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Radiological Indicators of Bone Age Assessment in Cephalometric Images. Review

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Summary

The ability to assess bone age accurately is important and allows to diagnose the patient correctly and to plan orthodontic treatment appropriately. The aim of the work is to present views of different authors on the subject of using cephalometric images to determine bone age and its significance for conducting appropriate orthodontic treatment.

Publications from the PubMed medical database were analyzed. Search criteria: bone age assessment, CVM method. Ultimately, 36 papers out of 1354 publications were selected.

The research of many authors confirms the usefulness of various methods using cephalometric images to assess skeletal age. Currently, the CVM method devised by Baccetti et al. is the most frequently mentioned one in literature.

It seems that bone age assessment methods based on evaluating the morphological structure of the cervical vertebrae in cephalometric images can clearly differentiate skeletal maturity in children regardless of their race or sex. Bearing in mind the constant technological progress in medicine and stomatology, bone age assessment methods need to be perfected in order to alleviate their impact on the patient as much as possible.

MeSH Keywords:

Age Determination by Skeleton • Cephalometry • Cervical Vertebrae

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Background

Usually four criteria are used to determine developmental age: the age of secondary sex characteristics, bone age, dental age and morphological age. Bone age assessment is the main element of orthodontic diagnostics because it allows to detect deviations from the correct growth, determines the choice of the treatment method, allows to identify the right moment to start treatment, helps establish the prognosis and plan retention procedures. It is important for scheduling surgical procedures and for analyzing treatment effects in patients in the same growth stage. The search for the best indicator of the skeletal maturity

level to be used in orthodontics has been going on for years. Maturity indicators based on secondary sex characteristics necessitate a physical examination, which is why they are difficult to determine in an orthodontic office. Orthodontists are able to evaluate sexual development by the occurrence of menstruation in girls and voice change in boys [1]. Thus, radiological indicators of bone age are used in order to assess bone age accurately [2-6]. Radiographs of the hand and wrist are used to determine the presence, size and shape of ossification centers, the width and shape of epiphyseal plates and the extent of the fusion of bone diaphyses with epiphyses. This technique involves visual assessment of particular bones, i.e. their first appearance

in a radiograph and ossification-dependent changes in their shape and size.

The main disadvantage of the method of assessing bone age based on a radiograph of the hand and wrist is the necessity to have an extra X-ray picture taken. Thus, the 1990s saw the comeback of the method using cephalometric images routinely taken while diagnosing the patient [2–5].

A correctly taken cephalometric picture also shows the cervical spine. Regardless of the method of bone age assessment skeletal maturity stages based on the analysis of cervical vertebrae are determined by observing the development of concavities in the lower edge of the vertebral bodies and the change of their shape from trapezoid tapering from posterior to anterior, through rectangular with a larger horizontal dimension of the rectangle, square and again rectangular with a larger vertical dimension of the rectangle [4–12].

The aim of the work is to present the methods and views of different authors on the subject of using cephalometric images (lateral pictures of the skull) allowing to determine bone age of the patients.

Material and Methods

Publications from the PubMed library database were analyzed. Search criteria included the following keywords: bone age assessment – 530 items, CVM method – 824 items. A literature survey was carried out through the following databases: Medline (Entrez PubMed, <http://www.ncbi.nlm.nih.gov/webcite>). The survey covered the period from 1955 to 2008, with no language restrictions. The following search algorithm was used in the databases: bone age assessment and CVM method. Finally, a manual search was also performed by scoring the references within the studies examined and the titles of the papers published in the following journals: American Journal of Orthodontics and Dentofacial Orthopedics, The Angle Orthodontist, European Journal of Orthodontics, Clinical Radiology and American Journal of Orthodontics. Ultimately, 36 papers out of 1354 publications were selected.

Results and Discussion

A cephalometric image is one of the main diagnostic tools in orthodontics. Along with plaster models and panoramic radiographs it is the main source of information for planning the treatment as well as evaluating its course and results. Assessing skeletal maturity of the patient plays a significant role in orthodontic diagnostics as the choice of the method of orthodontic and orthopedic treatment depends on it. Using methods of bone age assessment through the cervical vertebrae allows to limit the patient's exposure to X-rays and reduces the time necessary to plan the treatment [2,4,6–12].

The usefulness of the method of assessing skeletal maturity through the cervical vertebrae has been an area of interest for many researchers [2–6]. Its advantages include reliability in determining the beginning of the growth spurt, no need for an extra radiograph of the hand and wrist to be taken, high level of agreement among researchers in assessing the

Table 1. Comparison of different material and methods of skeletal maturity assessment using cephalometrics on the basis of the literature.

Ref.	No of cases	Method used for skeletal maturity assessment
[5]	24	Cervical vertebral maturation CVM
[9]	72	Cervical vertebral maturation CVM
[15]	141	Lamparski method
[16]	13	Lamparski method
[17]	72	Hassel and Farman
[18]	958	Lamparski method, Hassel and Farman
[19]	176	Mito, Sato and Mitani
[20]	280	Harfin
[21]	30	Cervical vertebral maturation CVM
[22]	30	Cervical vertebral maturation CVM
[23]	29	Cervical vertebral maturation CVM
[24]	42	Cervical vertebral maturation CVM
[25]	21	Cervical vertebral maturation CVM
[26]	1091	Cervical vertebral maturation CVM
[27]	30	Cervical vertebral maturation CVM
[28]	33	Mito, Sato and Mitani
[31]	79	Cervical vertebral maturation CVM

stages, ease of evaluation and the possibility to use it in both sexes. Until recently, an X-ray of the hand and wrist had been the most frequently used image to assess bone age.

Table 1. compares material and methods used by different authors to assess skeletal maturity.

Among the first to assess the changes in the size and shape of the maturing cervical vertebrae were Todd and Pyle in 1928 and Lanier in 1939 [13]. Taylor [14] noticed that the enlargement of the cervical vertebral bodies is associated with skeletal maturation. In 1972 Lamparski [15] was the first to obtain high correlations between bone age determined with the help of an X-ray of the hand and wrist and in a cephalometric image. The author noticed that the cervical vertebrae visible in cephalometric pictures change their shape with time and may be indicators of maturity, thus also of bone age. He examined 72 females and 69 males, aged 10 to 15, selected from amongst 500 patients from the Orthodontic Department of the University of Pittsburgh School of Dental Medicine to create standards, a group of lateral cephalometric images of patients whose chronologic and skeletal age were ± 6 months from the age under study. Those images were arranged in sequence from the least to the most mature based on vertebral development characterized by the presence of an inferior concavity from C2 to C6 and the shape of the third through the sixth

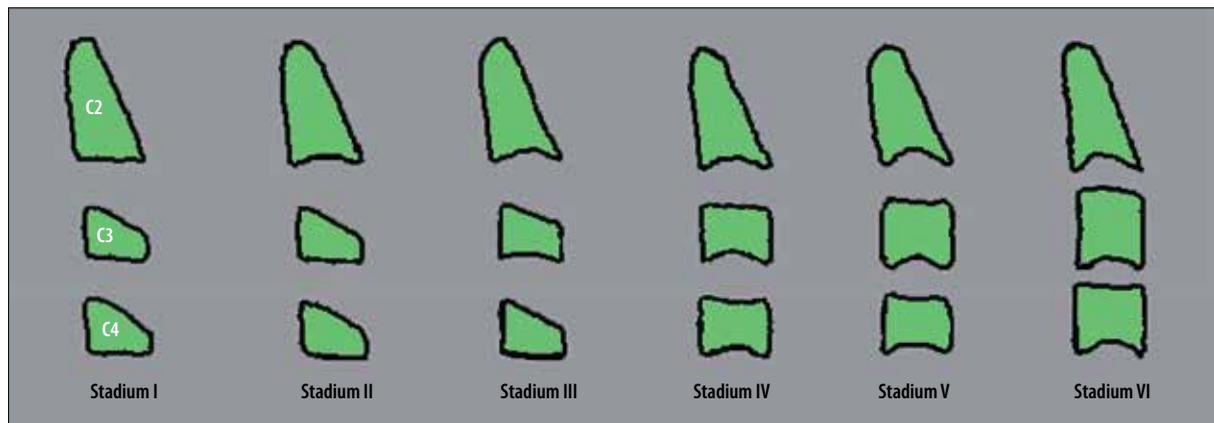


Figure 1. Maturation stages of the cervical vertebrae according to Baccetti et al.

vertebral bodies. The author created the first method of determining bone age based on morphological maturation of the cervical vertebrae. In his work he presented separate standards of morphological maturation of the cervical vertebrae of girls and boys connected with chronological age and bone age assessed through X-rays of the hand and wrist. Lamparski's method is based on the analysis of the changes in the size and shape of the bodies of five cervical vertebrae from C2 to C6 and covers 6 stages of CVS (Cervical Vertebral Stage) development. The author found a weaker correlation for boys than for girls. The CVS1–CVS3 stages are observed before growth peak, i.e. in the stage of growth acceleration, and CVS4–CVS6 stages take place after growth peak or in the stage of deceleration. Growth peak occurs between CVS3 and CVS4 stages [15].

A series of 6 standards was created for each sex, one for each age 10 through 15:

Stage 1 (Age 10): All inferior borders of the bodies are flat. The superior borders are strongly tapered from posterior to anterior.

Stage 2 (Age 11): A concavity has developed on the inferior border of the second cervical vertebra. The anterior vertebral heights of the bodies have increased.

Stage 3 (Age 12): A concavity has developed on the inferior border of the third vertebra.

Stage 4 (Age 13): All cervical bodies from C3 to C6 are rectangular in shape, a concavity has developed on the fourth vertebra. Concavities on C5 and C6 are just beginning to form.

Stage 5 (Age 14): The bodies are nearly square in shape, and the spaces between the bodies are visibly smaller. Concavity of the lower border of all 6 cervical bodies is well defined at this stage.

Stage 6 (Age 15): All cervical bodies have increased in vertical height and all concavities have deepened.

High correlations between bone age determined based on a radiograph of the hand and wrist and in a cephalometric picture were obtained also by O'Reilly and Yainiello in 1988 [16] and by Caltabiano et al. in 1990 [9].

Based on the results of Lamparski's research, Hassel and Farman [17] simplified the method. The Hassel and Farman's method establishes six stages. In this method C2, C3 and C4 vertebrae are analyzed according to their shape

and classified into one of these six stages [17]. They defined six categories of CVM:

Category 1: Was called Initiation; at this stage the inferior borders of C2, C3 and C4 are flat. The vertebrae are wedge-shaped, and the superior vertebral borders are tapered from posterior to anterior.

Category 2: Acceleration: concavities are developing on the inferior borders of C2 and C3. The inferior border of C4 is flat. The bodies of C3 and C4 are nearly rectangular in shape.

Category 3: Transition: distinct concavities are seen on the inferior borders of C2 and C3. A concavity begins to develop on the inferior border of C4. The bodies of C3 and C4 are rectangular in shape.

Category 4: Deceleration is characterized by distinct on the inferior borders of C2, C3, and C4. The vertebral bodies of C3 and C4 are becoming more square in shape.

Category 5: Maturation: more accentuated concavities are seen on the inferior borders of C2, C3, and C4. The bodies of C3 and C4 are nearly square in shape.

Category 6: Completion: Growth is considered to be complete at this stage. Deep concavities are seen on the inferior borders of C2, C3, and C4. The bodies of C3 and C4 are square.

Franchi et al. (2000) adopted Lamparski's original method (1972) for the appraisal of skeletal age in 34 subjects (25 females and 9 males) selected from the files of the University of Michigan Elementary and Secondary School Growth Study [5]. They confirmed the validity of the CVM stages as a biologic indicator for the appraisal of mandibular and skeletal maturity on the basis of a single cephalometric observation and without additional x-ray exposure.

San Roman et al. [18], Mito et al. [19], Harfin et al. [20], and Baccetti et al. [21–26] developed their own modifications of the method of bone age assessment through morphological changes in the cervical vertebrae. Lamparski's method was also modified by Baccetti, Franchi, and McNamara [22]. Similarly to Hassel and Farman they limited the number of vertebrae analyzed while assessing bone age. In 2000 they published the CVM (Cervical Vertebral Maturation) method to assess the maturation of the cervical spine [23]. According to this method only three vertebrae are assessed: C2, C3 and C4 that are visible even with a protective thyroid collar on (Figure 1).

Table 2. 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 (CVM 2)	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 (CVM 3)	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 (CVM 4)	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 (CVM 5)	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 (CVM 6)	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

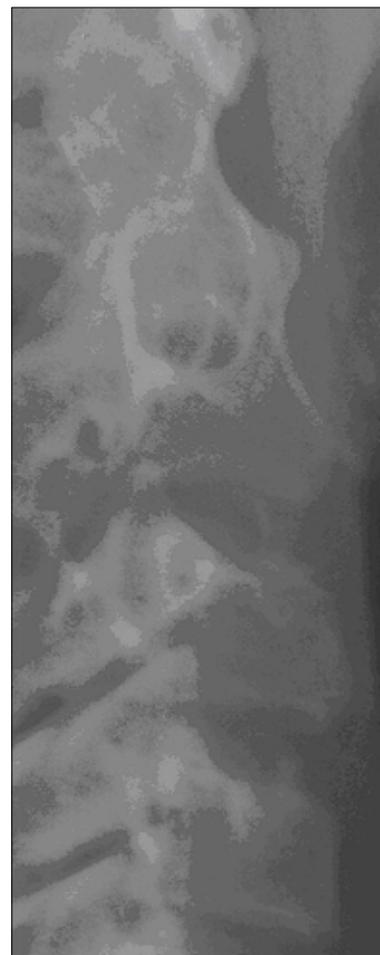
**Figure 2.** An example of stage 1 according to the method of Baccetti et al.**Figure 3.** An example of stage 2 according to the method of Baccetti et al.



Figure 4. An example of stage 3 according to the method of Baccetti et al.

In 2005 Baccetti et al. [22] presented a method to assess bone age through cervical vertebrae that consisted of six stages, CS1-CS6, and presented research results of its clinical application (Table 2, Figures 2–7).

The CS1 and CS2 stages take place before the growth peak, the peak occurs between the CS3 and CS4 stages, while CS5 and CS6 stages occur after the peak (CS6 approximately 2 years afterwards). The authors also evaluated the reproducibility of the classification of cervical vertebrae maturation stages and it is very high, >98% for experienced researchers. As with the previous versions of the method, the size and shape of the bodies of C2, C3 and C4 vertebrae were visually analyzed. The advantages of this method include a simple analysis technique, high level of agreement among researchers in interpreting growth stages and the possibility to use the method in both sexes. According to Baccetti et al. the assessment of the shape of vertebral bodies does not present any difficulties and can be used successfully to forecast growth peaks [22].

Gandini et al. [27] confirmed the correlation between radiographs of the hand and wrist and cephalometric images in relation to assessing skeletal age in patients undergoing orthodontic treatment. Thirty patients aged 7–18 that had both types of X-ray photographs taken were examined.



Figure 5. An example of stage 4 according to the method of Baccetti et al.

Levels of bone age maturation were evaluated with the help of Björk's method on the radiographs of the hand and wrist and with the help of the CVM method in the lateral pictures of the head. The conclusions unequivocally indicated the effectiveness of both methods. The authors reached agreement on the level of 83.3%.



Figure 6. An example of stage 5 according to the method of Baccetti et al.

There were several authors who claimed that bone age assessment on the basis of the cervical vertebrae was as effective in estimating skeletal maturity as radiographs of the hand and wrist. Those were: Baccetti et al. [21–26], Gandini [27], Mitani and Sato [28], Garcia-Fernandez et al. [29], Pancherz and Szyszka [30], San Roman et al. [31], and Flores-Mir et al. [32].

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Figure 7. An example of stage 6 according to the method of Baccetti et al.

Conclusions

The analysis of the cervical vertebrae in cephalometric images seems to be the most appropriate method to determine bone age. Carrying out the analysis through routinely taken cephalometric pictures eliminates the need for additional irradiation of the patient and reduces testing time. The CVM method developed by Baccetti et al. can certainly replace the hand-wrist method in assessing bone age.

Conflict of interests

There is no conflict of interests

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