Computer-assisted analysis of cervical vertebral bone age using cephalometric radiographs in Brazilian subjects

Maria de Paula Caldas[a]
Gláucia Maria Bovi Ambrosano[b]
Francisco Haiter Neto[c]

[a] DDS, MSc Resident, Division of Oral Diagnosis; [b] Agr Eng, PhD, Professor, Department of Community Dentistry; [c] DDS, PhD, Chairman, Division of Oral Diagnosis – Piracicaba Dental School, University of Campinas, Campinas, SP, Brazil.

Abstract: The aims of this study were to develop a computerized program for objectively evaluating skeletal maturation on cephalometric radiographs, and to apply the new method to Brazilian subjects. The samples were taken from the patient files of Oral Radiological Clinics from the North, Northeast, Midwest and South regions of the country. A total of 717 subjects aged 7.0 to 15.9 years who had lateral cephalometric radiographs and hand-wrist radiographs were selected. A cervical vertebral computerized analysis was created in the Radiocef Studio 2 computer software for digital cephalometric analysis, and cervical vertebral bone age was calculated using the formulas developed by Caldas *et al.*[17] (2007). Hand-wrist bone age was evaluated by the TW3 method. Analysis of variance (ANOVA) and the Tukey test were used to compare cervical vertebral bone age, hand-wrist bone age and chronological age ($P < 0.05$). No significant difference was found between cervical vertebral bone age and chronological age in all regions studied. When analyzing bone age, it was possible to observe a statistically significant difference between cervical vertebral bone age and hand-wrist bone age for female and male subjects in the North and Northeast regions, as well as for male subjects in the Midwest region. No significant difference was observed between bone age and chronological age in all regions except for male subjects in the North and female subjects in the Northeast. Using cervical vertebral bone age, it might be possible to evaluate skeletal maturation in an objective manner using cephalometric radiographs.

Descriptors: Cervical vertebrae; Orthodontics; Software; Radiography.

Introduction

Timing is a fundamental part of treatment planning in orthodontics. Starting treatment in a growing patient at the right time has demonstrated significant favorable effects in the correction of disharmonies in the sagittal, transverse, and vertical planes.[1,2]

Orthodontic movement, represented by the displacement of a tooth, can be performed regardless of age, as long as the mechanotherapy respects the biology of the periodontium. However, the repositioning of the apical bases for the correction of skeletal discrepancies with orthopedic appliances requires the support of facial growth. Thus, a treatment with orthopedic objectives is best performed while the forces of the physiological growth are active.[3] The prepubertal growth period is the best time

Corresponding author:
Maria de Paula Caldas
Av. Limeira, 901
Piracicaba - São Paulo - Brazil
CEP: 13414-900
E-mail: *caldasmaria@hotmail.com*

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to start orthopedic treatment of skeletal malocclusions because it is a favorable phase for craniofacial alterations, coordinating orthopedic-orthodontic procedures.[4]

In addition to the chronological age, there are many biological parameters involved in determining the stage at which a given subject is positioned in the growth curve. Among these parameters are dental development, sexual maturation characteristics, body height, weight, and skeletal age.[3-6]

The skeletal age represents the most reliable means and the most utilized method at the moment.[7] The standard method for evaluating skeletal maturity has been to use a hand-wrist radiograph to compare the bones of an individual's hand with those in published atlases.[7-11] However, to avoid taking an additional radiograph, the cervical vertebrae, as seen on routine lateral cephalograms, have been used to determine skeletal maturity.[12-14]

It is well known that the lateral view of the cervical vertebral bodies changes with growth. In recent years, evaluation of the cervical vertebrae has been increasingly used to determine skeletal maturation. Many authors have reported a high correlation between cervical vertebrae maturation and skeletal maturation of the hand-wrist.[13-16] They found that cervical vertebrae could offer an alternative method for assessing maturity without the need of hand-wrist radiographs. However, cervical vertebrae have been used to evaluate growth in a subjective manner because they have used only a qualitative comparison between the patient images and those from atlases.

Thus, Caldas *et al.*[17] (2007) developed two new formulas for objectively evaluating skeletal maturation in female and male Brazilian subjects using cephalometric radiographs. However, the sample used to derive the formulas consisted of subjects only from the state of São Paulo, which is located in the Southeast region of the country.

Table 1 - Patient distribution according to geographic region.

Region	Boys	Girls
North	43	41
Northeast	203	243
Midwest	56	41
South	34	56

Based on these formulas, the purpose of this study was to develop a computerized program for objectively evaluating skeletal maturation on cephalometric radiographs and to apply the new method to Brazilian subjects from the North, Northeast, Midwest and South regions of the country.

Material and Methods

This descriptive study was designed as a cross-sectional research project. The sample was taken from the patient digital files of six Oral Radiological Clinics from the North, Northeast, Midwest and South regions of the country. A total of 717 subjects (381 girls and 336 boys) aged 7.0 to 15.9 years were selected (Table 1). Ethical approval was obtained from the Piracicaba Dental School Committee after the Ethical Principles in Research Program examination.

Radiographic images taken between June 2000 and April 2008 were selected. Because the radiographs were selected from the digital files of Oral Radiological Clinics, no information about the patients was available. Thus, patients were included if they fulfilled the following criteria: (1) Subjects had a Brazilian ethnic origin, regardless of ethnic-racial classification, (2) the radiographs presented high quality and allowed good visualization of anatomical structures, specifically the third and fourth cervical vertebral bodies, (3) all lateral cephalometric radiographs and hand-wrist radiographs were taken at the same time.

A cervical vertebral computerized analysis was created in the Radiocef Studio 2 computer software for digital cephalometric analysis (Radio Memory Ltda., Belo Horizonte, MG, Brazil). On the digital lateral cephalograms, anatomical landmarks were marked on the third and fourth cervical vertebrae (Figure 1):

- **C4ai, C4pi:** the most inferior points of the anterior and posterior borders of the body of C4.
- **C4as, C4ps:** the most superior points of the anterior and posterior borders of the body of C4.
- **C4ai':** the intersection of the base line (C4ai-C4pi) with a perpendicular line passing through

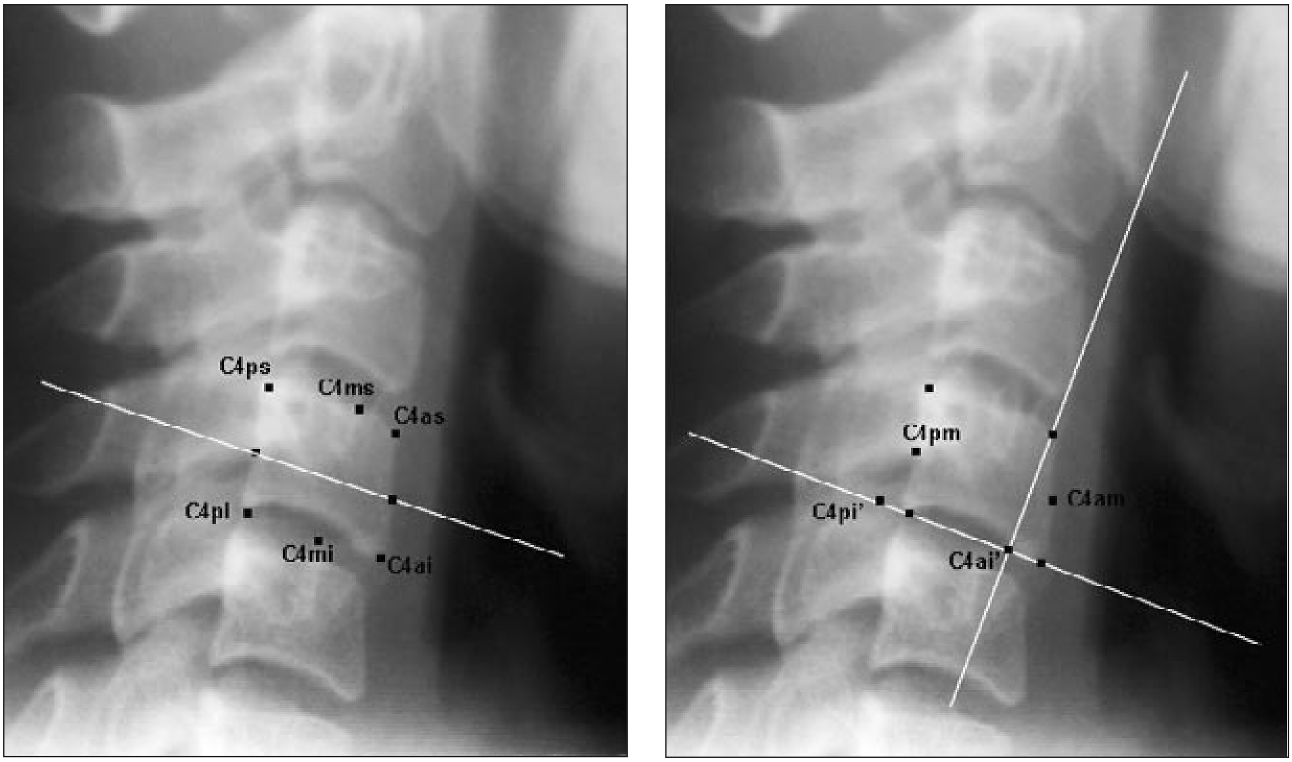

Figure 1 - Anatomical landmarks marked on the digital lateral cephalograms.

C4as.

- **C4pi':** the intersection of the base line (C4ai-C4pi) with a perpendicular line passing through C4ps.
- **C4mi:** middle point of the base line (C4ai-C4pi).
- **C4ms:** the intersection of the base line (C4ai-C4pi) with a perpendicular line passing through C4mi. It is marked on the superior border of the body of C4.
- **C4am:** middle point of the C4as-C4ai line.
- **C4pm:** the intersection of the C4as-C4ai line with a perpendicular line passing through C4am. It is marked on the posterior border of the body of C4.

The name and definition of each landmark were indicated on screen. Image improvement resources such as brightness control, inversion, pseudo-coloring, and zoom could be used to make it easier to find each point. With the aid of these landmarks, the following measurements were automatically obtained:

- **Anterior vertebral body height (AH):** distance from *C4as* to *C4ai'*.
- **Vertebral body height (H):** distance from *C4mi* to *C4ms*.
- **Posterior vertebral body height (PH):** distance from *C4ps* to *C4pi'*.
- **Anteroposterior vertebral body height (AP):** distance from *C4am* to *C4pm*.

Cervical vertebral bone age was automatically calculated using the formulas developed by Caldas *et al.*[17] (2007).

$$\text{Female cervical vertebral bone age} = 1.3523 + 6.7691 \times \frac{AH3}{AP3} + 8.6408 \times \frac{AH4}{AP4}$$

$$\text{Male cervical vertebral bone age} = 1.4892 + 11.3736 \times \frac{AH3}{AP3} + 4.8726 \times \frac{H4}{AP4}$$

Hand-wrist bone age was evaluated by the TW3 method, which assessed specific ossification centers of the hand and wrist (radius, ulna, and selected metacarpals and phalanges), leading to their classification into one of several stages. Scores were derived from each bone stage and calculated to compute the skeletal age.

Intra-operator error was calculated according to Dahlberg's formula[18] (1940) using 10 cephalometric radiographs selected randomly; these were measured with the computer software, and the same radiographs were measured again 10 days later. The formula revealed values below 1.0, indicating sufficient accuracy of the measurements.

Analysis of variance (ANOVA) was used to compare cervical vertebral bone age, hand-wrist bone age and chronological age. Follow up Tukey tests were used to identify specific differences. All analyses were performed with a significant level of 5%.

Results

Statistical analysis showed no significant difference between cervical vertebral bone age and chronological age in all regions studied (Tables 2-9).

Table 2 - North region: Mean and standard deviation (SD) of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the girls' sample.

Group	Mean	SD
CVBA	11.9088 b	1.9162
HWBA	12.3078 a	2.3322
CA	12.1934 ab	2.1838

Means followed by different lowercase letters differ statistically, with a significant p-value of 5% by the Tukey test. **(aplicable to tables 2 through 9)**

Table 3 - North Region: Mean and standard deviation of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the boys' sample.

Group	Mean	SD
CVBA	13.2272 b	1.9133
HWBA	13.8446 a	1.9618
CA	13.3995 b	1.8370

Table 4 - Northeast region: Mean and standard deviation of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the girls' sample.

Group	Mean	SD
CVBA	12.4083 b	2.0596
HWBA	12.6495 a	2.4617
CA	12.3849 b	2.3326

Table 5 - Northeast region: Mean and standard deviation of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the boys' sample.

Group	Mean	SD
CVBA	12.7582 b	2.2395
HWBA	13.0756 a	2.5405
CA	12.7987 ab	2.3484

Table 6 - Midwest region: Mean and standard deviation of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the girls' sample.

Group	Mean	SD
CVBA	11.9239 a	2.0430
HWBA	12.2836 a	2.5567
CA	12.0366 a	2.2363

Table 7 - Midwest region: Mean and standard deviation of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the boys' sample.

Group	Mean	SD
CVBA	12.4582 b	1.8105
HWBA	12.9093 a	1.9336
CA	12.7030 ab	1.9911

Table 8 - South region: Mean and standard deviation of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the girls' sample.

Group	Mean	SD
CVBA	11.3530 a	2.0549
HWBA	11.5673 a	2.0646
CA	12.3252 a	2.1217

Table 9 - South region: Mean and standard deviation of cervical vertebral bone age (CVBA), hand-wrist bone age (HWBA) and chronological age (CA) for the boys' sample.

Group	Mean	SD
CVBA	11.5912 a	1.3357
HWBA	11.7382 a	1.5833
CA	11.5620 a	1.9293

When analyzing bone age, it was possible to observe a statistically significant difference between cervical vertebral bone age and hand-wrist bone age for female and male subjects in the North and Northeast regions, as well as for male subjects in the Midwest region. However, the differences encountered were no more than 0.61, 0.31 and 0.45 years in the North, Northeast and Midwest regions, respectively (Tables 2, 3, 4, 5, and 7).

No significant difference was observed between bone age and chronological age in all regions except for male subjects in the North and female subjects in the Northeast, which were 0.44 and 0.26 years, respectively (Tables 3 and 4).

Discussion

The hand-wrist radiograph has classically been used to determine the maturation level of a child. To avoid taking additional radiographs, the cervical vertebrae investigation method has become more popular in recent years. Almost all authors found statistically significant correlations between hand-wrist and skeletal maturation of the cervical vertebrae.[5,13,14,16] The present study found a statistically significant difference between cervical vertebral bone age and hand-wrist bone age for female and male subjects in the North and Northeast regions, as well as for male subjects in the Midwest region. Even though the differences between cervical vertebral bone age and hand-wrist bone age were statistically significant, they were very low in both sex groups. Thus, these results question the necessity of taking hand-wrist radiographs when lateral cephalograms are routinely used for orthodontic documentation.

Similarly to this study, Soegiharto *et al.*[19] (2008) compared the cervical vertebral maturation (CVM) index and the skeletal maturation index (SMI) in both Indonesians and white subjects and found a statistically significant difference between both indexes. We agree that caution must be taken when interpreting the results of the present study because it was based on cross-sectional data, which have limitations for analyzing growth. Ideally, studies of this type should be longitudinal, but the difficulties involved in obtaining large sample sizes and the associated increase in the number of radiographic exposures tend to rule out the application of this methodology. Still, another factor to be considered in this study is that different sample sizes were used in each region studied, although the overall sample size was satisfactory. Even though the patient files of the Oral Radiological Clinics were large, it was very difficult to find lateral cephalometric radiographs and hand-wrist radiographs taken on the same day.

It has long been recognized that an individual's chronologic age does not necessarily correlate well with his maturation age. Skeletally, one may be retarded or advanced in various degrees of deviation from the actual chronological age.[20,21] In this study, no significant difference was observed between bone age and chronological age in all regions except for male subjects in the North and female subjects in the Northeast, which were 0.44 and 0.26 years, respectively. However, Hunter reported that the difference between bone age and chronological age is considered normal when it does not exceed one year.[22]

For the present study, radiographs were selected from the patient files of six Oral Radiological Clinics, presenting good visualization of the cervical vertebrae. As to the methodology employed in this work, masking of patient identification was a very important factor in preventing the influence of knowing the chronological age on the determination of the stage in which subjects were positioned in the growth curve. The randomized choice of radiographs pertaining to patients ranging from 7 to 15.9 years was intended to include all the maturation stages in the period during which patients seek orthodontic treatment and with the possibility of taking advantage of the craniofacial growth.

Almost all previous evaluations based on cervical vertebrae on cephalometric radiographs used the method reported by Lamparski[13] (1972) and modified by Hassel, Farman[15] (1995). This method takes into account morphological characteristics of the cervical vertebrae, such as concavity of the lower border and height and shape of the vertebral bodies. However, cervical vertebrae have been used to evaluate growth in a subjective manner. Özer *et al.*[23] (2006) reported that there are some situations where one maturational stage blends into the next, and it is difficult to classify in some borderline cases. For this reason, our study used the method of Caldas *et al.*[17] (2007) instead of the classification of Lamparsky[13] (1972), which is of great importance because it allows skeletal age to be calculated in an objective manner.

Many investigators have suggested that the size and shape of the cervical vertebrae change from birth to full maturity at each level of skeletal development.[6] Baccetti *et al.*[1] (2002) showed that only the shape changes of C2, C3, and C4 were enough to show skeletal maturation. However, C2 is very difficult to measure and it shows little morphological change. In this study, we measured the third and fourth cervical vertebral bodies because the cervical vertebras lower than C4 cannot be observed when a thyroid protective collar is worn during radiation exposure.

Brazil is the largest country in South America. It is divided into five geographic regions, each with its own distinct characteristics: the North, Northeast, Midwest, Southeast, and South. Many studies have been performed on skeletal maturation and its capacity to predict and identify the adolescence growth spurt. However, all of them were conducted in specific states of the country and, even though they were performed with Brazilian people, the obtained results present inherent limitations for interpretation, as they do not represent the overall population of the country. In this study, we selected individuals from the North, Northeast, Midwest, and South regions, since the Southeast region had already been studied by Caldas *et al.*[17] (2007).

Cephalometric analysis is an important tool in orthodontic diagnosis, treatment planning, evaluation of treatment results, and prediction of growth. Rapid advances in computer science have led to its wide application in cephalometry. As a result, in recent years, digital cephalometric analysis has gained popularity in orthodontic practices. The use of modern cephalometric software requires importing digital cephalograms or digital capture of analogue data.[24] Based on the fact that no study has assessed cervical vertebral maturation using a computer software for digital cephalometric analysis, in this research we developed a cervical vertebral computerized analysis for objectively evaluating skeletal maturation on cephalometric radiographs.

Conclusions

In determining the relationship among chronological age, cervical vertebrae and hand-wrist skeletal maturation, the results suggest that the method develop by Caldas *et al.*[17] (2007) for objectively evaluating skeletal maturation on cephalometric radiographs can be used to determine bone age in Brazilian subjects.

The computerized analysis created to automatically calculate cervical vertebral bone age is reliable and can be used to increase objectivity. The computer software used in the present study was found to be suitable for daily orthodontic diagnostics when treating Brazilian patients.

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