ORIGINAL ARTICLE

Increasing Source-Object Distance: A Computed Radiography-based Strategy to Reducing Radiation Dose in Occipital-Frontal Skull X-Ray.

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ABSTRACT

Introduction: Exploring potential optimization strategies and developing evident practices is critical. Previous studies show that radiation dose can be reduced by increasing the source-image distance (SID). Although most studies use digital radiography, many hospitals in underdeveloped countries still use computed radiography (CR). Therefore, research will investigate the relationship between SID and Entrance surface dose (ESD) using the CR. **Methods:** This study involved the measurement of radiation dose and image quality of a radiological procedure performed at a reference SID; 100cm and the tested SIDs; 110cm, 120cm, and 130cm, using constant technical factors (70kVp, 25mAs, grid). A LiF; Mg Ti thermoluminescence dosimeter (TLD-100) chip was placed in the center of the radiation field of the OF10° skull radiography examination to measure ESD. Image quality was assessed using the European Commission guidelines and graded using relative visual assessment analysis (VGA). **Results:** Significant ESD reduction from 21% and 45% when SID was increased from 100cm to 130cm (p <0.001), where SID was negatively correlated with ESD (r= - 0.98). The VGA scores showed no statistical difference in the image quality of the OF10° skull radiography examination for the tested and reference images (p=0.21). VGA scores for 120cm images showed the highest image quality among the SIDs tested with a dose reduction of 37%. **Conclusion:** ESD was statically reduced when SID was increased from 100cm to 130cm, while image quality was diagnostically acceptable. The study suggests that 120cm is the optimal SID when both dose and image quality are considered.
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Keywords: Source image distance, Skull radiography, Entrance surface dose, Occipital-frontal 10°, Dose optimization

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INTRODUCTION

Diagnostic radiography offers immense benefits, but the radiation energy absorbed by organs and tissues exposed to radiation can cause cellular damage, termed deterministic and stochastic effects (1). This has raised public concern and led to a drive to control radiation exposure during medical treatment.

It is crucial to investigate possible optimization methods and develop evidence-based practices for radiation exposure. When it comes to optimizing medical radiation exposure, the radiation dose administered to the patient should be as low as reasonably achievable (ALARA) (2) However, it is important to ensure that image quality is not compromised just to reduce the radiation dose. Low dose imaging with poor image quality would not be tolerated in medical practice as it leads to unnecessary radiation doses for repeated examinations (3). Even with minimal radiation exposure, the images produced by medical imaging must meet image quality requirements to enable accurate diagnosis (3). Due to economic constraints, X-ray examination of the skull is the first choice for most skull anomalies, especially in underdeveloped countries. According to Inyang et al. (2016), the risk of cancer incidence and cancer mortality due to X-ray skull examinations was 0.6 cases and 0.4 cases per hundred thousand, respectively (4). Given the potential for harm from this procedure, every effort should be made to ensure that all skull projections are optimized to minimise the dose to the patient, especially as some patients will most likely have a subsequent computed tomography scan.

One of the methods of reducing the dose is to move the radiation source, for instance, X-ray tube, away from the image receptor. This distance is called the source-image distance (SID). SID is composed of a distance from the source to the object (source-image distance (SOD)) and a distance from the object to the image receptor (object-image distance (OID)). A previous study reported that radiation exposure from OF was 21.9 percent lower at 150 cm SID compared to 100 cm SID using digital radiography (DR) (5). Based on Monte Carlo simulation, the reduction could reach 35.4% using the same system, but no reduction for computed radiography (CR) (6). This research focuses on CR, as there are many studies on SID and effective dose, but none specifically for OF.

Therefore, the research aims to investigate the relationship between SID the ESD and to propose an optimal SID that can reduce the dose without sacrificing image quality using the CR system.

MATERIALS AND METHODS

The head phantom (Kyoto Kagaku) was positioned for an OF10° skull projection so that the nose and forehead touch the image receptor (distance between phantom and image (OID) = 0 cm) and the orbitomeatal line (OML) at 10° caudal. The midsagittal plane (MSP) of the phantom was aligned perpendicular to the image receptor.

The X-ray tube (Siemens Multix Top Polydorus IT) was positioned so that the distance to the image receptor (SID) was 100 cm for the reference value. The horizontal X-ray beam was collimated to include the outer surface of the phantom laterally and the vertex of the skull superiorly, exiting at the glabella.

In this study, TLD-100 chips were used to measure the Entrance dose surface (ESD). Before the TLD-100 chips could be used, they were annealed using the TLD annealing oven. This oven was connected to a PC via the Windows-based oven software Thermosoft (RadPro International GmbH, 2009). The TLD-100 chips were first heated to 400°C for one hour and then to 100°C for three hours before being irradiated. After annealing, the TLD-100 chips rested for 24 hours before being irradiated.

The TLD-100 chips, enclosed in a radiolucent housing, were positioned on the head phantom at the intersection of the beam axis with the surface of the patient. The head phantom was irradiated with exposure parameters of 70 kVp, 25 mAs, grid, and 1.0 mm focal spot size (FSS) X-rays. This procedure was repeated six times, using different TLD-100 chips each time (total TLD chips = 24). The irradiated TLD-100 chips were then placed in the stainless-steel tray and left at room temperature for 24 hours to release the low-energy traps before scanning with the TLD reader (Harshaw 3500 TLD). The preliminary experiment resulted in a reader calibration factor (RCF) of 1nC = 1mGy. The TLDs were therefore converted to dosimetry data using the RCF.

Using the same positioning technique and exposure parameters, the experiment was repeated by increasing the SID (110cm, 120cm and 130cm) individually. For each SID, an X-Ray radiograph was printed using a printer (Carestream Dryview 5950 Laser Imaging System). Thus, four radiographs were used to assess image quality for this study (one reference radiograph, SID = 100 cm, and three test radiographs, SID = 110cm, 120cm and 130cm).

Four observers were assigned to assess the image quality of these radiographs. The observers were experienced radiographers with more than five years of clinical experience who currently work as a teacher for radiographers. Their visual acuity is routinely tested (and corrected if necessary) so that their ability to judge images is not affected, as they routinely perform this type of image assessment in an academic setting. Their participation in this study was considered appropriate as the observers only needed to assess the presence of important anatomical landmarks and image details in each image and therefore did not require expert training.

The observers received adequate introduction and guidance on the use of visual assessment analysis (VGA) to assess image quality. They were blinded to the imaging parameters and judged independently. Observers could select the tested radiographs in any order, sequently or randomly. Reference and test images were displayed in pairs on the LED illuminators with 9600k colour temperature and 1000-4500cd/m^2 luminance (Iz Med, Malaysia), with the reference radiograph on the right and the test radiograph on the left. The radiographs were evaluated according to the criteria for image quality published in the European guidelines (European Commission, 1996) (Table I). Each criterion was scored from zero to three using VGA (zero = poor; one = acceptable; two = optimal, three = excellent) (Table II).

Table I: Image Quality criteria to score the OF10° Skull Radiographs.

Criteria	Explanation
1	Symmetrical production of the skull, particularly orbits, cranial vault, and petrous bones
2	Projection of the apex of the petrous temporal bone into the centre of the orbits.
3	Visually sharp reproduction of the ethmoid cell, frontal sinus, and apex of the petrous temporal bones and the internal auditory canals.
4	Visually sharp reproduction of the inner and outer lamina of the cranial vault.

Table II: Four-point scoring scale (VGA scoring) used to assess the quality of each radiograph.

Score	Image Scoring Definitions
0	Poor; anatomy visualized on the test image is worse than the reference image and unacceptable
1	Acceptable; anatomy visualized on the test image is worse than the reference image but acceptable
2	Optimum; anatomy visualized on the test image is equal to the reference image
3	Excellent; anatomy visualized on the test image is better than the reference image

There was no time limit, so the observers had enough time to rate each radiograph.

The D'Agostino-Pearson normality test was used to ensure that the dosimetry data were normally distributed. A one-way analysis of variance (ANOVA) with Dunnet multiple comparisons was then performed for each data set. The correlation between SID and ESD was determined using the Pearson correlation coefficient. The VGAs score for the different SIDs was compared with the reference value of 100 cm SID using a Kruskal-Wallis test with Dunn multiple comparisons. A significance level was set to p <.05. The inter-observer variability was expressed as the Fleiss kappa.

RESULTS

Table III summarizes the average ESD and VGA values from the OF 10 Skull X-Ray (SXR) with different SIDs: 100cm, 110cm, 120cm, and 130cm. Dosimetry data showed that radiation exposure decreased with increasing distance between the phantom and the radiation source. Radiation dose was reduced by 21% for SID 110cm, 37% for SID 120cm, and 45% for SID 130cm. These reductions were statistically significant compared to the dosimetry data from the reference SID (p-value <0.001) (Fig. 1).

The observers visually assessed the tested radiographs against the reference radiograph to determine the image quality score (Fig. 2). Although 100 cm was a routine SID for clinical practice, none of the examiners gave this radiograph an excellent score for criteria one, two, and three. In fact, some of the radiographs tested exceeded the mean score for the reference radiograph for criteria two and three (mean VGA for criteria two; 100 SID = 2.00±0.00, 110 SID = 2.25±0.50, and mean VGA for criteria three; 100 SID = 2.00±0.00, 120cm SID = 2.50±0.57). The lowest score for all radiographs tested was diagnostically acceptable for all criteria. The reference radiographs received the highest mean VGA score, followed by the 120cm SID radiograph (Fig. 3). There was no statistically significant difference in image quality for radiographs acquired at any of the three SIDs (p-value = 0.21) compared to the reference image.

Table III: The mean entrance surface dose (ESD) and VGA score for OF 10° skill radiographs using different source image distances (SID)

Radiographic examination	SID (cm)	ESD ±SD (mGy)	VGAS ± SD
OF10° skull	100	17.85 ± 1.12	2.19±0.38
	110	14.14 ± 1.05	1.88±0.43
	120	11.20 ± 1.57	1.94±0.52
	130	9.70 ± 0.94	1.57±0.13

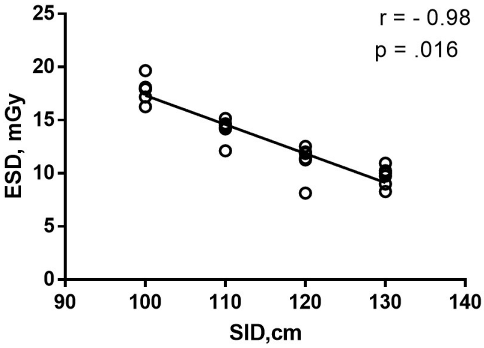

Figure 1: Statistical analysis showed a significant relationship between SID and ESD

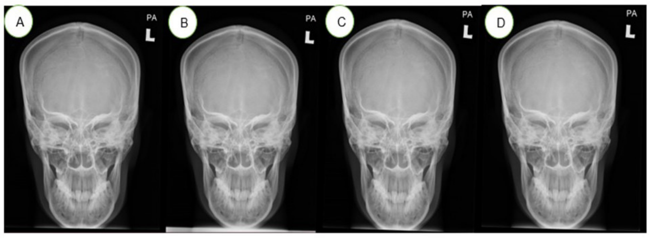

Figure 2: Image of OF10° skull radiograph obtained at different SID with A= 100cm, B= 110cm, C=120cm, and D=130cm, were assessed for Criteria 1, 2, 3, and 4 and scored according to VGA scoring.

Analysis of interobserver variability for the OF10° showed fair agreement for 2 observers (Fleiss kappa = 0.33 and 0.24) and poor agreement for the other 2 observers (Fleiss kappa values < 0.02).

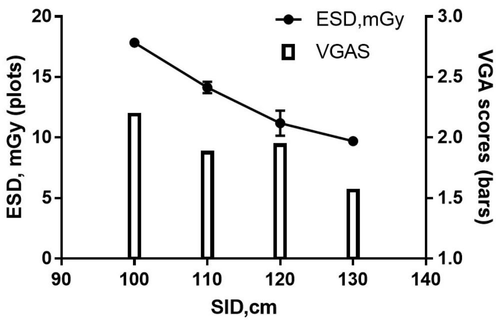

Figure 3: The graph illustrates a decreasing pattern for both ESD (plots) and VGA scores (bars).

DISCUSSION

This study investigated the effect of SID on image quality and radiation dose during an SXR examination with a computed radiography system.

It was found that radiation doses, as measured by ESD, were significantly correlated with SID in this study. This dose reduction is expected because the relationship between distance and radiation dose has been thoroughly explained by the inverse square law, which states that the dose can be reduced if a radiograph is acquired at a longer SID (7). Although the mathematical formula (7,8) can be used to calculate the radiation dose, this method neglects other dose-related factors such as scattered radiation and air gap filtering. In research to date, both automatic and manual control of radiation exposure have been used to optimize radiation dose (9–11), and each has its function and strength. Although the image quality is excellent when an automatic system is used, the absorbed dose is inadequately reduced. By using manual control, both absorbed dose and image quality can be further optimized. Therefore, the manual system used in this study is valid and can contribute to the body of knowledge.

To increase SID, the patient should be as far away from the X-ray source as possible. However, this would result in a radiograph with increased noise, penumbra effect, and geometric unsharpness (12). This effect can be observed on the radiograph of 130cm SID. Although the dose reduction was the greatest and the radiograph was diagnostically acceptable, it received the lowest quality score of all the radiographs analysed. This should be avoided as it can lead to erroneous judgments by the physician. This is especially important in SXR because there are many overlapping bones in the head region. For example, the image apex of the petrous temporal bone, ethmoid cell, frontal sinus, apex of the petrous and cranial vault is worse than the reference radiograph when taken at 130cm SID.

Many previous studies have reported that using a larger SID than 100 cm reduces the dose for examinations of the skull as well as the pelvis (13), spine (14) and chest (15). For SXR, reductions ranged from 35.4% in computer-simulated calculations (6) to 64% in patient studies (5,16). Compared to this work, Joyce et al. used a higher X-ray voltage of 75 kVp, but the dose is only reduced to 21.9% at the recommended optimal distance of 150 cm. Another recent study by Lorusso et al. used even higher kVp, which is 95 kVp, 2.5 mAs and 105 kVp, 1.7 mAs, and reported higher dose reductions of 45 % and 64 %, respectively (16). This could be due to the use of the exposure control system (AEC or manual). AEC is designed to keep image noise constant. It automatically adjusts the tube current to ensure that photons absorbed by the air between the object and the source are replenished in sufficient quantity to produce a high-quality diagnostic image (13). In the manual exposure system, the tube current is set based on the preselected current. There is no study comparing dose reduction between these exposure control techniques for SXR. However, the pelvic study by Tugwell et al. reported that ESD was reduced to 41.79% when using manual exposure control compared to 17.3% when using AEC (17).

However, increasing the SID to 120cm SID in this study further reduced the radiation dose by 37% while maintaining image quality similar to that of a routine radiograph by maintaining tube current and other exposure settings like routine SID. Although the 100-cm radiograph received the highest VGA rating in this study, it was not significantly different from the 120-cm radiograph. The 120-cm radiograph SID better visualized the ethmoid cells, frontal sinus, apex of the petrous temporal bones, and internal auditory canals. Visualization of the apex of the petrous temporal bone projected into the orbits was identical to the image acquired at 100cm SID.

Although many strategies have been proposed to reduce a patient's radiation exposure, many of them are not routinely used in the clinical setting due to time and/or cost constraints (18,19). The SID approach is a straightforward implementation of a basic practical method to optimize patient dose. However, it has rarely been used in the clinical setting16. Most radiographers know that increasing the distance between the x-ray source and the patient reduces radiation dose and are willing to implement it into practice (20). This implementation requires collaboration between radiographers, radiologists, medical physicists, and academics. For example, the main college reference source, especially books, still use SID 110cm for skull radiography. Therefore, it is necessary to compile the latest research in this field into a book that will serve as a new reference source for radiography students.

Although positioning the patient for OF10 requires the radiographer to bend down and put weight on certain limbs, increasing SID does not require a new or modified technique. The technique is similar to that used for the routine SID examination. Therefore, this approach could be used in clinical practise with existing skills and minimal discomfort for the radiographer. Other skull examinations acquired with a horizontal beam, such as the paranasal sinuses and facial bones, may also benefit from the increased SID.

There are several limitations to this research study. First, the skull phantom used for both dosimetry data collection and image quality analysis have no pathologic or anatomic variations and is also a fixed size. Both may alter the SXR image and the radiation dose received (21). Second, the images tested were acquired using X-ray grids that were not individually focused on each SID, so susceptibility to grid error, particularly grid cut-off. As the distance from the source increases, the radiation beam becomes more divergent. As a result, the grid strip, especially the one at the edge of the cassette, absorbs more primary radiation (22). However, all images evaluated in this study were found to be diagnostically acceptable. This could indicate that the effect of grid is less pronounced in the SID used for this study. Nevertheless, it is recommended to perform a radiographic examination with an appropriate grid at a higher SID. The final shortcoming of the study, as well as a suggestion for future research, is to quantify the effects on image quality parameters, including contrast and signal-to-noise ratio. The results of this analysis can then be compared with the results of the VGA evaluation panel.

CONCLUSION

Increasing SID from 100 cm is an effective optimization approach for OF10 and should be considered for clinical use. The proposed optimum SID is 120 cm, as it has resulted in an optimal reduction in effective dose while providing diagnostically acceptable images.Potential studies in this area will investigate the practicality of using a higher SID in clinical practice, as well as the possibility of using a higher SID to reduce dose in pediatric cranial examinations.

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