Correlation between dental maturation and bone growth markers in paediatric patients

R. MOURELLE, E. BARBERÍA, N. GALLARDO, T. LUCAVECHI

**ABSTRACT.** Aim Many studies have been made to evaluate the growth, development and maturation of cervical vertebrae. These studies make clear how those vertebrae have growth patterns and centre of ossification similar to those in carpal bones, therefore cervical vertebrae can be used to determine bone age. The aim of the present study is the observation of cervical vertebrae in cephalometric radiographs to determine the bone age in a paediatric population and relate it to dental maturation. **Materials and methods** The sample was composed of 203 children from Madrid, aged between 2 and 10 years. There were 86 males and 117 females, in each case a panoramic was taken to determine dental calcification using Demirjian method and a cephalometric radiograph was taken to evaluate cervical vertebrae maturation. Different vertical and horizontal dimensions were measured to determine maturation. **Results** The results show that there is a positive relationship between age and size of cervical vertebrae. The average horizontal measurements of the third, fourth and fifth cervical vertebrae presented statistically significant differences in size (p<0.05), being larger in boys than in girls. Statistical correlation was found between dental maturation and increased left vertical measures from third (C3VI) and fourth cervical vertebrae (C4VI), as well as middle vertical measure from fourth cervical vertebra (C4VMD). **Conclusion** Significant changes in size were observed only in vertical measurements and the predictive measurements for dental maturation were C4VI, C4VMD and C3VI.

**KEYWORDS:** Bone maturation, Vertebra development, First permanent molar.

**Introduction**

The study of growth and development is of special interest because this is a period of great growing activity during which each child or adolescent grows at their own rate, which is not just a reflection of their chronological age [Meredith, 1959; Spier, 1918; Hägg and Taranger, 1985; Cozza et al., 2005].

Skeletal maturation/bone age is a measure of the progress of ossification towards maturity and is usually assessed by bone morphology and mineralization. However, skeletal maturation can also be assessed by studying specific bones such as those of the hand or the cervical vertebrae [Burstone, 1963; Hägg and Taranger, 1984, Steward et al., 1982].

Assessment of growth, development and maturation of the cervical vertebrae in human beings has been extensively studied, showing patterns of development and ossification nuclei of vertebrae similar to those of the carpus so they too can be used to reliably evaluate bone age [Lamons and Gray, 1958; Franchi et al., 2000; Kucukkeles, 1999; García-Fernandez, 1998].

In 1963, Bench published a study stressing the apparent relationship between growth of the jaw and that of the cervical vertebrae. He noted great variations in growth up to age 6 and that this growth slowed down between ages 6 and 12 [Bench, 1963].

In 1972, Lamparski was the first to use the cervical vertebrae to assess bone maturation. He established a method of classifying bone development based on changes in the cervical vertebrae. This author identified and used morphological characteristics of the vertebrae as seen in lateral cephalometric radiographs in each of the periods studied to draw up a “descriptive atlas of standard radiographs”. His conclusions included that assessment of vertebral age using teleradiographs is statistically reliable and valid.
and is clinically as useful as bone assessment based on wrist radiographs [Lamparski, 1972].

According to O’Reilly and Yanniello [1988], many studies show that mandibular growth during puberty is closely related to certain specific times or stages of ossification described for the hand and wrist. In their study, they used the cervical vertebrae observed in the lateral cephalometric radiograph as a tool for validating bone age, comparing these measurements with wrist radiographs. Six easily-identifiable stages of development were established from the forms of the cervical vertebrae.

Hassel and Farman [1995] presented a study that aimed to provide a reliable tool for determining potential growth in adolescent patients. Using a lateral cephalometric radiograph and observing anatomical changes in the cervical vertebrae, the patient’s bone maturation could be determined. And since a successful treatment depends in many cases on the correct evaluation of this parameter, it is important to determine, in a clear and simple way, patients’ bone maturity and the potential for remaining growth at the time of observation.

In recent years, Toshinori Mito and co-workers carried out a study to establish the bone age of the cervical vertebrae in order to produce a new index for skeletal age based on lateral cephalometric radiographs. The results suggest that the cervical vertebrae are as reliable for estimating bone age as the Tanner-Whitehouse method using wrist radiographs. The lateral cephalometric radiograph can be used to reliably determine skeletal maturity [Toshinori Mito et al., 2002; Tanner, 1975].

In Spain, many studies have been carried out with the aim of relating lateral cephalometric radiographs to wrist radiographs. Vilar and co-workers [1994] related lateral cephalometric radiographs with those of the wrist, and with the orthopantomography used to assess the degree of calcification in the first, second and third molars based on the Nolla stages. An important correlation was found between bone age measured by the cervical vertebrae and the bones of the hand.

Carreño Carreño and co-workers analysed the link between bone age as determined by the hand radiograph and as determined from the cervical vertebrae in the teleradiograph using the Lamparski method. The study of these two variables showed only a slight correlation in the case of girls [Carreño Carreño et al., 2000; Lamparski, 1972].

San Román and co-workers [2002] carried out a study aiming to determine the validity of radiographic evaluation of maturation from the cervical vertebrae using radiographs of the left wrist and lateral cephalometric radiographs in a population of children with an average age of 11.5 years.

After analysing this research and consulting the above-mentioned studies, it was considered that one of the determining factors in diagnosis and treatment is to ascertain the bone age of the patient, since bone maturation is not directly related to dental development. This study aims to establish a correlation between the sizes of the cervical vertebrae and age, evaluating the validity of the vertebral measurements studied as predictive variables for dental maturity in a paediatric population.

**Materials and methods**

A total of 896 case histories were reviewed, taken from the “Programme for Integral Dental Care for Children” carried out in the Faculty of Odontology at Madrid’s Complutense University over the last six years.

The selected sample comprised 203 children (86 boys and 117 girls) aged between 2 and 10 years and was based on their orthopantomographs and lateral cephalometric radiographs, excluding any children with any sort of genetic syndrome or congenital buccal or facial malformation and whose lateral cephalometric radiographs the 5th cervical vertebra could not be clearly observed. All the radiographs were taken with the same x-ray equipment and were analysed by two observers using a conventional negatoscope.

The following parameters were measured.

- In the orthopantomography, the mandibular dental region was taken and, on it, the first lower left permanent molar, to determine its dental age on the Demirjian scale.
- On the lateral cephalometric radiograph, the area corresponding to the first five cervical vertebrae was scanned, using a digital Epson Express 1380 scanner (800 DPI). The images were then printed.
- The silhouettes of vertebrae C3, C4 and C5 were then drawn and the horizontal and vertical measurements shown in Figure 1 were taken using a Munchner Dentaurum 042-751 calibrator.

Measurements were noted in centimeters, down to the second decimal figure, and each measurement was classified as follows.

- Horizontal measurements (H): Upper (CHSUP), Middle (CHMD) and Lower (CHINF).
- Vertical measurements (V): Left (CVI), Middle (CVMD) and Right (CVD).

After establishing the measurements of each
vertebra (C3, C4 and C5), data were recorded for each subject, including number, name, age in years and months, sex and dental maturity of the first lower left permanent molar.

**Statistical methods.** Data were analysed using the SPSS 12.0 (SPSS; Chicago Illinois, USA) statistical program. In order to obtain the sample’s middle course measurements, descriptive statistics were used. With regard to inter-observer reliability, for the quality variable, that related to dental maturation, a Kappa index was used and for the quantity variable, that of cervical measurements, a Pearson correlation.

The correlations for the measurements of the cervical vertebrae between age and dental maturation were explored. Using a Student’s T test, it was determined whether there were statistically significant differences between the measurements of the cervical vertebrae and dental maturation in boys and girls. Variance analysis (ANOVA) was used to establish the differences between the measurements of the cervical vertebrae amongst the different age groups.

Regression analysis was carried out to try to establish whether the measurements of the cervical vertebrae could predict dental maturation.

**Results**

896 cases were analysed, of which 203 met criteria for inclusion. For the total sample, the average age was 6 years 10 months, and the standard deviation was 1 year 9 months; 57.4% (117) were girls and 42.2% (86) were boys. In the inter-observer reliability analysis, the agreement with regard to the dental maturation variable was evaluated, giving a result of 0.986. This showed a high degree of inter-observer agreement, so the estimate of dental maturation drawn up by both experts was almost exactly the same.

With regard to the measurement of the cervical vertebrae, 78% of the measurements by the two experts were comparable, while 22% showed slight differences. This indicates high levels of inter-observer agreement.

**Correlation between measurements of cervical vertebrae and age.** Correlations between age and measurements of cervical vertebrae are significant and positive in most cases (Table 1). There is therefore a positive relationship between age and the increase in size of the cervical vertebrae.

Examination of the extent of the correlations shows that the measurement that is most age-sensitive is the left vertical (VI), as it always shows the highest correlation.

**Relation between sizes of the cervical vertebrae and sex in the total sample.** It was noted that the average horizontal measurements of the C3, C4 and C5 cervical vertebrae presented statistically significant differences (p<0.05), with sizes being larger in boys than in girls. There were no differences in the vertical measurements.

**Relation between skeletal maturation in the cervical vertebrae and dental maturation.** The results show that the vertebral measurements correlate significantly and positively with dental maturation.

In addition, high inter-observer agreement was
noted, especially with regard to measurements of the C5 cervical vertebra (Table 2), in which all the correlations were statistically significant. This vertebra seems to be the most suitable for detecting dental maturation.

Finally, with regard to the different measurements on each of the three cervical vertebrae analysed, the left vertical measurement (VI) is the most suitable for relation to dental maturation because it always presented the highest positive correlation (Table 2).

Vertebral predictors of dental maturation. This analysis aims to show whether cervical vertebrae measurements can be used to predict dental maturation. After testing various types of regression models, the two (Table 3) which explained the greatest degree of variance are the following.

- In model 1, the C4VI measurement was used as a predictive or independent variable (p<0.01). This is the cervical vertebra measurement which shows the highest correlation with dental maturation (p<0.01). This variable can explain up to 24% of dental maturation so the hypothesis that prediction is 0% (p < 0.01) can be rejected. Figure 2 shows the dispersion diagram for the C4VI cervical vertebra and dental maturation and indicates a positive link.

- Model 2 is a multivariant model (Table 4) because it is based on the three variables which contribute significantly to prediction of dental maturation.

The measurements which best predict dental maturation are C4VI, C4VMD and C3VI. This model can explain 27% of dental maturation (R2...
= 0.27; p<0.01).

In model 2 (Table 4), regression analysis shows that the C4VI measurement is the one that mostly contributes to prediction of dental maturation although there is a negative relation with the C4VMD measurement. That is, even though it predicts dental maturation, the longer the vertebra the lower the dental maturation. The C3VI measurement also helps predict dental maturation.

### Discussion

In essence, the study of development and growth must be inter-disciplinary. In the field of dentistry, treatments can be improved if carried out when the subject reaches a specific stage of growth and development. It is therefore very important to be able to determine bone age in a reliable way as this provides key data for successful treatment.

Clearly, the most widely-used method for evaluating an individual’s bone age is the hand radiograph because of its reliability and accessibility. However, in paediatric dentistry, since routine radiographs often show the first cervical vertebrae, it is useful to use them for evaluating patients' bone age, by studying their appearance and growth.

Many research works have studied the relation between cervical vertebrae and bone age and great differences can be noted in the sample sizes used. Most of these studies cover samples of between 80 and 215 patients. There are also many smaller studies with 42 patients [Carreño et al., 2000], with 24 [Franchi et al., 2000], with 18 [Bujaldon-Daza et al., 1998], and even with 13 [O’Reilly and Yanniello, 1988].

This study obtained a sample of 203 patients, which can be considered large for this type of research and is similar to the sample size used by other studies.

![FIG. 2 - Regression coefficients between dental maturation and left vertical measurements in the fourth cervical vertebrae (C4VI).](image)

<table>
<thead>
<tr>
<th>Evaluation model</th>
<th>R</th>
<th>R²</th>
<th>Std error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.485 (a)</td>
<td>0.236</td>
<td>0.966</td>
</tr>
<tr>
<td>2</td>
<td>0.519 (b)</td>
<td>0.269</td>
<td>0.949</td>
</tr>
</tbody>
</table>

(a) Independent variables: (Constant), C4VI
(b) Independent variables: (Constant), C4VI, C4VMD, C3V

### Table 3 - Lineal multi-variant regression between cervical vertebrae measurements and dental maturation.

<table>
<thead>
<tr>
<th>Statistic Model</th>
<th>No Standard Coefficients</th>
<th>Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(Constant) 3.179 0.407</td>
<td>C4VI 4.047 0.514 0.485</td>
<td>7.818 0.000</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>(Constant) 3.663 0.463</td>
<td>C4VI 4.928 0.698 0.591</td>
<td>7.916 0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C4VMD -1.947 0.848 -0.191</td>
<td>7.057 0.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C3VI 0.263 0.130 0.125</td>
<td>2.025 0.044</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 - Lineal multi-variant regression between cervical vertebrae measurements and dental maturation.
[Moscoso et al., 1987; Hassel and Farman, 1995; Bacetti et al., 2001]. All these authors studied more than 200 individuals.

However, there are also studies such as that by Hong-Po and co-workers with 503 individuals and that by San Román and co-workers with 958 subjects, which use much larger samples [Hong-Po et al., 2001; San Román et al., 2002].

With regard to sex, all the studies had practically the same numbers of girls and boys. However, it is interesting that in three of the studies reviewed the sample was made up of girls only [O’Reilly and Yanniello, 1988; Vilar et al., 1994; Toshinori Mito et al., 2002]. Vilar explains this choice because it facilitates determination of the pubertal peak, because menarche had either not yet occurred or had occurred within six months [Vilar et al., 1994].

In this study, great importance was given to analysing results by sex, so a sample of 117 girls and 86 boys was used, following the approach adopted in most of the studies. The results showed that the horizontal measurements of the cervical vertebrae are greater in girls.

The children’s ages varied greatly in the different studies. Some research was based on very wide age ranges, from 5 to 17 [Moscoso et al., 1987], from 5 to 18 [San Román et al., 2002] and, the largest of all, from 3 to 18 [Franchi et al., 2000]. However, in this latter study there were only 24 boys, so the results from the point of view of age groups cannot be significant due to the small sample size.

In most of the other works studied, the sampling began at about age 9 or 10, this being when pubertal growth begins, and the upper age limit was 17 or 18.

However, in this research, it was considered that there had been little study of the correlation between dental and bone maturation in small children, so we selected a younger age range, starting with children aged 2 and including subsequent ages up to age 9, resulting in an average age of 6.3.

Toshinori Mito and co-workers tried to draw up a new index based on linear measurements for establishing skeletal age based on lateral cephalometric radiographs. They observed the anatomical changes on the concave part of the lower edge, as well as the height and the shape of the cervical vertebrae, with the exception of the atlas. For appearance and depth of the concavity they defined 6 stages, and for the height they determined a further 4 stages [Toshinori Mito et al., 2002]. In this study, we used an adapted version of the methodology used by these authors. The three vertical measurements were maintained but we increased the horizontal measurements to three in order to achieve a similar method for the two planes.

A comparison of our results with those of other authors shows that the latter do not publish numerical values, but some of them express results in proportions between height and width [San Román et al., 2002] or obtain markers for biological maturation using the appearance of the ossification nucleus of the odontoid apophysis (DEP) [Lamparski, 1972; O’Reilly and Yanniello, 1988; Hassel and Farman, 1995]. It was therefore not possible to compare vertebral sizes because of the age differences in the samples and the methodology used. The horizontal measurement was seen to be greater in boys than in girls. There is no difference in the vertical measurement. This may be related to the fact that in the ages studied the pre-pubertal growth spurt had not begun which is when girls grow taller than boys.

With regard to dental maturation, the stages established by Demirjian and co-workers were used. This system has been sufficiently validated by many studies [Demirjian et al., 1973; Demirjian et al., 1985].

The relationship between skeletal maturation, as measured from the cervical vertebrae, and dental calcification has been studied in Spain by several authors. The work by San Román [2002] related C3 and C4 with the maturation of canines, premolars and second and third lower molars. It concludes that the relation is positive if done individually with each tooth but that globally it should be taken with caution.

Vilar and co-workers [1994] looked for a link between vertebrae C2, C3, C4 and C5 and the third lower molars in girls, and concluded that there is a positive relationship. The authors observed a relationship between these biological maturation markers with a correlation of 0.84 and a level of significance of less than 0.01 between dental maturation and chronological age. In our case, the relation was established with the first permanent lower molars which were the easiest teeth to evaluate since the sample age was lower. The authors tried to demonstrate that the cervical vertebrae morphology changed as in patients reaching the pubertal peak. They showed that there are no such changes in young children but size does increase although this variable is not considered predictive of bone growth.

In conclusion, it should be highlighted that significant changes in size were observed only in vertical measurements and that the predictive measurements for dental maturation were C4VI, C4VMD and C3VI. Also, a significant increase was detected in the vertical measurements associated with an increase in chronological age.
In view of these results, the study could be continued in order to draw up a descriptive atlas to complement those obtained by other researchers in samples of older children.

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