



Relationship of Frontal Sinus Size and Maturation of Cervical Vertebrae for Assessment of Skeletal Maturity

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ABSTRACT

Objectives: This study aimed to assess the relationship of frontal sinus height and width with the cervical vertebral maturation (CVM) for assessment of skeletal maturity.

Materials and Methods: This retrospective study evaluated lateral cephalograms of 132 patients between 8 to 21 years, including 66 males and 66 females. For each of the six stages of the CVM, 22 patients (11 males and 11 females) were evaluated. The Ertuk's method was used to measure the height and width of the frontal sinus. The sinus height to width ratio was calculated and considered as the sinus index. The CVM was evaluated on the same lateral cephalograms using the Baccetti's method. The correlation of frontal sinus height and width with the CVM was analyzed, and comparisons were made using independent t-test, ANOVA, Mann-Whitney test, and Kendall's tau-b correlation coefficient.

Results: The sinus width was 10.85 ± 2.7 mm in males and 9.47 ± 2.6 mm in females. The sinus index was 2.43 ± 0.37 in males and 2.66 ± 0.32 in females ($P < 0.000$). The frontal sinus index and width were significantly greater in males but the sinus length was not significantly different between males and females ($P = 0.383$). Significant differences were found in stages 2 and 3, and also 4 and 5 in females and 2 and 3, 3 and 4, and 4 and 5 in males. The mean frontal sinus index had a significant correlation with the CVM stage in both groups.

Conclusion: According to the results, the frontal sinus index cannot be used as a predictor of skeletal maturity.

Keywords: Frontal Sinus; Cervical Vertebrae; Growth and Development; Cephalometry

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INTRODUCTION

Human growth and development, from the infancy to puberty, involves dynamic changes in shape and size. Assessment of growth potential during the growth spurt has a significant effect on the process of orthodontic diagnosis and treatment planning to predict the treatment outcome and stability of treatment [1].

Clinical decision making regarding the use of extraoral tensile forces, functional appliances, tooth extraction or non-extraction treatment, and orthognathic surgery is partially based on growth considerations [2]. Prediction of duration and magnitude of active growth especially in the craniofacial complex is important for orthodontists [3]. The stage of maturation of patients can be best determined

by determining the stage of physiological maturity. The chronological age is not sufficient to correctly determine the growth and developmental state in children, because children with similar chronological age may have different degrees of skeletal maturity [2]. Several parameters have been used for assessment of growth and development of children as an indicator of maturity and puberty. The classic parameters include changes in body height and weight, emergence of secondary sex characteristics, age of calcification and mineralization of tooth, and skeletal maturity that can be assessed on radiographs [4-6].

Evaluation of calcification and mineralization of the wrist is the most accurate method for this purpose. However, it has ethical limitations due to the need for X-ray exposure [5,6].

To decrease X-ray exposure, Lamparks and Nanda [7] evaluated the maturation of cervical vertebrae on cephalograms and reported that the stage of maturation of cervical vertebrae is correlated with skeletal maturity in children. Assessment of the maturation of cervical vertebrae is the most widely used technique for evaluation of growth status in children [8]. However, it has some limitations as well, such as difficult classification of the shape of the third and fourth vertebrae as trapezoidal, horizontal rectangular, square-shaped or vertical rectangular. On the other hand, growth and development occurs continuously over the years and its classification into distinct stages cannot well describe this continuous phenomenon [8,9].

Researchers have suggested different measures to find the best maturation and puberty index including height, weight, sexual puberty, chronological age, biological or physiological age, maturation of vertebrae, maturation of wrist bone, tooth eruption, and stage of tooth calcification. Evaluation of changes in the morphology of the frontal sinus during the growth spurt is a recently suggested method for evaluation of the status of growth and development [10].

Ruf and Pancherz [11,12] stated that the frontal sinus growth is correlated with

somatic maturity. Moreover, limited studies have evaluated the association of frontal sinus growth and skeletal maturity. A previous study revealed that the frontal sinus area expands up to the age of 19 years, and this growth is associated with general craniofacial growth and general skeletal maturity [13]. Many studies are available on the frontal sinus growth; but studies on the correlation of frontal sinus and other growth patterns are limited [1]. Methods used for this purpose have advantages and disadvantages. Researchers are still in search of finding the most efficient method for assessment of skeletal maturity in patients [2]. This study aimed to assess the relationship of the frontal sinus index and maturation of cervical vertebrae for assessment of skeletal maturity.

MATERIALS AND METHODS

This retrospective study evaluated lateral cephalograms of 132 patients between 8 to 21 years, including 66 males and 66 females. The lateral cephalograms were retrieved from the archives of the Orthodontics Department of Hamadan University, School of Dentistry. For each of the six stages of cervical vertebral maturation (CVM), 22 patients (11 males and 11 females) were evaluated. The inclusion criterion was having preoperative standard cephalograms with optimal quality. The exclusion criteria were affliction with any syndrome, history of trauma or surgery, frontal sinus anomalies, sinus conditions, and systemic diseases affecting growth and development.

Cephalometric landmarks were identified and analyzed on digital lateral cephalograms using Dolphin software. The Ertuk's [14] method was used to measure the height and width of the frontal sinus. In this method, the cephalograms were first aligned according to the SN horizontal plane, and the highest and the lowest sinus points were identified. The height of the line connecting these two points was considered as the sinus height. Next, a line was drawn connecting the most anterior and most posterior points of the sinus such that it was perpendicular to the sinus height and was considered as the sinus width [13]. To

eliminate magnification errors, the ratio of sinus height to width was calculated. This ratio was separately calculated for each patient and was considered as the sinus index and used for evaluation of the level of skeletal maturity of patients.

The maturation of cervical vertebrae was also evaluated on the same lateral cephalograms using the Baccetti's method [15]. Accordingly, the maturation of cervical vertebrae was divided into 6 stages based on the shape of C1, C2 and C3 cervical vertebra (Fig. 1).

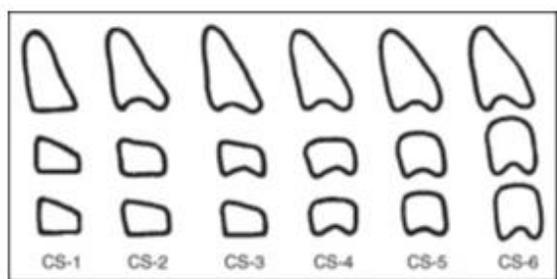


Fig. 1. Cervical vertebral maturation stages according to Baccetti et al, [15]

Stage 1: Two years before the growth peak; in this stage, the inferior border of the C2, C3 and C4 is smooth while their superior border has a posterior-anterior slope. Cervical vertebrae are trapezoidal in shape in this stage.

Stage 2: One year before the growth peak; in this stage, the inferior surface of C2 has a concavity, and the height of its anterior wall slightly increases.

Stage 3: Less than one year before the growth peak; in this stage, a concavity is formed in the inferior surface of C3; its shape is still trapezoidal.

Stage 4: One year after the growth peak; in this stage, a concavity is formed in the inferior surface of C4 and it is horizontal-triangular in shape.

Stage 5: More than one year after the growth peak; in this stage, the concavity of the vertebrae increases and they are square-shaped.

Stage 6: More than 2 years after the growth peak; in this stage, the vertebrae are vertical-triangular in shape. Sample size was calculated to be 132 according to previous studies [16-18],

considering the correlation coefficient of 0.40 for the H1 hypothesis and 0 for H0 hypothesis, power of 99%, and 0.01 level of significance, using the sample size calculation formula and the Pearson's correlation coefficient in PASS software. For each of the 6 stages of CVM, 22 patients (11 males and 11 females) were evaluated. For descriptive analysis of the data, the frequency tables were first drawn. Normal distribution of data was evaluated using the Shapiro-Wilk test.

Data were analyzed using independent t-test, ANOVA, non-parametric Mann-Whitney test, and Kendall's tau correlation coefficient. Twenty cephalograms were randomly chosen for evaluation of errors according to the Dahlberg's formula, and the rate of errors was found to be in the range of 0.01 to 0.03 mm. $P < 0.05$ was considered statistically significant.

RESULTS

The Shapiro-Wilk test was applied to assess normal distribution of data, which showed that the frontal sinus width and height data were not normally distributed.

According to the results of the Mann Whitney test, sinus width in males was significantly greater than that in females ($P = 0.003$). According to independent the performed t-test, the mean frontal sinus index in males was greater than that found in females ($P < 0.001$, Table 1).

Table 1. Descriptive data regarding the frontal sinus height (mm), width (mm) and index in males (n=66) and females (n=66)

Frontal sinus	Females Mean ± SD	Males Mean ± SD	P-value
Height	26.63±8.38	25.37±8.10	0.383
Width	9.47±2.61	10.85±2.70	0.003
Index	2.43±0.37	2.66±0.32	<0.001

SD: Standard deviation

ANOVA was applied to assess the correlation of frontal sinus height and width with the CVM. Significant differences were found in the frontal sinus height and width in different CVM stages in each sex ($P < 0.001$, Table 2).

Table 2. Comparison of frontal sinus measurements at different cervical vertebral maturation stages

Frontal sinus	Gender	Cs1	Cs2	Cs3	Cs4	Cs5	Cs6	P-value
Height (mm)	Females	13.84±0/90	17.75±1.41	23.96±0.90	27.48±0.86	32.43±2.48	36.74±1.40	<0.001
	Males	15.07±0.59	18.70±0.68	24.43±0.91	28.98±1.24	33.89±1.09	38.78±1.70	<0.001
Width (mm)	Females	5.56±0.47	7.39±0.52	8.90±0.71	11.10±1.07	11.50±1.35	12.38±1.22	<0.001
	Males	7.09±0.83	8.05±0.73	11.83±1.05	11.77±0.82	11.96±1.58	14.39±0.83	<0.001
Index	Females	2.50±0.27	2.40±0.18	2.70±0.25	2.49±0.28	2.84±0.19	2.99±0.32	<0.001
	Males	2.15±0.22	2.33±1.9	2.07±0.16	2.47±0.21	2.88±0.39	2.69±0.13	<0.001

To further validate our results and to find out whether these differences were present between the adjacent cervical stages, the post-hoc LSD test was applied (Table 3). This analysis showed that there were significant differences between stages 2 and 3, and also 4 and 5 in females, and between stages 2 and 3, 4 and 5, and 5 and 6 in males.

Table 3. P values related to comparison of frontal sinus index (FSI) between adjacent cervical stages in females (F) and males (M)

FSI	C1 vs C2	C2 vs C3	C3 vs C4	C4 vs C5	C5 vs C6
F	0.385	0.008	0.056	0.003	0.149
M	0.069	0.011	<0.001	<0.001	0.078

The correlations between the frontal sinus measurements and CVM stages showed a positive insignificant correlation in both males and females ($P>0.05$, Table 4).

Table 4. Correlation between the frontal sinus measurements and cervical vertebral maturation stages in females (F) and males (M)

Frontal sinus	Sex	Correlation Tau-b	P-value
Height (mm)	F	0.702	<0.001
	M	0.799	<0.001
Width (mm)	F	0.922	<0.001
	M	0.911	<0.001
Index	F	0.487	<0.001
	M	0.401	<0.001

DISCUSSION

The frontal sinus starts to develop in the fourth or fifth week of gestation, continues its growth during childhood, and reaches its final size and form in early adulthood. It is not visible radiographically until the age of 5 years [1]. By 6 years of age, the frontal sinus becomes visible radiographically and grows larger in size by late adolescence. Rapid growth of the sinus continues until the age of 12 years, when it reaches nearly adult size. The development of the frontal sinus is completed by 20 years of age, and remains stable until further enlargement of the chambers occurs as a result of bone remodeling with age [19]. According to previous studies [13,14], the frontal sinus growth can well reveal the growth spurt. Since the size of the frontal sinus may vary depending on gender and physical body size, use of sinus index is preferred to the use of sinus height or width alone. On the other hand, this index is used to eliminate the magnification error of radiographs. Many studies are available on the frontal sinus growth, but studies on the correlation of frontal sinus and other growth patterns are limited [13].

This study assessed the relationship of the frontal sinus index and the CVM for assessment of skeletal maturity. The results of this study showed that there was a significant relationship between the height and width of the frontal sinus and the CVM stages in both sexes. The frontal sinus height gradually increases through different cervical stages and

follows a linear pattern in both sexes. These findings are similar to those of Hanson and Owsley [20] and Ponde et al [21].

The width of the frontal sinus also gradually increases from cervical stage 1 to 6. The increase in width is significantly greater in males than in females. These findings are similar to those of Ruf and Pancherz [11,22]. They evaluated lateral cephalograms to assess the frontal sinus with 1 and 2-year intervals in 59 male patients. The hand wrist radiography was used to assess the skeletal maturity. They reported that the enlargement in the width of the frontal sinus could be considered as a maturity indicator, but their study was only performed on males. Based on our results, the frontal sinus index cannot serve as a reliable index for prediction of skeletal maturity. This finding was similar to that of Patil and Revankar [23]. Mahmood et al. [1] found that the frontal sinus index is not reliable for evaluation of skeletal maturity and cannot be used to determine different stages before, during, and after puberty and during the growth spurt.

Their findings were in agreement with ours. The main difference between the present study and that of Mahmood et al. [1] is related to the software used for measuring the height and width of the sinus. In the study conducted by Mahmood et al, [1] the Pro-X View software was employed, while in the present study, Dolphin software was utilized. As the growth estimation of patients is regarded as one of the principal requirements for orthodontic treatment planning of patients, and since Dolphin software is routinely used by clinicians for cephalometric assessments, there was no need to use a separate application, and time was saved as such. The growth and growth mutation peak induced by the environment, socioeconomic factors, race (as a genetic attribute), and genetics are the most effective factors on the size and form of sinus development.

The study by Mahmood et al. [1] was conducted on a Pakistani population. Thus, their findings are not applicable to the Iranian population. The novelty of the present study was its conduction on the Iranian population.

Patil and Revankar [23] stated that no significant association exists between the frontal sinus index and calcification of the third finger; thus, this index cannot be used for evaluation of skeletal maturity. Valverde et al. [13] evaluated Japanese females and showed that a correlation exists between the height growth spurt and enlargement of the frontal sinus. Variations in the frontal sinus can serve as an index for evaluation of skeletal maturity. This difference can be attributed to the study design because their study was performed only on female patients and they had a smaller sample size than ours. As shown in our study, the frontal sinus height and width increase with age. However, since the sinus index is computed by the ratio of height to width, its changes do not follow a specific, clinically significant pattern, as shown in our study. Therefore, it cannot be used as an indicator of skeletal maturity.

CONCLUSION

A significant correlation was noted between the frontal sinus height and width and CVM stage in both males and females, which had an increasing pattern. However, no significant correlation was noted between the frontal sinus index and the CVM stage. Hence, evaluation of the CVM stage remains the standard method for assessment of skeletal maturity in patients undergoing orthodontic treatment. Longitudinal studies using three-dimensional radiographic modalities are required to precisely assess the sinus growth and its correlation with the CVM and skeletal maturity.

CONFLICT OF INTEREST STATEMENT

None declared.

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