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ORIGINAL ARTICLE

New model for cervical vertebral bone age estimation in boys

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Abstract The objective of this study was to test the validity of a newly developed statistical model in establishing the cervical vertebral bone age in growing children. The sample of the study consisted of lateral cephalometric and hand-wrist radiographs of 122 Saudi male children. Subjects were divided based on their chronological age into six groups: 10–15 years. The metric dimensions of the vertebral body of the third and fourth cervical vertebrae were measured from the lateral cephalometric radiographs and a statistical model was developed through a stepwise multiple regression analysis to calculate the cervical vertebral bone age. The validity of the statistical model was assessed against the bone age and skeletal age determined from the hand-wrist radiographs using the Tanner–Whitehouse 3 method and the Greulich and Pyle atlas method. No significant ($P < 0.05$) difference and high correlation were found between the calculated cervical vertebral bone age and the bone/skeletal age established by the hand-wrist methods. No significant ($P < 0.05$) difference and high correlation were demonstrated between the calculated cervical vertebral bone age and the chronological age. The results of this study indicate that the established statistical formula for cervical vertebral bone age calculation is useful in determining the skeletal maturation in growing children as the other well-established hand-wrist methods.

1. Introduction

Assessment of physical body maturation is an essential element of multiple clinical health practices [4]. Generally, chronological age is not an accurate measure of the actual growth status and overall physical maturation [14]. Therefore, skeletal maturation is routinely evaluated to indicate the level of body maturation and to determine the remaining growth potential in children [9].

Skeletal maturation can be assessed by evaluating the degree of ossification of certain bony markers located within the skeletal system. Most commonly, the phalanges and

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metacarpal bones offer a convenient method of estimating the skeletal maturity level through hand-wrist radiographs [8]. Likewise, Greulich and Pyle atlas [13] and Tanner–Whitehouse 3 (TW3) methods [21] are considered as reliable methods for determining the skeletal/bone age from hand-wrist radiographs. However, all hand-wrist methods for skeletal maturation evaluation require the acquisition of hand-wrist radiographs with the risk of increased exposure of patients to radiation. More recently, the cervical vertebral maturation method has started to replace the conventional hand-wrist methods for the evaluation of individual skeletal maturation in the practice of orthodontics [3,10]. The direct visibility of cervical vertebrae in the routine lateral cephalograms obtained during orthodontic diagnosis and the established validity and reliability of the cervical vertebral maturation method in evaluating skeletal maturity have all contributed to its wide acceptance and application today [6,11].

The cervical vertebral bone age (CVBA) is a relatively new method of objectively evaluating the skeletal maturation through dimensional measurements of the vertebral body of the third (C3) and fourth (C4) cervical vertebrae [18]. The rationale of this study was to derive a statistical formula using a stepwise multiple regression analysis for the purpose of determining the CVBA in Saudi male children from the dimensional parameters of cervical vertebrae.

2. Materials and methods

The sample of this study consisted of standardized lateral cephalometric and hand-wrist radiographs of 122 Saudi male subjects (10–15 years of age) attending the Orthodontic Clinic at the College of Dentistry, King Saud University, Riyadh, Saudi Arabia. The subjects were divided into six groups based on the chronological age as determined from the birth date documented in the subject's dental chart. All subjects included in this study have fulfilled the following conditions: (a) Free of any serious illness and have normal growth events, (b) No previous trauma or injury to the head and neck region, and (c) No form of previous orthodontic treatment.

All cephalometric radiographs were traced and measured by a single experienced examiner in a darkened room using an illuminated viewing box. The following measurements were performed on the vertebral body of C3 and C4: anterior vertebral body height (AH), vertebral body height (H), posterior vertebral body height (PH), and anteroposterior vertebral body length (AP), as shown in Fig. 1. Also, the following ratios between these parameters for each cervical vertebra were calculated: AH/H, AH/PH, AH/AP, H/PH, H/AP, and PH/AP. The intra-examiner reliability of the method was assessed by re-tracing and re-measurement of 10 randomly selected cephalometric radiographs two weeks later. The correlation coefficient values between the two readings were calculated to determine the reliability of measurements.

The chronological age and the ratios between the measured parameters were used to derive a statistical model to determine the CVBA through a stepwise multiple regression analysis.

The hand-wrist radiographs were utilized to determine the skeletal/bone age of the subjects using the well-established methods of Greulich and Pyle atlas and TW3 [13,21]. The ability of the derived statistical model in establishing the CVBA was determined by studying the statistical difference in the average error between the bone age as established by the cervical vertebral method and the two hand-wrist methods by applying a paired *t*-test at 95% confidence ($P < 0.05$). Similarly, the difference in the average error between the CVBA and chronological age was studied using the same statistical test. Also, the correlation coefficient between the CVBA, the hand-wrist bone age established by the two methods, and the chronological age was calculated. All statistical analyses were

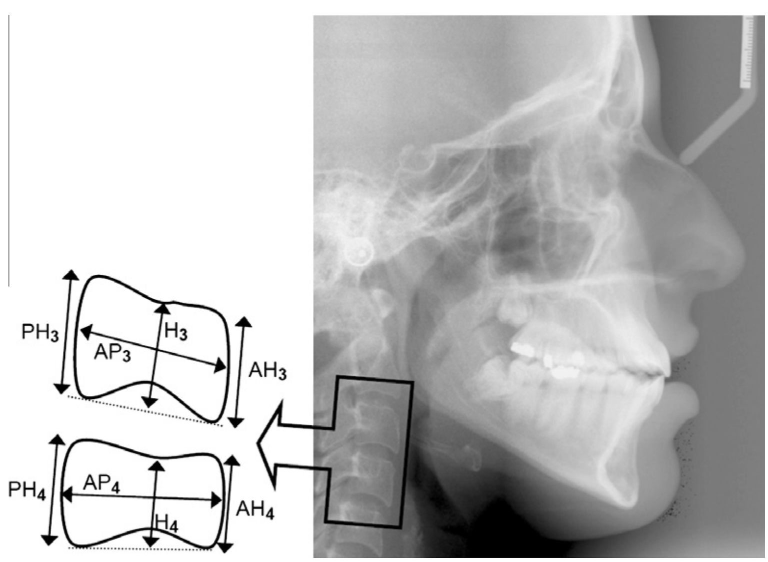

Figure 1 Measurements performed to calculate the cervical vertebral bone age on the third and fourth cervical vertebrae (C3, C4) appearing on lateral cephalometric radiograph. AH: distance from the most superior to the most inferior point on the anterior surface of the vertebral body; AP: maximum anteroposterior distance at the middle of cervical vertebral body; H: distance from the top of the middle part of the vertebral body to a tangent connecting the most inferior points of the lower border; PH: distance from the most superior to the most inferior point on the posterior surface of the vertebral body.

Table 1 The mean value (±*SD*) of vertebral body parameters of the third and fourth cervical vertebrae among different study groups.

Age group (years)						
(mm)	10 (n = 20)	11 (n = 19)	12 (n = 19)	13 (n = 22)	14 (n = 21)	15 (n = 21)
AH3	6.65 ± 0.76	7.95 ± 0.81	9.18 ± 1.08	10.68 ± 1.25	12.31 ± 0.98	13.17 ± 0.98
H3	9.25 ± 0.88	10.84 ± 0.93	12.03 ± 1.15	13.14 ± 1.36	14.24 ± 1.09	15.19 ± 1.36
PH3	11.43 ± 1.74	11.82 ± 0.90	12.87 ± 0.88	14.30 ± 1.00	14.17 ± 1.14	14.98 ± 0.91
AP3	12.93 ± 1.52	13.13 ± 1.01	13.87 ± 0.88	13.86 ± 0.90	13.24 ± 0.93	13.43 ± 0.83
AH4	7.13 ± 0.90	8.08 ± 0.82	9.21 ± 1.10	10.73 ± 1.25	11.05 ± 0.92	12.38 ± 0.82
H4	8.78 ± 0.99	9.68 ± 0.90	10.63 ± 1.15	12.25 ± 1.31	12.24 ± 0.85	13.62 v 0.91
PH4	11.25 ± 0.99	11.45 ± 1.10	12.24 ± 1.07	14.02 ± 1.11	14.52 ± 1.18	15.19 v 1.16
AP4	13.18 ± 0.83	13.42 ± 1.17	13.87 ± 0.85	12.82 ± 1.01	13.05 ± 1.02	14.02 ± 0.64

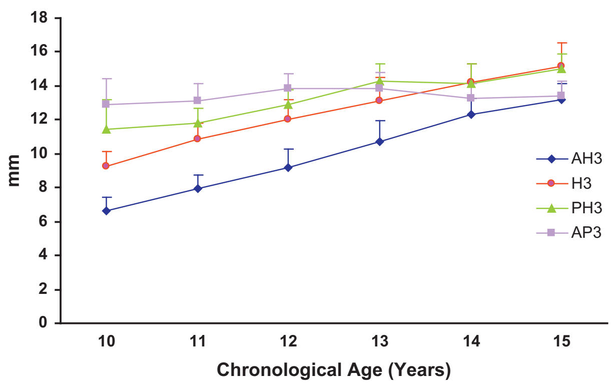

Figure 2 The mean value (±*SD*) of the vertebral body measurements of C3 at each chronological age group.

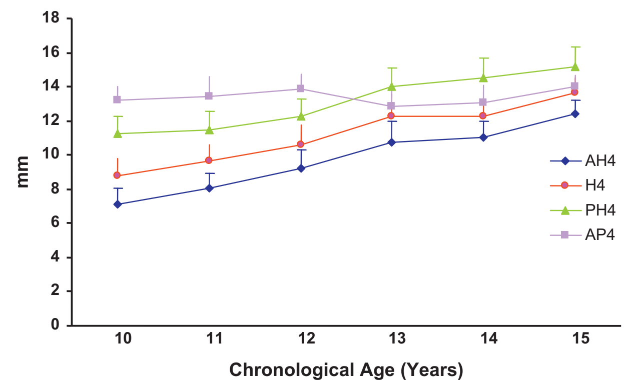

Figure 3 The mean value (±*SD*) of the vertebral body measurements of C4 at each chronological age group.

performed using SPSS software package (Version 12, SPSS Inc., Chicago, IL, USA).

3. Results

The mean values (±*SD*) of the measured vertebral parameters are presented by age group (Table 1). A high reliability of the measurement method was demonstrated by the high correlation value between the first and second readings for all parameters (r = 0.972, P < 0.01).

The mean values (±*SD*) of the vertebral body parameters of C3 and C4 at each chronological age group are plotted in Figs. 2 and 3, respectively. AH, H, and PH of both vertebrae showed a relatively steady increase between the ages of 10 and 15 years (Figs. 2 and 3). However, the AP parameter of both vertebrae remained relatively unchanged during the same age period (Figs. 2 and 3).

Also, the ratios between all parameters were calculated and applied through the stepwise multiple regression analysis to derive the most suitable statistical model for CVBA calculation. The ratio AH/AP of both C3 and C4 was chosen by the stepwise multiple regression analysis to calculate the CVBA according to the following formula:

$$\text{Cervical Bone Age} = 5.406 + 4.682 \times \text{AH3/AP3} + 4.925 \times \text{AH4/AP4}$$

Both AH3/AP3 and AH4/AP4 showed a steady increase between the ages of 10 and 13 years (Fig. 4). After that, only

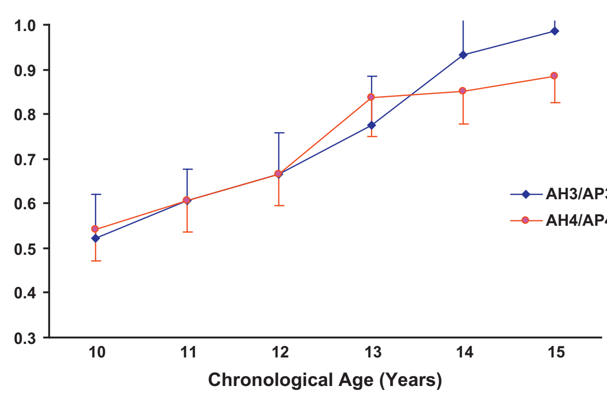

Figure 4 The ratio (±*SD*) between vertebral body measurements of C3 and C4 that had been chosen by stepwise multiple regression analysis at each chronological age group.

AH3/AP3 exhibited an accelerated increase until the age of 15 years (Fig. 4).

No significant (P < 0.05) difference between CVBA and chronological age was found as demonstrated by the small average difference and the high correlation coefficient value between the two ages (Table 2, Fig. 5). Also, the ability of the study method to establish the bone age was demonstrated by the insignificant (P < 0.05) difference between the calculated CVBA and the bone age established by the TW3 method

Table 2 Difference and correlation between cervical vertebral bone age (CVBA) and chronological age (CA), bone age as determined by TW3 method (TW3), and skeletal age as determined by Greulich and Pyle atlas method (GP).

	Average difference (absolute value) (years ± *SD*)	Correlation coefficient
CVBA – CA	0.298 ± 0.230	0.910
CVBA – TW3	0.197 ± 0.110	0.933
CVBA – GP	0.354 ± 0.115	0.905

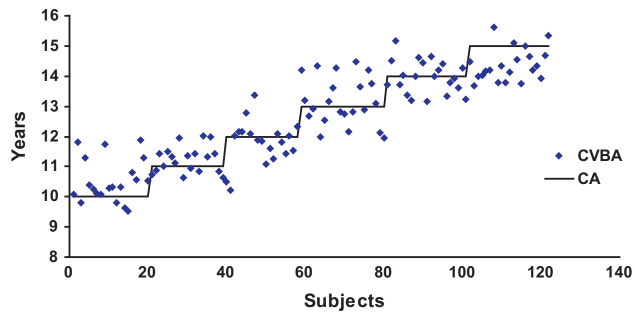

Figure 5 Scattergraph of cervical vertebral bone age (CVBA) and chronological age (CA) for all subjects.

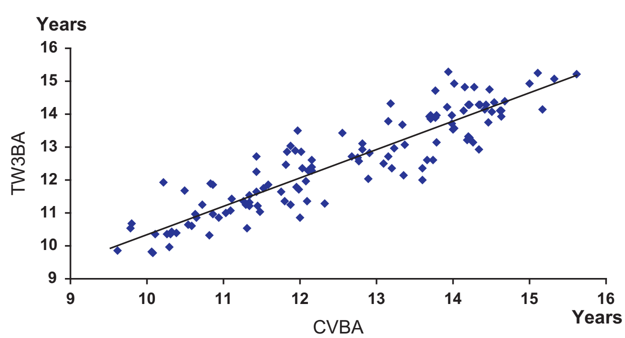

Figure 6 Scattergraph of cervical vertebral bone age (CVBA) and bone age determined by TW3 method (TW3BA).

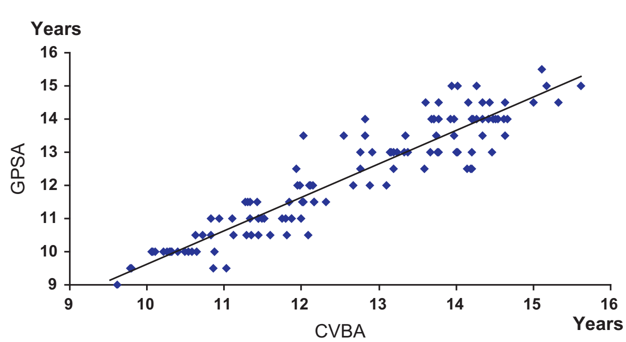

Figure 7 Scattergraph of cervical vertebral bone age (CVBA) and skeletal age determined by Greulich and Pyle atlas method (GPSA).

and the skeletal age determined by the Greulich and Pyle atlas method (Table 2, Figs. 6 and 7). Moreover, the correlation coefficient values demonstrated a high correlation between the CVBA and the bone/skeletal age determined by the two hand-wrist methods (Table 2).

4. Discussion

The use of cervical vertebrae to assess individual skeletal maturation is gaining an increased attention in the literature [12,6,11]. The conventional cervical vertebral maturation method for skeletal maturation assessment is based on subjective evaluation of the shape and dimensions of cervical vertebrae [3]. Cervical vertebral bone age calculation offers the increased advantage of objectively evaluating the skeletal maturation from lateral cephalometric radiographs by measuring the dimensional parameters of C3 and C4 [18]. In this study, a statistical model was derived through a stepwise multiple regression analysis to calculate the cervical vertebral bone age in a group of growing Saudi male children utilizing the ratios between vertebral body dimensions of C3 and C4.

Only male subjects were considered in the current study to avoid any sex-related variations in growth pattern and timing of maturational changes of the cervical vertebrae [17]. The age group of the sample was selected based on the observed morphological changes in the cervical vertebral body dimensions during this period of growth [15,3]. The C3 and C4 were chosen for evaluation in this study because of the difficulty in locating and measuring morphological body changes in the first top two vertebrae and the usual lack of appearance of the lower cervical vertebrae in routine lateral cephalometric radiographs [20]. The use of ratios between the vertebral body dimensions in developing the statistical model was to negate any possible magnification effect in the radiographic technique. The high intra-examiner reliability of the measurement method observed in this study reflects the strong predictability and usefulness of this technique in the clinical practice.

Previous investigations have used statistical models to calculate the cervical bone age in different populations [18,5]. However, the study of Mito et al. [18] was limited to Japanese girls and the formula developed by Caldas Mde et al. [5] was specific for Brazilians. Children with a different racial background and developing under different environmental conditions may exhibit a different growth velocity and/or pattern [1,2]. Thus, developing a specific formula to calculate the cervical bone age in Saudi children is useful for indicated clinical implications.

In this study, the ratio AH/AP of C3 and C4 was implicated in the formula to calculate the CVBA. This was in contrast to Mito et al. [18] who also utilized the ratio AH4/PH4 in their formula. However, Caldas Mde et al. [5] used the same ratios (AH3/AP3, AH4/AP4) in the formula to calculate the CVBA in females, whereas the ratios AH3/AP3 and H4/AP4 were used for the male subjects. These differences in the ratios selected by the stepwise multiple regression analysis model demonstrate and confirm the variation in morphological changes during cervical vertebral maturation related to gender and ethnic background.

All vertebral body parameters of C3 and C4 demonstrated an accelerated increase during the studied growth period except for the AP parameter which remained almost constant

after the age of 12 years (Table 1, Figs. 2 and 3). This finding is in agreement with the observation of Mito et al. [18] who reported minor change of the AP dimension of both C3 and C4 after the age of 12 years. However, the study by Caldas Mde et al. [5] reported an accelerated increase in the AP3 parameter from 12 to 15 years in the male sample only. Nevertheless, this finding of the current study, along with the reported findings from other studies [18,5], demonstrates that the anteroposterior morphological changes in the vertebral body of C3 and C4 are less evident than the vertical maturational changes during the studied growth period.

The two hand-wrist methods (TW3 method and Greulich and Pyle atlas method) to determine the skeletal/bone age were selected to evaluate the ability of the derived formula in establishing the bone age because of their established reliability and wide clinical use [16,19]. Both methods offer an objective evaluation of the skeletal maturation which is important for comparison with the findings of the current study. The average CVBA calculated by the derived statistical model was found to be closely related to the average bone age estimated by the TW3 method and the skeletal age determined by the Greulich and Pyle atlas method (Table 2). Also, the ability of the derived formula in establishing bone age was further assured by the high correlation between the calculated CVBA and the bone age established by the two hand-wrist methods (Table 2). In general, this finding is common among related previous studies [18,5], although the other studies have used only one hand-wrist method to evaluate the CVBA calculation method. Moreover, the study of Mito et al. [18] had utilized the TW2 method evaluation instead of the TW3 method used in this study.

The chronological age has long been considered as an unreliable marker for skeletal maturation [7,14]. However, in this study, a strong correlation was found between the CVBA and the chronological age (Table 2). Similar finding has also been reported by related previous studies [18,5]. This close association between chronological age and the skeletal maturity indicators established by various reported methods in this study and other similar studies indicates that chronological age might serve at the end as an acceptable general indicator of the skeletal maturation for clinical use in the studied population groups.

5. Conclusions

The results of this study indicate that the CVBA established by the described statistical formula is as dependable in determining the skeletal maturation as the other well-established hand-wrist methods of TW3 and Greulich and Pyle atlas. The chronological age remains to be an acceptable indicator of skeletal maturation in growing Saudi male children.

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