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Investigation of barium sulphate shielding during panoramic radiography

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Abstract

Background Radiation shielding in radiology has historically been achieved with lead; however, there has been an increasing demand for radiation shielding to be more environmentally friendly. Barium has shown promise as a substitute in many radiology applications. This study aims to investigate a barium sulphate shield in protecting the thyroid and the eye lens during panoramic radiography.

Methods During a simulated panoramic examination, an anthropomorphic phantom and a solid-state detector measured the radiation dose to the surface thyroid and the eye lens. The measurements were taken using no shield and a barium sulphate shield. A Welch's T-test was employed to compute the shield's effect on radiation. Two radiologists assessed the image quality with and without the thyroid shields.

Results The dose reduction was between 66 and 75% for the barium shield at the thyroid. The dose reduction ranged between 15 and 61% in the eye region. Images using a barium shield were deemed adequate for diagnostic interpretation.

Conclusions Barium shields effectively reduce the radiation dose in the thyroid region during panoramic radiography without degrading image quality. The dose reduction depends on the tube voltage and the area of interest.

Keywords Radiation shield, Barium sulphate, Panoramic radiography, Radiation safety

Background

Dental imaging contributes to less than 0.1% of the global population's radiation dose. Even though this portion is considered minor, the radiation risk should be considered when performing panoramic dental X-ray examinations. These examinations require ionizing radiation, increasing the patient's risk of radiation-induced malignancies. Several studies have assessed the dose for radiosensitive tissue during a dental procedure [1]. The thyroid and the eye lens are radiosensitive and are exposed to radiation during dental examinations [1, 2]. Although the radiation risk during panoramic examinations is low, it is three times greater in paediatric patients under ten than in adults above 30 [3]. Considering that in the context of radiation protection, it is assumed that there is no threshold for the risk of radiation-induced malignancies, it is

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relevant to consider reducing the dose in radiosensitive organs during panoramic examinations [4].

To ensure the best patient care, optimizing radiation exposure is vital. The as low as reasonably achievable (ALARA) radiation protection principle is pivotal in optimizing radiation exposure. The ALARA principle has three fundamentals: reducing the exposure time, increasing the distance from the radiation source, and employing shielding. A shield is a protective tool that can minimize radiation transmission, depending on its specification. The development and efficiency of shielding materials is a broad research area [5]. One practical approach is to employ a radioprotective shield during examinations.

Studies have shown that a lead thyroid shield significantly reduces the radiation dose to the thyroid during dental radiography [5]. However, the main drawback of lead in panoramic examinations is that it interferes with the primary beam, and artefacts have been reported [4]. Additionally, lead is classified as toxic and is slowly being eliminated from use in the medical setting [6]. Another shielding material examined in the research for dental procedures is bismuth. Bismuth’s efficiency in reducing the thyroid and eye doses in periapical imaging was reported [7]. However, they showed that the shield did not reduce the dose during panoramic and CBCT dental examinations. Barium is an environmentally friendly alternative to lead that provides radioprotective shielding. In the main range of medical radiation (60–100 kVp), 3.88 g/cm³ of barium has a similar shielding ability to 0.5 mm of lead [7]. Barium sulphate as a protection tool has been investigated in computed tomography and fluoroscopy and provides a good reduction in radiation without impacting the image quality [8]. The energy range for panoramic examinations is typically between 60 and 70 kVp. The barium K-edge is 37.4 keV, where the photoelectric absorption of photons increases noticeably after the K-edge energy. This makes barium a good candidate as a shielding material for the panoramic scan as it matches the mean energy produced in these examinations. Therefore, this study aims to examine the potential of using a barium sulphate shield in panoramic radiography examinations for radiation protection, specifically for the thyroid and the eye lens.

Methods

This study was conducted in a public hospital’s Oral and Maxillofacial Radiology department. This study used a phantom and did not include humans or animals. Therefore, ethical approval was not required.

Equipment

Two commercially available barium sulphate vinyl shields (GrayShield, Northern Ireland) were used for the thyroid

and the eye region. Both shields had a lead-equivalent thickness of 0.25 mm, as stated by the manufacturer. The commercial barium sulphate shield was designed for single use to prevent possible cross-contamination.

An anthropomorphic female phantom (Alderson Rando, The Phantom Laboratory, Salem, NY, USA) representing a female adult was used in this study. The phantom was constructed with a natural human skeleton covered by a soft tissue-simulating material with the same effective atomic number and mass density as human muscle tissue with randomly distributed fat. The head, neck, and shoulder sections (slices 1 to 11) were used. Two panoramic dental X-ray units (Planmeca ProMax 2D, X2-027, Finland) were used. The phantom was positioned and irradiated based on the clinical protocol at the hospital; see Table 1.

A Raysafe X2 R/F solid-state detector (Raysafe, Sweden) was used. This detector measures with an uncertainty of 5% in the 1 nGy–9999 Gy range. The detector is orientation-independent, and no corrections were required. The X2 R/F sensor has an advanced stacked sensor technology that prevents heel effects on the measurements. The X2 R/F sensor can be used on the energy range in this study without selecting ranges or modes. The detector had a current calibration certificate at the time of data collection. The surface doses were measured by placing the X2 R/F sensor on the phantom. Dose measurements are acquired in µGy.

Dose measurements

The dosimeter was taped on the thyroid region on phantom slice 9 for unshielded measurements. This slice was selected based on the thyroid surface dose measured in previous studies [2]. The dosimeter was positioned in the middle of the eye for the eye measurement. The detector was first taped to the selected region for shielded measurements, and then the shield was placed over the dosimeter.

Table 1 The parameters used for each panoramic X-ray machine, based on the clinical protocol

Machine 1			Machine 2		
Tube voltage (kVp)	Current (mA)	Time (s)	Tube voltage (kVp)	Current (mA)	Time (s)
70.00	12.50	15.50	70.00	12.50	16.70
68.00	10.00	14.80	68.00	10.00	16.20
66.00	8.00	14.80	66.00	8.00	16.20
64.00	6.30	14.80	64.00	6.30	16.20
62.00	5.00	12.80	62.00	5.00	14.00

To avoid machine-related bias, the reproducibility was assessed for each machine by taking three measurements per machine. For short-term reproducibility, three measurements were taken using a tube voltage of 66 kVp with the dosimeter positioned per the protocol for quality assurance. These measurements were repeated three times at 10-min intervals. The measurements were repeated three times over three months to assess long-term reproducibility. The reproducibility was evaluated by recording the average dose and the standard deviations for the three measurements at a given kVp.

Measurements were taken in two setups. Firstly, the surface dose without a shield and with the barium sulphate shield was measured in the thyroid region. Secondly, the surface dose without a shield and with the barium sulphate shield was measured in the eye region. These measurements were obtained from both machines using two kVp intervals for the clinical range of kVp (62–70). Each dose measurement was measured three times at each kVp interval with and without a shield, and SD was calculated. The same measurements were repeated on the second machine and averaged. The setup of the phantom is shown in Figs. 1 and 2.

Based on the following equation, the average thyroid and eye surface dose with and without shielding were computed to obtain the dose reduction value as a percentage.

$$\text{Dose Reduction} = \frac{\text{Dose}_{\text{Unshielded}} - \text{Dose}_{\text{Shielded}}}{\text{Dose}_{\text{Unshielded}}} \times 100$$

The reduction of doses from placing a shield on the other experimental region was also investigated. The thyroid shield was placed on the thyroid region, and a dosimeter was placed in the eye region. Similarly, the eye shield was placed on the eye region, and the dosimeter was positioned in the thyroid region. The measurements were obtained with and without shields for comparison.

Image quality assessment

The images of the dental region without and with the barium thyroid shields were obtained to visualize the impact of the shields for all setup parameters using one dental machine. For each setup, two images were acquired. Two independent radiologists used the image quality scoring criteria (IQSC) [8]. The radiologists were blind to the type of shielding. The radiologists visually evaluated the images and assessed the artefact presence and reproducibility in both images for a given setup. The images were ranked based on five criteria (Table 2).

Statistical analysis

A Welch's *t*-test was conducted to compare the effects of the radiation dose on the thyroid and the eye when no shield and a barium shield were used at a tube



Fig. 1 The phantom setup for the dose reduction measurements. Without a thyroid shield (left), with a barium sulphate thyroid shield (right)

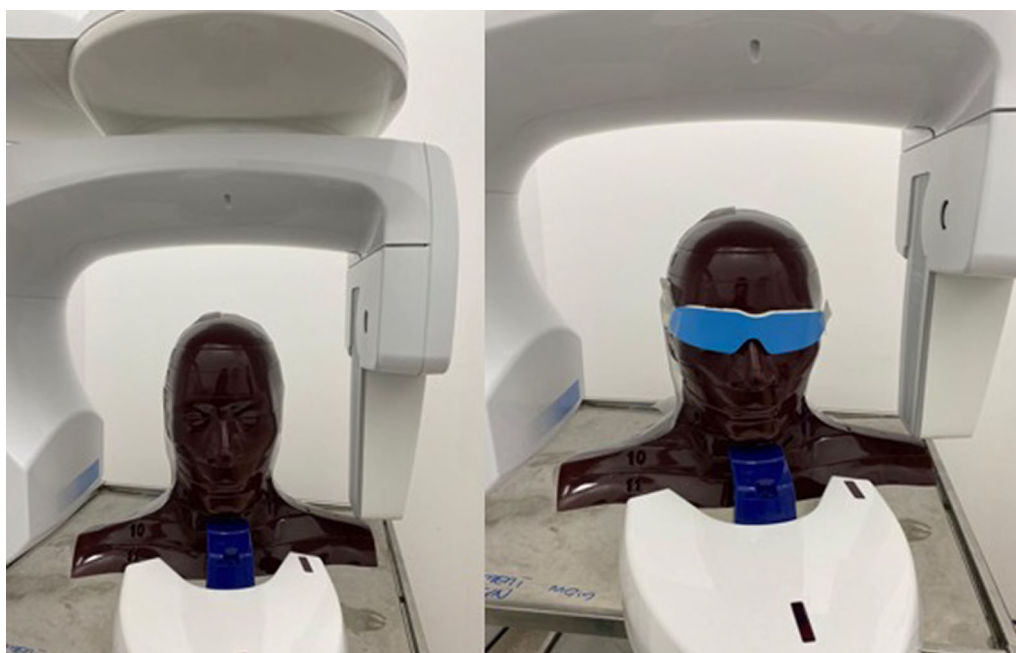


Fig. 2 The phantom setup for the dose reduction measurements. Without an eye shield (left), with a barium sulphate eye shield (right)

Table 2 The scoring chart for the image quality scoring criteria (IQSC)

0 s = Desired features not seen
0i = Anatomy not included in the images
1 = Unacceptable quality (images do not allow diagnostic interpretation)
2 = Limited quality (images are adequate only for limited clinical interpretation)
3 = Adequate quality (images are just adequate for diagnostic interpretation)
4 = Higher than needed quality (images are much better than needed for interpretation: images with little or no noise)

voltage of 66 kVp. Statistical analysis was conducted using GraphPad Prism version 9.3.1 for Windows (GraphPad Software, San Diego, California USA, www.graphpad.com).

Results

Both machines had good reproducibility for both short- and long-term time intervals. The variation in reproducibility was less than ±0.4% in the short and long term.

The surface radiation doses with no shield were measured at the thyroid and eye levels for the clinical range of kVp (62–70). Table 3 summarizes the unshielded dose per exposure at the thyroid and the eye regions.

Table 3 The mean surface doses with no shield and their SD, measured at the thyroid and eye regions

Tube voltage (kVp)	Thyroid (µGy) Mean ± SD	Eye (µGy) Mean ± SD
62	18.33 ± 0.82	1.04 ± 0.03
64	22.18 ± 2.15	1.75 ± 0.07
66	46.01 ± 1.43	2.65 ± 0.07
68	59.85 ± 1.62	3.38 ± 0.06
70	130.9 ± 2.52	4.00 ± 0.04

The highest surface doses to the thyroid and the eye were associated with the highest tube voltage applied. The maximum surface doses to the thyroid and the eyes were 130.9 ± 2.52 µGy and 4.00 ± 0.04 µGy, respectively.

The dose reduction results from the barium shield as a function of tube voltage are represented in Fig. 3 at the thyroid and eye, respectively. At all kVp applied, the dose reduction was significant and was dependent on the kVp selected. Barium provided a maximum dose reduction of 75% at 68 kVp. The dose reduction using shielding fell slightly at 70 kVp. The dose reduction using barium ranged between 15 and 61% in the eye region. In this region, the most significant dose reduction for the barium shield was associated with the lowest kVp.

When using the barium shield, the mean radiation dose at the thyroid was 14.28 (SD=1.20) µGy, whereas the mean dose when no shielding was used was 49.80

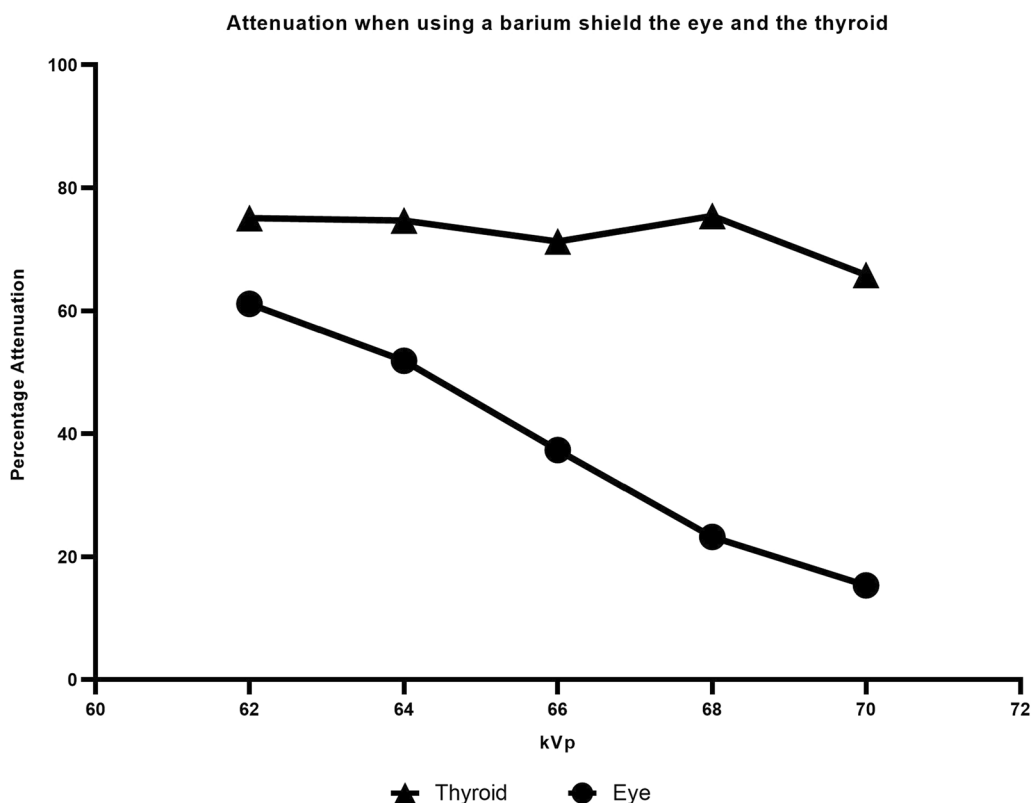


Fig. 3 The dose reduction as a function of kVp in the clinical range at the thyroid and eye region

(SD=2.20) μGy . A Welch's t -test showed that the difference was statistically significant, $t(3.09)=24.55$, $p<0.0001$. When using the barium shield, the mean radiation dose at the eye lens was 1.67 (SD=0.14) μGy , whereas the mean dose when no shielding was used was 2.73 (SD=0.07) μGy . A Welch's t -test showed that the

difference was statistically significant, $t(2.94)=11.73$, $p=0.0015$; see Figs. 4 and 5.

When the barium shield was placed in the thyroid region while the dosimeter was in the eye region, or vice versa, no changes in surface doses were noticed for the doses in the unshielded area.

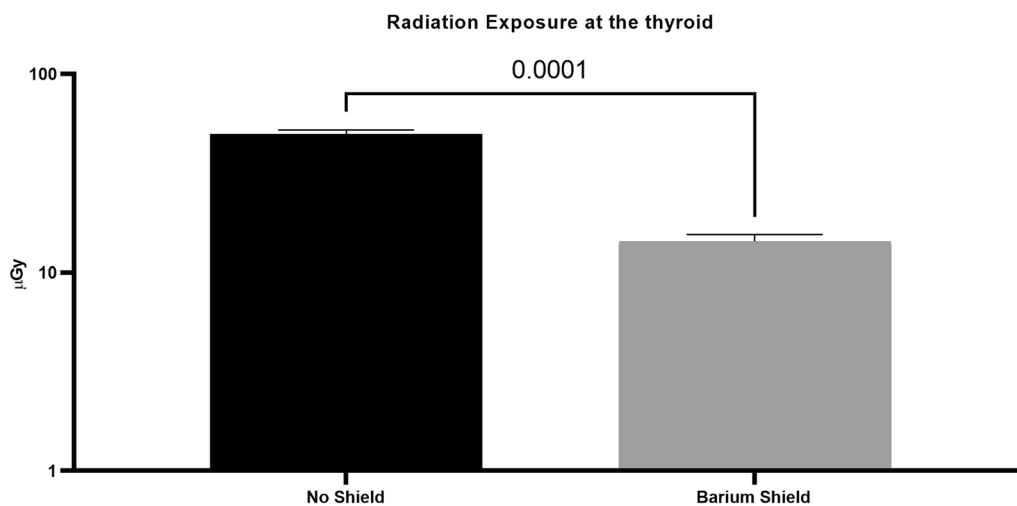


Fig. 4 The exposure of the thyroid to radiation with no shield and a barium shield



Fig. 5 The exposure of the lens of the eye to radiation with no shield and barium shield

Table 4 The evaluated quality of the images

	Images taken while not using a shield	Images taken while using a barium shield
Score for the image quality	3	3
Artefact presence and pitfalls	The scattered radiation degrades the radiographic image by adding a layer of fog that impairs the detailed visibility of the lower mandible The edges of small features exhibit a degree of unsharpness or blurriness	Improved visualization of the entire ROI. The edges of small features are more visible
Note		Higher spatial resolution



Fig. 6 Examples of images using panoramic scan. Left: without a shield; right: with the barium shield

Table 4 presents the image quality results, and Fig. 6 shows the images taken with and without the barium shields. Images taken while using and not using a barium shield received similar scores, and the images were deemed adequate for diagnostic interpretation. For each setup, radiologists confirmed the reproducibility for scoring the artefacts.

Discussion

The need to shield sensitive organs such as the thyroid and the eye during dental radiographic examinations remains debatable. However, some reports recommend using a thyroid shield for paediatric patients, and some reports indicate that a thyroid shield should be used for

adults as long as it does not interfere with the examination [4, 9].

In response to these recommendations, this study examined barium sulphate as an environmentally friendly option to protect the thyroid and the eyes during panoramic radiography. Barium sulphate shields are commercially available and are designated for single use to eliminate the possibility of contamination. Therefore, they do not require specially designed storage or quality assurance considerations compared to lead shields. Moreover, a barium shield is classified as lightweight and environmentally friendly. Barium is a well-known non-hazardous chemical material extensively used in X-ray examinations as an oral contrast medium [10]. A box of 50 eye or thyroid shields costs between 100 and £125 at the time of writing.

Our study findings show barium is an effective dose-reduction tool for the thyroid region, with a dose reduction between 65 and 75%. This efficiency is attributed to the thyroid region receiving primary radiation with an effective energy range higher than the K-edge for barium, which is 37.4 keV. In all kVp used, the dose reduction when using a thyroid shield was statistically significant.

Images acquired with the barium shield indicate that barium lowers the radiation dose without negatively impacting image quality, as seen in Fig. 6. The image quality while using a barium shield was maintained over the entire ROI. This helps protect the thyroid gland from unnecessary exposure to scattered radiation.

In general, barium demonstrated that for a greater kVp, the shield provided less dose reduction (Fig. 3). This result indicates that shielding is more useful at lower kVp ranges, such as for protocols tailored to paediatric patients. However, it is not as effective for protocols targeted at large adults. Thus, shielding should be considered for younger patients due to the cohort's increased radio sensitivity and the dose reduction efficiency at a lower kVp.

The efficiency of the barium shield in the eye region is less than in the thyroid region. It was between 15 and 61%. This is because the eye region receives scattered radiation at further distances that may be less than the K-edge for barium. The surface dose was low (1–4 μ Gy), and the highest dose reduction for the eye was when using kVp aimed at paediatric protocols (62 and 64 kVp). It is unlikely that patients would receive a significant enough dose to trigger any changes in the eye lens that could lead to future cataracts; however, a definitive threshold for radiation-induced cataracts is debated in the literature [11]. Therefore, there could be some beneficial dose reduction, particularly when using lower kVp.

Our study's surface dose was similar to previous studies at the thyroid and eye. The mean surface dose at

the thyroid was 48.20 μ Gy using five panoramic X-ray machines and medium kVp [4]. Our result for surface dose is similar for the eye lens than that of a previous study [12].

This is a phantom-based study, and phantom studies have well-known limitations. The phantom only accounts for one body type without reflecting different sizes, shapes, or body weight. In addition, our results are surface dose measurements that show the magnitude difference between shielded and unshielded scenarios. These measurements should not be used to infer the equivalent dose and cancer risk in the thyroid or the eye lens. Available shields only cover the neck's anterior portion; future studies could examine the effect of a wrap-around shield, which would protect the entire neck.

Conclusions

This study examined the efficiency of a barium shield in reducing the radiation dose in the thyroid and eye regions during panoramic radiography examinations. The barium shield in the thyroid and eye region significantly reduced the dose and did not negatively impact image quality. The degree of dose reduction depends on the tube voltage and the region of interest. The dose reduction was higher in the thyroid region compared to the eye over the entire clinical range.

Abbreviation

CBCT Cone-beam computed tomography

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Author contributions

OB designed of the work, performed the measurements, analysed data, and wrote the manuscript. AF performed the measurements, analysed data, and reviewed the manuscript. MA analysed data and reviewed the manuscript. YB analysed data and reviewed the manuscript. AA performed the measurements and reviewed the manuscript. SK performed the measurements, analysed data, and reviewed the manuscript. NA analysed data and reviewed the manuscript. AA performed the measurements, analysed data. SB analysed data and reviewed the manuscript. SA-Q analysed data and reviewed the manuscript. MA analysed data and reviewed the manuscript. NA performed the quality imaging work and reviewed the manuscript. MB helped in substantial contributions to design of the work, analysed data, and was contributor in writing the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was performed using phantom and did not include humans or animals. Therefore, ethical approval was not required.

Consent for publication

Not applicable.

Competing interests

The author declares that they have no conflicts of interest for this work.

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