Introduction

Skeletal age is an essential aspect of any growth related study, and skeletal age evaluation is a clinically important tool in orthodontics. It corresponds to the chronological age at which the children on whom the standards were based usually attained the same degree of skeletal development. The technique for assessing skeletal age consists of visual inspection of the initial appearance of bones and their subsequent ossification changes in shape and size [Garn and Rohmann 1960; Hansman 1962; Garn et al., 1966; Benso et al., 1996; Carpenter and Lester 1993; Groell et al., 1999; Mora et al., 2001].

A growth event is of primary importance in clinical orthodontics. Growth events usually occur in a predictable manner. However, mean growth changes provide only a group pattern, and there is as much chance for the individual to follow the mean growth pattern as there is to be different from it. Even though growth can be predicted in a very general way, such predictions cannot provide the essential specifics at the moment of treatment for an individual patient. The unique individual timing, direction, rate, and increments of growth while treatment is actually taking place cause much of the variability in treatment responses [Bishara et al., 1984, 2000; Nanda, 1988, 1990].

Hand-wrist radiograph, due to certain requirements such as extra patient radiation exposure and chair time, has proven to be unpractical in everyday clinical practice. In contemporary orthodontics, an effort is under way to overcome those shortcomings by using the cervical vertebral evaluation method, which requires only the lateral cephalogram, a routinely taken X-ray. Digital cephalometric radiography, which is rapidly expanding, minimizes the problems mentioned above even more. Furthermore, researches have indicated that cervical vertebral maturation is strongly correlated to statural body height, which is the most reliable indicator for growth status, as well as to mandibular growth [Franchi et al., 2000; Hassel and Farman 1995; O’Reilly and Yaniello 1988]. The aim of this study was to investigate the relationship between cervical skeletal age, hand-wrist skeletal age and chronological age.

Methods and materials

Cephalometric analysis

On the lateral cephalometric radiographs, the following points of third and fourth vertebral bodies as described by Hellsing [1991] were traced (Rotring T 0.1 pencil) on acetate paper (GAC International):

- C3sp, C3a: the uppermost points of the anterior and posterior vertical heights of the body of C3.
- C3ip, C3m, C3ia: the most posterior the deepest and the most anterior points on the lower border of the body of C3.
- C4sp, C4a: uppermost points of the anterior and posterior vertical heights of the body of C4.
- C4ip, C4m, C4ia: the most posterior the deepest and the most anterior points on the lower border of the body of C4.
GROWTH INDICATORS IN ORTHODONTIC PATIENTS

With the aid of C3ip, C3ia, C4ip, and C4ia landmarks, tangent lower lines were drawn at the inferior border of the third and fourth vertebral bodies. The following dimensions of each cervical vertebral body were measured by a digital micrometer caliper as described by Mito and co-workers [2002]:

- AH3 (Anterior Vertical Height of C3): Distance from C3sa to the tangent of the lower border of the vertebrae.
- AH4 (Anterior Vertical Height of C4): Distance from C4sa to the tangent of the lower border of the vertebrae.
- H3, H4 (Middle Height of C3, C4): Distance from the superior border of the middle part to the tangent of the inferior border of the vertebrae.
- PH3: Distance from C3sp to the tangent of the inferior border of C3.
- PH4: Distance from C4sp to the tangent of the inferior border of C4.
- AP3, AP4: Anterior-posterior distance at middle of cervical vertebral body.

Skeletal age assessment from the lateral cephalometric radiograph

The ratios of AH3/AP3, AH4/AP4 and AH4/PH4 were calculated for each subject. Cervical vertebral skeletal age was estimated for each individual according to the formula obtained by Mito, Sato and Mitani [2002]: cervical vertebral skeletal age = \(-20 + 6.20 \times \frac{AH3}{AP3} + 5.90 \times \frac{AH4}{AP4} + 4.74 \times \frac{AH4}{PH4}\).

Skeletal age assessment from the hand-wrist radiograph

Skeletal age assessment for each individual was calculated according to Schopf's data [1978]. The ossification events of hand bones developed by Bjork, Grave and Brown [Rakosi et al., 1993] was used to estimate average values of skeletal age for males and females between 8 to 18 years of age (Table 1).

Statistical methods

Correlation and regression analysis

Pearson correlation coefficients (r) were calculated to assess the linear relationship between chronological, cervical bone and hand-wrist skeletal age, because these data are of parametric nature.

We also used the regression technique, which fits a straight line to the data that in some sense gives the "best" description of cervical skeletal age for any value of chronological age and hand wrist skeletal age. The regression line gives an estimate of the relation between cervical skeletal age and chronological age in the sample, so we should consider the uncertainty of this estimated line.

Error of method

Intra-observer method error was investigated by reevaluating 60 lateral cephalometric and hand-wrist radiographs at the end of the original investigation.

The standard deviation of the differences between replicates is a measure of the random error. However, the variance (the square of the standard deviation) of the difference between two measures is double that of a single measurement, and thus it should be halved to give a correct estimate of the error of the single measurement. Dahlberg proposed the formula

$$S(i) = \sqrt{\frac{\sum(X_a - X_b)^2}{2N}}$$

for those cases with double measurements, for all the examined parameters as a measure of the error variance, and this has been used in many orthodontic investigations [Hulley and Cummings, 1988]. For the repeated measurements of 60 cases, in addition to the Dahlberg formula, a one-sample t test and the Pearson correlation coefficients were calculated for the parametric data of the cephalometric analysis, and the cervical skeletal age calculation. For hand-wrist skeletal age, all calculations were identical; therefore, the method error was irrelevant.

Results

Evaluation of the error of method

According to our evaluation by the Dahlberg's formula the smallest random error was observed in H3 (0.26 mm) and the highest in H4 (0.51 mm). Furthermore, the Pearson's correlation exceeded 95% for all measurements. No systematic errors were detected.

Descriptive statistics

The mean chronological age of our female subjects was 13.1 years with 2.5 years standard deviation and age range extending from 8 to 18.5 years. For males, the mean chronological age is 13 years with 2.4 years standard deviation, minimum 8 years and maximum 18.4 years. The corresponding chronological age for each hand-wrist and CVM stage, for both females and males are shown in Tables 2 and 3. Cervical skeletal age also

<table>
<thead>
<tr>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
<th>9.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>PP2=</td>
<td>MP3=</td>
<td>PSI</td>
<td>H1</td>
<td>S</td>
<td>H2</td>
<td>MP3cap</td>
<td>DP3u</td>
</tr>
<tr>
<td>Females</td>
<td>10.6</td>
<td>12.0</td>
<td>12.6</td>
<td>13.0</td>
<td>14.0</td>
<td>15.0</td>
<td>15.9</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>8.1</td>
<td>8.1</td>
<td>9.6</td>
<td>10.6</td>
<td>11.0</td>
<td>13.0</td>
<td>13.3</td>
<td>13.9</td>
</tr>
</tbody>
</table>

TABLE 1 - Correlation between the nine maturational stages and skeletal age.
was assessed for both genders (Table 4). In all stages, mean chronological age of males was higher than in females, whereas cervical skeletal age matched closely.

**Pearson’s correlation**

According to our results the cervical skeletal age correlated significantly with both, chronological and hand-wrist skeletal ages for each gender. However, the correlation coefficient between hand-wrist skeletal age and cervical bone age was higher (0.8) than the other relationships (0.7) (Table 5).

**Regression analysis**

We used the regression analysis to estimate the relationship between cervical skeletal age, hand-wrist skeletal age and chronological age in the sample. In the female sample, Figure 1 shows the regression line together with the 95% confidence interval (CI) for the line. The slope is statistically significant (p<0.001), and the R² statistic is 66.5% higher than that between the cervical skeletal age and chronological age (R²=53.8%) (Fig. 2). Similar for males (Fig. 3) the slope is statistically significant (p<0.001), and the R² statistic is 58.3% higher than that between the cervical skeletal age and chronological age (R²=53.8) (Fig. 4).

**Discussion**

It has long been recognised that a person’s chronologic age does not necessarily correlate well with his maturational age. One may be skeletally accelerated or delayed in terms of maturational development. There is a wide variation in the chronological age of persons pertaining to the onset and duration of the adolescent growth spurt for both boys and girls [Bjork 1971; Fishman 1979; Hagg and Pancherz 1988; So 1997; Franchi et al., 2000].

According to our results the cervical skeletal age correlated significantly with both the chronological and the hand-wrist skeletal age for each gender. However, the correlation coefficient between cervical skeletal age and hand-wrist skeletal age for both females (r=0.81) and males (0.76) is higher than that between cervical skeletal age and chronological age (females r=0.73; males r=0.72). We are in agreement with Mito et al., who found that cervical vertebral skeletal age is more closely approximating skeletal age than chronological age. Sato and co-workers [2001], as well as Chen and co-workers [2004, 2005] suggested that cervical skeletal age depicted on the single cephalogram appears to have the same accuracy as hand-wrist skeletal age in order to predict the
mandibular growth potential.

The lower correlation in males than females may be explained by the fact that Mito et al. [2002] created their formula based on an investigation carried out only in females. Another important factor is the age range of the study group. The above authors created their formula based on an investigation on Japanese females from 7 to 15 years old. These authors investigated only females, based on Lamparski’s observations [1972]. The subject sample in Lamparski’s study reached only up to 15 years of age, whereas longitudinal investigations have shown that although 15-year-old females reached adult sizes of the vertebrae bodies, 15-year-old males have not yet completed their vertebral growth potential [Wang et al., 2001]. Lamparski, at 1972, did not consider this sexual divergence in the growth pattern of cervical vertebrae.

Furthermore, if the patient looks markedly advanced or retarded, it is necessary to determine the skeletal age in a quantitative rather than in a qualitative format in order to avoid the subjective nature of the inspectional assessment as well as the error margin among subsequent measurements. For those patients it is essential that both, skeletal vertebral stage, and skeletal vertebral level, must be assessed. The respective stages are designated by utilising specific skeletal maturity indicators identified on cervical vertebrae (CVMs). The skeletal vertebral level refers to the rate of maturational development, whether it be early, average, or delayed with respect to chronological age. Under these circumstances, individuals will exhibit differences in the lengths of time between the skeletal stages. By comparing quantitative cervical bone age with chronological age cervical vertebral level could be determined. Individuals can demonstrate the same skeletal stage but a different skeletal level. Therefore, individualisation, in order to increase the accuracy, seems to be of paramount importance particularly more so for those children.

Another question that should be answered was the importance of ethnic disparity. Ontell et al. [1996] published an excellent article in the American Journal of Roentgenology concerning skeletal age and ethnicity. They supported that “when determining skeletal age, ethnicity of each child must be considered, particularly in Black and Hispanic adolescent girls and Asian and Hispanic adolescent boys”.

Based on our research’s outcome, extending the age range to 18 years old, we created a new formula to assess cervical skeletal age, separately for males and females. Our equation is based on the ratio height/width of third and fourth cervical vertebral bodies in the Caucasian
population — clearly depicted in the lateral cephalogram — which increases until the end of growth period (Table 6 and 7). These ratios are easy to use in clinical practice and in research work both in retro-and prospective studies, because they are independent of magnification factors (Remes et al., 2000).

Conclusion

The cervical skeletal age shows higher correlation with hand-wrist skeletal age than chronological age, for both sexes.

Cervical skeletal age reflects skeletal maturity because of its high correlation with hand-wrist skeletal age.

Acknowledgements

A great deal of thanks goes to the professors of orthodontics N. Erverdi and A.E. Athanasiou.

References


Hansman CF. Appearance and fusion of ossification centers in the human skull. Am J Roentgen 1962; 88:476-482.


