that had consented to participate. Two government institutions and one private institution in the Free State province of South Africa participated in the study.

A total of 450 images were assessed for image quality – 150 per participating institution. Only neonatal mobile chest images produced by qualified radiographers upon request by a referring physician were evaluated; no additional images were produced for the purpose of this study.

No patient or institutional information was recorded as part of the results, and ethical approval for this study had been obtained from the Ethics Committee of the Faculty of Health Sciences at the University of the Free State (ECUFS No. 163/2011). Chest images developed by means of computerised radiography (CR) systems were viewed in their static form directly after the chest examination, before being archived permanently. Images are stored temporarily on a CR system for a short period of time (± 48 hours) before being deleted or replaced by other images. These temporarily stored images can be viewed in their unprocessed, original, static format before the radiographer alters (post-processes) the image quality.

The researcher retrieved images from the temporary archive of the CR systems at each institution during unannounced visits, which were aimed at ensuring that radiographers were not influenced by the researcher during their normal routine in the NICU. The neonatal chest image quality was evaluated using a checklist that served as a research instrument.

The checklist was piloted to ensure that it was practical, and also to enable the researcher to familiarise herself with the normal routines of the different institutions. The evaluation skills needed to complete the checklist effectively were refined and benchmarked with a radiologist in relation to the knowledge and skills necessary to judge image quality of a neonatal chest image. Finally, the pilot study established the relevance of criteria that were included and ensured that any vague or unclear criterion areas were removed.

This piloted checklist was compiled and benchmarked from available literature specific to evaluation criteria for neonatal radiography. This checklist reflected the criteria specified by international boards, such as the European Commission (EC, 1996) and the evaluation criteria described by Bontrager and Lampignano (2014) and McQuillen Martensen (2011), who are book authors with clinical experience in the field of radiography. The checklist also contained quality control criteria featured in checklists by other researchers in their studies; for example, Dougeni *et al.* (2007), Loovere *et al.* (2008); Lowe *et al.* (1999); and Slade, Harrison, Morris, Alfaham, Davis, Guildea and Tuthill (2005), in addition to general guidelines by Morris (2003). The reason for using a checklist was that it ensured constant, standard evaluation of image quality, which is reliable and valid. The design of the checklist entailed a structured process that considered various aspects of image quality from various sources.

The checklist comprised three general sections: patient position, breathing technique/lead marker placement/radiation protection, and exposure technique/collimation. The position of the patient's body during the examination was assessed by evaluating the rotation of the chest cavity; tilt of the main radiation beam visible on the chest image; whether all relevant anatomy was included on the image; the centring of the chest cavity in the middle of the image and the absence of artefacts superimposing relevant anatomy on the image. Specific anatomical relations giving rise to the interpretation of these criteria were found in the radiography sources consulted (Bontrager & Lampignano, 2014; McQuillen Martensen, 2011).

The correct breathing technique was also judged according to guidelines of other research checklists (Dougeni *et al.,* 2007; Loovere *et al.,* 2008; Lowe *et al.,* 1999) and described in radiographic sources (Bontrager & Lampignano, 2014; McQuillen Martensen, 2011), that is, by assessing the visibility of posterior ribs. Likewise, the correct anatomical sides had to be indicated by including an anatomical lead marker on the image (Slade *et al.,* 2005). Furthermore, radiation protection, which is mandatory in South Africa (RSA DoH: 1973), exposure parameters and collimation criteria given by the European Commission were included in this checklist. These and other criteria listed by the European Commission (1996) in a document entitled, European guidelines on quality criteria for diagnostic radiographic images in paediatrics, echoed the criteria described in the radiography sources (Bontrager & Lampignano, 2014; McQuillen Martensen, 2011).

A coding system formed part of the mechanics of analysing the data obtained from the checklist, and was designed with the assistance of a statistician. Descriptive statistics, namely, number of images and percentages, were calculated for quantitative data. No distinction was made between data obtained from the different participating institutions.

A radiographer should always strive to achieve optimal alignment of the neonatal anatomy and the image receptor. Correspondingly, the image should not exhibit photographic or geometric distortion errors. In order to create an image that is free of these errors, a radiographer must position a neonate optimally.

4. RESULTS

To assess patient positioning according to the criteria in the first section of the checklist, five specific criteria were evaluated, namely, rotation, tilt, included anatomy, centring and artefacts (Figure 1). Rotation was evaluated by determining if the vertebral column was at an equal distance from the bilateral lung borders (EC, 1996; Loovere *et al.,* 2008; Morris, 2003). Figure 1 shows that, in 56.7% of images (n=225), the distance was not the same, indicating that there was rotation on the image. Rotation was partial in 8.9% of images (n=40) – these were cases involving anatomical structures above or below the chest showing signs of rotation in addition to a rotated chest (skull in an oblique position for 4 images or in a lateral position for 36 images).

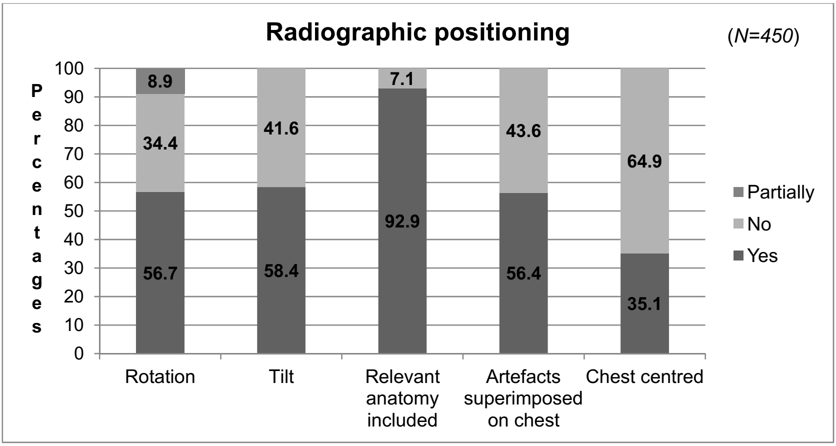

Figure 1: Radiographic positioning

The tilt of the main radiation beam for the neonatal chest images was evaluated by the trapezoid shape of the chest and horizontal rib appearance (McQuillen Martensen, 2011). In 58.4% of images (n=263), the amount of tilt was correct, because the chest visualised as a trapezoid shape, and in 41.6% of images (n=187), the tilt was evaluated as incorrect due to the horizontal rib appearance (Figure 1).

All relevant anatomy included was evaluated by determining if the entire lung fields were visualised on the image (Bontrager & Lampignano, 2014; EC, 1996; McQuillen Martensen, 2011; Morris, 2003; Slade et al., 2005). It was found that 92.9% of images (n=420) met this criterion (Figure 1). Anatomical structures that were excluded on 30 images (7.1%) were the costophrenic angles (24 images) or both lung apices (6 images).

Centring was deemed correct if the fourth thoracic vertebra was seen in the middle of the image (Bontrager & Lampignano, 2014; Loovere et al., 2008; McQuillen Martensen, 2011;) and, as seen in Figure 1, in 35.1% of images (n=153) this was the case. Other structures were found to be in the centre of the image in 64.9% of images (n=297). Centring was inferior to the fourth thoracic vertebra – more towards the abdominal cavity – in 99.7% (296) of images, and in 0.3% (1 image) it was more superior, towards thoracic vertebrae two and three.

Lastly, patient position was evaluated in reference to artefacts superimposed on chest anatomy – no foreign structure should be superimposed on chest anatomy (Loovere *et al.,* 2008; Morris, 2003). Figure 1 reports that 56.4% of images (n=254) contained artefacts. Artefacts that were found to superimpose chest anatomy on these 254 images are summarised in Figure 2. The artefacts found on images were mostly electrocardiogram (ECG) lines (61.9% or 157 images), followed by the neonatal mandible (24.4% or 62 images).

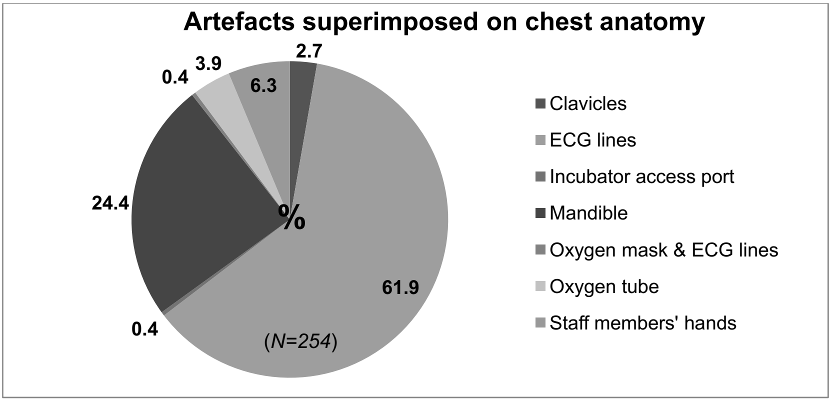

Figure 2: Artefacts superimposed on chest anatomy

The second section of the checklist assessed breathing technique, lead marker placement and radiation protection. The correct breathing technique for chest radiography is suspended inspiration, and this was reflected in the checklist (EC, 1996; Morris, 2003). Figure 3 illustrates that the correct suspended inspiratory breathing technique was utilised in 54.2% of cases (n=244). The incorrect breathing techniques observed (45.8% or 206 images) can be subdivided, into 30.2% (n=136) with normal respiration and 15.6% (n=70) with suspended expiration.

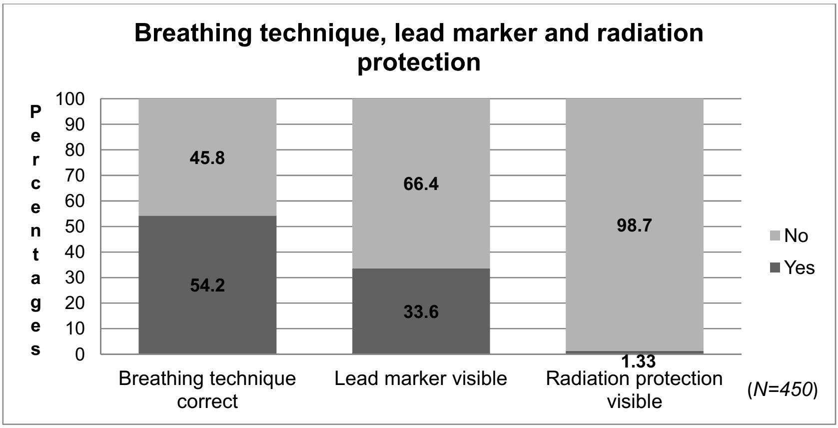

Figure 3: Breathing technique, lead marker and radiation protection

Guidelines defining the scope of the radiography profession require that a lead marker is placed on an image, in the correct format and without it superimposing any important anatomy, as part of patient care and use of equipment (McQuillen Martensen, 2011; Morris, 2003; Slade *et al.,* 2005). Furthermore, regulations require that paediatric patients, especially neonates, receive lead shielding over the pelvic region when chest imaging is performed (RSA DoH, 1973). Figure 3 shows that a lead marker was visible on 33.6% of images (n=151), and radiation protection as pelvic lead shielding was visible on 1.33% of images (n=6).

Finally, the third section of the checklist assessed the exposure technique and collimation. An optimal exposure technique will enable a referring physician to evaluate the condition of the lung tissue itself (McQuillen Martensen, 2011). The exposure technique was evaluated utilising 11 criteria. These criteria were included to compensate for the fact that the actual selected exposure parameters were not included in the data accumulation; doing so enabled the researcher to compensate for any pathology that might obscure some areas.

The first four criteria in Table 1 relate to the visibility of lung patterns. Reasons for lung patterns not being visible could include the selection of inadequate exposure parameters, and/or pathology overshadowing lung patterns. If the milliampere per second exposure selection is optimal, vascular patterns should be visible in the central half of the lungs (as shown by 61.1% or 275 images) and parenchymal markings throughout the lung field (60% or 270 images) (McQuillen Martensen, 2011). The peak kilovoltage exposure selection was evaluated in the lung fields by evaluating the visibility of the proximal bronchi (72% or 326 images) and retrocardiac lung (64.9% or 292 images) (McQuillen Martensen, 2011).

Table 1: Exposure technique

Evaluation criteria	Percentage	Number of images (*N=450*)
LUNG PATTERNS		
Vascular pattern	61.1	275
Parenchymal markings	60	270
Proximal bronchi	72	326
Retrocardiac lung	64.9	292
OTHER CHEST STRUCTURES		
Trachea	72.4	326
Mediastinum	71.6	322
Spine and paraspinal structures	81.6	367
Diaphragm and costophrenic angles	86.7	390
Catheter tips	89.3	402
OVERALL APPEARANCE		
Exposure technique	61.8	275
Exposure indices	37.3	168

The next five criteria in Table 1 evaluated the visualisation of other chest structures in or around the lung fields. More than one structure was evaluated, in order to compensate for possible pathological overshadowing of some structures (McQuillen Martensen, 2011). The trachea was visible in 72.4% of images (n=326), which correlates well with the other centrally located mediastinum, seen in 71.6% of images (n=322).

The final two criteria in Table 1 considered the overall appearance of the exposure technique utilised with the corresponding exposure index. Optimal exposure techniques were visually noted for 61.8% of images (n=275) when they were evaluated; however, in only 37.3% of images (n=168) the recorded exposure indices were within the recommended range.

The last element evaluated by section three of the checklist was inclusion of any additional anatomy, which causes an increase in the radiation dose to the neonate without making a significant contribution to the diagnostic process. Therefore, close four-sided collimation should be visible (McQuillen Martensen, 2011). Specific chest structures that should be included inside the close collimation are, superiorly, cervical vertebra number seven, inferiorly, the costophrenic angles and, for bilateral sides, the shoulders (EC, 1996; McQuillen Martensen, 2011; Bontrager & Lampignano, 2014; Slade *et al.,* 2005; Morris, 2003). Figure 4 presents the results of this part of the checklist. Collimation was found in 25.1% of images (n=113). In the 450 images examined, most of the required anatomical structures were included inside the collimation.

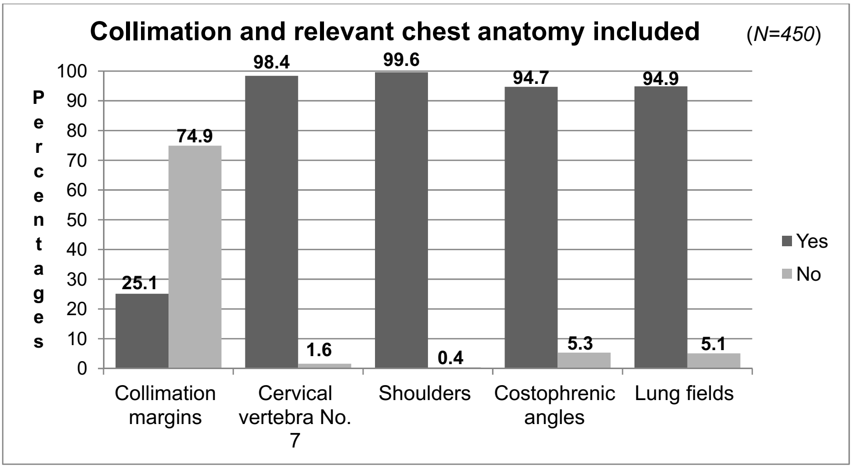

Figure 4: Collimation and relevant chest anatomy included

Additional anatomical structures that are included inside the collimation have no diagnostic value and only serve to increase patient dose. As shown in Table 2, additional anatomy was included superiorly on 72% of images (n=324). In neonatal chest imaging, specifically, referring physicians may wish to see more of the cervical spine region, in order to evaluate endotracheal tube positions (McQuillen Martensen, 2011). The cervical spine and mandible were additionally included in 141 images (43.6%) and, in some instances, cervical vertebra one was included (35% or 14 images).

Table 2: Additional anatomical structures included in collimation

Anatomical structure	**Percentage**	**Number of images**
SUPERIORLY ADDITIONAL ANATOMY	72	324 (*N=450*)
Mandible and cervical spine	43.6	141 (*N=324*)
Skull, mandible and cervical spine	18	58 (*N=324*)
First cervical vertebra	35	114 (*N=324*)
Fourth cervical vertebra	3.4	11 (*N=324*)
LATERAL ADDITIONAL ANATOMY	42.9	193 (*N=450*)
Humeri	65.4	128 (*N=193*)
Elbows and humeri	16	30 (*N=193*)
Fingers to humeri	11.9	22 (*N=193*)
Hands of staff members	6.7	13 (*N=193*)
INFERIOR ADDITIONAL ANATOMY	76.4	344 (*N=450*)
Lower costal margin	3.5	12 (*N=344*)
Third lumbar vertebra	0.3	1 (*N=344*)
Iliac crest	31.8	110 (*N=344*)
Anterior superior iliac spine	0.3	1 (*N=344*)
Whole pelvis	30.6	106 (*N=344*)
Femurs	28.6	99 (*N=344*)
Knees	2	6 (*N=344*)
Lower leg	0.9	3 (*N=344*)
Feet	2	6 (*N=344*)

Table 2 also shows that, on 42.9% images (n=193), additional anatomy or structures were included bilaterally. The humeri were included most frequently (65.4% or 123 images). Lastly, 76.4% (344 images) showed the inclusion of additional anatomy inferiorly. The leading additional anatomy included inferiorly were the iliac crest (110 images), the whole pelvis (106 images) and the femurs from above the knees (99 images).

5. DISCUSSION

Positioning technique was evaluated by the checklist, which found incorrect centring on 287 images (64.9%), with 296 of these images centred more to the abdominal area. Collimation on four sides was visible on 113 images (25.1%). Radiation protection in the form of pelvic shielding was seen on only 6 images (1.33%). These findings correlate with other studies done in the United States of America (Hellwig & Wilson, 2013), Canada (Loovere *et al.,* 2008) and other provinces of South Africa (Hlabangana, 2012).

Additional anatomy was included superiorly on 324 images (72%), inferiorly on 344 images (76.4%) and laterally on 193 images (42.9%). Artefacts were found on 254 images (56.4%), with ECG lines the most common, on 157 images.

Rotation was seen on 225 images (56.7%), which was also found by another South African study (Hlabangana, 2012), and lead markers were found on 151 images (33.6%). Exposure techniques visualised anatomy in more than 50% of images (Table 1), and exposure indices were inside the recommended range on only 168 images (37.3%). This correlates with the disconnection theory between image display and acquisition due to the increased display latitude of CR systems (Bontrager & Lampignano, 2014).

The results show various areas in which the image quality could be improved through optimal positioning techniques and implementation of regulations set out by South Africa's Department of Healh (RSA DoH, 1973). The checklist was shown to be a valuable assessment tool for identifying these areas in image quality and radiation protection. However, a single observer can lead to research bias and an additional observer could have ensured that the evaluation process was more trustworthy. The checklist can be adjusted to include further evaluation criteria relating to the superimposition of the mandible over lung apices and scapulae superimposed over lateral lung fields. Furthermore, when an image is optimally collimated, pelvic shielding will not always be visible, and this is, therefore, a limitation of the checklist in its current format.

6. CONCLUSION

The checklist that was designed for this study assisted the researchers to assess neonatal images in a structured manner. The majority of images (92.9%) included the relevant anatomy. Noteworthy is that the anatomical lead markers were visible on 33.6% of images, and radiation protection was not visible on most of the images. A recommendation based on this study's results is that radiological management should ensure and enforce the implementation of the radiation regulations obligated by the Department of Health in relation to lead marker placement and lead shielding (RSA DoH, 1973). Considering the mobile neonatal chest images evaluated by this study, radiographers seem unable to adhere to this important regulation, and managerial support could assist in ensuring compliance – this is also recommended by other authors (Hellwig & Wilson, 2013) as part of a radiation safety quality improvement process. The checklist could be included in similar radiation safety improvement processes as a standardised evaluation tool for image quality, because it could identify areas of image quality.

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