Original Article

A New Method of Predicting Mandibular Length Increment on the Basis of Cervical Vertebrae

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Abstract: The purpose of this study was to establish an equation to predict incremental mandibular length on the basis of the analysis of the cervical vertebrae in a single cephalometric radiograph and to compare the predictive accuracy with other methods. Data comprised two groups of 23 Japanese girls between CVMS I and CVMS V. Group A was examined to construct the predication equation. Group B served to compare the predictive accuracy with the growth potential method and the growth percentage method. The following results were obtained: (1) an equation was determined to obtain mandibular length increments on the basis of the measurements in the third and fourth cervical vertebral bodies, and (2) the average error between the predicted increment and the actual increment was 1.5 mm for the equation method, 2.4 mm for the growth potential method, and 2.8 mm for the growth percentage method. These results suggest that with the use of cervical vertebral measurements, it may be possible to evaluate the mandibular growth potential. (*Angle Orthod* 2004;74:630–634.)

Key Words: Growth; Mandible; Cervical vertebrae

INTRODUCTION

The prediction of mandibular growth potential provides important information for planning treatment and for evaluating occlusal stability after the adolescent orthodontic treatment. Several reports[1–3] have been published on the prediction of mandibular growth. Five methods based on hand-wrist radiographs are available to predict growth potential and mandibular growth increments using skeletal maturation as an indicator ie, (1) the ossification events method, (2) the growth potential method, (3) the growth percentage method, (4) the growth chart method, and (5) the multiple regression method. However, these methods require expert knowledge and expenditure of time by the operator and their accuracy is not very high.

Recently, many studies have focused on skeletal-maturation evaluation using cervical vertebrae. Lamparski[4] created separate standards of cervical vertebral maturation (CVM) for female and male subjects as related to both chronological age and observed skeletal maturation shape changes in the bodies of five cervical vertebrae. Hassel and Farman[5] developed an index based on the second, third, and fourth cervical vertebrae (C2, C3, C4) and proved that atlas maturation was highly correlated with skeletal maturation of the hand-wrist. Mito et al[6] established cervical vertebral bone age as an index for evaluating skeletal maturation and proved that cervical radiographic evaluation was also a reliable method to evaluate skeletal maturation.

Baccetti et al[7] reviewed lateral cephalometric and hand-wrist radiographs from the files of the University of Michigan Elementary and Secondary School Growth Study and found that no statistically significant discrimination could be made between CVM1 and CVM2. These two stages could be merged into one single stage. A new system (CVMS) was created for CVM.

The relationship between CVM and mandibular growth changes was studied by O'Reilly and Yanniello,[8] who suggested that the increment in mandibular length was associated with specific maturation stages in the cervical vertebrae. More recently, Franchi et al[9] confirmed the validity of six CVM stages as biological indicators for both mandibular and somatic skeletal maturity in 24 growing untreated subjects.

Until now, cervical vertebrae were only used to decide the time of the pubertal peak or the skeletal age[5–13] and no reports based directly on cervical vertebrae have predicted mandibular length. The purpose of this study was to use to cervical vertebrae to establish a method of mandibular length prediction with a regression equation and to compare the predictive accuracy of this with other available methods.

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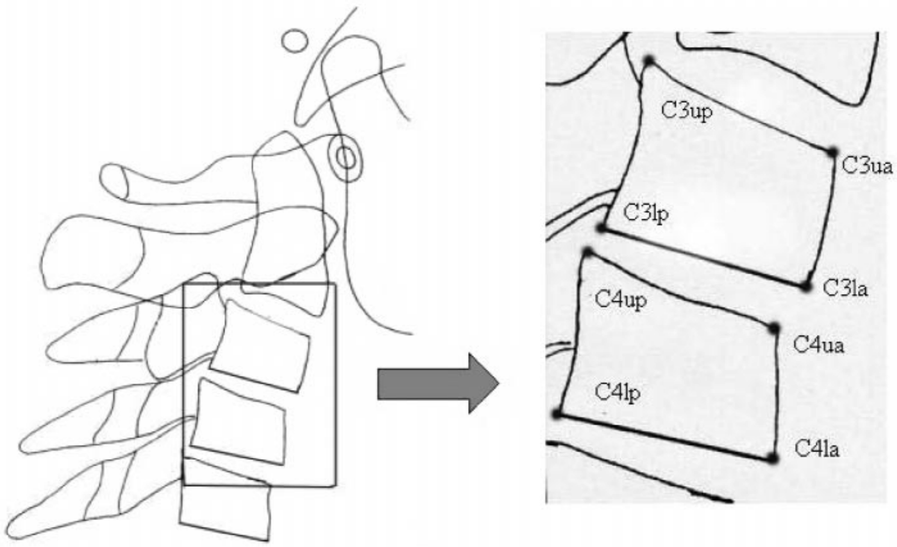

FIGURE 1. Cephalometric landmarks for the quantitative analysis of C3 and C4.

MATERIALS AND METHODS

The study comprised 46 girls from Japan selected from the files of the Department of Orthodontics, Niigata University. They fulfilled the following criteria: female; Class I or Class III in the molar relationship; no systemic disease that could affect general development; hand-wrist and cephalometric radiographs that were taken between CVMS I and CVMS V; no orthodontic treatment that could affect the mandibular growth before CVMS V; no mandibular orthodontic treatment.

The CVMS I and V stages were decided according to the Baccetti's definition[7].

CVMS I: the lower borders of the vertebrae C2, C3, and C4 are flat, with the possible exception of a concavity at the lower border of C2 in almost half the cases. The bodies of the both C3 and C4 are trapezoid in shape.

CVMS V: the concavities at the lower borders of C2, C3, and C4 are evident. At least one of the bodies of C3 and C4 is rectangular vertical in shape, if not rectangular vertical; the body of the other cervical vertebra is squared.

Forty-six Japanese girls were separated into two groups (Table 1). Group A was examined to construct the predication equation and Group B served to compare the predictive accuracy with other methods.

Cephalometric analysis

Cervical vertebral bodies. On the lateral cephalometric radiographs, the following points and lines for the description of the morphologic characteristics of the cervical vertebral bodies (Figure 1) were traced by pencil and measured with micrometer calipers:

- C3up, C3ua: the most superior points of the posterior and anterior borders of the body of C3;
- C3lp, C3la: the most posterior and the most anterior points on the lower border of the body of C3;
- C4up, C4ua: the most superior points of the posterior and anterior borders of the body of C4;
- C4lp, C4la: the most posterior and the most anterior points on the lower border of the body of C4;
- AH3, AH4 (anterior vertebral body height of the C3 and C4): the distance between C3ua and C3la, the distance between C4ua and C4la;
- PH3, PH4 (posterior vertebral body length of the C3 and C4): the distance between C3up and C3lp, the distance between C4up and C4lp;
- AP3, AP4 (anteroposterior vertebral body length of the C3 and C4): the distance between C3la and C3lp, the distance between C4la and C4lp.

Mandible. In the mandible (Figure 2), articulare to pogonion (Ar-Pog) was used to stand for the mandibular length. Gonial angle was defined as the angle formed by Ramus plane (Rp) and Mandibular plane (Mp). Mandibular length increment (MLI) is determined by the Ar-Pog differences between CVMS I and CVMS V

$$\text{MLI} = \text{Ar-Pog(CVMS V)} - \text{Ar-Pog(CVMS I)}.$$

If there were more than one lateral cephalometric radiographs in CVMS I, the measurement averages were used. On the other hand, if there were more than one lateral cephalometric radiographs in CVMS V, the cephalometric radiographs at the lowest age was used. To determine the measurement errors, all the cephalometric radiographs that were traced and measured were remeasured again 10 days later. The differences between the measurements were evaluated by the Student's *t*-test with the paired design.

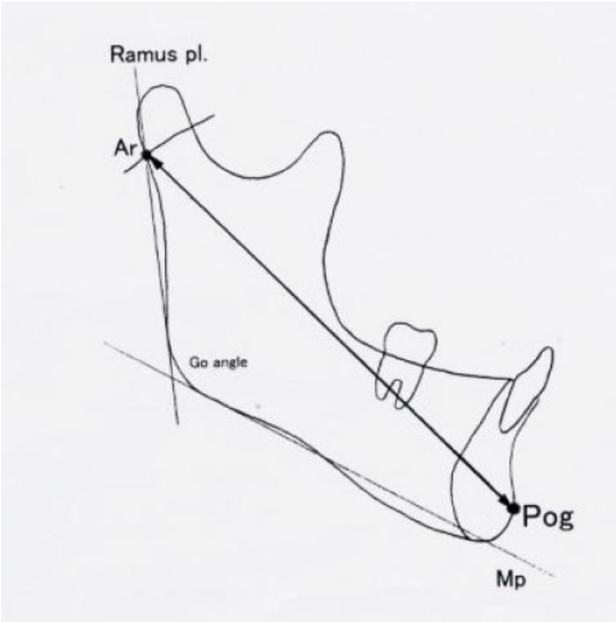

FIGURE 2. Cephalometric landmark measurements of mandibular length and Go-angle.

Statistical analysis

The data obtained in Group A was analyzed by statistical software SPSS Version 10.0 for Windows (SPSS Inc, Chicago, Ill). In the multiple regression analysis, the values of the MLI between CVMS I and CVMS V were used as dependent variables, and the values of the cervical vertebrae at CVMS I were used as independent variables. The selections of the independent variables were completed according to the stepwise method.

The predictive accuracy

Two other methods, the growth potential and the growth percentage method, proved as the best methods to predict mandibular growth,[11] were used to compare the predictive accuracy with the equation in the group B.

RESULTS

Measurements

Means and standard deviations and the results of Student's *t*-test between CVMS I and CVMS V are shown in Table 2. All the measures in CVMS I were significantly smaller than in CVMS V except for the Go-angle. The mandibule had significant growth from CVMS I to CVMS V. Class III and Class I have no significant differences in the measurement of the cervical vertebrae in the same stage.

Measurement error

The size of the combined method error (ME) was calculated by $ME = \sqrt{\Sigma d^2/2n}$, in which d was the difference between two registrations of a pair and n was the number of double registration. No significant differences were found between the measurements at the different occasions ($P <$ .05), and the standard deviations ranged from 0.20 to 0.32 mm.

TABLE 1. Composition of Group A and Group B

	Number	Age of CVMS I[a] (y)	Age of CVMS V (y)
Group A			
Class I	12	8.49 ± 0.79	14.35 ± 0.91
Class III	11	8.64 ± 0.60	14.35 ± 1.14
Group B			
Class I	15	8.40 ± 0.55	14.50 ± 1.03
Class III	8	8.55 ± 0.79	14.57 ± 0.96

[a] CVMS indicates system for cervical vertebral maturation.

TABLE 2. The Measurements of C3, C4, and the MLI in the Group A[a]

	CVMS I[a]	CVMS V	*P*
Class III			
Ar-pog (mm)	98.27 ± 5.25	113.69 ± 4.26	1.23E-16*
Go-Angle (°)	130.57 ± 6.98	129.00 ± 7.27	0.69
AH3 (mm)	7.66 ± 0.84	14.92 ± 1.02	4.51E-20*
PH3 (mm)	8.94 ± 0.99	14.83 ± 1.04	4.51E-15*
AP3 (mm)	13.11 ± 1.04	14.45 ± 1.06	6.32E-15*
AH4 (mm)	7.45 ± 1.01	14.50 ± 0.94	1.62E-16*
PH4 (mm)	9.06 ± 1.09	14.67 ± 0.97	1.65E-16*
AP4 (mm)	12.61 ± 0.87	14.65 ± 0.79	5.30E-10*
Class I			
Ar-pog (mm)	94.45 ± 6.89	109.76 ± 4.34	5.43E-17*
Go-Angle (°)	123.45 ± 5.29	122.73 ± 7.80	1.10
AH3 (mm)	7.34 ± 1.35	15.01 ± 1.29	3.32E-18*
PH3 (mm)	8.75 ± 1.09	14.92 ± 1.13	4.98E-16*
AP3 (mm)	13.06 ± 1.12	14.60 ± 1.11	5.64E-05*
AH4 (mm)	7.32 ± 1.11	14.56 ± 1.04	1.87E-13*
PH4 (mm)	9.41 ± 1.28	14.45 ± 1.05	1.34E-14*
AP4 (mm)	12.72 ± 0.57	14.75 ± 0.38	6.74E-08*

[a] MLI indicates mandibular length increment; CVMS, system for cervical vertebral maturation.

Multiple regression analysis

We selected six factors as independent variables and MLI as the dependent factor. The equation is:

$$MLI = 36.20 - 0.71 \times AH3 - 0.97 \times PH3 - 0.90 \times AH4.$$

In the present study, R^2 was 61.3%; R^2 indicated the portion of the variability of the dependent variables. The combination of the AH3, AH4, and PH3 explained the variability of MLI by 61.3%.

The predictive accuracy

In Tables 3 and 4, the average errors between the predicted and actual MLI and the average errors of the absolute

TABLE 3. Average Predicted Errors Between this Method and the Growth Potential Method in Group B

	This Method	The Growth Potential	*P*
Average error (mm)	0.34 ± 1.97	1.48 ± 2.34	.048*
Average error (mm) (absolute value)	1.58 ± 1.14	2.84 ± 1.45	.013*

* $P < .05$

TABLE 4. Average Predicted Errors Between this Method and the Growth Percentage Method in Group B

	This Method	The Growth Percentage Method	*P*
Average error (mm)	0.34 ± 1.87	1.50 ± 2.21	.043*
Average error (mm) (absolute value)	1.58 ± 1.14	2.92 ± 1.60	.011*

* $P < .05$

value for each prediction method are listed. Average errors ranged from 0.34 to 1.50 mm and average errors of the absolute value were between 1.58 and 2.92 mm. The average error of this method was the smallest and the largest for the growth percentage method. The accuracy of this method had significant differences compared with the other two methods.

DISCUSSION

The size and shape of the cervical vertebrae in growing subjects have gained increasing interest as biological indicators of individual skeletal maturity. The main reasons for the rising popularity of the method is that the analysis of CVM is performed on the lateral cephalometric radiograph of the patient's head, a type of film used routinely in orthodontic diagnosis. The purpose of this study was to provide the orthodontist with an easy tool to help determine mandibular growth potential.

In this study, Japanese girls were examined because of sex-dependent differences with regard to the timing of morphological changes in cervical vertebral bodies.[4] The cervical vertebra, lower than C4, could not be observed, when a thyroid protective collar was worn during radiation exposure. Baccetti et al[7] showed that only the shape change of C2, C3, and C4 was enough to show skeletal maturation. However, C2 shows very little morphological change and is difficult to measure. In this study, we only measured C3 and C4.

Mandibular length is often defined as the linear distance between Co (the most superior point on the head of the condyle) and Pog. The use of Co for determining mandibular length is technically difficult because Co is often obscured in the standard closed-mouth lateral cephalometric radiograph by superimposition of cranial base and middle cranial fosse structures.[14] Some researchers have shown that Co cannot be located accurately and consistently on the closed-mouth lateral cephalograms.[15,16] Haas et al[17] examined the validity of articulare for mandibular length measurements. According to their result, Ar is a good substitute for Co when measuring overall mandibular length. In this study, we used Ar-Pog to stand for the mandibular length; the difference between the two stages was used as the MLI.

In this study, the stepwise regression analysis was used to define prediction models that could be used to forecast individual future growth changes of the mandible. The stepwise method was used to select the explanatory variables. In the stepwise procedure, the variable that has the highest correlation with the dependent variable is selected first, and the next variable to be considered is the one that significantly increases R^2 by the largest amount. The procedure continues until there are no remaining independent variables that provide a significant increase in R^2 and the regression coefficients of the selected variables are described to formulate an equation.

The variability of the dependent variable that could be the regression equation is characterized by R^2, which is considered high for biological data when it ranges from 30% to 67%.[18] In the present study, R^2 was 61.3%. According to the statistical rule, the number of samples must be at least twice as many as the number of independent variables.[19] The present sample consisted of 23 cases because this was the satisfactory number to make the regression coefficients and the R^2 values true representatives of the actual population.

As the result of the statistical analysis on the present sample, a set of three independent variables (AH3, AH4, and PH3) was significantly selected among the parameters studied to explain the dependent variable. After completion of endochondral ossification, the growth of the vertebral body takes place only at the front and sides.[20] The result of the stepwise regression was in accordance with the growth pattern.

We compared the predictive accuracy of this equation with the other two available methods. The result is shown in Tables 3 and 4. The present study used the Japanese standardized bone age reported by Murata et al[21] Clinically, if the error of the prediction could be within 3 mm during puberty, it might be considered acceptable and could be used to predict mandibular potential. Although the average errors of the three methods were all lower than 3 mm, the most accurate prediction was made using this equation.

Ngan et al[22] compared the skeletal growth changes between Class II division 1 and Class I girls between ages 7 and 14. MLI was found smaller in Class II division 1 than in Class I. Sugawara and Mitani[23] reviewed the craniofacial growth of skeletal Class III and Class I Japanese subjects during the prepubertal, pubertal, and postpubertal periods and found that the Class III subjects and the Class I subjects showed similar MLI during the three periods. Our result was in accordance with his study. The smaller MLI in Class II was not reflected in the other two predictive methods, but in Group B, there were only Class I and Class III Japanese girls. This reason may cause the higher predictive accuracy of this equation.

Another reason for the higher accuracy of the equation could be that the growth potential and the growth percentage methods were determined by analyzing bone age on the basis of hand-wrist radiographs. Usually in analyzing hand-wrist radiography, nine stages (A to I) are used to show the bone maturity. Using discontinuous values to predict continued mandibular growth certainly is not precise. In our study, we used, continuous values of the cervical vertebral measurement, and this might cause the higher predictive accuracy of this equation.

The third reason may be that the mandibular bone is located next to the cervical vertebrae. The time of mandibular bone formation is closer to that of the cervical vertebral bone than that to the hand-wrist bone. Therefore, the mandibular length would have a closer relationship with cervical vertebral bone than with hand-wrist bone.

From Table 2, we can see the Go-angle from the CVMS I to the CVMS V. There was a tendency for this angle to become smaller, but there was no significant difference. The Go-angle changes had little influence on the mandibular length (Ar-Pog) increment. This finding was in accordance with the result of Sugawara and Mitani.[23]

This equation predicted the MLI between the initial time of CVMS I and CVMS V. In this study, we used the patients who had no mandibular treatment as the sample. In fact, orthodontic treatments might have little influence on the mandibular length growth,[24,25] and we could use this equation to predict the MLI of the patient having orthodontic treatment.

CONCLUSION

In this study, we established a new equation to predict mandibular growth and compared it with the other predictive methods. The equation might be a useful method for predicting mandibular growth potential on the basis of only a single cephalometric radiograph.

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