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Bone age assessment using cephalometric photographs

Magdalena Durka-Zając[1], Agata Marcinkowska[2], Maria Mituś-Kenig[3]

[1] Private Specialist Orthodontic Practice, Mierzyn, Poland
[2] 5th Military Research Hospital and Polyclinic Independent Public Healthcare Centre, Specialist Dental Clinic, Cracow, Poland
[3] Department of Orthodontics, Specialist District Outpatient Clinic Zbigniew Żak Memorial, Cracow, Poland

Author's address: Agata Marcinkowska, Leszczynowa 7B St., Cracow 30-211, Poland, e-mail: agata.marcinkowska@wp.pl

Summary

Background: The assessment of bone age comprises the basic element of orthodontic diagnostics as it enables the recognition of deviations from normal growth, determines the choice of treatment, helps determine the appropriate moment to begin treatment, establish prognosis and plan a retention strategy. In order to make an assessment of skeletal maturity possible in a single examination, radiological methods were adopted. The following characteristics are evaluated on a radiograph: the appearance, size and shape of ossification centers, the width and the shape of growth cartilage and the degree of fusion between diaphyses and epiphyses. In order to assess the maturity of bones, hand-wrist radiographs were introduced in the second decade of the 20th century. Bone age assessment of bone age could also be made based on an analysis of a morphological maturity of cervical vertebrae utilizing cephalometric radiographs.

Objective: The objective of the study was to evaluate the correspondence between bone age assessments made from hand-wrist radiographs and those from cephalometric radiographs.

Material/Methods: In order to fulfill the objectives, hand-wrist radiographs as well as cephalometric radiographs of 30 patients (15 girls and 15 boys) between 10 and 17 years of age were collected. Bone age of hand, wrist and cervical spine was assessed. Bone age on hand-wrist radiographs was evaluated using the Björk method, whereas cephalometric radiographs were analyzed by the Baccetti et al.method.

Results: A strong and statistically highly significant ($r=0.98$; $p<0.00001$) Pearson's correlation was found between bone age assessed from hand-wrist radiographs using Björk's method and bone age assessed from cephalometric radiographs using the method by Baccetti et al.

Conclusions: The analysis of cervical vertebrae in cephalometric radiographs appears to be the most desirable method of bone age assessment. Performing the analysis on routinely taken cephalograms eliminates the need for additional exposure to X-ray radiation and shortens the duration of examination.

Key words: **bone age • dental age • skeletal maturity**

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Background

In order to assess the developmental age, four criteria are generally used: secondary sexual characteristics, bone age, dental age and morphological age. Due to individual variations between the patients, their development cannot be evaluated based on chronological age alone. Of greater significance is the biological age, which is determined from dental age, bone age and psychosomatic development. The assessment of bone age comprises the basic element of orthodontic diagnostics as it enables the recognition of deviations from normal growth, determines the choice of treatment, helps determine the appropriate moment to begin treatment, establish prognosis and plan the retention strategy. It is important for the timing of surgery and for the analysis of treatment effects in patients who are in the same growth stage. The diagnosis of growth abnormalities is possible by making comparison with standards established for a given age, sex and race, taking familial tendencies into account. Identification of the periods of accelerated and intensified growth in a patient is fundamental when it comes to planning orthodontic treatment and predicting its outcomes, because growth can facilitate, hinder or even nullify the desired therapeutic effect. The assessment of growth potential and the stage of development during pre-puberty and puberty provides valuable information about the best time to arrange for an orthopedic treatment of skeletal abnormalities. Therefore, the necessity of using an objective indicator of a patient's skeletal maturity arises. The search for the best skeletal maturity indicator in orthodontics has been going on for several decades. Maturity indicators based on secondary sexual characteristics require physical examination and are consequently difficult to determine at an orthodontic office. Orthodontists can assess sexual development from the presence of menstruation in females and voice mutation in males [1]. Radiological indicators were created to assess the bone age.

To make the assessment of skeletal maturity possible in a single examination, radiological methods were adopted. The following characteristics are evaluated on a radiograph: the appearance, size and shape of ossification centers, the width and shape of growth cartilage and the degree of fusion between diaphyses and epiphyses.

In order to assess the maturity of bones, hand-wrist radiographs were introduced in the second decade of the 20^{th} century. This method relies on visual assessment of individual bones i.e. their first appearance on a radiograph and ossification-related changes in their shape and size. However the biggest drawback of using hand-wrist radiographs to assess bone age is the need for taking an additional radiograph. For this reason, the method utilizing cephalometric radiographs, which are routinely performed for diagnostic purposes, came back into favor in the 1990s,.

Objective

The objective of the study was to evaluate the correspondence between bone age assessments made from hand-wrist radiographs and from cephalometric radiographs.

Material and Methods

In order to fulfill the objectives, hand-wrist radiographs as well as cephalometric radiographs of 30 patients (15 girls and 15 boys) between 10 and 17 years of age were collected. Bone age of hand, wrist and cervical spine was assessed. The data were collected from patients, who reported to the Department of Orthodontics of Pomeranian Medical University in Szczecin for the first time. The patients had not been treated orthodontically before. Radiographs of patients with bone growth disorders, congenital or acquired disorders of cervical spine, hand or wrist, hormonal abnormalities or general diseases were excluded from the study. They went through a selection process, involving quality, visibility of hard and soft tissue, visibility of at least three cervical vertebrae and the absence of artifacts. The hand-wrist radiographs and cephalometric radiographs of each patient were taken either at the same day or within 2 weeks from each other. Bone age on hand-wrist radiographs was evaluated using the Björk method, whereas cephalometric radiographs were analyzed by the Baccetti et al. method.

Results

A strong and statistically highly significant ($r=0.98$; $p<0.00001$) Pearson's correlation was found between bone age assessed from hand-wrist radiographs using Björk method and bone age assessed from cephalometric radiographs using the method by Baccetti et al. (Figure 1).

Discussion

The duration and effectiveness of orthodontic treatment, as well as the permanence of its effects, depend on the timing of the treatment. In order to optimize these cofactors of orthodontic therapy, the methods to find the best time to undergo the treatment are being researched. The synchronization of timing and treatment effectiveness is based on skeletal growth and maturation assessment. This assessment can be made from the time when secondary sexual characteristics appear. However, this method is inaccurate and insufficient. Similarly, chronological age does not always correspond to the rate of growth and maturation. Radiological examination of hand and wrist, which has been done for years, is more accurate in bone age assessment. The development of wrist bones is considerably

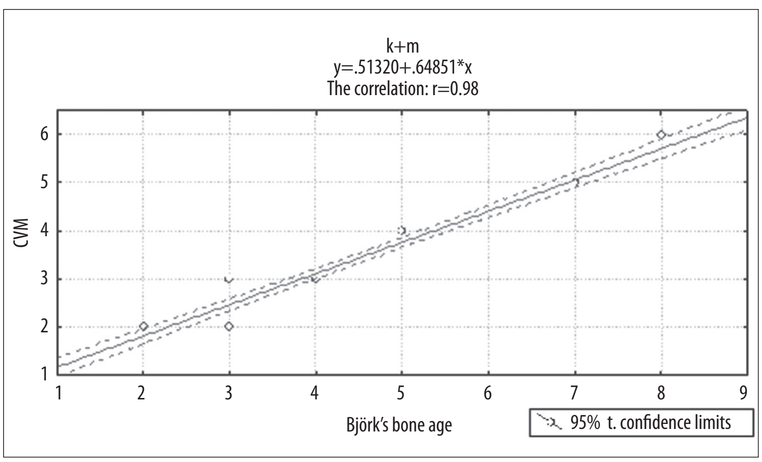

Figure 1. Correlation between bone age assessed using the method by Baccetti et al. and Björk's method in both sexes.

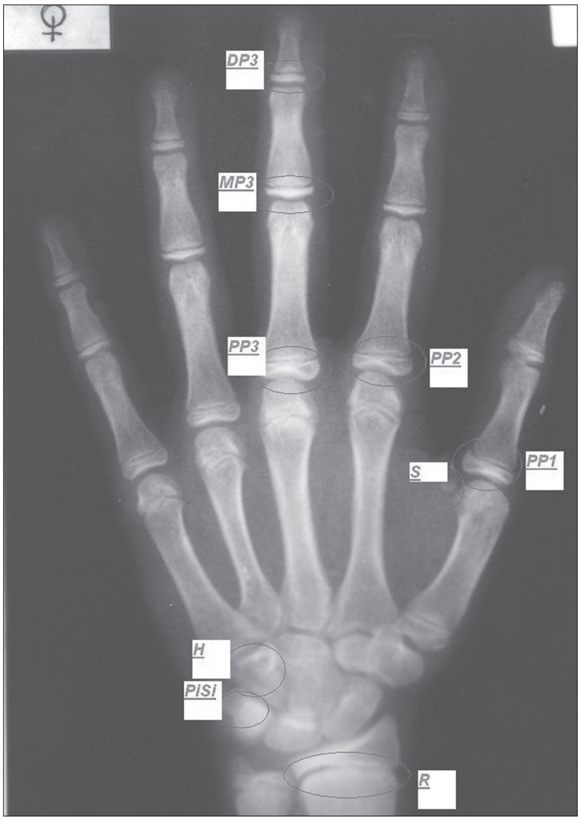

Figure 2. A hand-wrist radiograph with selected regions assessed in Björk's method.

delayed in comparison with all other bones of the upper limb. The ossification of cartilages begins after birth. Complete development of epiphyses and their fusion with diaphyses occur during puberty. In females, ossification happens earlier than in males.

At the beginning of the 20th century, the first tables describing the degrees of skeletal maturity were developed. They were based on a series of hand-wrist radiographs. The very first atlas of human hand ossification was compiled by Siegert in 1935. Subsequently, Todd (1937), followed by: Greulich and Pyle (1950), Schmid and Moll (1960), Björk et al. (1966), Kopczyńska-Sikorska (1969), Tanner et al. (1975), de Roo and Schröder (1976) published atlases of hand skeletal maturation. Rakosi, Grave and Brown also worked on this subject [2–5].

According to Nötzel and Schultz, the indications for a hand-wrist X-ray are as follows:

- When there is a need to take advantage of growth during orthodontic treatment,
- When there is a risk of complications resulting from growth during or after orthodontic treatment,
- When there is a discrepancy between chronological age and dental age,
- When significant palatine suture expansion is planned,
- In interdisciplinary treatment: orthodontic-surgical cases in which the surgery is planned between 16 and 20 years of age.

For skeletal age assessment, hand and wrist have been chosen most frequently, because most of the usable ossification zones are located there. One of the most popular methods of assessing the degree of skeletal development from hand-wrist radiographs was described by Björk (Figure 2). According to the author, growth spurt and puberty begin in females about 2 years earlier than in males. Assessment of the stage of development by Björk allows inferring at which stage of skeletal development the patient is, whether he or she is before, during or after the peak growth period. It also helps determine the expected growth in the facial region of the skull [6–11].

For diagnostic purposes, lateral cephalography has also been performed in parallel to determine the direction of mandibular growth. These radiographs also include imaging of cervical spine. They reveal the age-related changes that take place in cervical spine. Regardless of the method being applied to assess bone age, the stages of skeletal maturity based on the analysis of cervical vertebrae are determined from visual observation of the development of concavity in the lower border of vertebral bodies and their transition in shape from trapezoidal, sloping down and forward, through rectangular with width greater than the height, square, to rectangular with height greater than the width (Figure 3). Exclusion of the first cervical vertebra from the analysis results from the lack of vertebral body and an insufficient visibility of this structure on a radiograph.

One of the first researchers to evaluate the changes in size and shape of maturing cervical vertebrae were Todd and Pyle in 1928, and Lanier in 1939 [12]. At the beginning of the 1970s, subsequent authors proved that the increase in size of cervical vertebral bodies is linked to skeletal maturation [13].

In 1972, Lamparski noticed that the cervical vertebrae visible on cephalometric radiographs change their shape with age and can be indicators of maturity and therefore indicators of bone age. The author created the first method of assessing bone age from the morphological maturity of cervical vertebrae. In his master's thesis, he presented the standards for measuring morphological maturity of cervical vertebrae, separately for the girls and the boys, with respect to chronological age and bone age assessed from hand-wrist radiographs. Lamparski's method is based on the analysis of changes in size and shape of five cervical vertebral bodies – from C2 to C6 – and covers 6 stages of development, called CVS (Cervical Vertebral Stadium). The author found a weaker correlation in boys than in girls. Stages CVS1-CVS3 are observed before the peak growth period, i.e. the growth acceleration phase, whereas stages CVS4-CVS6 are observed after the peak growth period, i.e. the growth deceleration phase. Peak growth period itself occurs between stages CVS3 and CVS4 [14].

Based on the results of Lamparski's studies, Hassel and Farman, San Roman et al., Mito et al., Harfin et al., Baccetti et al. made their own modifications of the method of bone age assessment from morphological changes in cervical vertebrae [15–20].

The authors, who modified Lamparski's method, were: Baccetti, Franchi and McNamara [16,21–24]. Similarly to Hassel and Farman, they reduced the number of vertebrae taken into account in bone age assessment. In 2000, they published the CVM (Cervical Vertebral Maturation) method

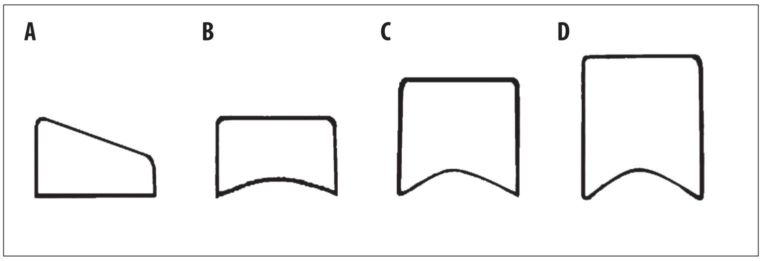

Figure 3. The shape of cervical vertebrae upon visual assessment. (**A**) Trapezoidal shape. The upper border runs obliquely from the back downward and forward. (**B**) Rectangular horizontal shape. The front and the back border of the vertebra are equal. The upper and the lower border of the vertebra are longer than the front and the back border. (**C**) Square shape. The upper, the lower, the front and the back border of the vertebra are equal. (**D**) Rectangular vertical shape. The front and the back border are longer than the upper and the lower border.

of assessing the cervical spine maturity [21]. According to this method, only three cervical vertebrae are evaluated: C2, C3 and C4, which are visible even with a thyroid collar put on.

In 2005, Baccetti et al. presented a method of assessing bone age from cervical vertebrae, covering six stages CS1-CS6, and demonstrated the results of studies in the clinical application of this method. Stages CS1 and CS2 take place before the peak growth period, which itself occurs between stages CS3 and CS4, stages CS5 and CS6 occur after the peak growth period, with CS6 taking place approximately 2 years after. The authors also measured the reproducibility of classifying cervical vertebrae maturation stages, which proved to be very high, >98% for experienced examiners. As in the previous versions of the method, the size and shape of the second (C2), third (C3) and fourth (C4) cervical vertebral bodies were visually analyzed. Among the benefits of using the method are: an easy analysis technique, a high level of agreement between the interpretations of growth stages, and the possibility of using it in both sexes. According to Baccetti et al., the assessment of vertebral body shape is not difficult and can be successfully used to predict the peak growth period [16]. We show characteristics of each of the stages in Table 1 (Figures 4–10).

The usefulness of assessing skeletal maturity from cervical vertebrae was a matter of interest to many researchers [14,16,20,25,26]. Among the benefits were: reliability in determining the onset of growth spurt, no need for an additional hand-wrist radiograph, high level of agreement in stage determination between examiners, simplicity of the assessment and possibility of use in both sexes.

In oral and maxillofacial surgery, the period of accelerated growth in teenage patients has great significance, because the growth potential can be exploited by using functional appliances. The rate of viscerocranial growth is correlated with the increase in body length and skeletal maturity [27].

Hand-wrist radiographs are generally used to assess bone age. In own studies, a very high correlation was obtained between bone age assessed from hand-wrist radiographs and that from cephalometric radiographs. A high and statistically significant correlation was reported between

Table 1. Method of bone age assessment by Baccetti et al. (Cervical Vertebral Maturation Method CVM method).

	Presence of concavity at the lower border of cervical vertebrae	Shape of cervical vertebrae	Time of peak growth
Stage 1 (CVM 1)	Lower borders of all three cervical vertebrae C2-C4 are flat	Bodies of cervical vertebrae C3 and C4 are trapezoid in shape (the upper border slopes from the back downwards)	Peak of growth will start not earlier than 2 years after this stage
Stage 2 (CVM2)	The lower border of the body of cervical vertebra C2 shows a concavity	The bodies of cervical vertebrae C3 and C4 are trapezoid in shape	The peak of growth will start 1 year after this stage
Stage 3 (CVM3)	Lower borders of cervical vertebrae C2 and C3 shows concavity	Bodies of cervical vertebrae C3 and C4 may be trapezoid/rectangular horizontal in shape	Peak of growth starts within a year from a diagnosis of this stage
Stage 4 (CVM4)	All lower borders of cervical vertebrae C2,C3 and C4 show concavities	Bodies of cervical vertebrae C3 and C4 are rectangular horizontal in shape	Peak of growth occurred a year or two years before this stage
Stage 5 (CVM5)	All lower borders of cervical vertebrae C2,C3 and C4 still show concavities	At least one of the bodies of cervical vertebrae C3 and C4 is squared in shape	Peak of growth ended one year before this stage
Stage 6 (CVM6)	Concavities of all lower borders of cervical vertebrae C2,C3 and C4 are marked	At least one of the bodies of C3 and C4 is rectangular vertical	Peak of growth ended at least 2 years before this stage

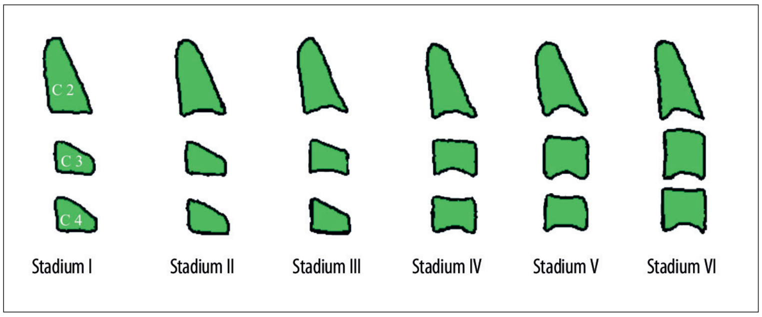

Figure 4. Stages of cervical vertebral maturation by Baccetti et al.

Figure 5. An example of stage 1 according to Baccetti et al. method.

Figure 6. An example of stage 2 according to Baccetti et al. method.

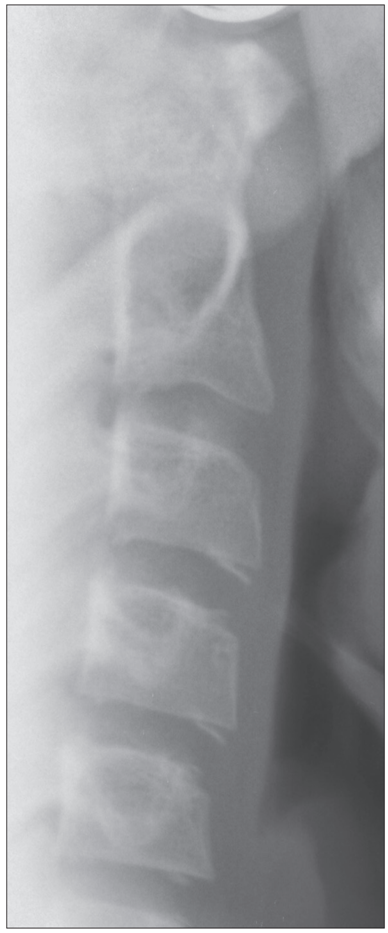

Figure 7. An example of stage 3 according to Baccetti et al. method.

the bone age assessed using Björk's method on hand-wrist radiographs and the bone age assessed using Baccetti et al method. High correlations were also obtained previously by other researchers, such as: Lamparski in 1972, O'Reilly and Yainiello in 1988, and Caltabiano et al. in 1990 [14,28–31].

Gandini et al. compared the bone age assessed from hand-wrist radiographs using Björk's method and from cervical vertebrae on cephalometric radiographs using CVMS method by Baccetti, Franchi and McNamary. The study group consisted of 30 patients (14 boys and 16 girls) aged 7–18. The authors proved that the assessment of bone age from cervical vertebrae can be considered an accurate and reproducible method and they confirmed this by reexamining the radiographs after a period of 6 months [32].

The studies of subsequent authors, such as: Mitani and Sato in 1992; Garcia-Fernandez et al. in 1998; Baccetti, Franchi and McNamara Jr. in 2000, 2002 and 2005; Pancherz and Szyszka in 2000, San Roman et al. in 2002, Flores-Mir et al. in 2006 and Gandini et al. in 2006 confirmed that bone age assessed from cervical vertebrae is an equally good method for evaluation of skeletal maturity as hand and wrist radiographs [15,16,21–24,26,27,33–35].

According to Baccetti, Franchi and McNamary, there is no difference between assessing skeletal maturity using CVM method and using hand-wrist method [15].

The ability to accurately assess skeletal maturity from cervical vertebrae without the need to take additional

Figure 8. An example of stage 4 according to Baccetti et al. method.

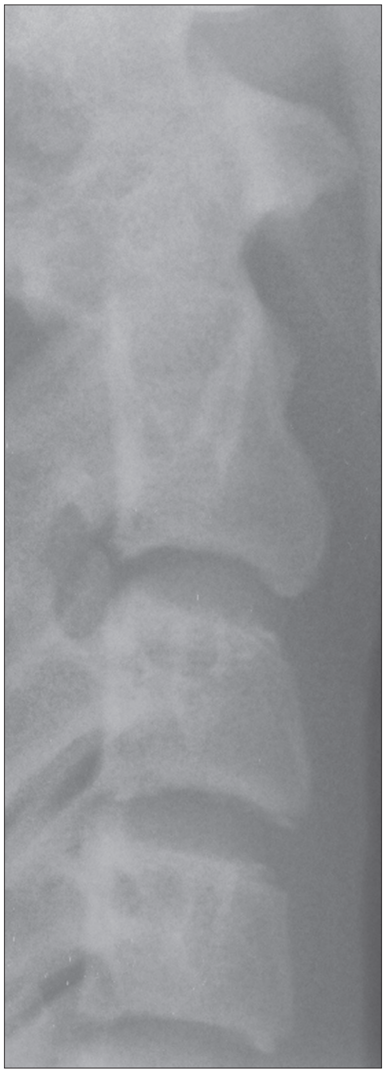

Figure 9. An example of stage 5 according to Baccetti et al. method.

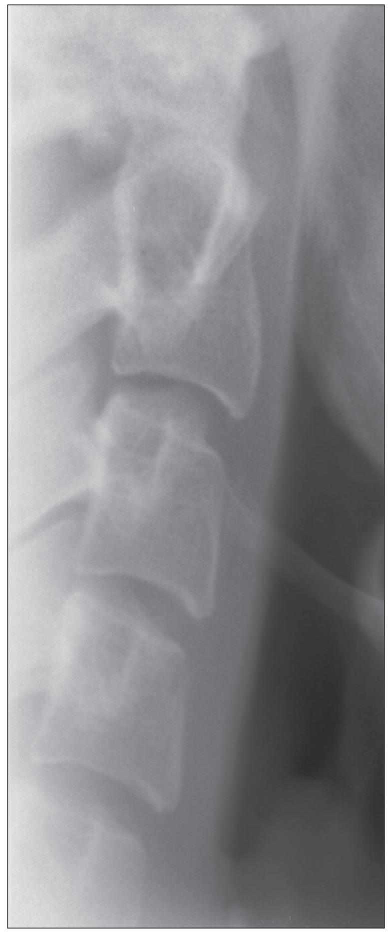

Figure 10. An example of stage 6 according to Baccetti et al. method.

radiographs could improve orthodontic diagnostics and therapeutic decisions. The simplicity of the technique and ease of use should encourage orthodontists to employ this method for assessing skeletal maturity.

Conclusions

The analysis of cervical vertebrae in cephalometric radiographs appears to be the most desirable method of bone age assessment. That is why a cephalometric radiograph is one of the main diagnostic tools used in orthodontics. Together with dental casts, they constitute the main source of information regarding treatment plan as well as evaluating its course and outcome. The assessment of a patient's skeletal maturity holds a particularly important place in orthodontics, because the choice of orthodontic and orthopedic treatment depends on it. The application of bone age assessment methods using cephalometric radiographs to evaluate cervical vertebrae helps limit patient's exposure to X-ray radiation and reduces the time needed to plan the treatment.

Performing the analysis on routinely taken cephalograms eliminates the need for additional exposure to X-ray radiation and shortens the duration of examination.

The CVM method by Baccetti et al. can certainly replace the hand-wrist method in bone age assessment.

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