Original Article

Predictive Factors of Vertical Bone Depth in the Paramedian Palate of Adolescents

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ABSTRACT

Objective: To determine whether a relationship exists between the vertical bone depth in the paramedian palate (PP) of growing patients and age, gender, and palatal morphology. Clinically detectable traits may decrease the need for further imaging prior to implant placement for orthodontic anchorage.

Materials and Methods: Cone beam computed tomagraphic scans (Newtom-9000, Verona, Italy) were acquired in 183 orthodontic patients (10–19 years old). Vertical bone depth was measured at nine unilateral locations in the PP of each subject. Measurements were analyzed with univariate and multivariate statistical tests.

Results: Significant variability in the bone thickness was found among locations and among subjects. Male subjects had significantly greater mean bone thickness in six of the nine locations measured, showing a mean of 1.22 mm more vertical bone than females showed at these locations. Age and palatal measurements did not demonstrate a clinically useful relationship with bone depth.

Conclusions: Age and palatal morphology are not valid predictors of bone height in the PP. Because of the large variability of bone thickness in this region, computed tomographic imaging remains valuable prior to paramedian implant placement in growing individuals. The paramedian palate presents a promising region for palatal implant placements when the midpalatal suture is to be avoided.

KEY WORDS: Cone beam CT; Adolescent; Implant; Palate

INTRODUCTION

The paramedian palate (PP) of adolescents has become an area of interest to orthodontists desiring absolute, noncompliance-dependent anchorage. The use of titanium implants for orthodontic anchorage has become more accepted as a viable treatment alternative in recent years. Most research has focused on their use in adults, with the midpalatal suture as the implantation site of choice. In adolescents, it has been recommended to avoid the midpalatal suture because of its nature as a growth center.[1] The potential degree of alteration of maxillary growth due to disruption of the suture by placement of an implant is unknown. Other studies have suggested that the placement of implants in the midpalatal suture of growing patients is contraindicated because of the questionable quality of bone and the uncertain effect of an ankylotic fixture in a growth site.[2]

Because growing patients make up the majority of orthodontic patients, recent research has focused on the PP as a potential implantation site. Bernhart et al[1] and Gahleitner,[3] by dental computed tomagraphy (CT), demonstrated regions of adequate vertical bone volume for implant placement in the PP of man.

Published research has shown a clinical focus, with sample sizes in the range of 20 to 30 patients, and fewer growing patients.[2–4] To obtain an understanding

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of the anatomy of the PP that applies to the population requiring PP implantation, a study of a large number of adolescent subjects is required. It is hoped that the identification of predictors of vertical bone depth in the PP of adolescents may be possible with a large population sample examined by CT. Such predictors could be used by orthodontists and surgeons to aid treatment planning decisions.

The aim of this study is to determine whether the age, gender, or palatal form of the adolescent patient can serve as predictors of the vertical bone depth available for orthodontic implant placement in the PP.

MATERIALS AND METHODS

The population tested comprised individuals between the ages of 10 and 19 years seeking orthodontic treatment who had their pre-orthodontic records taken at Edmonton Diagnostic Imaging Inc. Cone beam CT (CBCT) scans (Newtom-9000, Verona, Italy) of 183 adolescents, obtained for the purposes of pre-orthodontic treatment planning, were available.

The range of age groups was designed to encompass the ages that make up the majority of orthodontic patients. Male patients made up 32% of the sample, which is in line with the results of Huang et al,[5] who found that male patients made up 36% of patients seeking orthodontic care in a study of the demographics of demand for orthodontic care.

The lower age limit was set by the earliest age at which comprehensive orthodontic treatment is generally undertaken,[6] and the upper limit by the age at which palatal growth is considered complete enough to have little consequence on treatment options.[7] To provide a wide range of ages for analysis, the lower and upper ages were set at 10 and 19 years, respectively. These subjects were divided into three age groups strictly defined by year, month, and day, such that the age group 10–13 started on the 10th birthday, and ended on the day before the 13th birthday. Similarly, the age group 13–16 began on the 13th birthday and ended the day before the 16th birthday.

Only subjects who demonstrated normal development were included. Those who exhibited conditions such as supernumerary teeth in the area of interest or cleft palate were excluded from the study. Those who had previous orthodontic treatment or were in the process of orthodontic treatment were also excluded. Out of the 189 data sets available within the age groups selected, six were omitted because of such concerns. Distribution of the sample by age and gender is provided in Table 1.

Multiplanar reformatting of the obtained CBCT data was performed with eFilm workstation software (Milwaukee, Wis). The volume of data is initially visible as

Table 1. Distribution[a] of Sample by Age and Gender

Age, y	Female (%)	Male (%)	Total (%)
10–13	43 (23.5)	15 (8.2)	58 (31.7)
13–16	45 (24.6)	32 (17.5)	77 (42.1)
16–19	36 (19.7)	12 (6.6)	48 (26.2)
Total	124 (67.7)	59 (32.2)	183 (100)

[a] Percentages are mean (SD).

Figure 1. Multiplanar reformatting along the line shown in this axial view results in the sagittal image seen in Figure 2.

a two-dimensional image in the axial orientation. The midsagittal plane was located by creating a line that bisected the incisive foramen and the odontoid process of the second cervical vertebrae. The odontoid process was chosen because of its midline position and distance from the incisive foramen, to reduce the influence of local asymmetry on the ability to choose a reproducible midline (Figure 1).

Multiplanar reformatting was performed along this line to create a midsagittal view. Reference lines in the software were used to coordinate this view precisely with the selected line in the axial view. In this sagittal view, measuring lines were placed along the hard palate on the oral side. With the distal margin of the incisive foramen as the starting point of the measurements, multiplanar reconstructions of paracoronal sections were made at intervals of 4, 8, and 12 mm distal from the foramen. The resulting paracoronal reconstructions were made perpendicular to the curvature of the palate to simulate the best possible path of insertion of an orthodontic implant,[2,8,9] and these reconstructions are referred to as Planes 4, 8, and 12 (Figure 2).

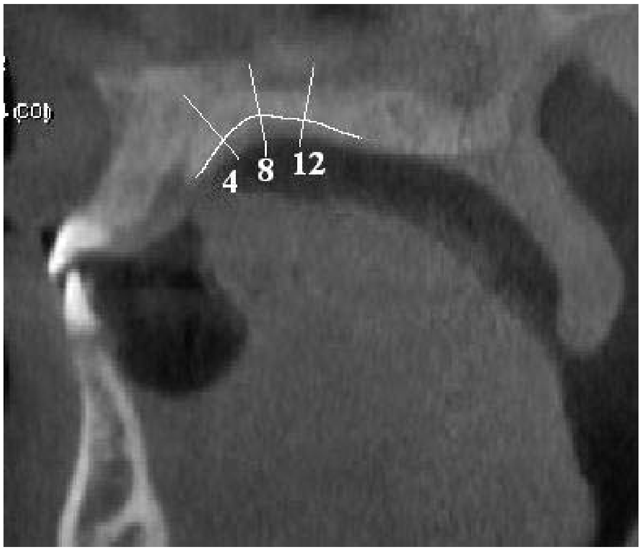

Figure 2. Sagittal view showing the planes (located 4, 8, and 12 mm from the incisal canal) in which the paracoronal views were generated.

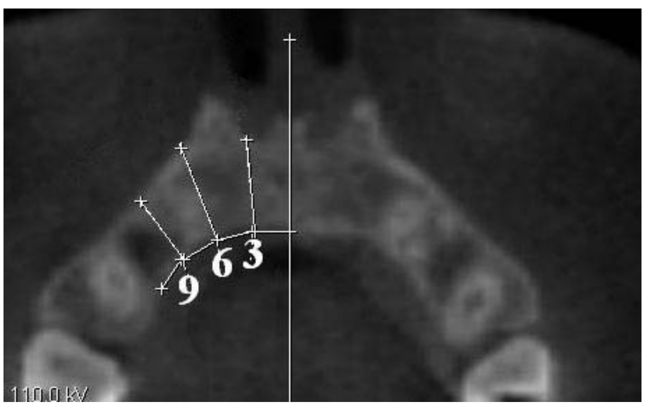

Figure 3. Paracoronal view at Plane 4, in which Distances 3, 6 and 9 were established at 3, 6, and 9 mm from the midline. The intersection of Plane and Distance results in the measuring locations P4D3, P4D6, and P4D9.

In each of the three reconstructed paracoronal planes, measuring lines were established on the subject's left side at intervals of 3, 6, and 9 mm, starting from the median-sagittal plane on the oral side of the hard palate. These measuring lines were also made perpendicular to the curvature of the palate to simulate the best possible path of insertion of an orthodontic implant in all three planes of space.[2,8,9] These lines are referred to as Distances 3, 6, and 9 (Figure 3). An earlier pilot study confirmed that the subjects were symmetrical, and therefore, only one side of the palate was measured in each paracoronal reconstruction.

The resulting intersections of Plane and Distance are nine locations in the paramedian palate of each subject. The name of the location is a description of its orientation to the distal margin of the incisive foramen, in millimeters. The nine locations are P4D3, P4D6, P4D9, P8D3–9, and P12D3–9. The least available vertical bone depths were measured at these nine locations (Figure 4). Any measurement that was in the path of an erupting tooth was not included in the analysis. Measurements that encountered fully erupted teeth were recorded at that level.

The form of the hard palate demonstrates great variability. In qualitative clinical terms, palatal vaults are often described as ''high and narrow'' or ''low and broad''. Describing various palatal forms in terms of an easily understood index allows clinicians to make treatment planning decisions without relying on such subjective descriptors.[10] Attempts to categorize palatal forms mathematically have met with little success. There are hardly any normal standards to determine accurately whether a palate is deformed, and this can conceivably be a reason for the divergent results observed in previous studies regarding palatal morphology.[11]

CT scanning presents the ability to base measurements on easily defined hard tissue landmarks and

Measuring Location	Relationship to the incisive foramen (mm distal, mm lateral)
P4D3	4,3
P4D6	4,6
P4D9	4,9
P8D3	8,3
P8D6	8,6
P8D9	8,9
P12D3	12,3
P12D6	12,6
P12D9	12,9

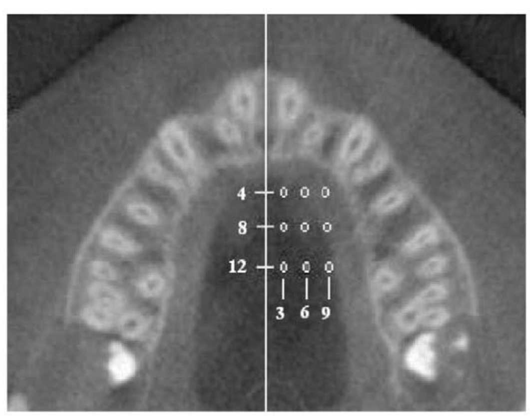

Figure 4. Map of the location of each vertical bone depth measurement as they related to the distal margin of the incisive foramen, in millimeters.

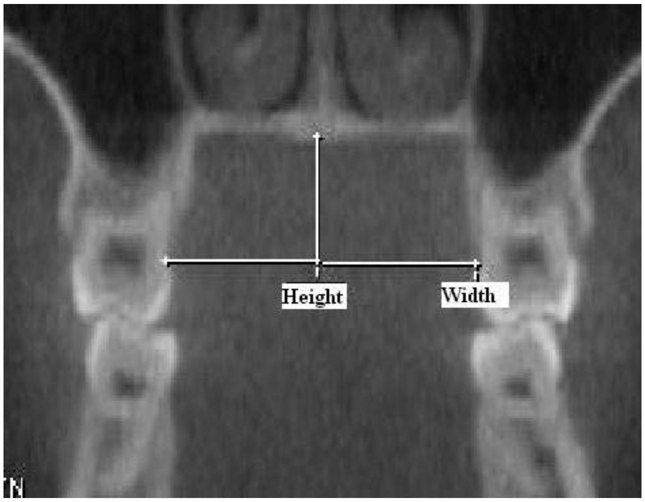

Figure 5. The palatal dimensions of height and width were taken at the most lingual point of the first permanent molars from CEJ to CEJ. Palatal index = palatal height/palatal width.

orthogonal measurement techniques, resulting in reproducible, accurate measurements.[12] In this paper, the palatal width (PW) was measured as the largest palatal distance between the maxillary first molars at the cemento-enamel junction (CEJ), and the palatal height (PH) was measured as the distance from the bony cortex of the hard palate at the midline of the palate perpendicular to the line measuring the width (Figure 5). The ratio between the palatal height and width (PH/PW), expressed as a percentage, can serve as an easily understood palatal index (PI).[10] The same investigator completed the multiplanar reformatting and bone depth measurements for the 183 subjects.

A pilot study was conducted to determine measurement reliability, palatal symmetry, and sample size requirements. These measurements of vertical bone depth were tested for reliability by the Intra-Class Coefficient test, and values ranged from 0.98 to 0.85. These subjects were examined for palatal symmetry and demonstrated no significant difference between the right and left sides of the palate, allowing the use of nine vertical bone depth measurements for each subject in addition to palatal height, width, and index measurements. A recent study by Gahleitner et al[3] confirmed that the same symmetry existed.

Repeated measures MANOVA of the associations of age category, gender, and palatal measurements on the mean vertical bone depth at the nine measured locations was carried out. Post hoc power analysis of the results of the MANOVA was done. The association between palatal factors (palatal height, width, and index) with age and gender were analyzed by linear regression analysis, and an independent sample *t*-test was used to further elucidate the relationship between gender and palatal factors (SPSS 12.0, Chicago, Ill).

RESULTS

The combination of three planes with three measurements per plane resulted in nine measurements for each of 183 patients, totaling 1,647 measurements of palatal bone depth. A total of 28 measurements were removed from the analysis because of contact with unerupted teeth (all of which were found in age category 1), resulting in 1,619 measurements for further analysis. Measurements that encountered erupted teeth were taken at that level.

The association of gender with the mean vertical bone depth at each of the nine locations is itemized in Table 2 and illustrated in Figure 6. At six of the nine locations, males had significantly more vertical bone depth than females (range 0.98 to 1.46 mm more; $P < .05$). The locations P4D6, P4D9, and P8D9 did not demonstrate significant differences in vertical bone depth between genders.

At eight of the nine locations, no significant relationship between the age of the subjects and vertical bone depth in the paramedian palate existed. A statistically significant relationship existed only at location P12D9, where age categories 1 and 2 had more (1.20 and 0.85 mm, respectively) vertical bone depth on average than age category 3 (Figure 7). Bone depth was found

Table 2. Measurements[a] of Mean Vertical Bone Depth at Each of the Nine Paramedian Locations

Location	Male Subjects		Female Subjects		Gender Difference, mm	*P*	Power
	Mean (SD), mm	n	Mean (SD), mm	n			
P4D3	7.48 (3.10)	59	6.43 (2.53)	123	1.05	.016	0.676
P4D6	5.07 (3.41)	55	4.49 (2.79)	120	0.58	.226	0.227
P4D9	2.09 (1.42)	55	2.06 (1.21)	120	0.03	.889	0.052
P8D3	5.56 (2.03)	59	4.10 (1.65)	124	1.46	.000	0.999
P8D6	5.95 (2.95)	58	4.52 (2.13)	124	1.43	.000	0.961
P8D9	4.75 (2.83)	55	4.58 (2.99)	121	0.17	.723	0.064
P12D3	4.03 (1.48)	59	2.96 (1.16)	124	1.07	.000	1.000
P12D6	4.32 (2.02)	59	3.35 (1.89)	124	0.98	.002	0.887
P12D9	5.90 (2.80)	58	4.60 (2.48)	122	1.30	.002	0.886

[a] Measurements excluded were in the path of erupting teeth (28 total).

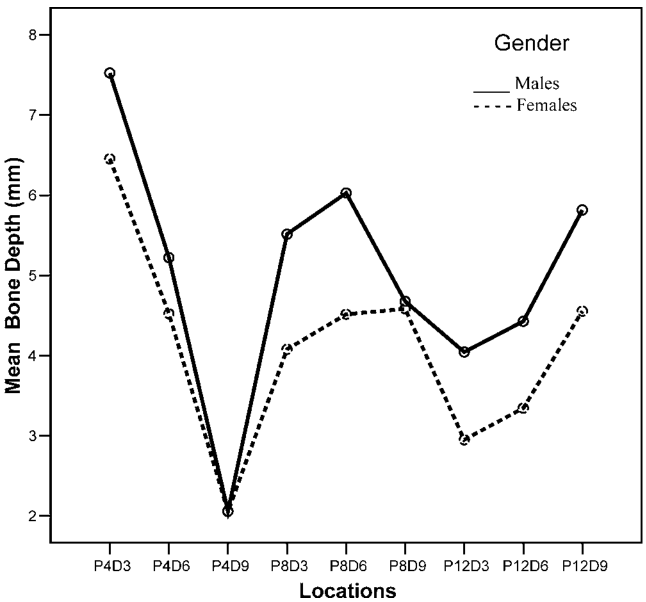

Figure 6. Average bone depth for males and females at each palatal location.

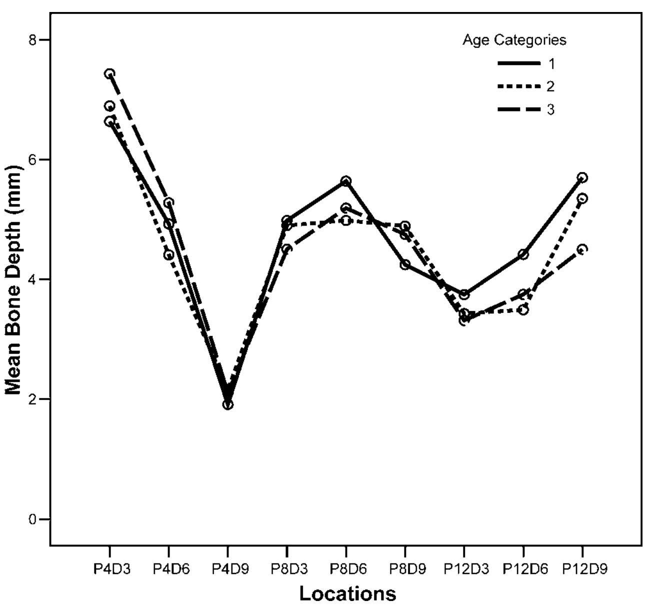

Figure 7. Average bone depth for age groups at each palatal location.

to be associated with palatal height, width, and index after gender and age have been accounted for (Table 3).

Regression analysis of the association between palatal height with gender and age revealed an R^2 value of 0.194. The association between palatal height and age was statistically significant ($P = .000$); the association between palatal height and gender was not statistically significant ($P = .095$). Regression analysis of the association between palatal width with gender and age revealed an R^2 value of 0.038. The association between palatal width and age was not statistically significant ($P = .331$); but the association between palatal width and gender was statistically significant ($P = .013$). Regression analysis of the association between palatal index with gender and age revealed an R^2 value of 0.131. The association between palatal index and age was statistically significant ($P = .000$); but the association between palatal index and gender was not statistically significant ($P = .908$) (Table 4). An independent sample *t*-test of the association between palatal width and gender revealed that male widths were 1.18 mm wider on average than female widths ($P = .014$) (Table 5).

Table 3. Locations in which Bone Depth was Associated with Palatal Factors[a]

Palatal Factor	Location	Rate of Change	P
Height	P12D3	−0.12	.008
Width	P4D9	0.07	.040
	P12D3	−0.06	.045
	P12D6	−0.14	.002
Index	P4D6	−0.06	.034
	P8D9	−0.08	.009
	P12D6	−0.04	.040

[a] The association is described by rate of change. A 1-mm increase in the palatal factor corresponds to an increase or decrease in the average bone depth in millimeter amount equal to the rate of change at the locations listed.

Table 4. Regression Analysis: Association Between Palatal Factors and Age and Gender

		P	
Palatal Factor	R^2	Age	Gender
Height	0.194	.000	.095
Width	0.038	.331	.013
Index	0.131	.000	.908

Table 5. Independent *t*-test of the Relationship Between Palatal Factors and Gender

	Mean Difference Between Genders			
			95% Confidence Interval	
	Mean, mm	P	Lower	Upper
Height	.50	.174	−0.22	1.23
Width	1.18	.014	0.24	2.13
Index	.03	.984	−2.48	2.43

DISCUSSION

Clinical trials using implants of varying lengths have demonstrated that the paramedian palate is a suitable host site for implants in orthodontic treatment. Investigators have utilized both conventional radiographic examinations and CT methods to determine which subjects had appropriate vertical bone depth for implant placement and the best location for implantation.[1,2,4,7–9,13] A common finding has been the great variability in the vertical bone depth among patients, and the use of conventional radiographs for presurgical planning has provided results that were consistently different from surgical findings.[8]

To date, the literature has not explored factors that may be predictive of vertical bone depth availability, in addition to conventional radiographs and diagnostic records. As a result, the need for diagnostic imaging tools such as CBCT has intensified. Identification of predictive factors might decrease imaging requirements, aid in treatment planning of palatal implants, or both.

CBCT produces images that are anatomically true, three-dimensional representations with one-to-one correlation, from which slices can be displayed from any angle in any part of the imaged region and archived digitally; anatomical structures can even be printed at their true size. The effective radiation dose of a CBCT scan is lower than that of conventional CT and within the range of traditional dental imaging modalities.[12,14,15] It also allows secondary reconstructions, such as sagittal, coronal, and para-axial cuts, and three-dimensional reconstructions of different craniofacial structures that are not magnified nor distorted in size or shape.[12]

By using CBCT and appropriate software for data reconstruction, our results demonstrate that male adolescents consistently have more vertical bone depth in the PP than do female adolescents. Six of nine locations studied had on average 1.22 mm more mean vertical bone depth. Three of the locations did not demonstrate a significant gender difference, probably because of the large number of measurements that were limited by the presence of teeth at these locations. Post hoc power analysis was done because of impractical a priori sample size calculations. The results demonstrate adequate power to determine the differences in bone depth seen between genders at the six locations. The measurements at P4D6, P4D9, and P8D9 did not demonstrate adequate power, again, possibly because of the large number of measurements limited by the presence of teeth at these locations.

Eight of the nine locations examined did not demonstrate a relationship between vertical bone depth and age. One location, P12D9, demonstrated increased bone depth in the 10–13 and 13–16 age groups, with those ages having 1.20 and 0.85 mm more bone depth, respectively, than the same location in the 16–19 age group. These findings complement those of Howell et al,[16] who reported an increase in palatal index from the mixed to the permanent dentition, measured distal to the second premolar, while the area between the first and second premolars remained stable as children aged. An increased palatal index resulted primarily because of increased palatal height (at the level of the first permanent molars in this study), which might be expected as palatal remodeling with age expresses most of its effect in this area.[16–18] Bone quality in the posterior hard palate has been identified as being of generally poorer quality than the bone in the anterior; thus age-related changes in bone depth at this location may have limited practical usefulness.[19]

The association between the palatal factors (palatal height, width, and index) with bone depth, although statistically significant, demonstrated that large changes in these factors correspond to minimal change at the measured location. For example, a 10-mm change in palatal height corresponds to 1.2 mm less average bone depth at P12D3. The clinical usefulness of these observations is questionable.

Palatal width did not increase with age. Regression analysis of the association between palatal factors with age and gender, although statistically significant, was a poor fit, describing only 19.4% of the variance in palatal height, 3.8% of the variance in palatal width, and 13.1% of the variance in palatal index. Gender was related to palatal width, with male widths 1.18 mm wider on average than female widths.

CONCLUSIONS

- Vertical bone depth availability in the paramedian hard palate is similar over the age range of 10 to 19 years.
- Palatal form, aside from surgical access considerations, has no relationship to the vertical bone depth present.
- Male patients have, on average, 1.22 mm more vertical bone depth than female patients at the locations P4D3, P8D3, P8D6, P12D3, P12D6, and P12D9.
- Thorough pre-operative imaging remains essential in treatment planning of palatal implants for orthodontic anchorage because of the lack of readily identifiable predictors of vertical bone depth in the palate.

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