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# Is the use of the cervical vertebrae maturation method justified to determine skeletal age? A comparison of radiation dose of two strategies for skeletal age estimation

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SUMMARY The aim of this study was to assess effective doses of a lateral cephalogram radiograph with and without thyroid shield and compare the differences with the radiation dose of a hand-wrist radiograph.

Thermoluminescent dosimeters were placed at 19 different sites in the head and neck of a tissue-equivalent human skull (RANDO phantom). Analogue lateral cephalograms with and without thyroid shield (67 kV, 250 mA, 10 mAs) and hand-wrist radiographs (40 kV, 250 mA, 10 mAs) were obtained. The effective doses were calculated using the 2007 International Commission on Radiological Protection recommendations.

The effective dose for conventional lateral cephalogram without a thyroid shield was 5.03 microsieverts (μSv). By applying a thyroid shield to the RANDO phantom, a remarkable dose reduction of 1.73 μSv could be achieved. The effective dose of a conventional hand-wrist radiograph was calculated to be 0.16 μSv. Adding the effective dose of the hand-wrist radiograph to the effective dose of the lateral cephalogram with thyroid shield resulted in a cumulative effective dose of 3.46 μSv. Without thyroid shield, the effective dose of a lateral cephalogram was approximately 1.5-fold increased than the cumulative effective dose of a hand-wrist radiograph and a lateral cephalogram with thyroid shield.

Thyroid is an organ that is very sensitive to radiation exposure. Its shielding will significantly reduce the effective dose. An additional hand-wrist radiograph, involving no vulnerable tissues, however, causes very little radiation risk. In accordance with the ALARA (As Low As Reasonably Achievable) principle, if an evaluation of skeletal age is indicated, an additional hand-wrist radiograph seems much more justifiable than removing the thyroid shield.

## Introduction

In orthodontic treatment planning, there are several reasons why the skeletal age of a patient should be evaluated. First, dentofacial orthopaedic appliances are a main treatment modality to correct mandibular deficiency by modifying mandibular and maxillary growth. The effectiveness of these growth modifications, however, depends on patient's skeletal maturity stage with the optimal time for growth modification being around the pubertal growth spurt (Hägg and Taranger, 1980a, b; Baccetti *et al.*, 2009). Second, some orthognathic surgical procedures and the insertion of dental implants should not be performed before the cessation of the individual's growth has been clarified (Kokich, 2004; Noble *et al.*, 2007; Chen *et al.*, 2010). Some authors, however, have questioned the clinical value of skeletal age assessment for craniofacial growth (Moore, 1997).

Numerous approaches to assess skeletal maturation have been suggested: biological indicators such as the rate of body height changes (Bjork, 1963; Hunter, 1966), menarche, or voice changes (Tofani, 1972; Hägg and Taranger, 1980a, b); dental development and eruption (Hellman, 1923; Lewis and Garn, 1960; Bjork and Helm, 1967); hand-wrist radiographs (Greulich and Pyle, 1959; Bjork and Helm, 1967; Tofani, 1972; Hägg and Taranger, 1980b); and more recently, cervical vertebrae maturation (CVM) (O'Reilly and Yanniello, 1988; Hassel and Farman, 1995; Baccetti *et al.*, 2002).

For decades, hand-wrist radiographs have been used routinely in orthodontics to determine the peak of growth spurt (Hägg and Taranger, 1980a). However, concern has been voiced over the extra radiation exposure caused by an additional radiograph. Since the introduction of the assessment of skeletal age by means of the CVM method on a lateral cephalograph, it seems therefore questionable if an additional hand-wrist radiograph should be taken for the sole purpose of skeletal age evaluation. In accordance to this apprehension, the British Orthodontic Society stated in its guidelines of 2008 that hand-wrist radiographs are no longer indicated to predict the onset of the pubertal growth spurt (Isaacson *et al.*, 2008).

The rationale behind this guideline is obvious. A lateral cephalograph is routinely required for orthodontic diagnosis and treatment planning. By using the CVM method, no additional radiograph is needed. Since radiation risks are cumulative, it is imperative that strategies for dose reduction, including the amount of radiographs taken, be considered. And although the amount of radiation utilized in dentistry is typically fairly low (White, 1992), acceptable radiological policies and practices are based on the assumption that some risk does exist, and this risk must be clearly outweighed by benefits, i.e. the quantity and quality of needed diagnostic information.

Another option to reduce radiation exposure is the use of a thyroid shield. This shield, however, would forfeit the possibility to determine the skeletal age with the CVM method and would render a hand-wrist radiograph necessary in cases were skeletal maturation has to be assessed.

The aim of this study was therefore to examine the radiobiological risk of a lateral cephalogram with and without a thyroid shield and of a hand-wrist radiograph by means of phantom dosimetry. Based on the obtained average absorbed doses, the effective doses are calculated to estimate the potential risk of the radiographs and to enable a comparison.

## Material and methods

Thermoluminescent dosimeter (TLD) chips (3 mm × 1 mm × 1 mm) were used on selected locations in the head and neck region of an adult male tissue-equivalent phantom (RANDO—radiation analog dosimetry system; The Phantom Laboratory, Salem, NY, USA) to record the distribution of the absorbed radiation dose. The 19 sites measured in this study are listed in Table 1. These locations reflect critical organs known to be sensitive to radiation. For the assessment of the effective dose of hand-wrist radiographs, a TLD was exposed directly in the respective distance to the ray tube. The TLD chips were supplied by the Institute of Applied Radiophysics (IAR.) from the University of Lausanne, Switzerland. The exposed dosimeters were analyzed by the IAR in a blinded fashion. One unexposed dosimeter served as control for environmental radiation.

**Table 1** Locations of thermoluminescent dosimeter (TLD) chips on the RANDO phantom.

| Organ | Location | TLD number | Phantom level |
|---|---|---|---|
| Brain | Anterior/posterior | 18, 19 | 1 |
| | Right/left | 16, 17 | 2 |
| | Hypophysis | 13 | 3 |
| Eyes | Right/left lens | 14, 15 | 3 |
| Skull | Right/left maxillary sinuses | 9, 10 | 5 |
| Salivary glands | Right/left parotid | 11, 12 | 5 |
| | Right/left submandibular gland | 7, 8 | 6 |
| | Sublingual gland | 5 | |
| Thyroid | Right/left | 1,2 | 9 |
| Spine | B2 | 6 | 6 |
| | Right/left | 3, 4 | 7 |

The radiological examinations were performed on a custom-made X-ray unit (COMET, 3175 Flamatt, Switzerland) with the following parameters for the lateral cephalogram: 67 kV tube voltage, 250 mA tube current, 0.04 second exposure time, and 10 mAs tube current time product and for the hand-wrist radiograph: 40 kV tube voltage, 250 mA tube current, 0.04 second exposure time, and 10 mAs tube current time product. These parameters correspond to the clinical exposure parameters commonly used. For the lateral cephalogram with a thyroid shield, a commercially available thyroid shield (3534-TS, WIROMA, 3145 Niederscherli, Switzerland) with 0.5 mm Pb was placed on the phantom. No intensifying screens were used.

Because of the relatively small amount of radiation required for a single examination, multiple exposures for each radiographic technique were performed to provide reliable measure of radiation in the dosimeters. Ten exposures were made to provide more reliable data and the mean value was used for further calculations. Doses from TLDs at different positions within a tissue or organ were averaged to express the average tissue-absorbed dose in micrograys (µGy). These values were used to calculate the equivalent dose $H_T$ using the following equation:

$$H_T = \sum W_R D_T.$$

The equivalent dose $H_T$ for a tissue or organ is defined as the product of the radiation weighting factor $W_R$ ($W_R$ equals 1 for x-radiation) and the measured absorbed dose $D_T$ averaged over a particular tissue or organ (Valentin, 2007).

Effective dose $E$ has been recommended by the International Commission on Radiological Protection (ICRP) as a means of comparing detriment of different exposures to ionizing radiation to an equivalent detriment produced by a full-body dose of radiation. Thus, the risk to the whole body is determined as the summation of the equivalent doses established for all tissues and organs (Valentin, 2007). The effective dose ($E_{ICRP60}$), expressed in microsieverts (µSv), was calculated using the equation

$$E = \sum W_T H_T,$$

where $E$ is the product of the tissue weighting factor $W_T$, which represents the relative contribution of that organ or tissue to the overall risk, and the equivalent dose $H_T$. The weighting factors of the equivalent doses in accordance with the ICRP guidelines of 2007 for the lateral cephalogram and for the hand-wrist radiograph are given in Table 2a and 2b, respectively.

## Results

The absorbed doses, equivalent doses, and effective doses are given in Table 3 for lateral cephalogram without a thyroid shield and in Table 4 for lateral cephalogram with a

**Table 2a** Weighting of the equivalent dose ($H_T$) for lateral cephalometric radiation exposure.

| Tissue | ICRP-identified organ | Fraction of total organ irradiated (%) | Corresponding TLD numbers | Fraction irradiated (%) | Weighting | Weighting in % |
|---|---|---|---|---|---|---|
| Bone marrow | | | | 16.5 | 1.98 | 17.86 |
| | Mandibula | 1.30 | Mean 7, 8 | | | |
| | Calvarium | 11.80 | Mean 16, 17, 18, 19 | | | |
| | Cervical spine | 3.40 | Mean 3, 4, 6 | | | |
| Esophagus | Esophagus | 10.00 | Mean 1, 2 | 10.0 | 4.00 | 36.08 |
| Thyroid | Thyroid | 100.00 | Mean 1, 2 | 100.0 | 0.40 | 3.61 |
| Bone surface | | | | 16.5 | 0.77 | 6.91 |
| | Mandible | 1.30 | 4.64 Mean 7, 8 | | | |
| | Calvarium | 11.80 | 4.64 Mean 16, 17, 18, 19 | | | |
| | Cervical spine | 3.40 | 4.64 mean 3, 4, 6 | | | |
| Brain | Brain | 100.00 | Mean 13, 16, 17, 18, 19 | 100.0 | 1.00 | 9.02 |
| Salivary glands | | | | 100.0 | 0.05 | 0.45 |
| | Parotid | 33.00 | Mean 11, 12 | | | |
| | Submandibular | 33.00 | Mean 7, 8 | | | |
| | Sublingual | 33.00 | 5 | | | |
| Skin | Skin | 5.0 | Mean 11, 12, 14, 15 | 5.0 | 1.00 | 9.02 |
| Muscle | Muscle | 5.0 | Mean 1–8, 11–13 | 5.0 | 0.05 | 0.41 |
| Remainder | | | | | 1.85 | 16.64 |
| | Lymphatic nodes | 5.0 | Mean 1–8, 11–12 | | | |
| | Extrathoracic airway | 100.00 | Mean 1–8, 11–14 | | | |
| | Oral mucosa | 100.00 | Mean 1–8, 11–15 | | | |

**Table 2b** Weighting of the equivalent dose ($H_T$) for hand-wrist radiation exposure.

| Tissue | ICRP-identified organs | Fraction of total organ irradiated (%) | Corresponding TLD numbers | Fraction irradiated (%) | Weighting | Weighting in % |
|---|---|---|---|---|---|---|
| Bone marrow | Bone | 0.5 | — | 0.5 | 0.06 | 58.71 |
| Bone surface | Bone | 0.5 | — | 0.5 | 0.02 | 22.70 |
| Skin | Skin | 1.0 | — | 1 | 0.01 | 9.78 |
| Muscle | Muscle | 1.0 | — | 1 | 0.01 | 8.81 |
| Remainder | — | | — | | | |

**Table 3** Radiation exposure: lateral cephalogram *without* thyroid shield.

| Tissue | Fraction of total organ irradiated (%) | Absorbed dose (mGy) | Equivalent dose (µSv) | TWF ICRP 2007 | Effective dose (µSv) | Effective dose (%) |
|---|---|---|---|---|---|---|
| Bone marrow | 16.50 | 0.04 | 6.01 | 0.12 | 0.72 | 14.33 |
| Thyroid | 100 | 0.05 | 45.00 | 0.04 | 1.80 | 35.79 |
| Esophagus | 10.00 | 0.05 | 4.50 | 0.04 | 0.18 | 3.58 |
| Bone surface | 16.50 | 0.17 | 27.87 | 0.01 | 0.28 | 5.54 |
| Salivary glands | 100.00 | 0.06 | 59.99 | 0.01 | 0.60 | 11.93 |
| Skin | 5 | 0.06 | 2.88 | 0.01 | 0.03 | 0.57 |
| Brain | 100 | 0.03 | 30.00 | 0.01 | 0.30 | 5.97 |
| Muscle | 5 | 0.05 | 2.70 | 0.009 | 0.02 | 0.48 |
| Remainder | — | 0.06 | 124.54 | 0.009 | 1.12 | 22.29 |
| **Total Effective Radiation Exposure Dose** | | | | | **5.03** | **100.00** |

TWF ICRP 2007: Tissue weighting factor according to the International Commission on Radiological Protection.

**Table 4** Radiation exposure: lateral cephalogram with thyroid shield.

| Tissue | Fraction of total organ irradiated (%) | Absorbed dose (mGy) | Equivalent dose (µSv) | TWF ICRP 2007 | Effective dose (µSv) | Effective dose (%) |
|---|---|---|---|---|---|---|
| Bone marrow | 16.50 | 0.04 | 6.01 | 0.12 | 0.72 | 21.85 |
| Thyroid | 100 | 0.01 | 8.00 | 0.04 | 0.32 | 9.70 |
| Esophagus | 10.00 | 0.01 | 0.80 | 0.04 | 0.03 | 0.97 |
| Bone surface | 16.50 | 0.17 | 27.87 | 0.01 | 0.28 | 8.45 |
| Salivary glands | 100.00 | 0.06 | 59.99 | 0.01 | 0.60 | 18.18 |
| Skin | 5 | 0.06 | 2.88 | 0.01 | 0.03 | 0.87 |
| Brain | 100 | 0.03 | 30.00 | 0.01 | 0.30 | 9.09 |
| Muscle | 5 | 0.05 | 2.70 | 0.009 | 0.02 | 0.48 |
| Remainder | — | 0.05 | 113.23 | 0.009 | 1.02 | 30.89 |
| **Total Effective Radiation Exposure Dose** | | | | | **3.30** | **100.00** |

TWF ICRP 2007: Tissue weighting factor according to International Commission on Radiological Protection.

**Table 5** Radiation exposure: hand-wrist radiograph.

| Tissue | Fraction of total organ irradiated (%) | Absorbed dose (mGy) | Equivalent dose (µSv) | TWF ICRP 2007 | Effective dose (µSv) | Effective dose (%) |
|---|---|---|---|---|---|---|
| Bone marrow | 0.50 | 0.16 | 0.80 | 0.12 | 0.096 | 58.71 |
| Thyroid | 0 | — | — | — | — | — |
| Esophagus | 0 | — | — | — | — | — |
| Bone surface | 0.50 | 0.16 | 3.71 | 0.01 | 0.037 | 22.70 |
| Salivary glands | 0 | — | — | — | — | — |
| Skin | 1 | 0.16 | 4.75 | 0.01 | 0.016 | 9.78 |
| Brain | 0 | — | — | — | — | — |
| Muscle | 1 | 0.16 | 1.60 | 0.009 | 0.014 | 8.81 |
| Remainder | 0 | | | | | |
| **Total Effective Radiation Exposure Dose** | | | | | **0.164** | **100.00** |

TWF ICRP 2007: Tissue weighting factor according to International Commission on Radiological Protection.

thyroid shield, respectively. Analogously, these doses for the hand-wrist radiograph are listed in Table 5.

It is noteworthy that the thyroid is the most vulnerable organ followed by the salivary glands. The use of a thyroid shield decreased the effective dose of the thyroid considerably (from 1.8 to 0.32 µSv).

The overall effective dose for conventional lateral cephalograms without a thyroid shield was 5.03 µSv. By applying a thyroid shield to the RANDO phantom, a remarkable dose reduction could be attained, resulting in an effective dose of 3.30 µSv. This equals a reduction of approximately 34 per cent. The effective dose for a conventional hand-wrist radiograph was calculated to be 0.16 µSv. Adding the effective dose of the hand-wrist radiograph to the effective dose of the lateral cephalogram with thyroid shield results in a cumulative effective dose of 3.46 µSv. This equals a reduction of approximately 31 per cent over the effective dose of a lateral cephalogram without thyroid shield. Hence, without thyroid shield, the effective dose of a lateral cephalogram was approximately 1.5-fold increased than the cumulative effective dose of a hand-wrist radiograph and a lateral cephalogram with thyroid shield.

## Discussion

In the last decade, the radiological depiction of the cervical spine area has been the subject of increasing interest in orthodontics. Scientific contributions have shown that diagnostic data can be obtained from the cervical spine on a lateral cephalogram. In addition to skeletal age evaluation, it is possible to assess the natural head position by using the cervical spine as the reference structure (Kylamarkula and Huggare, 1985). Furthermore, cervical vertebrae anomalies (CVA) such as fusions have been associated with craniofacial syndromes, sleep apnea, and dentoskeletal malocclusions (Sonnesen, 2010).

However, some of these potential benefits have been severely questioned. Natural head position can be assessed clinically without the help of a radiograph. In fact, many perform the lateral cephalogram with the head fixed parallel to the Frankfort plane and not in natural head posture. Moreover, it has been argued that the oblique facets of the joint render lateral cephalograms entirely inappropriate to evaluate fusions and that Cone Beam CT (CBCT) remains the gold standard for assessing CVA (Koletsis and Halazonetis, 2010; Bebnowski *et al.*, 2012).

All of this reduces the benefit of depicting the cervical area to determine skeletal age. Yet, it has been reported that the exact evaluation of the skeletal age based on the cervical spine is at best very difficult. According to recent studies, the reproducibility of evaluating the skeletal age based on the spine is disappointingly low (Gabriel *et al.*, 2009; Nestman *et al.*, 2011; Zhao *et al.*, 2012). All of this implies that the benefit of exposing the cervical spine to radiation—and with it the thyroid—is very limited.

In contrast to the CVM method, bone age assessment based on hand-wrist radiography shows good reproducibility (King *et al.*, 1994) and a high reliability (Flores-Mir *et al.*, 2004). A further strength of a hand-wrist radiograph is that the cumulative results of different methods such as Greulich and Pyle (GP), Tanner and Whitehouse (TW), and Bowden or Fishman can be used to assess the skeletal age (Flores-Mir *et al.*, 2004). For endocrinologists, the concordant result of GP together with TW still remains the gold standard with TW being the method of choice (Gilli, 1996), whereas certain sources of error (such as poor positioning of the hand or inter- and intra-observer reliability) undeniably affect the accuracy of hand-wrist radiography as well (Cox, 1996).

The thyroid is an organ that is highly sensitive to radiation exposure. Our study reveals that a thyroid shield will reduce the effective dose remarkably. In light of the questionable benefits of radiological exposure of this sensitive area, our findings give strong support to the use of a thyroid shield. Alternatively, the beam could be collimated to exclude the thyroid and hence reduce the effective dose. Whatever the personal approach might be to reduce the radiation of the thyroid, should a clinical indication to assess the skeletal age arise, an additional hand-wrist radiograph is to be recommended, even if extra costs of an additional radiography have to be taken into account.

A possible limitation of our study is that different radiographical equipment may generate slightly different results, although a comparison with other studies seems to suggest that the differences are very small (Ludlow *et al.*, 2008). Furthermore, the image acquisition was performed with analogue radiographs and not with digital imaging generating less radiation when a digital system based on a charged-coupled device (CCD) is used. Yet digital image acquisition would reduce all absolute values of the effective doses but will leave the ratios almost unaffected. In fact, absolute values are not very useful for comparative research as they depend on device, protocol, and film sensitivity. Visser *et al.* (2001) demonstrated that even analogue cephalometry can generate diverse doses. This is why our study describes the differences achieved in dose reduction as percentages and as ratios.

Hassel and Farman (1995) have claimed that C3 and also C4 can be visualized even when a thyroid shield is worn. This assertion is based on the fact that in adulthood, the topographical location of the thyroid corresponds to C5–C7. However, it is important to realize that the location of the thyroid is age dependent as the thyroid experiences a caudal movement through puberty (Crelin, 1973). Also, it should be appreciated that the thyroid position reportedly highly varies from person to person (Gray *et al.*, 2005). All this implies that the thyroid shield should cover the cervical spine above C5 as well, especially in pre-pubertal children and would hence, if applied correctly, forfeit the CVM method. In post-pubertal subjects, however, the thyroid would most of the time be lower than C4 and, theoretically, the use of a neck shield would be commendable. In practical setting, it is however very challenging to determine clinically by visual inspection and neck palpation the correct location of C5. A recent retrospective survey also demonstrated that the thyroid shields are used inconsistently and if applied, C3 and C4 were entirely depicted in only 14% of all subjects (Hujoel *et al.*, 2006).

Exposure to natural radiation sources is more significant for the world's population than most exposures to medical radiation sources (UNSCEAR, 2000). The average worldwide exposure to environmental radiation sources of about 2.4 mSv per year would seem to indicate that the described dose reduction achieved with the thyroid shield to be negligible. However, it must be stated that the average exposure probably does not pertain to any one individual, since there are wide distributions of exposures from each source and the exposures combine in various ways at each location, depending on the specific concentrations of radionuclides in the environment and in the body, the latitude and altitude of the location, and many other factors (UNSCEAR, 2000). And on the other hand, scientific evidence has recently been provided that exposure to routine dental X-rays appears to be associated with an increased risk of intracranial meningioma (Claus *et al.*, 2012). Thus, unless proven differently, the task to reduce the ionizing risk of medical radiation will remain on dentists.

It is indeed a perplexing conclusion that an additional X-ray means less radiation exposure (provided the thyroid shield is applied). As mentioned, the British Orthodontic Society considers the hand-wrist radiograph to be obsolete, an opinion echoed by many others (EU, 2004; Turpin, 2008; Chen *et al.*, 2010; Litsas and Ari-Demirkaya, 2010). But our findings strongly corroborate that the conclusions of the British Orthodontic Society ought to be reconsidered and the use of a thyroid shield to be enforced.

In summary, this study demonstrates that, based on the overriding ALARA (As Low As Reasonably Achievable) principle, the assessment of skeletal maturation of cervical vertebrae on a lateral cephalogram is to be questioned and the use of a thyroid shield is strongly to be advocated. If an evaluation of skeletal age is deemed necessary, an additional hand-wrist radiograph seems much more justifiable than removing the thyroid shield, which would cause highly vulnerable tissue to be exposed to direct radiation.

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