Maturation of cervical vertebrae and chronological age in children and adolescents

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ABSTRACT
In maxillary orthopedics and related areas, it is essential to determine patient growth peak in order to provide timely diagnosis and treatments. This requires the use of biological indicators that enable children and adolescents to be assigned to maturation stages. The aim of this study was to determine the correlation between cervical vertebrae maturation stages and chronological age in children and adolescents. In this study were evaluated 93 lateral cranium radiographs of 6- to 17-year-old patients who visited the Postgraduate Maxillary Orthopedics Clinic at the School of Dentistry at Universidad del Zulia. Two examiners made independent assessments of cervical vertebrae maturation stage using the method described by Baccetti et al. For each stage, descriptive statistics for chronological age were evaluated, classified according to sex. In addition, parametric and non-parametric tests were performed in which p <0.05 was considered significant. Mean age of the children and adolescents studied was 9.6 years, with standard deviation 2.5 years. The correlation coefficient (r=0.771) certified a high positive correlation between bone maturation and chronological age. This correlation coefficient was highly positive for girls (r=0.858) and moderately positive for boys (r=0.688). The model obtained explains 59.4 % of the variation between bone maturation and chronological age, evidencing an average age increase of three years when maturation stage increases by approximately 1 year. The results suggest that although the degree of covariance between chronological age and maturation stages was highly positive in this study, chronological age does not allow bone maturation to be determined precisely, since it may be influenced by genetic and/or environmental factors.

Key words: Cervical vertebrae, age, bone age.

INTRODUCTION
Throughout human life, the different periods of growth and development involve biological transformations that characterize an individual and are influenced by genetic and environmental factors. The study of craniofacial growth is essential for diagnosis and therapeutic planning in orthodontics and maxillary orthopedics. Some authors¹⁻⁵
highlight the need to identify the degree of skeletal maturation in order to begin treatment of certain craniofacial skeletal alterations in a timely manner. Treatments with removable appliances in functional or dentofacial orthopedics during the early developmental stage or during the pubertal phase increase the therapeutic efficacy of the treatment of class II dysgnathia, according to Perinetti et al. and at dentoalveolar level.

Bone maturation is evaluated by means of different biological indicators such as height, weight, chronological age, dental age, carpal x-rays or cervical vertebrae. When the degree of biological maturity is evaluated according to dental, skeletal and chronological age, there may be inconsistencies, and all three indicators are often studied for patient diagnosis. Nevertheless, skeletal age is the most reliable method for determining an individual’s physical development.

The determination of growth periods through the evaluation of cervical vertebrae has been supported by Baccetti et al., Haseel et al. and McNamara et al. Other studies criticize the subjective nature of such evaluations. Gray et al. claim that the analysis of cervical vertebrae may be useful for determining whether mandibular growth spurt has occurred.

Bone maturation can be studied in the cervical vertebrae viewed in lateral cephalic radiographs instead of by taking left-hand radiographs, thereby reducing patient exposure to radiation. The study of cervical vertebrae bone maturation is controversial, so further research is needed to contribute more in-depth knowledge to different areas. The aim of the current study was to determine the correlation between cervical vertebrae maturation stages and chronological age, categorized according to sex, in a group of children and adolescents aged 6 to 17 years.

**MATERIALS AND METHODS**

**Patients**

One hundred and three (103) patients of both sexes, 6 to 17-year-old, who attended the clinic in the program “Atención integral del niño y adolescente” (Comprehensive child and adolescent care) of the Postgraduate Degree in Maxillary Orthopedics at the School of Dentistry of University del Zulia (FACOLUZ), Maracaibo City, Zulia State, Venezuela, between March 2012 and June 2016, were selected for this study. Inclusion criteria were: children and adolescents born in Venezuela, with lateral cephalic x-ray of cranium taken at beginning of orthopedic treatment and showing up to fourth cervical vertebra, and complete clinical history. Exclusion criteria were: patients undergoing orthodontic treatment, patients with craniofacial syndromes or malformations, patients with structural problems in cervical vertebrae or related diseases, patients with special healthcare needs, lateral cephalic radiographs with distortion. All parents and/or representatives of the children who participated in the study signed an informed consent after having the purpose of the study explained to them and in accordance with the Ethics Code for Life of the Ministry of Popular Power for Science, Technology and Intermediate Industries of the Bolivarian Republic of Venezuela and the principles of the Declaration of Helsinki.

**Study Design**

A cross-sectional correlational study was conducted. The selected images were assessed by two raters who made independent assessments of cervical vertebral maturation stage using the method described by Baccetti. A lateral cephalic cranial x-ray is requested as part of the examinations required for the FACOLUZ maxillary orthopedics post-graduate diagnostic protocol. All radiographs were taken at the same radiological center.

**Estimation of bone maturation**

To estimate the cervical vertebrae maturation, the selected radiographs were digitalized using a SONY DSC-W220 digital camera. To obtain the images, the radiographs were placed on a conventional portable negatoscope, without flash. Subjects’ sex and age in years were recorded. Digitalized images were evaluated using Adobe Photoshop software. Brightness, contrast and magnification features were used during assessment. The two raters were trained and calibrated following the method described by Baccetti, by evaluating 10 lateral cephalic radiographs of children and adolescents. The Kappa coefficient was calculated, finding intra-rater reliability 0.85 to 0.92 and inter-rater reliability 0.81.
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Statistical analysis of results

After obtaining the database on an Excel file, statistical analysis was performed using the IBM SPSS Statistics 24 package. Descriptive statistics were used to obtain frequency tables, contingencies, central tendency measures and dispersion, which enabled adequate interpretation of the set of qualitative and quantitative variables included in the study. Normality assumptions for ages per comparison group were tested using Shapiro-Wilk’s test, and equality of variances were tested by Levene’s test. In both cases, rejection of the null hypothesis indicated the need to use non-parametric tests to compare age means (Kruskal-Wallis test). All tests used a statistical significance level of 0.05.

RESULTS

A total of 93 child and adolescent lateral cephalic radiographs were included in the study. Ten radiographs were excluded due to problems of image distortion. Of the cephalic radiographs included in the study, 51 were females (54.8%) and 42 males (45.2%). Subject age ranged from 6 to 17 years, with mean age 9.6 years and standard deviation 2.5 years, median and mode 9.0 years. Average age for females was 9.4 years with standard deviation 2.5 years, and average age for males was 9.9 years with standard deviation 2.5 years. Mann-Whitney’s U test for comparison of means between girls and boys indicated no significant difference (p =0.332) (Table 1).

Analysis of cervical bone maturation showed that the percentages of children and adolescents in stages I, II, III, IV, and V were 33.3%, 28.0%, 24.7%, 10.8%, and 3.2%, respectively. Bone maturation stages according to sex were similar to those described above. For stage I, percentage was 33.3% for both girls and boys, decreasing progressively up to stage V, where it was 3.9% for girls and 2.4% for boys (Table 1). The chi-square test applied to determine the association between the variables, ‘sex’ and ‘bone maturation stage’ showed independence between these variables (p=0.489). This result needs to be interpreted with caution considering that in cross tabulation, more than 20% of the expected frequencies were lower than 5.

The average difference between the mean values for chronological ages was 1.5 years between stages I, II and III, and 2.4 years between stages III, IV and V (Table 2).

Considering that at each stage (I, II, III, IV, V) the number of subjects is approximately 30 (in stage I) or lower than 30 (Table 2), Shapiro-Wilk’s test was used to test the normality assumption for ages in each group, finding that age distribution is not normal at all stages. Levene’s test for the assumption of homogeneity of variances found p=0.010, therefore the null hypothesis was rejected and variances considered unequal.

The Kruskal-Wallis test to determine variability of mean chronological ages among the different stages showed that they differ significantly (p<0.001). The dispersion diagram (Fig. 1) relating chronological age to the different stages of cervical maturation shows that bone age increases as chronological age increases in the children and adolescents of both sexes studied, reflecting a positive correlation between these variables. Pearson’s correlation coefficient (r=0.771) shows a positive correlation between

Table 1: Mean values for ages and cervical bone maturation stages according to sex.

<table>
<thead>
<tr>
<th></th>
<th>Girls</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard deviation</td>
<td>Mean</td>
<td>Standard deviation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>9.4</td>
<td>2.5</td>
<td></td>
<td>9.9</td>
<td>2.5</td>
<td>0.332</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>17</td>
<td>33.3</td>
<td>14</td>
<td>28.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>11</td>
<td>21.6</td>
<td>12</td>
<td>4.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>8</td>
<td>15.7</td>
<td>2</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>2</td>
<td>3.9</td>
<td>1</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>51</td>
<td>100.0</td>
<td>42</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
these two variables, and was highly positive for girls ($r=0.858$), and moderately positive for boys ($r=0.688$).

A simple linear correlation model was obtained between chronological age and bone age. The result of the ANOVA test ($p < 0.05$) indicated the possibility of constructing a linear regression model with these two variables, with the following predictive model:

\[
\text{STAGE} = -1.07 + 0.34 \cdot \text{AGE}
\]

According to Pearson’s correlation coefficient ($r$), the correlation between chronological age and cervical bone maturation stage in this model is moderate, while the coefficient of determination ($R^2$) indicates that the model can predict 59.4% of the variability of the stage through the variability of chronological age. Moreover, the equation indicates that when chronological age is increased by one year, stage will vary by 0.34 years.

For female subjects, the correlation between chronological age and bone age was highly positive, while for males it was moderately positive. The linear model obtained for females predicts 73.6% of the variability of bone maturation through chronological age, while for males it predicts 47.4%. The linear regression model for females and males can be seen in the following equations, respectively.

\[
\begin{align*}
\text{STAGE} &= -1.545 + 0.411 \cdot \text{AGE} \\
\text{STAGE} &= 0.277 \cdot \text{AGE}
\end{align*}
\]

**DISCUSSION**

The results of this study on 93 children and adolescents show great variability regarding age and sex in the different maturation stages. The percentages for the whole sample decrease successively as bone maturation increases, as do the percentage of males and females independently. Similar results were reported in the study by Plazas$^{16}$.

The Chi square test applied to determine the association between the variables sex and bone maturation stage provided a non-statistically significant result ($p=0.489$), thereby demonstrating independence between these variables. Similar results were reported by Bedoya$^{17}$ ($p=0.120$), who found no association between those variables.

The results of the current study show that bone age increases as in chronological age of children and adolescents of both sexes increases, with a highly positive correlation between the variables, expressed with the result of Pearson’s correlation coefficient $r=0.771$. When the samples of both sexes were studied separately, the correlation was highly positive for females, $r=0.858$ and moderately positive for males, $r=0.688$.

Considering the results reported by Bedoya$^{17}$, with a highly positive correlation ($r=0.69$), the results reported by Seyed$^{18}$ in a study on 196 females aged 9 to 14 years, with a low correlation ($r=0.62$) between chronological age and cervical maturation.

<table>
<thead>
<tr>
<th>Stage</th>
<th>N</th>
<th>Mean chronological age</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>31</td>
<td>7.71</td>
<td>1.296</td>
</tr>
<tr>
<td>II</td>
<td>26</td>
<td>9.04</td>
<td>1.865</td>
</tr>
<tr>
<td>III</td>
<td>23</td>
<td>10.61</td>
<td>1.699</td>
</tr>
<tr>
<td>IV</td>
<td>10</td>
<td>13.00</td>
<td>1.491</td>
</tr>
<tr>
<td>V</td>
<td>3</td>
<td>15.33</td>
<td>2.082</td>
</tr>
</tbody>
</table>

**Fig. 1: Dispersion diagram for the variables chronological age and bone age.**
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stage, and adding the results of the current study regarding Pearson’s correlation coefficient, it can be inferred that even though the degree of covariance between the variables ‘chronological age’ and ‘maturation stages’ in the current study was highly positive, chronological age does not enable bone maturation to be determined precisely as reported by Bedoya. The paper by Bedoya highlights the fact that the values of maturation stage increase as chronological age increases in both sexes, in agreement with the current study. However, according to Bedoya, Tukey’s post-hoc test indicates that this occurs only up to stage 3. In the current study, the non-parametric tests used did not allow this type of analysis to be performed.

The model obtained in the current study explains 59.4% of the variation in maturation stage and chronological age, showing that when average age increases by three years, bone maturation stage increases by approximately 1 year, in contrast to other studies which explain 50.4% of the variability in chronological age in children and adolescents.

The results of the current study show that female children and adolescents attained higher maturation stages at earlier ages, in agreement with Bedoya.

CONCLUSIONS
There is no association between sex and bone maturation stage.
There is a positive correlation between chronological age and cervical bone maturation stages. Bone age increases as chronological age increases. For girls, the correlation was highly positive, while for boys it was moderately positive.
This study shows once again that girls attain bone maturation stages at earlier ages than boys do.

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