RESEARCH ARTICLE

Ultrasonographic localization of the thyroid gland for its optimal shielding prior to lateral cephalometric radiography: a pilot study

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Objectives: Lateral cephalometric radiography is a common radiographic examination technique in children. The exclusion of the thyroid gland from the primary X-ray beam is important especially with children. However, patient treatment might require displaying the four most cranial cervical vertebrae (C1–C4) for the assessment of cervical vertebral maturation. Our aim was to present a safe way to display C1–C4 and exclude the thyroid gland from the X-ray beam during lateral cephalometric radiography.

Methods: The thyroid glands of 25, 7- to 12-year-old patients were localized by ultrasound examination and shielded prior to lateral cephalometric radiography. A roentgen-positive mark was taped on the patient's skin at the level of most cranial level of the thyroid gland in the midsagittal plane. After exposure, each lateral cephalometric radiograph (LCR) was analyzed for the visibility of the cervical vertebrae. The distance between the ear post and the highest edge of the thyroid shield (TS) at the lateral part of the neck was measured and compared with the distance between the centre of the radiological external auditory meatus, and a roentgen-positive mark was made on the LCR.

Results: 68% of the LCRs displayed C1–C4, and the rest of them displayed C1–C3. In all of the patients, the highest edge of the TS in the lateral parts of the neck was located in a higher position than the actual most cranial level of the thyroid gland.

Conclusions: Despite localizing the thyroid gland prior to lateral cephalometric radiography, simultaneous visualization of C1–C4 and exclusion of the thyroid gland from the primary X-ray beam during lateral cephalometric radiography might not be completely possible in children because of the design and poor fitness of the TS.

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Introduction

Lateral cephalometric radiography is mainly performed for orthodontic diagnosis. In addition to the visualization

of the desired parts of the skull including the maxillary and mandibular structures, lateral cephalometric radiograph (LCR) reveals at least a part of the cervical spine. In order to maximize the influence of growth during treatment, the timing of orthodontic treatments will often depend on the predicted peak mandibular growth rate and consequently on skeletal maturity. The cervical vertebral maturation (CVM) method is one commonly

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used technique for determining the stages of skeletal maturity particularly with respect to the peak mandibular growth rate.^{1–3} The CVM method means assessing the morphology of the C2, C3 and C4 cervical vertebrae which are commonly seen on lateral cephalometric radiography. One advantage of the CVM method is that it does not require an additional radiographic investigation to assess skeletal maturity and growth timing other than the LCR which is commonly taken for orthodontic diagnosis. Only one image is sufficient, with no need to compare earlier images. The CVM method has been shown to have acceptable diagnostic accuracy and repeatability, although there have been recent question marks over its use in patients with some malocclusions.^{4,5}

Radiosensitivity of the thyroid gland especially among children and young individuals is a well-known issue.^{6,7} The threshold of radiation-induced thyroid cancer is lower for younger individuals.⁸ There is an increased risk of thyroid cancer during multiple exposures during dental radiography.⁹ In 2008 in Finland, the majority of lateral cephalometric radiography (75%) was performed on patients younger than 17 years.¹⁰ lateral cephalometric radiography was reported as the second most common dental radiological examination after dental panoramic tomography in patients aged 7–12 years,¹⁰ and all LCRs were taken for orthodontic reasons.¹¹ In radiation protection of paediatric orthodontic patients, the widely neglected usage of the thyroid shield (TS) and its positioning at various levels during lateral cephalometric radiography¹² are a matter of serious concern and bring up the following question: is an orthodontic paediatric patient more susceptible to irradiation of the thyroid gland?

During lateral cephalometric radiography, the thyroid gland may be exposed to radiation either partially or wholly depending on (i) the selected size of the field of view, (ii) whether a TS is used, (iii) the shape and material of the TS and (iv) the positioning of the TS.

It is recommended that a TS be used during lateral cephalometric radiography.¹³ Application of the TS has been shown to result in a dose reduction to the thyroid gland from 1.80 μ Sv (when TS not used) to 0.32 μ Sv in an adult male tissue-equivalent phantom.¹⁴ Proper positioning of the TS in order to visualize C2–C4 and simultaneously exclude the thyroid gland from the primary X-ray beam area during lateral cephalometric radiography is challenging; particularly in children because of their still relatively short neck, no easily detectable clinical landmarks are present. There are no specific instructions available for how to place the TS correctly in the vertical dimension in order to avoid radiation exposure of the thyroid gland during lateral cephalometric radiography.

Despite good availability of the TS and its cost-effectiveness in lateral cephalometric radiography, its application in daily practice varies widely. The disuse of TS has been reported to be as high as 80%,^{15,16} and thyroid shielding was less frequently observed in children than in adults.¹⁵ Presumably, in children, the thyroid

gland is located at a higher position than in adults.¹⁵ In children, the absence of a TS results in more vertebrae and neck structures being exposed to radiation during lateral cephalometric radiography. The question is: how to place the TS in order to avoid direct irradiation of the thyroid gland during lateral cephalometric radiography exposure, and yet visualize the four most cranial cervical vertebrae for age determination.

Size, volume and morphology of the thyroid gland vary with age.^{17,18} In adults, the thyroid gland is located in the vertical direction between the level of the fifth cervical vertebra and the first thoracic vertebra.¹⁹ In the study of Banna *et al*,²⁰ the most superior parts of the thyroid gland did not reach to the midpoint of the thyroid cartilage, which is located at the level of the fourth or fifth cervical vertebra. In adults, visualization of the four most cranial cervical vertebrae and protection of the thyroid gland from ionizing radiation can be principally achieved when a TS is placed at the level of the thyroid cartilage.

The aim of the present preliminary study was (i) to determine the most cranial level of the thyroid gland in relation to the cervical vertebrae in children at ages between 7–9 and 10–13 years and (ii) to help the positioning of the TS at a proper level to ensure (a) visualization of the cervical vertebrae C2–C4 and (b) exclusion of the thyroid gland from the primary X-ray beam area during lateral cephalometric radiography. Our study hypothesizes that by positioning the TS at the level of the most cranial parts of the thyroid gland, the cervical vertebrae C2–C4 are visible in LCRs taken from children at age 7–9 and 10–13 years.

Methods and materials

Study design and sample size determination/ sample selection/allocation

Based on the methods and results of previous similar pilot studies, we determined that a sample size of 25 should be used.^{21,22} 25 orthodontic patients diagnosed with cleft lip and/or palate but without craniofacial syndrome at the Cleft Palate and Craniofacial Centre of Helsinki, Helsinki, Finland, participated in the present study. Patients with non-syndromic cleft lip/palate were used in this study, as this group of patients had lateral cephalometry performed at at least two ages for diagnostic purposes (7–9 and 10–13 years). The standard protocol of the Cleft Palate and Craniofacial Centre for orthodontic treatment of these patients includes lateral cephalometric radiography. The patient selection took place as follows: an oral radiologist at the Helsinki University Hospital (EPE) visited Roentgen Division of Töölö Hospital, Helsinki, Finland, twice a week during a 6 month period when 7- to 12-year olds had appointments for lateral cephalometric radiography. The first 25 patients examined by the EPE were selected for this study.

Figure 1 Thyroid shield (a, b) used for 25, 7- to 12-year-old patients during lateral cephalometric radiography.

Ethical issues

Approval for conducting research was obtained from the Coordinating Ethics Committee of the Helsinki and Uusimaa Hospital District. Each patient and his/her parent were given written information of the research plan and a consent form for participation in the study (two different forms for 7- to 9-year olds and 10- to 13-year olds). Patients and their parents gave their consent by signing the consent forms.

Assessment of thyroid gland position

The most cranial levels of the thyroid gland were identified by ultrasound examination through the study subjects' neck, and the level was marked with a skin marker pen. A roentgen-positive mark with a different contrast than the TS was taped on the study subjects' skin in the midsagittal plane at the level of the most cranial level of the thyroid gland. Two types of portable ultrasound devices (SonoSite® MicroMaxx®, Sonosite, Inc., Bothell, WA and LOGIQ™ e v. 5; GE Healthcare,

Milwaukee, WI) were used, depending on the availability of the devices. The same TS (MAVIG Pb 0.5 mm, Munich, Germany) was used for every patient (Figure 1). The TS was placed as horizontally as possible with respect to the highest level of the thyroid gland skin mark.

Lateral cephalometric radiography

Following ultrasound examination and the placement of the TS by the EPE, the patients were positioned in the digital cephalostat (Orthopantomograph® OP200 D; Instrumentarium Dental, Tuusula, Finland). Ear posts were placed in the external auditory meatus (EAM), and a nasal positioner was placed into the nasion. To enable the measurement of the distance between the EAM and the highest edge of the TS, the manufacturer designed a special head positioner, equipped with an extension piece below the ear post on the right-hand side of the patient and labelled with a measuring scale with a maximum of 8 cm (alternatively 11 cm). Before the exposure, the vertical distance between the ear post (a) and the

Figure 2 Main clinical (A) and radiological landmarks (B) used in measurement. a, Ear post; b, the highest edge of the thyroid shield (TS) (clinical), b' the highest edge of the TS (radiologically); c, roentgen-positive midsagittal mark; d, centre of the radiological external auditory meatus; e, the horizontal level of the roentgen-positive midsagittal mark used in measuring; f, posterior vertebral body height of the third vertebra; g, vertical distance between the posterosuperior body part of the fourth cervical vertebra and the horizontal level of the roentgen-positive mark; h, vertical distance between the highest edge of the TS and the horizontal level of the roentgen-positive mark; k, most inferior part of the image field.

highest edge of the TS in the area of the cervical vertebrae on the lateral parts of the neck (b) (Figure 2A) was measured and registered in order to find out clinically the vertical distance between the EAM and the level of the most cranial parts of the TS. The LCR was taken with the head in the Frankfort horizontal plane, including a bite in the intercuspal position.

Evaluation of lateral cephalometric radiograph

After the exposure, the number of the visible cervical vertebrae was counted from the LCR.

The vertical distance between the centre of the radiological EAM (d) and the horizontal level (e) of the roentgen-positive mark in the midsagittal level (c) was measured and registered in order to find out radiologically the vertical distance between the EAM and the level of the most cranial parts of the thyroid gland verified using ultrasound. If the roentgen-positive mark was outside the image field, the field measurement was taken from the centre of the radiological EAM (d) and the inferior part of the image field (k); because in these cases, the roentgen-positive mark was located more inferior than the inferior part of the images (Figure 2B). Clinically taken measures (a–b) were compared with the radiologically taken measures (d–e or alternatively d–k) in order to evaluate the equality between the radiological and clinical measurements (the centre of the EAM and the most cranial level of the thyroid gland).

Of these study subjects demonstrating only cervical vertebrae C1–C3 on the LCRs, the posterior vertebral body height of the third vertebra (f) was measured and compared with the vertical distance between the most posterosuperior body part of the fourth cervical vertebra and the horizontal level of the roentgen-positive mark (g) or alternatively compared with the vertical distance between the highest edge of the TS in the area of the cervical vertebrae and the horizontal level of the roentgen-positive mark (h), if the fourth cranial cervical vertebra was covered completely by the TS. This comparison was made in order to evaluate the extent of the shielded part of the cervical vertebrae above the most cranial parts of the thyroid gland.

Results

25 subjects (13 females and 12 males) were recruited into the study.

Number of the cranial vertebrae

LCRs of 17 subjects (68%) showed completely the first LCRs four most cranial cervical vertebrae (C1–C4) (Table 1). Only C1–C3 were completely visible in LCRs of the other subjects (32%). Of the eight LCRs showing three cervical vertebrae, seven (87.5%) showed at least a part of the fourth cervical vertebra.

Clinical and radiological vertical measurements

In all images, the highest edge of the TS in the area of the cervical vertebrae on the lateral parts of the neck (b')

Table 1 Age distribution of the 25 study subjects based on the number of cervical vertebrae visible in the lateral cephalometric radiographs

Age (years)	Number of patients demonstrating:	
	Four cervical vertebrae	Three cervical vertebrae
7	5	0
8	4	4
9	1	1
10	0	1
11	5	1
12	2	1
Total	17	8

was in a higher position than that of the roentgen-positive mark (e-level: actual level of the most cranial part of the thyroid gland) despite our efforts to place the TS in the horizontal level (Figure 2). As Table 2 shows, unexpectedly, in all patients, clinically measured distance between the ear post and the highest edge of the TS in the area of the cervical vertebrae on the lateral parts of the neck was less than the radiologically measured distance between the centre of the EAM and roentgen-positive mark ($a-b < d-e$) or alternatively less than the vertical distance between the EAM and the most inferior part of the image field ($a-b < d-k$). The difference between these two levels (e-level and b'-level) in the vertical plane arises from the elevated part of the TS above the actual level of the most cranial parts of the thyroid gland.

Vertebral body height

In all patients demonstrating three cervical vertebrae on the LCRs, the posterior vertebral body height of the third vertebra (mean: 0.9 cm; range: 0.7–1 cm) was less than the vertical distance either between the most posterosuperior body part of the fourth cervical vertebra and the horizontal level of the roentgen-positive mark (g) or the vertical distance between the highest edge of the TS and the horizontal level of the roentgen-positive mark (h) (Figure 2B) (mean 2.8 cm; range: 1.8–4.2 cm) (Table 3). This means that height of the shielded area above the horizontal level of the roentgen-positive mark is more than the body height of the third cervical vertebra.

Discussion

Radiation protection of children during lateral cephalometric radiography

Radiation safety of the thyroid gland in children undergoing lateral cephalometric radiography should not be underestimated. European guidelines on radiation protection in dental radiology states unambiguously: "In cephalometric radiography lead thyroid protection is necessary if the beam collimation does not exclude the thyroid gland" in line with the As Low As Reasonably Achievable principle (keep exposure as low as reasonably achievable).¹³

Table 2 Clinical and radiological vertical measurements in 25, 7- to 12-year-old subjects

Patient number	Age (years)	Gender	Clinical vertical measurements ^a (cm)		Radiological vertical measurements ^b (cm)	
			Mean		Mean	
1	7	M	5.0	6.7	7.9	8.7
2	7	M	6.5		8.5	
3	7	M	7.2		8.9	
4	7	M	7.5		9.2	
5	7	M	7.5		9.2	
6	8	F	4.5	5.6	7.3	8.3
7	8	F	4.5		7.6	
8	8	F	4.7		7.6	
9	8	F	5.5		8.3	
10	8	M	5.5		8.4	
11	8	F	5.7		8.9	
12	8	F	7.0		9.0	
13	8	M	7.5		9.0	
14	9	M	5.5	5.5	8.3	8.4
15	9	F	5.5		8.4	
16	10	F	5.0	5.0	8.2	8.2
17	11	F	6.0	7.1	9.5	9.2
18	11	F	6.5		7.5	
19	11	M	6.5		9.5	
20	11	F	8.0		9.5	
21	11	F	8.0		9.5	
22	11	F	8.0		9.5	
23	12	F	5.5	6.1	9.5	9.2
24	12	M	6.0		9.5	
25	12	F	7.0		8.5	

F, female; M, male.

^aClinically measured distance between the ear post and the highest edge of the thyroid shield in the area of the cervical vertebrae on the lateral parts of the neck.^bRadiologically measured distance between the external auditory meatus and roentgen-positive mark level or alternatively the most inferior part of image-field level (if roentgen-positive mark was outside the image field).

Design and fitness of the thyroid shield

In the present study, we tried to find a way to make possible visualization of the four most cranial cervical vertebrae while the thyroid gland is protected from the ionizing radiation in children during lateral cephalometric radiography. Our study showed that despite localizing the thyroid gland prior to lateral cephalometric radiography and placing the TS at the level of the thyroid gland, elevated lateral parts of the TS that extend beyond the patient's neck and failure in horizontally placing the TS cause unwanted partial or total coverage of the fourth cervical vertebra in 32% of the study subjects. The problem seems to arise from the inappropriate fitness and design of the TS, especially in children. Although thyroid developmental anomalies, including agenesis, have been associated with some syndromic forms of orofacial clefting, to our knowledge, thyroid positional abnormalities have not been reported in patients with non-syndromic clefting.^{23,24}

Our results indicate that during lateral cephalometric radiography if the highest lateral edge of the TS in the area of the cervical vertebrae was located at the same vertical level of the roentgen-positive mark, the fourth vertebra would have been visible in the final image because the height of the elevated part of the TS in the area

of the cervical vertebrae (h) was more than the posterior vertebral body height of the third vertebra (f) and consequently of the fourth vertebra (Figure 2B), because the posterior vertebral body height of the third and fourth cervical vertebrae is in average approximately the same.²⁵

It has to be mentioned that during lateral cephalometric radiography, the lateral parts of the TS naturally are located either closer or further to the focal spot in relation to the midsagittal plane (where the roentgen-positive mark was located). Because of the divergence of the X-ray beam, this, respectively, results in the magnification of the side of the TS that is closer to the focal spot. This, in turn, leads to some extent the unwanted coverage of the cervical vertebrae in the final image, even though the TS is located precisely at the most cranial level of the thyroid gland. We do not know, however, how much unwanted coverage of the fourth cervical vertebra arises from the magnification factor. New designs of the TS such as modified thyroid protector²⁶ with a narrow metallic circular part around the neck can be placed mainly on the area of the lobes of the thyroid gland with minimum interference with the area of the cervical spine on the final image. Such a shielding is recommended as a means to visualize the four cervical vertebrae and for radiation protection of the thyroid gland especially in children.

Limitations of the study and future studies

Because of difficulties in placing the TS in a horizontal position, we could not benefit the head positioner equipped with an extension piece below the ear post labelled with a measuring scale as was expected. In the future, the thyroid glands of children could be localized by ultrasound examination and use of a measuring scale in the cephalostat without any exposure and in this way try to find out the approximate cranial level of the thyroid gland in different age groups. However, our pilot study

Table 3 Height of the third cervical vertebra and shielded area in eight 8- to 12-year-old subjects demonstrating three cervical vertebrae on lateral cephalometric radiography

Patient number	Age (years)	Gender	Height of the third cervical vertebra (cm)		Shielded area ^a (cm)	
			Mean		Mean	
8	8	F	0.8	0.9	2.0	2.8
9	8	F	0.9		2.7	
10	8	M	1.0		2.8	
11	8	F	1.0		4.2	
14	9	M	0.7		2.4	
16	10	F	0.9		3.9	
18	11	F	1.0		1.8	
25	12	F	0.9		2.7	

F, female; M, male.

^aVertical distance between the most posterosuperior part of the fourth cervical vertebra (or alternatively the highest lateral edge of the thyroid shield if the fourth vertebra was completely covered by the thyroid shield) and the horizontal level of the roentgen-positive mark (or alternatively the most inferior part of the image field if the roentgen-positive mark was outside the image field).

with low number of study subjects already shows that there is a variation in this respect.

On the other hand, a retrospective survey of previous CT or MR images of children taken from the area of neck can be beneficial to locate the thyroid gland level. In a report by Hidalgo *et al.*,²⁷ the location of the thyroid gland in 10-year-old patients was estimated based on the analysis of a limited number of CT and MRI examinations. Benefiting retrospective three-dimensional radiographic examinations of children in different age groups is a safe way to localize the thyroid gland in respect to the cervical vertebrae in order to optimize the use of the TS in lateral cephalometric radiography. The use of the modified thyroid protector²⁶ could also be evaluated, and its use could be optimized with the help of ultrasound examination.

Our results show that obtaining an optimal LCR for orthodontic diagnostic purposes with the TS in the correct

position can be challenging. By positioning the TS at the level of the thyroid gland, the four most cranial cervical vertebrae could not be visualized in all our study subjects during lateral cephalometric radiography. The optimal placement of the TS could not be achieved because of short neck in children and inappropriate design of the TS. New designs of the TS that might minimize coverage of the cervical vertebrae is desired. There is a need for more studies regarding localization of the thyroid gland of children and its shielding during lateral cephalometric radiography.

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