Estimation of cervical vertebral bone age by using mathematical formula: A cephalometric study

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ABSTRACT

Introduction: Craniofacial growth is an integral part of orthodontic diagnosis and treatment. Optimal effectiveness of orthodontic/orthopedic appliance is achieved during pubertal growth spurts, evaluation of maturation and growth potential is important. Radiographic assessment of hand-wrist bones is a reliable indicator of skeletal maturation, however, it requires a separate radiograph. The objective of this study was to evaluate skeletal maturation using cervical vertebral dimensions. **Methods:** This is an analytical cross-sectional study using lateral cephalograms of 52 subjects (26 males and 26 females). Manual tracing was done on the collected sample. Landmarks on C3 and C4 were marked. Measurement was recorded and cervical vertebral bone age was calculated by using the formula. Mandibular growth potential was calculated from cervical vertebral bone age. Paired-t test was performed to compare the cervical vertebral bone age and the chronological ages among the samples and between sexes. The correlation between the cervical vertebral bone age and the mandibular growth potential was determined by use of Pearson's correlation coefficient. **Results:** The mean chronological and cervical vertebral bone age was 13.38±1.42 and 14.08±1.83 years respectively and was significant. No significant differences was found among male samples (p=0.230) whereas it was significant among females (p=0.002). A strong negative correlation was found between the cervical vertebral bone age and mandibular growth potential (r=-0.943). Linear regression equation was derived as CVBA=-4.2857+1.4286CA. **Conclusions:** The study showed a strong negative correlation between cervical vertebral bone age and mandibular growth potential.

Keywords: Cervical vertebral bone age, chronological age, growth potential, skeletal maturation.

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INTRODUCTION

Growth is characterized by variation in the amount, rate, time, pattern, and progress toward maturity.[1] Bone growth is a fundamental process in human development and is almost entirely responsible for the increase in stature. It is known that bone tissue develops, grows, and matures along defined lines, from a primary ossification center until it reaches the stage of completely developed bone.[2] Morphological maturity is inevitable in all individuals, with different growth spurts, occurring earlier in some individuals and later in others. Dental tissue mineralization, ossification in epiphyses and posterior fusion with diaphysis, the beginning of pubertal growth spurt, variation in height, and coming up of sexual characteristics are considered indicators of maturation.[3] In adolescence, there is a period in which growth occurs at the maximum rate, known as the pubertal growth spurt. Due to the large number of ossification centers in a relatively small area, simple radiographic technique, and the patient's exposure to a small amount of radiation, hand-wrist radiographs have been frequently used in the evaluation of bone growth and maturation.[3-4]

The lateral cephalometric radiographs routinely used for orthodontic and/or functional orthopedic treatment contain important information that requires the knowledge of head and neck anatomy, as well as the cervical vertebrae. Therefore, changes in the size and shape of the vertebrae during the individual's growth may be used as an indicator of bone maturation.[5] It is known that the morphology of the cervical vertebral bodies changes with growth. To reduce both radiation exposure and diagnostic cost to the patient, assessment of cervical vertebral maturation has been explored.[6]

Lamparski was the first to suggest that morphological changes occurring in cervical vertebral bodies during growth could be used to assess skeletal maturation.[5-7] He found this method as a reliable and valid alternative to radiographic assessment of hand-wrist bones for determination of skeletal age. Since then, the cervical vertebral maturation method has been increasingly used to determine skeletal maturation in dentofacial orthopedics, without the need for hand-wrist radiographs. These studies were based on subjective evaluation, where cervical vertebrae were evaluated comparing the patient's radiographic images with a standard atlas. There are concerns that these methods may be prone to inter-operator variability and error. Mito et al.[5] derived a mathematical formula to calculate the individual bone age by stepwise multiple regression analysis with the chronological age as a dependent variable and the dimensional changes in cervical vertebral bodies as an independent variable. Objective methods of evaluation have been developed by certain authors using regression formulae based on ratios of measurements in third and fourth cervical vertebral bodies.[4-7] Till date, there is inadequate literature on the evaluation of cervical vertebra in growth estimation in the Nepalese sample. The present study aimed to evaluate the skeletal maturation from cervical vertebra maturation indicators.

METHODS

An analytical cross-sectional study was conducted on lateral cephalograms of patients from the orthodontic records at Kantipur Dental College and Hospital. The inclusion criteria were lateral cephalograms of good quality and contrast showing the cervical vertebra clearly. Patients with craniofacial trauma, craniofacial neoplasm, craniofacial deformity, and patients having malformation of the cervical vertebrae were excluded from the study. The data collection period was from November 2022 to December 2022. Ethical clearance was obtained from the Institutional Review Committee (IRC Ref. No.41/022).

The sample size was calculated using the data from the study done by Verma et al.[8]

$$N = f(\alpha, \beta)\ 2SD^2/M^2 = 23$$

Where f (α, β) = 10.5 at 90% power. SD was the average of standard deviation (1.06) and M is the mean difference (1.01) from the similar study.[8]

The sample obtained from the above equation was 23. Since two groups of males and females were taken, the sample size was 2×23 = 46. Adding 10% permissible error, a total sample size of 52 was taken. The samples were divided into 26 each for males and females. Data were obtained from the departmental records. Manual tracing of the films was done on matte acetate tracing paper using a 0.5 mm thick lead pencil and the outline of the C3 and C4 vertebrae were traced (Figure 1-a). The measurements were recorded in the proforma sheet by a single observer.

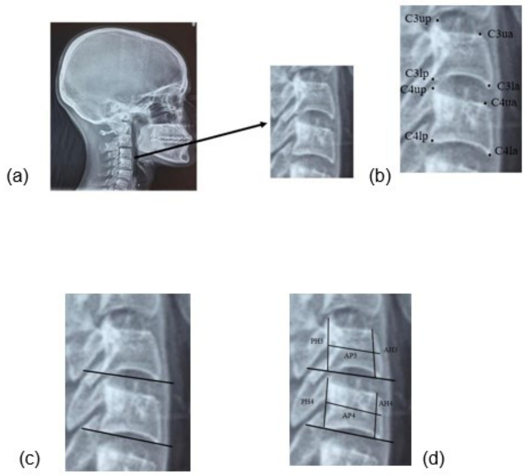

Figure 1: C3 and C4 cervical vertebra a) Outline b) Anatomical landmarks c) Reference planes d) Measurements taken on 3rd and 4th cervical vertebrae

Anatomical landmarks used for recording the measurements (Figure 1-b):

1. C3ua (cervical vertebra 3 upper anterior): The most superior point on the upper anterior border of the body of C3
2. C3la (cervical vertebra 3 lower anterior): The most anterior point on the lower border of the body of C3
3. C3up (cervical vertebra 3 upper posterior): The most superior point on the upper posterior border of the body of C3
4. C3lp (cervical vertebra 3 lower posterior): The most posterior point on the lower borders of the body of C3
5. C4ua (cervical vertebra 4 upper anterior): The most superior point on the upper posterior border of the body of C4
6. C4up (cervical vertebra 4 upper posterior): The most superior point of the upper anterior border of the body

of C4

7. C4la (cervical vertebra 4 lower anterior): The most anterior point on the lower border of the body of C4
8. C4lp (cervical vertebra 4 lower posterior): The most posterior point on the lower border of the body of C4

Reference planes used in the study (Figure 1-c):

9. Tangent on lower border of C3: Tangent drawn at the lower border of C3 passing through C3la and C3lp
10. Tangent on lower border of C4: Tangent drawn at the lower border of C4 passing through C4la and C4lp

Measurements taken (Figure 1-d):

11. AH3 (anterior vertebral body height of the C3): Distance between the point C3ua and the point drawn perpendicular from C3ua to tangent on the lower border C3
12. AP3 (anteroposterior vertebral body length of C3): Anteroposterior distance at the middle of the cervical vertebral body (C3) measured parallel to the tangent on the lower border of C3
13. PH3 (posterior vertebral body length of the C3): Distance between the point C3up and the point drawn perpendicular from C3up to the tangent on the lower border of C3
14. AH4 (anterior vertebral body height of C4): Distance between the point C4ua and the point drawn perpendicular from C4ua to tangent on the lower border C4
15. AP4 (anteroposterior vertebral body length of C4): Anteroposterior distance at the middle of the cervical vertebral body (C4) measured parallel to the tangent on the lower border of C4
16. PH4 (posterior vertebral body length of the C4): Distance between the point C4up and the point drawn perpendicular from C4up to the tangent on the lower border of C4

The cervical vertebral bone age was calculated by measuring the dimensions on third and fourth cervical vertebral bodies (CV3 and CV4) and the regression equation given by Mito et al.[5]

Cervical vertebral bone age (in years) =

$-0.20+6.20\times AH3/AP3+5.90\times AH4/AP4+4.74\times AH4/PH4$

The mandibular growth potential was calculated using the following formula given by Mito et al.[9]

Mandibular growth potential (mm) = −2.76×cervical vertebral bone age+38.68

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) version 20. A paired t-test was used to compare the means of chronological age and cervical vertebral bone age. The level of significance was set at $p<0.05$. The correlation between the cervical vertebral bone age and the mandibular growth potential was determined by the use of Pearson's correlation coefficient. A linear regression equation relating cervical vertebral bone age to chronological age was derived. Ten random samples were selected and retraced by the same examiner after two weeks. Intra-class Correlation Coefficient (ICC) was used to test intra-examiner reliability, where the ICC showed high levels of agreement (>0.9).

RESULTS

The mean chronological age of the total sample was found to be 13.38±1.42 which was less as compared to cervical vertebral bone age (14.08±1.83) and was statistically significant. (Table 1)

Table 1: Descriptive statistics and t-test of significance of CA and CVA (N=52)

	Mean (years)±SD	Standard error of mean	Confidence interval		p-value
			Upper	Lower	
Chronological age	13.38±1.42	0.196	-0.27	-1.11	0.002*
Cervical vertebral bone age	14.08±1.83	0.254			

*p<0.05 denotes statistical significance, CA=Chronological age, CVBA= Cervical vertebral bone age SD= Standard deviation

The mean cervical vertebral bone age in females was found to be 13.86±1.71 which is higher as compared to chronological age (12.81±1.26) and statistically significant. In males, no significant differences occur between chronological age and cervical vertebral age. (Table 2)

Table 2: Descriptive statistics for CVBA and t-test of significance among sex (N=52)

Parameters	Male				Female			
	Mean±SD	CI		p-value	Mean±SD	CI		p-value
		Upper	Lower			Upper	Lower	
CA	13.96±1.34	0.22	-0.88	0.230	12.81±1.26	-0.41	-1.69	0.002*
CVBA	14.29±1.34				13.86±1.71			

*p<0.05 denotes statistical significance

The remaining mandibular growth potential between male and female were found to be 0.22±5.40mm and 0.44±4.71mm respectively which showed no significant difference. (Table 3)

Table 3: Association of MGP with sex (N=52)

Sex	Mean(mm)± SD	Standard error of mean	Confidence interval		p-value
			Upper	Lower	
Male	-0.22±5.40	1.06	1.42	-3.68	0.639
Female	0.44±4.71	0.92			

MGP= Mandibular growth potential

There is a negative correlation between chronological age and mandibular growth potential, and cervical vertebral bone age and mandibular growth potential which is statistically significant. (Table 4)

Table 4: Pearson's Correlations of CA and CVBA with MGP (N=52)

Parameters	Correlation	p-value
CA-MGP	-0.601	<0.001*
CVBA-MGP	-0.943	<0.001*

*p<0.05 denotes statistical significance

A new formula was derived by regression equation using chronological age as independent variable and cervical vertebral bone age as dependent variable.

Y= -4.2857 + 1.4286X

Where, X = chronological age

Y = cervical vertebral bone age

DISCUSSION

The present study estimated the cervical vertebral bone age in males and females for evaluating skeletal maturation on a cephalometric radiograph. The study showed a significant difference between chronological age and cervical vertebral bone age similar to result found by Mito et al.[5] Similar results were found by Uysal et al.[10] and Murthy et al.[11] in 2013. However, no significant result was shown in a study done by Reddy et al.[7]

This study showed a statistically significant difference between chronological age and cervical vertebral bone age among females and no significant among males. A similar result was found in a study done by Chalkoo et al.[12] in 2022. Kumar et al.[13] found a statistically significant difference in ages among males and not in females opposite to the result obtained from this study.

A strong negative correlation was found between cervical vertebral bone age and mandibular growth potential (r=-0.943) in this study which is opposite to the result obtained by Verma et al.[8] This showed more the cervical vertebral bone age of an individual, the lesser the remaining growth potential of mandible. The result of this study showed that cervical vertebral bone age can be used as a reliable indicator in assessing mandibular growth potential.

Hagg et al.[14] reported that pubertal growth spurt begins at the age of 10 years in girls and 12 years in boys. In both genders, the growth peak occurs two years after the spurt begins and the growth goes up to the age of 15 and 17 in girls and boys respectively. Considering the growing phase, samples of age group 10-15 years for females and 12 to 17 years for males were taken. Maturational changes occur in all seven cervical vertebrae, however third and fourth cervical vertebra was chosen for the study. The first cervical vertebra (atlas) does not have a body and is also not visible clearly. The second cervical vertebra (axis) shows minimal morphological changes and is difficult to measure and the cervical vertebra below the fourth cannot be seen when a thyroid protection collar is used by the patient during radiation exposure.[4,5,7,8,13,15]

Various equations have been derived previously by Caldas et al.[4], Chandrasekar et al.[6], Reddy et al.,[7] Kumar et al.[13] for the estimation of cervical vertebral bone age. The regression equation derived by this study CVBA=-4.2857+1.4286CA can be used in the estimation of cervical vertebral bone age in the Nepalese sample which in turn can be used in assessing the skeletal maturation and growth potential.

The limitations of the current study were a small sample size and a cross-sectional design. Therefore the findings from this study could not be generalized to the entire Nepalese population. For accurate and reliable results longitudinal studies must be done.

The clinical application of this study will be during the planning of the growth modification procedure. The estimation of mandibular growth potential in Class II patients will help us in predicting the amount of skeletal changes that can be achieved by functional therapy. Similarly, in Class III malocclusion associated with mandibular prognathism, estimation of mandibular growth potential can help us in deciding the type of treatment possible, i.e. orthodontics alone or in combination with the surgical approach.

CONCLUSIONS

The current study showed a strong correlation between cervical vertebral bone age and mandibular growth potential. The formula derived from this study could be used in the calculation of the cervical vertebral bone age in individuals and thus the prediction of remaining mandibular growth potential.

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AUTHORS' CONTRIBUTION

RB did concept designing, literature search, clinical studies, data acquisition and compilation, statistical analysis, manuscript preparation, RMS contributed conceptualization, data analysis, editing, and review. JD contributed conceptualization, data analysis, editing, and review. Final editing and confirmation have been given by all authors.

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