Estimating physiologic age using cervical vertebral maturation

Valiullah Arash [a] , Reza Nosrati [b], Mahmoud Hajiahmadi [c]

Abstract

Objective: The use of lateral cephalometric radiography for evaluating cervical vertebral bone age is a method that can substitute for the hand-wrist radiography method. The aim of this study was to determine the correlation between the cervical vertebral bone age, chronological age and hand-wrist bone age.

Methods: Lateral cephalometric and hand-wrist radiographs of 125 girls (8-13 years) who needed orthodontic treatments were chosen. The dimensions of the 3rd and 4th cervical vertebral bodies were measured by a digital micrometer caliper with 0.02-mm accuracy and determined a regression formula to obtain cervical vertebral bone age. The data were collected and analyzed by a stepwise multiple regression analysis, and the results were compared with those obtained using the hand-wrist radiography method.

Results: Our investigation shows that the correlation coefficient between cervical vertebral bone age and hand-wrist bone age (0.734) is significantly ($p<0.01$) higher than that obtained for the relationship between cervical vertebral bone age and chronological age (0.367).The correlation between hand-wrist bone age and chronological age was 0.701. In addition, we show that the average difference (absolute value) between cervical vertebral bone age and hand-wrist bone age (0.71±0.59 years) is significantly ($p<0.05$) lower than that between cervical vertebral bone age and chronological age (1.27± 0.92 years).

Conclusions: By using lateral cephalometric radiography, it is possible to carry out a proper evaluation of skeletal maturity without any need for exposing the patient to extra radiation.

Key Words: Physiologic age, Chronological age, Hand-wrist radiography, Lateral cephalometric radiography, Cervical vertebral bone age

It is important to evaluate skeletal maturation in orthodontic treatment. Skeletal maturation can be assessed by various indicators: body height, hand-wrist measurements, menarche, voice change and dental development. Bone age determined with hand-wrist radiographs, as in the Tanner-Whitchouse 2 (TW2), method is the most popular and reliable parameter for evaluating skeletal maturation. However, this method requires hand-wrist radiographs and cervical vertebrae appear on cephalometric radiographs that orthodontists usually use in planning treatment. Lamparski published an atlas that simulated the morphological changes in cervical vertebral bodies in puberty and used these changes to evaluate skeletal maturations.[1]

Grave[2] and Caltabiano[3] have shown a considerable statistical relation between cervical perfection age and skeletal age in men and women. Hellsing [4] and Kuckkeles[5] have observed similarities between perfection of

[a]Assistant Professor, Orthodontics Department, Babol University of Medical Sciences
[c]Epidemiologist, Babol University of Medical Seinces

Corresponding author:
Valiullah Arash
Email: 1344@yahoo.com

vertebra and skeletal maturity indicators in hand-wrist . McNamara [6] and Chen [7] found out that Cervical vertebral maturation appears to be an appropriate method for the appraisal of mandibular skeletal maturity in individual patients on the basis of a single cephalometric observation and without additional x-ray exposure. The accuracy of the cervical vertebral method in the detection of the onset of the pubertal spurt in mandibular growth can help in treatment timing of mandibular deficiencies. These studies indicated that skeletal age assessment derived from the maturational changes of cervical vertebrae were reliable, reproducible and valid. Roman etal. [8] reported A new method to evaluate the cervical maturation. They studied the changes in the concavity of the lower border, height, and shape of the vertebral body. The best morphological vertebral parameter to estimate the maturation, is the concavity of the lower border of the body.Mito [1] suggested that cervical vertebral bone age reflects skeletal maturity while it approximates hand-wrist bone age, which is considered to be the most reliable method for evaluating skeletal maturation. Using cervical vertebral bone age, it may be possible to evaluate maturity in a detailed and objective manner on cephalometric radiographs.Mito[9] assessed the possibility of using cervical vertebral bone age determined from cephalometric radiographs to predict mandibular growth potential. The formula derived from this study might be useful in the treatment of orthodontic patients who are in the growth stage. Carlos [10] studied correlation between the Fishman maturation prediction (FMP) and the cervical vertebral maturation (CVM) method for skeletal maturation stage determination. A Spearman correlation value of 0.72 ($P < .001$) was found between the skeletal maturation stages of two methods. Paola etal. [11] assessed radiographic hand-wrist bone analysis and cephalometric cervical vertebral analysis of 30 patients. The hand-wrist bone analysis was evaluated by the Bjork index, whereas the cervical vertebral analysis was assessed by the cervical vertebral maturation stage (CVMS) method. They concluded that Vertebral analysis on a lateral cephalogram is as valid as the hand-wrist bone analysis with the advantage of reducing the radiation exposure of growing subjects. Ozer [12] reported, The cervical vertebrae have 6 maturation phases and the medial phalange of the third finger has 6 stages. The purpose of his study was to determine the correlation of the cervical vertebrae maturation index with the medial phalange index .The results showed that the 6 medial phalange stages correlate with the 6 cervical vertebral maturation stages. Liu [13] investigated correlation between the skeletal maturation determined by cervical vertebrae and hand-wrist. The spearman correlation coefficient was 0.882 for females. Soegiharto etal. [14] aimed to determine the effectiveness of the skeletal maturation index (SMI) and the cervical vertebrae maturation (CVM) index in discriminating between patients who are going to attain their peak pubertal growth, compared with those who have reached or passed it. The results put the necessity of taking hand-wrist radiographs and exposing a child to additional radiation in doubt while the discriminatory ability is similar with the CVM index, which is readily derived from most lateral cephalograms.Chen[15] investigated to establish a quantitative cervical vertebral maturation (CVM) system for adolescents with normal occlusion. This study showed that quantitative CVM method is an efficient, objective, and relatively simple approach to assess the level of skeletal maturation during adolescence. Al Khal etal. [16, 17] reported that CVM is a valid indicator of skeletal growth maturation during the circumpubertal and has a high correlation with the hand wrist maturation (HWM) for the Southern Chinese population.

Uysal [18] investigated about (1) the relationship between chronologic age and maturation of cervical vertebrae, (2) identification of the relationship between chronologic age and maturation stage evaluated by hand-wrist radiographs. The results showed cervical vertebrae maturation stages are clinically useful maturity indicators of the pubertal growth period. We are going to do more studies to clear up this method properties and its potential for determining skeletal age. The purpose of this study is to evaluate the use of cervical vertebrae

maturation Method (CVM) for evaluating of skeletal maturity by lateral cephalometry.

Materials and methods:

One hundred and twenty five female patients were divided into 5 equal size groups (Table 1).

Age group (year)	Number	Mean age
8-8.9	25	8.45
9-9.9	25	9.44
10-10.9	25	10.49
11-11.9	25	11.35
12-12.9	25	12.57

Table1: Composition of groups

Hand-wrist and lateral cephalometric radiographies were prepared by the same center at the same time. The dimensions of the third and fourth cervical vertebrae were traced with pencil (0.5 mm) in lateral cephalometric radiographies and measured by digital micrometer For the third and fourth vertebrae in all samples, we measured anterior height of the vertebral body (AH), vertebral body height (H), height of the vertebral body posterior (PH), and anterior-posterior length of the vertebral body (AP).1 Initially, we traced a line comprising inferior anterior dots (A) and inferior posterior dots (B) (AB line). The AB line is the inferior limit of the cervical vertebrae. Then a perpendicular line was drawn from the anterior superior (D) and posterior superior (C) dots on the AB line.

As a result, the anterior height (AH) and cervical vertebral posterior height (PH, the distance between superior dots and the inferior line) were obtained by tracing perpendicular to cervical vertebral anterior height. We also drew a line parallel with AB to represent vertebral body posterior-anterior length (AP). Body height was determined by tracing the bisector perpendicular to AB (Figure 1).

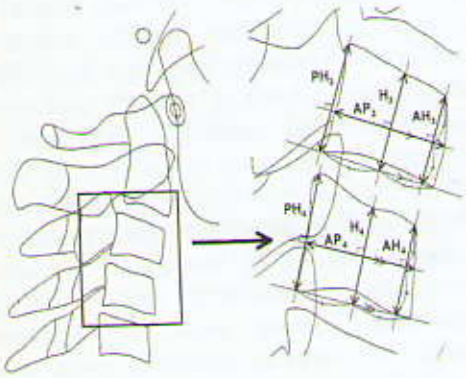


Figure 1. Method for measuring third and fourth cervical vertebral dimensions.

The formula used required the following ratios between these measures:

AH/AP, H/AP, PH/AP, AH/H, H/PH, AH/PH.

Next, several models were created using different vertebral dimension ratios, and the ability of each model to predict bone age was evaluated. Among the different models, AH4/AP4, AH4/PH4, and AH3/AP3 were significant. Using these ratios and physiologic age (hand-wrist bone age), The following formula was extracted through step-wise multiple regression:

$Wi = \alpha + \beta Xi + \upsilon \gamma_i + \eta z_i + \cdots$. In order to determine cervical vertebral bone age, the following values were used in this formula:

Wi = cervical vertebral bone age, xi=AH3/AP3, Yi=AH4/AP4, and Zi =AH4/PH4.

Hand-wrist bone age and cervical vertebral bone age were evaluated to validate this formula; for this purpose, the relationship between these two parameters, as well as between chronological age and cervical vertebral bone age, was determined. To determine chronological age, we calculated the difference between the birth date as presented on the birth certificate and the date from the radiograph sheets. Hand-wrist bone age was reported by a radiologist on the basis of the Brown's Atlas.

All lateral cephalometric radiographs were traced and measured by one person. Cervical vertebral bodies were measured because several researchers have reported a correlation between changes in cervical vertebral body and growth.[1,3,5-18] Furthermore, vertebral bodies can be measured easily. Abnormal cervical vertebral bodies result from laceration, deformation, destruction, inflammation, tumors and other causes. However, such abnormalities are rare and were not observed in this study. We selected only the third and fourth cervical vertebrae because the first cervical vertebra (atlas) has no distinguishing body. The second cervical vertebra (axis) displays few figure changes and is rarely measured. The final cervical vertebra cannot be seen clearly in lateral cephalometric radiography. The ratio between dimensions was used for calculating cervical vertebral bone. Using this method, only the shape of the cervical vertebra was considered and its size was not calculated. In hand-wrist radiography, bone age is used for determining cervical vertebral bone age. The techniques used in this study estimate bone age more accurately in relation to chronological age. Operator error was determined from ten lateral cephalometric radiographs that were chosen randomly and traced after ten days. For data analysis we used the following statistical methods:

1) Regression (forward, backward, and stepwise) for determining significant coefficients in predicting bone age.
2) Stepwise multiple regression for the cervical vertebral bone formula.
3) t-test for measuring operator error.

Results:

Lateral cephalometric and hand-wrist radiographs of 125 girls (8-13 years) who needed orthodontic treatments were chosen in Babol Dental School. After data analysis, The average error between the first and the second measurements for all parameters (absolute value) was 0.064. The ratios of third and fourth cervical vertebrare demonstrated a steeper ascending order between 8-13years olds.

Next, to solve determinant according to Keramer method , we used a regression formula for calculating cervical vertebral bone age based on the ratio of 3th and 4th cervical vertebral body measurements (Figures 1,2,3). Hand-wrist bone age was the dependent variable and the ratios between variables were independent.

$$Wi = -0.049 - 0.417\,X_i + 10.875\,Y_i + 5.587\,Z_i$$

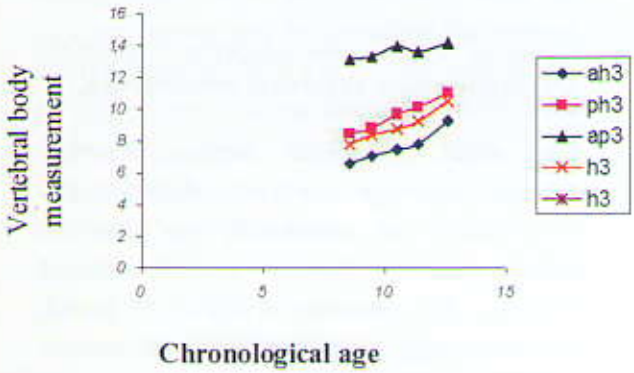


Figure 1: Mean size of the third cervical vertebral dimension relative to chronological age.

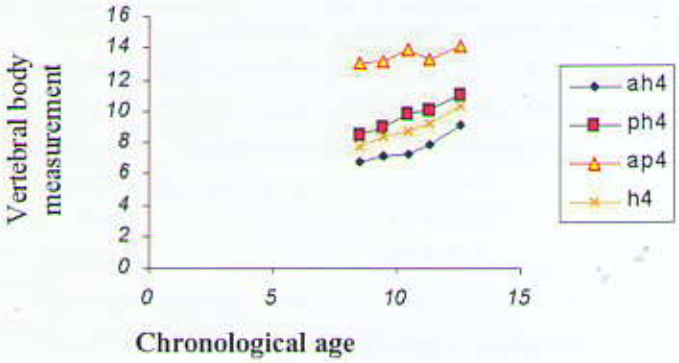


Figure 2: Mean size of the fourth cervical vertebral dimension relative to chronological age.

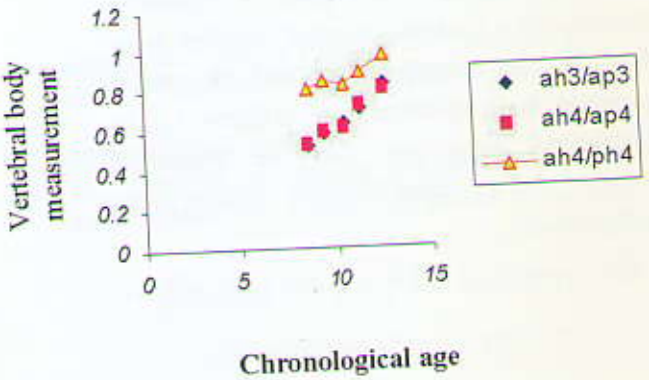


Figure 3: The ratios AH/AP4, AH4/PH4, AH3/AP3 relative to cervical vertebral age.

The mean difference between cervical vertebral bone age and hand-wrist bone age (0.71 years) was considerably less than the average difference between cervical vertebral bone age and chronological age (1.27 years). The correlation coefficient between cervical vertebral bone age and hand-wrist bone age (0.734) was considerably greater than the correlation coefficient between cervical vertebral bone age and chronological age (0.367) (Table 2, Figures 4 and 5).

	Mean difference (years)
CVA & HBA	0.71± 0.59
CVA & CA	1.27± 0.92
HBA & CA	0.79± 0.55
	Correlation coefficient
CVA & HBA	0.734
CVA & CA	0.367
HBA & CA	0.701

CVA=cervical vertebral age
HBA=Hand-wrist bone age
CA=chronological

Table 2: The average difference between cervical vertebral bone age, hand-wrist bone age, and chronological age.

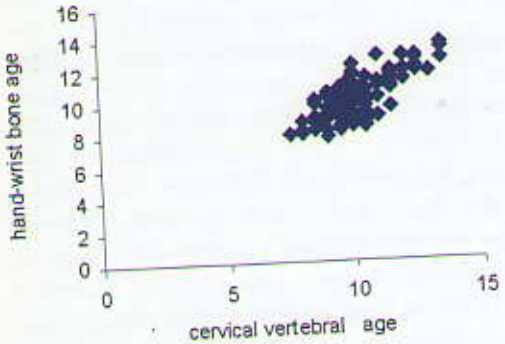


Figure 4: Correlation between vertebral age and hand-wrist bone age

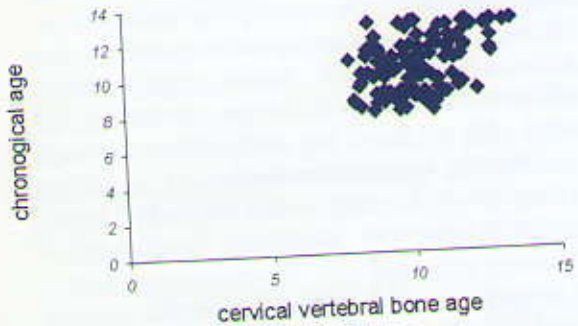


Figure 5: Correlation between vertebral bone age and chronological age

Discussion:

The present study highlights the fact that CVM is accurate enough to evaluate skeletal perfection. When using the nine-step hand-wrist method(Hand-wrist bone age) , the correlation coefficient between cervical vertebral bone age and bone age (r =0.734) was considerably ($p<0.01$) greater than the correlation coefficient between cervical

vertebral age and chronological age (r =0.324) (Figure 4, 5). Furthermore, the difference between cervical vertebral bone age and bone age (0.71 years) was considerably ($p<0.05$) less than the difference between cervical vertebral bone age and chronological age (1.27years). Therefore the correlation between cervical vertebral bone age and hand-wrist bone age (according to the nine-step method) was much greater than the correlation between cervical vertical bone age and chronological age (table 2, 3). Various groups [1,3,5-18] have used CVM method and all of these studies accepted the relationship between hand-wrist radiography and lateral cephalometry, using lateral cephalometery as an indicator of growth maturity.

While Roman[8] used cervical vertebral figural properties (vertebral inferior edge concavity and the square shape of vertebrae) to determine the natural growth step, we used the ratio between vertebral dimensions in this study. If cervical vertebral figural properties are used, it is important to remember that skeletal maturity is an extended process and skeletal maturity indicators in hand-wrist and cervical vertebrae are grouped by limited properties. Each stage of maturity mixes with the next, and sometimes diagnosing the middle stage point can be difficult. However, from a clinical viewpoint, these differences should not be important. When using the ratio between vertebral dimensions and analytical formulas, the result should be a defined figure for the patient's bone age (with acceptable error), which is an advantage.

In our data analysis, we used hand-wrist bone age as a dependent parameter, while Mito[1] used chronological age. Using chronological age has a disadvantage; there are independent parameters (vertebral ratios) on one side of the equation and dependent parameters (considered age) on the other side. Hence, if chronological age is used, the result for the next stages and future predictions will be chronological age, rather than bone age. The formula obtained cannot be used as a scale for evaluating lateral cephalometric radiography as a natural growth indicator and comparing it with hand-wrist radiography.

Mito[9] highlighted the precision of chronological age in comparison with hand-wrist bone age. Brown's nine-stage hand-wrist radiographic method for determining bone age is a well-known and valid method that guesses the real bone age with a maximum error of 2-6 months. Given that the nine-stage method for determining bone age using hand wrist radiography is the most reliable method for measuring maturity degree and skeletal age, cervical vertebral bone age can also identify skeletal maturity, because it closely approximates hand-wrist bone age. Therefore, future studies on skeletal maturation should take this factor into consideration. A larger sample size may be required to confirm the findings of this study. In the present study, the relationship between cervical vertebral bone age and hand-wrist bone age was explored. Future studies could investigate the relationship between cervical vertebral maturity and Insulin-like growth factor I (IGF-I).Our limitations were difficult in providing hand-wrist radiographs and low quality of some lateral cephalograms.

Conclusions:

Cervical vertebral bone age determined by cephalometric radiography has sufficient reliability to allow bone age estimation, similar to that obtained with the hand-wrist radiography method. Thus, patients for whom cephalometric radiographs are available need not be exposed to additional radiation.

Acknowledgments:

We appreciate the sincere cooperation of employees in the Sina Haghanifar Office and the Kaghaz Institute.

References:

1. Mito T, Sato K, Mitani H. Cervical vertebral bone age in girls . Am J Orthod Dentofacial Orthop.2002;122: 380-5.
2. Grave K, Brown T. Skeletal Ossification and adolscent growth spurt. Am J Orthod Dentofacial Orthop . 1976;6: 611-19.
3. Caltabiano M, Leonardi R, Zaborra G. Evaluation of cervical vertebrae for determination of skeletal age. Riv Ital. Odonthoiatr Infant.1990; 1:15-20.
4. Hellsing E. Cervical vertebral dimensions in 8-11 and 15-year-old children. Acta Odontol Scand.1991 ;49:207-13.
5. Kucukkeles N , Acar A , Biren S , Arun T .Comparison between cervical vertebrae and hand-wrist maturation for the assessment of skeletal maturity. J Clin Pediatr Dent.1999 ;24:47-52.
6. McNamara JA Jr, Baccetti T, Franchi L .Mandibular growth as related to cervical vertebral maturation and body height .AmJ Orthod Dentofacial Orthop.2000;118:335-40.
7. Chen KC , Chang HF, Yang YH , Liao CH ,Chan HP .Correlation of cervical vertebra maturation with hand-wrist maturation in children. Kaohsing J Med Sci .2001;17:29-35.
8. Roman PS, Palma JC, Oteo MD, Nevado E .Skeletal maturation determined by cervical vertebrae development. Eur J Orthod .2002; 24:303-11.
9. Mito T , Sato K , Mitani H .Predicting mandibular growth potential with cervical vertebral bone age .Am J Orthod Dentofacial Orthop.2003;124:173-7.
10. Flores-Mir C, Burgess CA, Champney M, Jensen RJ, Pitcher MR, Major PW . Correlation of skeletal maturation stages determined by cervical vertebrae and hand-wrist evaluations. The Angle Orthodontist 2006; 76(1):1-5.
11. Paola G, Mancini M, Andreani F. A comparison of hand-wrist bone and cervical vertebral analyses in measuring skeletal maturation. Angle Orthod .2006; 76: 984-9.
12.Ozer T, Kama JD, Ozer SY. A practical method for determining pubertal growth spurt. Am J Orthod Dentofacial Orthop 2006; 130:131 -6.
13. Liu HH ,Sun Y, You QL. Correlation of adolescents skeletal maturation determined by cervical vertebrae and hand wrist in Shanghai region. Shangai Kou Qiang Yi Xue .2007;16:365-9
14- Soegiharto BM, Moles DR, Cunningham SJ. Discriminatory ability of the skeletal maturation index and the cervical vertebrae maturation index in detecting peak pubertal growth in Indonesian and white subjects with receiver operating characteristics analysis. Am J Orthod Dentofacial Orthop 2008 ;134:227-37
15. Chen LL,Xu TM,Jiang JH,Zhang XZ,lin JX. Quantitative cervical vertebral maturation assessment in adolescents with normal occlusion: a mixed longitudinal study. Am J Orthod Dentofacial Orthop 2008; 134(6):720.e1-720.e7
16. ALkhal HA,Wong RW,Rabie AB . Correlation between chronological age, cervical vertebral maturation and Fishman's skeletal maturity indicators in Southern Chinese.Angle Orthod. 2008 ;78:591-6.
17. Alkhal HA, Wong RW, Rabie AB. Elimination of hand-wrist radiographs for maturity assessment in children needing orthodontic therapy. Skeletal Radiol. 2008 ;37:195-200.
18. Uysal T, Ramoglu SI,Basciftci FA, Sari Z.Chronologic age and skeletal maturation of the cervical vertebrae and hand-wrist : is there a relationship? Am J Orthod Dentofacial Orthop. 2008 ;78:591-6