Reiability of an Objective Method of Evaluating Skeletal Maturity based on Cervical Vertebral Bone Age as Compared with the TW2 Method

Vasu Murthy, Asiya Begum, Pavan Kumar, CH Lalitha

ABSTRACT

Objectives: Skeletal age is an indicator of level of physiological maturity and growth potential. Determination of skeletal age helps clinician in decision making in terms of modality and timing of orthodontic treatment. There are various methods to determine physiological maturity, most of which are not quantitative. This can be overcome by using any of the quantitative methods like TW2 (Tanner-Whitehouse), which uses hand-wrist radiographs and provides a numeric skeletal age. Mito et al have proposed a regression formula to derive skeletal age using measurements on cervical vertebrae C3 and C4. The present study aims to estimate the reliability of this formula by determining a correlation between cervical vertebral bone age and the age estimated by TW2 method using hand-wrist radiographs.

Materials and methods: One hundred and fifty subjects, 75 boys and 75 girls within the age range of 8.0 to 14.9 years were selected. Both lateral cephalograms and hand-wrist radiographs of each subject were taken. Cervical vertebral bone age was determined by the formula given by Mito et al. Bone age from hand-wrist radiographs was determined by using TW2 method. Correlations between chronological age and vertebral age and between vertebral age and bone age were determined by the use of Pearson’s correlation coefficient.

Results: In both comparisons, correlation was significantly higher in girls than in boys. The results suggest that cervical vertebral bone age reflects skeletal maturity; hence, it might be possible to evaluate maturity in a detailed and objective manner.

Keywords: Skeletal age, Cervical vertebrae, Hand-wrist radiograph, TW2 method.

INTRODUCTION

The evaluation of craniofacial growth is an essential part of diagnosis and treatment planning in orthodontics, especially when growth modification is needed. Many clinicians believe that orthodontic treatment is more effective if it is started during the peak of pubertal growth. Growth factor is a critical variable in orthodontic treatment. A treatment plan can vary from growth modification to orthognathic surgery, depending on the growth status. Furthermore, an understanding of percentage of growth remaining after completion of orthodontic intervention may be important in predicting posttreatment relapse.

Skeletal maturation can be assessed by various indicators, such as chronological age, dental development, peak growth velocity in standing height, weight, sexual maturation characteristics, skeletal development and vertebral development. Skeletal maturation staging from radiographic analysis is a widely used approach to predict timing of pubertal growth, estimate growth velocity and to estimate the proportion of growth remaining.

Individual variations in the timing, duration and velocity of growth is difficult to quantify with the conventional methods. This led to the development of methods like TW2 (Tanner Whitehouse), to assess skeletal maturity from the bones of hand-wrist. This in turn facilitated assessment of the timing of onset and termination of pubertal growth spurt.

However, the need for an additional radiograph and consequent exposure for evaluation skeletal maturity is not desirable. To overcome this problem correlation between the skeletal maturity of the bones of hand-wrist and cervical vertebrae was done and it was found that the cervical vertebrae are reliable predictors of sexual and somatic maturity. A regression formula was given by Mito et al to derive skeletal age which is based on ratios of widths and heights of cervical vertebrae C3 and C4.

Cervical vertebral bone age (in years) = $-0.20 + \{(6.20 \times AH_3/AP_3) + (5.90 \times AH_4/AP_4) + (4.74 \times AH_4/PH_4)\}$

To adopt this method in our diagnostic protocol, a study was performed to assess the reliability of this regression formula by determining a correlation between cervical vertebrae...
vertebral bone age and the age estimated by TW2 method using hand-wrist radiographs.

**MATERIALS AND METHODS**

The present study was a cross-sectional study involving 150 patients (75 girls and 75 boys) who visited the Department of Pedodontics and Orthodontics, Kamineni Institute of Dental Sciences, Narketpally. The subjects ranged in age from 8.0 ± 14.9 with a mean age 11.0 ± 1.57 years. A lateral cephalogram and a hand-wrist radiograph were taken for each patient with good clarity and contrast. The third and fourth cervical vertebrae were traced on 0.003” thickness matte acetate cephalometric tracing paper with a 0.3 mm diameter lead pencil. The parameters measured were (Fig. 1) as follows:  
- Anterior vertebral body height (AH)  
- Vertebral body height (H)  
- Posterior vertebral body height (PH)  
- Anteroposterior vertebral body length (AP).

The ratios of these parameters were then calculated, i.e. AH3/AP3, AH4/PH4 and AH4/AP4. Cervical vertebral bone age was then determined by the formula given by Toshinori Mito, Koshi Sato and Hideo Mitani.  

Hand-wrist radiographs were taken using an extraoral machine. Bone age by hand-wrist radiograph was determined by the Tanner-Whitehouse method. In the TW2 method, 20 hand-wrist bones were considered for bone age evaluation which includes the bones of the first, third and fifth fingers and the carpal bones. The development of each ROI is divided into discrete stages and each stage is given a letter (B, C, D, ..., I) as is shown in Figure 2. A numerical score is associated with each stage of each bone (Tables 1 to 4). By adding the scores of all ROIs, an overall maturity score was obtained. This score was correlated with the bone age differently for males and females.

The correlation between cervical vertebral bone age and bone age using hand-wrist radiographs was determined and also compared with the chronological age of the patient.

**RESULTS**

The following results were derived from the statistical analysis done using the Pearson correlation coefficient. Table 5 shows

![Fig. 1: Measurements used in calculating skeletal age from cervical vertebrae C3 and C4](image1.png)

![Fig. 2: Stages of development for regions of interest of hand-wrist radiograph](image2.png)

<table>
<thead>
<tr>
<th>Bone</th>
<th>Boys</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Radius</td>
<td>15</td>
</tr>
<tr>
<td>Ulna</td>
<td>22</td>
</tr>
<tr>
<td>First metacarpal</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bone</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Radius</td>
<td>17</td>
</tr>
<tr>
<td>Ulna</td>
<td>22</td>
</tr>
<tr>
<td>First metacarpal</td>
<td>5</td>
</tr>
</tbody>
</table>
the mean, minimum, maximum and standard deviation values of the variables—chronological age, cervical vertebral bone age and hand-wrist bone age.

**DISCUSSION**

The timing of orthodontic treatment for most dentofacial problems is affected by concurrent growth regardless of appliance mechanics. In this regard, knowledge of early facial growth and any associated growth accelerations can be very useful to the orthodontist to take advantage of the growth for a preliminary phase of treatment. The use of carpal radiographs in the assessment of skeletal maturation was reported as early as 1896 by Ranke. The approximate skeletal age may be estimated by the number of carpal bones showing centers of ossification and by the degree of ossification.

Skeletal maturation assessed on hand-wrist radiographs is generally considered to be closely related to the growth spurt. Its main drawback is that an additional radiograph is required. Cephalometrics provides orthodontists with measurement of growth changes within the craniofacial complex. Changes in contours of cervical vertebrae during adolescence may be used to predict phases of growth. Lamparski was the first to use cervical vertebrae as indicators for skeletal maturation. The original cervical vertebral maturation (CVM) method composed of six different stages that related to changes in morphology of the second to sixth cervical vertebrae. Hassel and Farman in 1995 used only second, third and fourth cervical vertebrae and stated that shapes of cervical vertebrae were seen to differ at each level of skeletal development.

Most of these methods are not quantitative. TW2 method provides a numeric bone age using hand-wrist radiographs. Mito et al have proposed a regression formula to derive skeletal age using measurements on cervical vertebrae C3, C4.

$$\text{Cervical vertebral bone age (in years)} = -0.20 + \{(6.20 \times \text{AH}_3/\text{AP}_3) + (5.90 \times \text{AH}_4/\text{AP}_4) + (4.74 \times \text{AH}_4/\text{PH}_4)\}$$

The present study was designed to estimate the reliability of this regression formula for quantifying skeletal maturation by determining a correlation between cervical vertebral bone age and the age estimated by TW2 method using hand-wrist radiographs.

Vertebral bodies in cervical vertebrae were measured because various investigators have suggested a relationship between changes in cervical vertebral bodies and growth. The third and fourth vertebrae were selected and the other were omitted for the following reasons:

1. Body of the first vertebra (atlas) is not directly seen.
2. Second vertebra (axis) shows very little changes in morphology and is difficult to measure.
3. Fifth cervical vertebra might not appear clearly on the cephalogram.

The results of this study showed that the correlation between chronological age and cervical vertebral bone age in boys was weak ($r = 0.264$ at $p < 0.05$) when compared with that of girls ($r = 0.601$ at $p < 0.001$) as shown in Tables 6 and 7. The correlation between cervical vertebral bone age and the bone age determined by hand-wrist radiographs in girls

**Table 3: Tanner-Whitehouse boys bone age (BBA) for given maturity score (MS) (sample table)**

<table>
<thead>
<tr>
<th>MS</th>
<th>114</th>
<th>116</th>
<th>119</th>
<th>123</th>
<th>126</th>
<th>129</th>
<th>133</th>
<th>136</th>
<th>139</th>
<th>142</th>
<th>146</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBA</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
<td>1.7</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**Table 4: Tanner-Whitehouse girls bone age (GBA) for given maturity score (MS) (sample table)**

<table>
<thead>
<tr>
<th>MS</th>
<th>131</th>
<th>136</th>
<th>140</th>
<th>146</th>
<th>152</th>
<th>159</th>
<th>163</th>
<th>172</th>
<th>179</th>
<th>186</th>
<th>192</th>
</tr>
</thead>
<tbody>
<tr>
<td>GBA</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.5</td>
<td>1.6</td>
<td>1.7</td>
<td>1.8</td>
<td>1.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**Table 5: Descriptive data for the sample**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Chronological age (CA)</th>
<th>Cervical vertebral bone age (VA)</th>
<th>Hand-wrist radiographic bone age (BA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Minimum 8.00</td>
<td>5.40</td>
<td>5.50</td>
</tr>
<tr>
<td></td>
<td>Maximum 14.00</td>
<td>13.90</td>
<td>14.90</td>
</tr>
<tr>
<td></td>
<td>Mean 11.2800 (SD, 1.46638)</td>
<td>8.9161 (SD, 1.40776)</td>
<td>10.3747 (SD, 1.99229)</td>
</tr>
<tr>
<td>Female</td>
<td>Minimum 8.00</td>
<td>7.00</td>
<td>6.60</td>
</tr>
<tr>
<td></td>
<td>Maximum 14.00</td>
<td>14.80</td>
<td>14.80</td>
</tr>
<tr>
<td></td>
<td>Mean 11.8000 (SD, 1.66847)</td>
<td>10.2615 (SD, 2.06917)</td>
<td>10.9380 (SD, 2.21321)</td>
</tr>
<tr>
<td>Total</td>
<td>Minimum 8.00</td>
<td>5.40</td>
<td>5.50</td>
</tr>
<tr>
<td></td>
<td>Maximum 14.00</td>
<td>14.80</td>
<td>14.90</td>
</tr>
<tr>
<td></td>
<td>Mean 11.5400 (SD, 1.58699)</td>
<td>9.5888 (SD, 1.88842)</td>
<td>10.6553 (SD, 2.11738)</td>
</tr>
</tbody>
</table>

Number of subjects (N): 75 boys and 75 girls (total 150)
Table 6: Correlation between chronological age and cervical vertebral bone age in boys

<table>
<thead>
<tr>
<th>Chronological age (CA)</th>
<th>Pearson correlation</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.264**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.022</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed)

Table 7: Correlation between chronological age and cervical vertebral bone age in girls

<table>
<thead>
<tr>
<th>Chronological age (CA)</th>
<th>Pearson correlation</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.601**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.000</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.001 level (2-tailed); Males: \( r = 0.265 \) correlation is significant at \( p < 0.05 \); females: \( r = 0.331 \) correlation is significant at \( p < 0.001 \)

Table 8: Correlation between cervical vertebral bone age and hand-wrist radiographic age in boys

<table>
<thead>
<tr>
<th>Cervical vertebral bone age (VA)</th>
<th>Hand-wrist radiographic age (BA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson correlation</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.331**</td>
</tr>
<tr>
<td></td>
<td>0.004</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.001 level (2-tailed)

Table 9: Correlation between cervical vertebral bone age and hand-wrist radiographic age in girls

<table>
<thead>
<tr>
<th>Cervical vertebral bone age (VA)</th>
<th>Hand-wrist radiographic age (BA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson correlation</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>0.654**</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.001 level (2-tailed); Males: \( r = 0.331 \) correlation is significant at \( p < 0.001 \); Females: \( r = 0.654 \) correlation is significant at \( p < 0.001 \)

(r = 0.654) was significantly higher than in boys (r = 0.331) as shown in Tables 8 and 9. In total, the correlation coefficient between cervical vertebral bone age and bone age was significantly higher than the correlation coefficient between cervical vertebral bone age and chronological age, signifying that the cervical vertebral bone age more closely approximated the bone age by the TW2 method rather than chronological age. So, cervical vertebral bone age might reflect skeletal maturity because it can approximate bone age by the TW2 method on hand-wrist radiographs. This also signifies that the objective method of determining skeletal age can be considered as a reliable method.

The results of this study were found to be similar to a study by Mito et al, where cervical vertebral bone age was established as a new index for objectively evaluating skeletal maturation on cephalometric radiographs and correlated with bone age using TW2 method and found significant correlation between the two.

Also in a study by Roman PS et al, correlation values between skeletal maturation values obtained by both classifications of vertebral maturations and the skeletal maturation at the wrist were calculated and all correlation values obtained were statistically significant (p < 0.001). Their results match with the findings of the present study.

The findings of this study are similar to a study conducted by Kamal M et al where a comparative evaluation of hand-wrist and cervical vertebrae was done to know the validity of cervical vertebrae as maturity indicators in a sample of 50 subjects in the age group of 10 to 12 years and the result showed that cervical vertebrae can be used with the same confidence as hand-wrist radiographs to evaluate skeletal maturity.

From all the above findings, it can be concluded that cervical vertebrae like hand-wrist radiographs can be used as maturation indicators. Neither the chronological age nor the stages of dental development are reliable in helping to establish the child’s stage of skeletal development. It might be better and would permit a more objective diagnostic evaluation if skeletal age is considered as a basis to help formulate a treatment plan. Cervical vertebrae have the same potential as the hand-wrist radiographs for determining the skeletal maturation of an individual, thus protecting the patient from an additional radiographic exposure.

**SUMMARY AND CONCLUSION**

This study was undertaken to evaluate the reliability of an objective method of determining skeletal age and comparing it with another maturation indicator that is the hand-wrist.
radiograph by employing the TW2 method. The conclusions of the study are as follows:
1. The objective method of cervical vertebral bone age estimation is an effective means of determining skeletal age.
2. The use of this method is as reliable as that of the bone age determined by using hand-wrist radiograph method.
3. Both the methods of skeletal age estimation are easily feasible to the clinician, are noninvasive and provide less radiation exposure to the patient.

REFERENCES