RESEARCH ARTICLE

The reduction of dose in paediatric panoramic radiography: the impact of collimator height and programme selection

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Objectives: The aim of this work was to estimate the doses to radiosensitive organs in the head of a young child undergoing panoramic radiography and to establish the effectiveness of a short collimator in reducing dose.

Methods: Thermoluminescent dosimeters were used in a paediatric head phantom to simulate an examination on a 5-year-old child. The panoramic system used was an Instrumentarium OP200 D (Instrumentarium Dental, Tuusula, Finland). The collimator height options were 110 and 140 mm. Organ doses were measured using exposure programmes intended for use with adult and child size heads. The performance of the automatic exposure control (AEC) system was also assessed.

Results: The short collimator reduced the dose to the brain and the eyes by 57% and 41%, respectively. The dose to the submandibular and sublingual glands increased by 32% and 20%, respectively, when using a programme with a narrower focal trough intended for a small jaw. The effective dose measured with the short collimator and paediatric programme was 7.7 μ Sv. The dose to the lens of the eye was 17 μ Gy. When used, the AEC system produced some asymmetry in the dose distribution across the head.

Conclusions: Panoramic systems when used to frequently image children should have programmes specifically designed for imaging small heads. There should be a shorter collimator available and programmes that deliver a reduced exposure time and allow reduction of tube current. Programme selection should also provide flexibility for focal trough size, shape and position to match the smaller head size.

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Introduction

In the healthcare environment panoramic radiographs are usually taken on children in support of either orthodontic treatment or the management of facial trauma. The European guidelines on radiation protection in dental radiology published in 2004 recommended that during panoramic radiography, the radiation field should be restricted.¹ The irradiated

volume should be limited to produce an image showing only the anatomy necessary for clinical diagnosis. Where the panoramic imaging system is to be used to image both adult and paediatric patients, there should be a choice of at least two different collimator slit heights. Collimator slit heights at the image detector are typically 140 mm for an adult head and 110 mm for a child's head. Although, many systems are sold without the child slit option. Dental clinics or hospital departments often install panoramic radiography systems that have only the longer collimator slit. The consequence of this is the likely increase in dose to the radiosensitive

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organs in the head when taking panoramic radiographs on children. The dose delivered to the patient will be determined by the radiographic exposure factors (kilovoltage, milliamps, exposure time) as well as the selected collimator slit height. On some, but not all, panoramic system exposure factors can be fully adjusted to appropriately irradiate a large or a small head. If a child height slit is not available, however, the extent of irradiation above the jaw cannot be reduced for a small head.

In comparison with adults, children are inherently at greater risk of cancer induction from radiation exposure. This is owing to increased radiosensitivity of the tissues and a longer life span. The key organs of interest when investigating exposure from panoramic radiography are the thyroid, salivary glands, brain and red bone marrow. The radiation risk for these organs is cancer induction. This is a stochastic risk with increased dose resulting in increased risk.

It is also of value to consider the dose to the lens of the eyes. At high enough exposures, the risk to the eyes from irradiation is cataract formation. The formation of cataracts, however, is a deterministic effect, which means that the dose must be above the threshold level for that tissue effect. The current dose threshold for lens opacities is 0.5 Gy with a single exposure and 5 Gy with highly fractionated or protracted exposures.²

There are very few published studies stating organ doses to paediatric patients from digital panoramic imaging. Hayakawa *et al*³ published doses from work using a phantom representing a 5- to 6-year-old child with paediatric and adult exposure protocols. The study looked at doses for two panoramic machines with different exposure protocols. Their results, however, do not establish the extent of dose reduction, which can be achieved solely through use of a short collimator slit. That work also pre-dates the changes made by the International Commission on Radiological Protection in 2007² to the tissues weighting factors for radiosensitive organs.

A review of radiographic practice during panoramic imaging on children had previously been undertaken by the authors of this article. That review was undertaken at the Queen Alexandra Hospital, Portsmouth, a large acute hospital trust in the UK. The findings established that of the 287 paediatric panoramic examinations carried out in a 6-month period, 91% were imaged in the maxillofacial department and 9% in the emergency department. The youngest age for panoramic imaging was typically 5 years, although occasionally younger children were imaged. The collimator used depended on whether there was a choice available on the panoramic system. Some small children were by necessity imaged using a large collimator when a smaller one was not available.

This work estimates the doses to the organs in the head when imaging a small child's head with a long-length collimator. The results are compared with the organ doses delivered when a shorter collimator is used. Effective dose and risk are also considered.

Methods and materials

Anthropomorphic phantom

An anthropomorphic head phantom loaded with thermoluminescent dosimeters (TLDs) was the chosen method for dose estimation. A CIRS ATOM[®] dosimetry verification phantom model 705 was selected (CIRS, Norfolk, VA). The manufacturer's specification literature states that it represents a 5-year-old child of weight 19 kg and 110 cm in height. In practice, the circumference of the phantom head is 49.2 cm. This makes it rather small when compared with the 50.7–52.1 cm circumference values quoted by Ounsted *et al*⁴ for a typical 4 year old. Nevertheless, this phantom was considered a reasonable representation of the smallest children who have panoramic radiographs within the hospital. The ATOM model 705 phantom is made up of slabs which are 2.5 cm thick. There are holes in the phantom at positions that match the locations of radiosensitive organs in the head. The holes are designed to hold TLDs. Some organ positions are marked on the slabs of the phantom during manufacture. Co-ordinates for the centres of these organs are also provided in the manual supplied with the phantom. The manufacturer states that they used a number of anatomical references when defining organ position, which included images from CT scans. The position of these and other organs was checked through comparison with an anatomy reference text book.⁵

Measurements with thermoluminescent dosimeters

Harshaw TLD[™]-100 lithium fluoride (LiF:Mg, Ti) TLDs were used to measure dose (Thermo Fisher Scientific, Inc., Waltham, MA). These TLDs are circular discs, which are 5 mm in diameter and 0.9 mm thick. The TLDs were annealed in a Carbolite TLD28 oven (Carbolite, Hope Valley, UK). Annealing was carried out at 400 °C for 1 h and then at 80 °C for 16 h to ensure signal stability.^{6,7} The TLDs had previously been batched to ensure a uniform response of within $\pm 10\%$ of the average. A single batch calibration factor was applied following irradiation of a subset of the TLD batch. For the calibration, a conventional radiographic set was used with 2.6-mm aluminium filtration and kilovoltage set to 66 kV. A calibrated Radcal 9010 6-cc ionization chamber (Radcal Corporation, Monrovia, CA) was used to measure irradiated dose during the TLD calibration process. Ten TLDs were used to measure background radiation. A Harshaw 5500 TLD reader (Thermo Fisher Scientific, Inc.) was available to read out the TLDs after exposure. After irradiation, the TLDs were stored in the dark and then read out the next day. The read out regime was a 10-s pre-heat cycle of 150 °C followed by a 10 s read cycle at 300 °C.

The panoramic radiographic system used for the measurements with the head phantom was a 2-year-old Instrumentarium OP200 D (Instrumentarium Dental, Tuusula, Finland). It had a charge-coupled device detector and high-frequency direct current generator. The system had an automatic exposure control (AEC) that adjusted

X-ray tube current for the different sizes of patients. There was also automatic spine compensation to reduce shadowing from the spine on the image. A dose-area product (DAP) metre was available in the system. The accuracy of the DAP metre was checked using a Radcal 9010 10.3 CT ionization chamber (Radcal Corporation) taped across the collimator for the duration of a single exposure. The ion chamber had been calibrated at a calibration laboratory with traceable national standards. The width of the X-ray beam at the collimator was measured with Gafchromic™ XR QA2 film (Ashland Inc., Covington, KY). This enabled the accuracy of the indicated DAP value to be assessed. It was established that the DAP metre was over reading by 15%. The Instrumentarium OP200 D system was used, as the authors considered it to have good dose efficiency. Previous audits of panoramic dose for adult patients had determined the typically indicated DAP for an adult to be around 87 mGy cm², which was below the reference value of 93 mGy cm² used in the UK.⁸ Image quality was judged by clinical users to be good. This panoramic radiography system also had variable kilovoltage, tube current and a reduced collimator slit height option for paediatric imaging, thus making it fully adjustable for experimental work. The collimator slit height on this system at the image detector was 111 mm for paediatric imaging and 140 mm for adult imaging. An unusual feature of this panoramic system was a slightly tapered collimator slit with the base of the collimator wider than the top. This was to ensure the system delivered increased doses to the lower jaw where the bone is generally denser. The shorter length collimator was a truncated version of the long collimator but reduced in height. The collimator slit width was approximately 3 mm at its widest point for both height settings when measured at the detector. When aligning the patient prior to the radiograph, it was possible to adjust the focal trough position by ± 3 mm from the default position set for the selected programme.

The ATOM 705 head phantom was loaded with TLDs placed in positions within the phantom, which represented key organs at risk. Six TLDs were placed in each hole. On two separate occasions, the phantom was irradiated using the panoramic radiography system; firstly with the child collimator slit selected and secondly with the adult collimator slit selected. In routine radiographic practice, the positioning of the patient's chin on the machine's chin rest results in the alignment of the lower edge of the panoramic field with the lower border of the chin. That practice was followed when aligning the phantom.

From a previous review of clinical imaging on children aged around 5 years, the exposure factors on the Instrumentarium OP200 D were noted as follows: the kilovoltage was 66 kV, the tube current ranged from 6 to 14 mA with an average of 8.8 mA and the DAP ranged from 29.2 to 64.3 mGy cm² with an average of 42.6 mGy cm². Exposure time for all these examinations was 13.4 s. This information was used to support the experimental work. The first measurements made were with the child collimator. Exposure settings were 66 kV, 10 mA and programme P2 that

Figure 1 Phantom head showing irradiated section for the two different height collimators.

has a 13.4-s rotation time. The second set of measurements was made with the adult collimator. Exposure settings were 66 kV, 10 mA and programme P1 that has a 14.1-s rotation time. Ideally, rotation times would have been exactly matched in both cases but that was not possible. The unit appropriately reduced the rotation slightly on the paediatric programme to allow for a smaller jaw size. It should also be noted that P2 delivered an exposure with a focal trough more suited to a narrower paediatric jaw than that of P1.⁹ Spine compensation was set to increase the kilovoltage from 66 to 71 kV as the X-ray beam passed through the spine. Figure 1 shows the head phantom with the sections irradiated from the two different collimators. The phantom was irradiated ten times for each set of measurements to ensure doses were well above the minimum dose threshold of the TLDs.

Finally, a further set of measurements were made using the AEC system to set the tube current rather than having the tube current fixed. The phantom head was irradiated using the child collimator slit with the paediatric exposure programme P2 and 13.4 s selected and a starting kilovoltage of 66 kV. The AEC delivered an exposure that initially set the tube current to 11 mA and then settled at 6.2 mA. Automatic spine compensation increased the kilovoltage to 72 kV in the middle of the exposure. When reviewing the results, all doses were normalized to 8.8 mA to match the average tube current for a 5-year-old child.

Figure 2 Image from the use of adult programme P1 and long collimator.

Organ dose calculations

To convert the doses measured with the TLDs into absorbed dose in tissue, it was necessary to multiply by the ratio of mass absorption factors for materials involved. The lithium fluoride TLD doses had been converted to in-air dose values through the calibration process. The in-air dose was then converted to the dose in a specific tissue type.¹⁰ An X-ray beam spectrum simulation package had been used to establish that the mean beam energy was close to 50 keV.¹¹ This resulted in calculated ratios of mass absorption coefficients of 1.02 and 5.40 for air to water and air to bone, respectively. Tissue composition was assumed to match water in all cases except for the bone.¹²

Dose measurements made using TLDs placed on the upper part of the torso in a preliminary experiment had been found to be negligible. Therefore, for all organs below the upper torso, the assumption was made that the dose was zero. The calculation of effective dose required knowledge of doses delivered to the oesophagus, brain, thyroid, salivary glands, red bone marrow, bone surface, skin, oral mucosa, extrathoracic region, lymph nodes and muscle. Where organs in the head were only partially irradiated, estimates had to be made of the portion of the organ irradiated. This was carried out through review of the beam path as illustrated by Figure 1, the maps of the organ area in each slab shown in the phantom manual, the panoramic image and the pattern of rotation. The technique used by Huda and Sandison¹³ to calculate organ dose using the organ's slab mass fraction was then applied. For these calculations, a number of assumptions or estimates were used. The dose to the bone surface was taken to be a good match of the dose to the red bone marrow. The dose to the muscle was assumed to be equal to that of the skin. The volume of the muscle in the head was taken as 5% of that in the whole body.¹⁴ For the salivary glands, doses were calculated separately for the parotid, submandibular and sublingual glands and an average taken. For the lymphatic nodes, the volume in the head and neck region was taken as 5%.¹⁵ The dose to the parotid gland was taken to be an approximation of the dose to the lymph nodes in this region. Estimates of percentage of red bone marrow for a 5-year-old by Cristy¹⁶ were used; namely,

that the cranium contains 15.9% and the mandible 1.6% of all the red bone marrow in the body. For the skin, the surface area on the whole body was calculated using the formula by Haycock *et al.*¹⁷ The surface area on the head was estimated using the formula for an elliptical cylinder. The dose to the extra thoracic region was estimated by averaging doses to the larynx, pharynx, nasal and oral passages.

Results

Figures 2 and 3 show images of the phantom head obtained with the exposure times and collimator selection set for an adult and child, respectively.

Table 1 shows the results from the dose measurements made using settings of 66 kV and 8.8 mA with the two different collimator heights. Dose values measured when the short collimator and programme P2 were selected are generally lower than for the long collimator and programme P1. The exceptions are the dose values for the submandibular and sublingual glands, which are higher. The reason for this dose increase is thought to be the change in the position and shape of the focal trough rather than any effect of collimation. The focal trough represents the areas of maximum dose within the rotation where the collimated beam paths cross as the X-ray tube rotates. For programme P1, intended for use on a large adult jaw, the shape of the focal trough is wider and longer. When imaging a small jaw using P1, the tails of the focal trough are closer to the spine and away from the submandibular and sublingual glands therefore resulting in reduced doses. The shorter collimator is most effective at reducing dose to the brain and extra-thoracic region, primarily the nasal and oral passages. The exposure of the upper part of the eyes is also reduced with the shorter collimator. The high standard deviation values generally indicate significant variation of dose across organs that are close to the edge of the radiation field and subject to significant dose gradients.

Additionally, the complete TLD dose data also showed an increase in the dose to the spine at the level of slab 6 when using the long collimator and programme P1. The dose increase was almost 70%. This cannot be accounted for simply by the increased collimation. Scattering factors from different size radiation fields are available.¹⁸

Figure 3 Image from use of child programme P2 and short collimator.

Table 1 Organ doses with different collimators and percentage dose change relative to long collimator (tube current fixed at 8.8 mA)

Organ	Weighting factor	Long collimator and P1		Short collimator and P2		Dose change (%)
		Dose (μGy)	SD	Dose (μGy)	SD	
Eyes	–	17	2.0	10	2.0	–41
Thyroid	0.04	37	5.0	30	5.0	–21
Brain	0.01	43	48.0	19	16.0	–57
Salivary glands	0.01	94	47.0	103	23.0	+10
Parotid	–	126	64.0	112	11.0	–11
Submandibular	–	82	8.0	108	9.0	+32
Sublingual	–	74	14.0	88	29.0	+20
Red bone marrow	0.12	1.9	0.3	1.5	0.5	–21
Remainder organs	0.12					
Bone surface	–	1.9	0.3	1.5	0.5	–21
Skin	–	20	3.0	18	3.0	–10
Lymph nodes	–	6	3.0	6	1.0	–11
Muscle	–	4	1.0	3.4	0.2	–20
Oral mucosa	–	57	8.0	55	3.0	–4
Extrathoracic region	–	193	18.0	93	17.0	–52
Effective dose (μSv)		11.4		7.7		–32

SD, standard deviation.

Published data show that the extent of backscatter increase from the increased collimation would be significantly less than the factor of 1.7 indicated here. Scatter can therefore be discounted as the only source of this dose increase. The images in [Figures 2](#) and [3](#) showed that the longer exposure time associated with P1 resulted in extra unnecessary exposure to the spine at the very start and the end of the rotation and hence increased dose to the spine.

[Table 2](#) shows the results of tests where the AEC was used. A multiplication factor of 1.4 has been applied to match a delivered tube current of 8.8 mA typical for a child aged 5 years. The tube current delivered when imaging the phantom head using the AEC had originally been 6.2 mA. This was lower than that seen in the patient sample, as would be expected, since the phantom head was of a smaller diameter than is a typical 5-year-old child's. A comparison of the parotid, submandibular and sublingual gland doses in [Tables 1](#) and [2](#) for a short collimator reveals an interesting difference. For the exposure with the fixed tube current, dose to these organs

was lower than for the exposure where AEC was used, even when normalizing the values to the same tube current of 8.8 mA. The full TLD data set showed significantly higher doses to these glands on the right side than the left. This was due to the functioning of the AEC. In the early part of the exposure, a higher tube current was delivered that then reduced. This resulted in a higher dose delivered to the right-side salivary glands. The left-side salivary glands were exposed towards the end of the rotation with the lower tube current.

Discussion

The results from this work show that the short collimator is effective at reducing the dose to the brain and the eyes of a small child undergoing panoramic radiography. A comparison of measured dose values against other studies shows them to be very similar to those published by Hayakawa *et al*³ with the highest doses delivered to the salivary glands, brain and thyroid. The programme selected affects the pattern of radiation distribution across the head. This matches what was seen by Lecomber *et al*¹² in their study, which looked at organ doses to an adult phantom head from 12 different panoramic programmes. If exposure factors are matched, there is also reasonable agreement with the organ dose values published by Gijbels *et al*,¹⁹ although care must be taken with interpretation as that study was for adult imaging.

It should be noted that the dose to the lens of the eye is low even when imaged with the long collimator. At 10–17 μGy , the doses are well below the 0.5-Gy threshold dose level above which opacities might be seen in the lens. Reduction of dose to the salivary glands, brain and thyroid should be the priority for panoramic imaging of children. The risk factor for all types of cancer resulting from radiation exposure is between 3.0 and 4.5 times higher for a 5 year old than for a 50 year old.²⁰ For thyroid cancer, the risk factor is between 76- and 105-

Table 2 Organ dose measurements using the automatic exposure control, short collimator and with dose corrected to a tube current typical for a 5-year-old child (66 kV, 8.8 mA, P2)

Organ	Dose (μGy)	Standard deviation
Lens of the eyes	11	1
Thyroid	34	5
Brain	17	15
Salivary glands	166	79
Parotid	170	64
Submandibular	190	72
Sublingual	137	90
Red bone marrow	3	1
Bone surface	3	1
Skin	18	3
Extrathoracic region	90	16
Lymph nodes	9	3
Muscle	4	1
Oral mucosa	48	3
Effective dose (μSv)	8.6	

times higher for a 5 year old than for a 50 year old. The higher factors are for females and the lower ones for males. One recent study reported that for examinations on some, but not all, digital panoramic systems, the use of thyroid collars can be effective at reducing the dose to the thyroid.²¹ This could be considered as a dose reduction measure provided there is no risk of the thyroid collar adversely affecting the imaging process.

The errors in the measurement method should be considered when reviewing the results. There are a limited number of holes in the phantom, which means it is difficult to fully sample the dose in the organs across the head. This is a particular problem for organs that are close to the edge of the X-ray field. Calculation of the irradiated volume for some organs is difficult owing to the beam divergence pattern, the angulation of the X-ray tube and the rotation pattern. When considering the match to the clinical imaging environment, any variation in the patient position relative to the vertical position of the X-ray beam and also any tilt of the head will result in a different pattern of irradiation and different organ doses. Adjustment of the focal trough position will also have an impact. The pattern of exposure variation within the head during panoramic imaging is complex owing to the sophisticated movement patterns of the X-ray tube and the detector. Useful future work would be the development of Monte Carlo simulation programme to model the dose distribution for the various panoramic

exposure programmes. This would allow faster estimation of organ doses and would aid optimization.

In conclusion, the use of a short collimator is effective at reducing the dose delivered to children undergoing panoramic radiography. Panoramic systems that will be used to image significant numbers of children on a regular basis should be equipped with a short collimator. The system should also have exposure protocols designed for the imaging of small heads. Panoramic machines where AEC is in use may deliver higher doses to one side of the patient than to the other side, as the X-ray tube current settles at the start of the rotation. The use of a well-adjusted AEC, however, will usually appropriately set the delivered dose and reduce the dose for small patients when compared with fixed exposure factors. This study has added to the very limited data available for the doses delivered to children from panoramic imaging.

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