Morphological variations of the posterior mandible: Proposing a classification for ridge morphology based on cone-beam computed tomography data

Yaser Safi[1], Reza Amid[2], Hamed Mortazavi[3], Maryam Alizad –Rahvar[4]

[1]Associate Professor, Department of Oral and Maxillofacial Radiology, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2]Associate Professor, Department of Periodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[3] Professor, Department of Oral Medicine, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[4] Assistant Professor, Department of Oral and Maxillofacial Radiology, Shahid Beheshti University of Medical Sciences, Dental School, Tehran, Iran

Corresponding author: Maryam Alizad-Rahvar, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology, Shahid Beheshti University of Medical Sciences

Abstract

Objectives: This study sought to assess the morphological variations of the posterior mandible and propose a classification for ridge morphology based on cone-beam computed tomography (CBCT) data.Materials and Methods: This retrospective, cross-sectional study evaluated 130 CBCT scans of patients with edentulous mandibles. Qualitative variables including lingual and crestal concavity, vertical, horizontal and angular limitations, and ridge morphology were assessed at 631 sites on CBCT scans of 87 males and 43 females. A classification for ridge morphology in the posterior mandible was proposed based on the collected data. The kappa coefficient was calculated to assess the intra-observer agreement, and data were analyzed using the chi-square test and Pearson's correlation test.Results: The frequency of lingual concavity increased from the anterior towards the posterior region relative to the mental foramen (P<0.05). The maximum frequency of lingual concavity (11.1%) was noted at 21 mm distance from the mental foramen while its minimum frequency (4.1%) was noted at 5 mm from the mental foramen (P<0.05). Conclusion: Ridge morphology, defined as ridge angulation <15°, no lingual or crestal concavity, no limitation in width, and 8-10 mm height, had the highest frequency. Its suggested treatment plan included a 10-mm implant without width limitation or severe angulation. The majority of common morphologies had no width limitation with ridge angulation <15°. Height limitation was only present in two of them, which can be resolved by placement of a short implant or ridge augmentation. Keywords: Ridge Morphology; Mandible; Edentulism; Cone-Beam Computed Tomography

Introduction

Considering the high success rate of dental implants, the number of patients demanding dental implant treatment is increasingly worldwide [1]. As a result, the number of dental clinicians practicing dental implant treatment is also on the rise.

The first step in dental implant treatment planning is to comprehensively assess the height, width, density and thickness of cortical bone and evaluate the adaptation and alignment of the implant fixture and the final prosthetic restoration [2]. Moreover, determination of the convexity and concavity of the jawbone at the site of implant placement is imperative to assess the need for corrective or reconstructive surgical procedures, bone grafting, application of bone substitutes, and their required amount. On the other hand, the exact location and position of anatomical landmarks and the neurovascular bundles should be identified to minimize peri- and postoperative complications. Furthermore, lesions remaining in bone after tooth extraction should not be overlooked.

Imaging is the first step in implant treatment planning [2-4]. Two-dimensional radiographic modalities have potential shortcomings in visualization of three-dimensional structures due to their two-dimensional nature. Thus, they have been widely replaced with three-dimensional imaging modalities such as cone-beam computed tomography (CBCT) [5]. According to Scarfe et al, [6] multi-slice computed tomography (MSCT) and CBCT are highly accurate for implant placement and linear and angular measurements. Poeschl et al. [7] reported that CBCT can be used to obtain more accurate clinical results compared with MSCT. Also, evidence shows that CBCT has higher accuracy than computed tomography (CT) due to lower linear mean error rate [8]. Small size, lower patient radiation dose, shorter scanning time and lower cost are among the advantages of CBCT compared with MSCT [7]. Thus, CBCT is currently considered as a cost-effective modality for preoperative assessments in implant treatment [7].

Considering the influential factors in implant placement, there seems to be an obvious need for a comprehensive classification of ridge morphology particularly in the posterior mandible for more accurate treatment planning based on ridge morphology. Thus, this study aimed to use the CBCT scans of edentulous mandibles to offer a systematic classification of ridge morphology in the posterior mandible for more accurate treatment planning. The treatment plans suitable for each ridge type are also discussed.

Materials and Methods

This was a retrospective, cross-sectional study. A total of 130 CBCT scans of patients with complete mandibular edentulism were collected from two private oral and maxillofacial radiology clinics in Tehran during the first 6 months of 2019. The CBCT scans belonged to patients requiring implant-supported fixed partial dentures.

For sample size calculation, a pilot study was carried out on 30 CBCT scans. The sample size of the main study was calculated to be 130 CBCT scans assuming Z=1.6, standard deviation (SD) of the ridge height and width to be 2.8 and 2.7, respectively, and d=0.5 using the sample size calculation formula: $N = (Z^2 \times SD^2)/d^2$.

The inclusion criteria were complete mandibular edentulism (absence of teeth and residual roots in the mandible), bone height > 6 mm posterior to the mental foramen, and distinct mandibular cortical borders.

The exclusion criteria were bone height < 6 mm posterior to the mental foramen, distorted or foggy images with high scattered radiation or severe beam hardening, presence of pathological lesions, history of mandibular fracture or trauma, history of mandibular grafts or dental implant placement in the mandible, and history of recent tooth extraction and incomplete healing of the extraction socket.

The CBCT scans had been taken by HDX WILL CBCT system (Dentri, Korea) with the exposure settings of 100 kVp and 10 mAs or NewTom Giano (Verona, Italy) with the exposure settings of 110 kVp and 10 mAs. The exposure time and the size of field of view were adjusted based on the region of interest. The CBCT scans had been requested for diagnostic purposes not related to this study. The cross-sectional images of the right and left sides were reconstructed with 1 mm slice thickness and 1 mm slice interval.

Some quantitative and qualitative measurements were made at 5, 12.5 and 21 mm distance distal to the mental foramen in the right and left sides to ensure presence of a minimum of 6 mm bone height from the ridge crest to 2 mm distance from the mandibular canal. If the required condition was met, further measurements were carried out on the images.

Selection of 5, 12.5, and 21 mm distances from the mental foramen was due to the following reasons:

5 mm distance from the mental foramen: Respecting 3 mm distance distal to the mental foramen + half of the diameter of a 4-mm implant

12.5 mm distance from the mental foramen: Respecting 3 mm distance distal to the mental foramen + full diameter of a 4-mm implant + respecting 3 mm distance from the adjacent implant + half of the diameter of a 5-mm implant

21 mm distance from the mental foramen: Respecting 3 mm distance distal to the mental foramen + full diameter of a 4-mm implant + respecting 3 mm distance from the adjacent implant + half of the diameter of a 6-mm implant

The following qualitative parameters were assessed at the designated sites using OnDemand 3D Application version 10 software:

Lingual concavity: The points of maximum superior and inferior prominences of the ridge in the lingual surface were connected with a straight line. Presence of a concavity above the mental foramen relative to this line was recorded.

Crestal concavity: The superior part of the buccal ridge was evaluated for presence of concavity, and its presence was recorded.

Ridge morphology: Based on the quantitative measurements reported elsewhere (unpublished data) and the Misch classification for ridge morphology based on the ridge height and width [9], we proposed a classification for edentulous mandibular ridges (Figures 1-3):

A1H1W1: Ridge angulation <15°, no lingual or crestal concavity, height >12 mm and width > 5 mm

A1H2W1: Ridge angulation <15°, no lingual or crestal concavity, no limitation in width, and 8-10 mm height

A1H3W1: Ridge height < 8 mm, ridge angulation <15°, no crestal or lingual concavity

A2H2W1: Ridge angulation <15°, no crestal concavity, presence of lingual concavity, ridge height 8-12 mm, and width > 5 mm

A9H1W2: Ridge width limitation, ridge angulation >25°, adequate height, no lingual or crestal concavity

A2H1W1: Presence of lingual concavity, absence of crestal concavity, no limitation in ridge height, width or angulation

A3H1W1: Presence of crestal concavity, absence of lingual concavity, adequate ridge height and width, ridge angulation <15°

A4H3W1: Ridge height limitation, presence of lingual and crestal concavity

Calibration:

A postgraduate student of oral and maxillofacial radiology was calibrated with a periodontist for 30 cases. Next, all measurements were made by the postgraduate student of oral and maxillofacial radiology and double-checked by an oral and maxillofacial radiologist. For assessment of intra-examiner reliability, the measurements in both sides were repeated for 15 cases with a 2-week interval. The kappa coefficient was then calculated. The mean difference was evaluated and the limits of agreement and error range for each variable were calculated as follows:

- Limits of agreement: (Mean difference ± 1.96) × standard deviation of difference
- Error range: measurement error × critical value
- Measurement error: (SD of difference) /√2
- Critical value: 1.96

Data were analyzed by SPSS version 21 (SPSS Inc., IL, USA). The Chi-square test was used to compare the qualitative variables. The kappa coefficient was calculated to assess the intra-observer agreement. Correlations were analyzed using the Pearson's correlation test. Level of significance was set at 0.05.

Results

A total of 130 CBCT scans of 43 females and 87 males with edentulous mandibles were assessed. The mean age of patients was 63±11.76 years (range 33 to 89 years). Of 130 cases, information regarding the age of 11 patients was missing.

Lingual concavity:

Presence/absence of lingual concavity was evaluated at 631 sites; out of which, 343 did not have lingual concavity while 288 had lingual concavity. The maximum frequency of lingual concavity (11.1%) was noted at 21 mm distal to the mental foramen in the left side while the minimum frequency was noted at 5 mm distal to the mental foramen at both sides (4.1%). The percentage of lingual concavity significantly increased from the anterior towards the posterior region (P=0.00).

Crestal concavity:

Presence/absence of crestal concavity was evaluated at 631 sites; out of which, 598 did not have crestal concavity while 33 had crestal concavity. The maximum frequency of crestal concavity was noted at 5 mm distal to the mental foramen in the left side (1.4%) while minimum frequency was noted at 5 mm distal to the mental foramen in the right side (0.8%).

Vertical and horizontal limitations:

Ridge height > 8 mm was noted at 462 sites (74%) while ridge height < 8 mm was seen at 169 sites (26%). Also, width > 6 mm was found at 505 sites (80%) while width < 6 mm was noted at 126 sites (20%).

Angular limitation:

Seven sites had severe angulation (>25°), 126 sites had moderate angulation (15-25°) and 499 sites had mild angulation (0-15°).

Ridge morphology:

The frequency of different types of ridge morphology according to ridge angulation, height and width is presented in Figure 4. The six morphologies with the highest frequency were as follows (Figure 5): A1H2W1>A2H2W1>A1H1W1>A1H3W1>A2H1W1>A2H3W1.

Figure 6 shows the frequency of different morphologies at different distances from the mental foramen. At 5 mm distal to the mental foramen, the A1H2W1 morphology had the highest frequency. The A1H2W1 and A2H2W1 had the highest frequency at 12.5 mm distal to the mental foramen, and the A2H2W1 morphology had the highest frequency at 21 mm distal to the apical foramen.

The frequency of ridges in terms of angulation and lingual and crestal concavity was as follows:

A1 (straight, without crestal concavity, without lingual concavity): 40%

A2 (straight, without crestal concavity, with lingual concavity): 30%

A5 (angulated, without crestal concavity, without lingual concavity): 8.3%

A6 (angulated, without crestal concavity, with lingual concavity): 9.8%

Others: 12%

Table 1 presents a summary of the most important ridge morphologies along with their image and suggested treatment plan for each type.

Correlation of variables with age:

Table 2 shows the correlation of qualitative variables with age. As shown, angulation limitation had an inverse correlation with age (P=0.015) such that ridge angulation decreased with age, and severe angulation shifted to mild-moderate angulation. Horizontal limitation had an inverse correlation with age (P=0.004) such that the ridge width increased to over 8 mm with age. Presence/absence of lingual concavity, presence/absence of crestal concavity, and vertical limitation had no correlation with age (P>0.05).

Correlation of variables with gender:

Angulation limitation (P=0.00) and vertical limitation (P=0.012) had significant correlations with gender such that angulation limitation was higher in males. Females had a higher frequency of height limitation (33% versus 23%).

Change in variables from the anterior towards the posterior region:

Lingual concavity:

The prevalence of lingual concavity from the anterior towards the posterior region significantly increased (P=0.00).

Horizontal limitation:

The change in horizontal limitation was also significant from the anterior towards the posterior region (P=0.00) such that horizontal limitation decreased from the anterior towards the posterior region, and ridge width shifted to > 6 mm.

Angulation limitation:

Angulation limitation significantly increased from the anterior towards the posterior region and shifted from mild angulation to severe angulation (P=0.00).

A significant correlation was noted between ridge angulation and lingual concavity such that by an increase in angulation, the lingual concavity increased as well (P=0.00).

Correlation of ridge angulation (straight/angulated) with other variables:

Ridge angulation had a significant correlation with lingual concavity such that angulated group had averagely 0.3 mm greater concavity than the straight group (P=0.00). It also had a significant correlation with ridge width (P=0.00).

Ridge height had a significant correlation with crestal (P=0.003), buccal (P=0.000), and lingual (P=0.000) cortical bone thicknesses and ridge width (P=0.000).

Ridge width had a significant correlation with crestal cortical bone thickness such that W2 ridges (ridges with 2.5-5 mm width) had lower crestal cortical thickness by 0.7 mm than W1 ridges (ridges with > 5 mm width). Also, ridge width had a significant correlation with ridge height (P=0.00) such that W2 group had 2.12 mm lower height than W1 group.

Intra-examiner reliability:

The kappa coefficient was calculated to assess the intra-examiner reliability for the qualitative variables and the percentage of agreement between the two times of assessments was calculated. The kappa values for different variables are presented in Table 3.

Discussion

This study used CBCT scans of edentulous mandibles to offer a systematic classification of ridge morphology in the posterior mandible for more accurate treatment planning. The treatment plans suitable for each ridge type are also discussed. Assessment of qualitative factors was strength of this study since none of the previous studies assessed the correlation of qualitative factors such as presence/absence of lingual concavity and crestal concavity, vertical limitation, horizontal limitation and angular limitation with age. This study showed that aging decreased ridge angulation, and the ridge morphology shifted from angulated form to straight form with age.

Lingual concavity is a common finding in the posterior mandible, which can complicate implant placement [10]. In case of perforation of this area during implant surgery, bleeding can cause sublingual or submandibular hematoma and obstruct the upper airways [11]. Moreover, infection of the site can extend to the parapharyngeal space [12]. Watanabe et al. [13] classified the mandibular ridge morphology and showed that around 40% of their study population had lingual concavity. Froum et al. [14] reported that the risk of lingual perforation during immediate implant placement at the site of mandibular first and second molars was 9% to 31%. On the other hand, implant placement by use of a surgical guide to provide an ideal implant position often disregards the anatomical limitations of the underlying structures and increases the risk of lingual perforation, causing serious peri-operative complications [10]. In our study, 54% of the sites did not have lingual concavity while it was present in 46% of them. Another study reported the presence of lingual concavity (>2 mm depth) in the submandibular fossa area in 80% of the study population [15]. Aside from the complications caused by the presence of concavity in the posterior mandible during implant placement, presence of concavity in the buccal bone and ridge crest also affects osseointegration and primary and secondary implant stability [16]. In our study, 5.2% of 631 sites evaluated had crestal concavity. No significant correlation was noted between distance from the mental foramen and prevalence of crestal concavity. Studies on the prevalence of crestal concavity in the posterior mandible are limited.

Biomechanically, the implant angulation should be in alignment with the longitudinal axis of the opposing tooth or direction of application of occlusal loads [17]. The bone can better tolerate tensile and shear forces as such [18]. Increased ridge angulation on cross-sectional images affects the implant angulation. A meta-analysis showed a significant correlation between implant angulation (straight/angulated) and peri-implant marginal bone loss [19]. Nonetheless, use of prefabricated angulated abutments with 15°, 25° and 35° angulations allows acceptable, but not ideal, restoration placement over the angulated fixture [20].

In our study, the mean ridge angulation was measured at 631 sites to be 10.91° (range 0° to 30.9°), and divided into two groups of straight (<15°) and angulated (> 15°) based on the type of abutment used. Accordingly, 79% of the cases were categorized as straight.

Our study found a significant inverse correlation between horizontal limitation and distance from the mental foramen due to the greater width in the posterior areas. Our study showed an increase in ridge angulation and prevalence of lingual concavity from the anterior towards the posterior region, relative to the mental foramen. Increased prevalence of lingual undercuts in the posterior mandible has also been reported by some other studies [21-23]. Increased ridge angulation in the posterior area limits the correct alignment of implant fixture and affects ideal restoration placement in the future.

In our study, angulation limitation, or in other words, moderate and severe angulations were more common in males. Height limitation had a higher frequency in females (33% versus 23%). Evidence shows that bone loss has a higher frequency in females [24-26]. Our study showed that angulation limitation and horizontal limitation had an inverse correlation with age. Presence/absence of lingual concavity, presence/absence of crestal concavity, and vertical limitation had no correlation with age. Parnia et al. [27] measured the depth of submandibular fossa in areas requiring implant placement and found no association between age and depth of lingual concavity, which was in accordance with our findings.

In this study, four major factors of ridge height, ridge width, ridge angulation, and lingual and crestal concavity were used to offer a classification for ridge morphology in the posterior mandible. Accordingly, ridge morphology was divided into two groups of straight and angulated based on ridge angulation. The ridge morphology was also classified according to presence/absence of lingual and crestal concavity, and based on ridge height and width according to Misch classification [9]. The results showed that A1H2W1 morphology (indicating straight ridges without lingual or crestal concavity, with a width > 5 mm and height between 8-12 mm) had maximum frequency. A total of 92% of the sites evaluated in this study had > 5 mm width; 44% of them had a height between 8-12 mm and 40% were straight with no lingual or crestal undercut. Thus, it may be concluded that placement of a conventional 10 x 4 mm implant would be easy in the majority of our cases.

In our study, the correlation between ridge angulation (straight/angulated) and ridge width, and lingual concavity was significant such that angulated ridges with >15° angulation had lower width and higher lingual concavity. In fact, it may be concluded that implant placement in angulated ridges would encounter greater width limitation and may require ridge augmentation or ridge splitting. Also, in angulated ridges, implant fixtures should be placed with higher angulation to prevent lingual perforation. Moreover, ridge width had significant correlations with crestal cortical thickness and height, such that ridges with lower width had lower crestal cortical thickness and lower height. Thus, decreased ridge width affects primary and secondary osseointegration of implants due to its correlation with decreased crestal cortical thickness. On the other hand, decreasing the ridge width decreases the height as well, and increases the need for augmentation and use of shorter implants. Ridge height also had a significant correlation with cortical bone thickness such that by a reduction in height, cortical bone thickness decreased. This indicates that progression of bone resorption decreases both the cancellous bone thickness and the cortical bone thickness. German et al. [28] classified the mandibular ridge morphology based on the observation of observers (without measuring any parameter) into five groups of S-shaped, oblique, straight, hourglass and basal bone. They evaluated partially edentulous patients and only assessed one side of the jaw (even in cases of bilateral edentulism). Herranz-Aparicio et al. [21] offered a classification for ridge morphology at the site of mandibular first molar with three groups of (U type) convergent ridges with a narrow base, a wider buccolingual crest and presence of lingual undercuts, (P type) parallel U-shaped ridges with no significant undercuts and (C type) convergent ridge type with no obvious lingual undercut. They reported higher prevalence of U type ridges, followed by P type and then C type. In contrast to our results, they reported that 64% of the cases in their study had lingual concavity. It should be noted that they only evaluated the CT scans of edentulous first molar site of the mandible. Watanabe et al. [13] classified the mandibular ridge morphology into three groups of (I) round in the buccal and concave in the lingual,

(II) concave in the buccal and round in the lingual, and (III) round at both sides. They measured the ridge height and width at several sites on cross-sectional images and did not mention whether the ridges were edentulous or dentate.

Availability of a classification system for ridge morphology can help the surgeon in treatment planning. At present, virtual implant placement by use of CBCT software programs can greatly help the surgeons in correct surgical planning. These programs are easily available, fast and reproducible and can greatly aid in determination of a safe range for changes in implant angulation prior to placement and analyzing the possible risks of traumatization of anatomical structures at the site. They can also help in more accurate selection of implant height and diameter [29]. Nickenig and Eitner [30] evaluated the reliability of virtual implant placement using CBCT and reported that it increased the accuracy of preoperative assessments. Thus, in this study, we used virtual implant placement program to assess the limitations of implant placement in each ridge morphology. Standard 10 x 4 mm implants were used for this purpose.

Different treatment plans have been proposed in the literature based on ridge limitations. For instance, Yildiz et al, [31] Chan et al, [10] and Herranz-Aparicio et al. [21] suggested the use of implants with smaller diameter and higher taper in case of presence of severe lingual concavity. Alternatively, they suggested more angulated placement of implants with an angulated abutment. In order to compensate a small ridge width, the surgeon can perform guided bone regeneration or decrease height to obtain greater width. Braut et al. [32] suggested bone reduction instead of guided bone regeneration in combination with placement of short (6 and 8 mm) implants considering their high success rate [33, 34]. However, it should be noted that bone reduction is less important in case of full-mouth reconstruction compared with partial edentulism, because coordination of restoration with the adjacent teeth is harder in partial edentulism [15]. Simion et al. [35] suggested ridge splitting to compensate small ridge width. In this method, a greenstick fracture is induced in the atrophic alveolar ridge, and bone regeneration is induced by orthopedic force application. This technique requires a minimum amount of cancellous bone to provide blood supply to the fracture site. However, according to Katranji et al, [36] alveolar ridge ≤ 3 mm is not suitable for this technique due to inadequate volume of cancellous bone (< 1 mm) and inadequate blood supply to the site.

In case of height limitation, short implants can be used instead of long (> 8 mm) implants [37-39]. A meta-analysis by Camps-Font et al. [40] reported that short implants are preferred to ridge augmentation and use of long implants in the posterior mandible because the rate of complications is higher in ridge augmentation surgery while the survival rate and preservation of marginal bone were equal in both techniques at 1 year.

This study had some limitations. It had a retrospective cross-sectional design and the patient records did not disclose any information regarding the underlying systemic conditions of patients, which could serve as confounders and affect the results. Also, cause and effect relationships could not be evaluated due to our study design. Future prospective clinical trials are required to elucidate these topics. Small sample size due to the scarcity of patients with mandibular edentulism with a minimum of 6 mm of bone height was another limitation of this study. Moreover, this study employed one observer to assess the mandibular morphology and offer a classification for ridge morphology in the posterior mandible. Future studies with higher number of observers are required to assess interobserver agreements considering the high variability in the morphology of edentulous posterior mandible.

Conclusion

The classification proposed in this study can be used by dental surgeons for more accurate dental implant treatment planning.

Conflict of interest:

None.

Abbreviations

CBCT: cone-beam computed tomography; A: angulation; H: height; W: width

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Captions to figures

Figure 1. Ridge morphology classification based on ridge angulation, lingual concavity and crestal concavity

Figure 2. Ridge morphology classification based on height

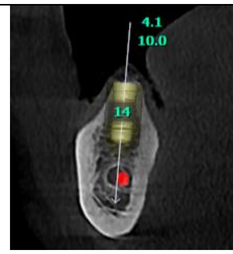
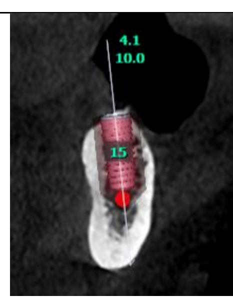
Figure 3. Ridge morphology classification based on width

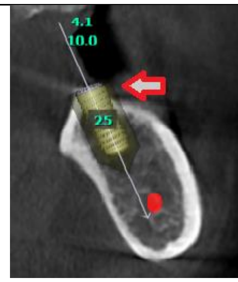
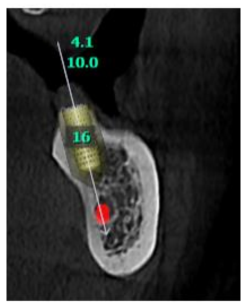
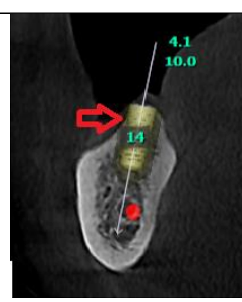
Figure 4. Frequency of different ridge morphologies (morphologies with a frequency lower than 4 are not shown)

Figure 5. A sample of different ridge morphologies based on ridge angulation, and presence/absence of lingual and crestal concavity. A=A1, B=A2, C=A3, D=A4, E=A5, F=A6, G=A7, H=A8, I=A9, J=A10, K=A11

Figure 6. Frequency of different morphologies at different distances from the mental foramen (morphologies with a frequency < 3% are not shown)

Table 1. A summary of the most important ridge morphologies along with their image and suggested treatment plan for each type

Morphology	Scan	Treatment plan
A1H1W1 Ridge angulation <15°, no lingual or crestal concavity, height >12 mm and width > 5 mm		No limitation in ridge width, height or angulation
A1H2W1 Ridge angulation <15°, no lingual or crestal concavity, no limitation in width, and 8-10 mm height		No limitation in ridge width and angulation. If bone height is > 10 mm, a 10-mm implant can be placed with no limitation. If bone height is < 10 mm, a short implant or ridge augmentation may be used.
A1H3W1 Ridge height < 8 mm, ridge angulation <15°, no crestal or lingual concavity		No limitation in ridge width or angulation. Height limitation, however, necessitates ridge augmentation.

A9H1W2 Ridge width limitation, ridge angulation >25°, adequate height, no lingual or crestal concavity		No limitation in ridge height, presence of lingual and crestal concavity, and width limitation necessitate using a narrower implant or increasing the ridge width by ridge splitting.
A2H1W1 Presence of lingual concavity, absence of crestal concavity, no limitation in ridge height, width or angulation		No limitation in ridge height, width or angulation, and presence of lingual concavity necessitate buccally-angulated implant placement or use of a narrower implant or ridge augmentation.
A3H1W1 Presence of crestal concavity, absence of lingual concavity, adequate ridge height		No limitation in ridge height, width or angulation, and presence of lingual and crestal concavity

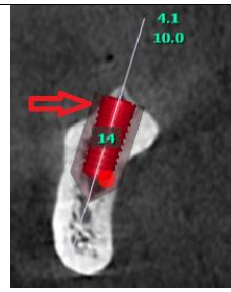
and width, ridge angulation <15°		necessitate the use of a narrower implant or lingually-angulated implant placement.
A4H3W1 Ridge height limitation, presence of lingual and crestal concavity		Limitation in ridge height and presence of crestal and lingual concavity often necessitate ridge augmentation.

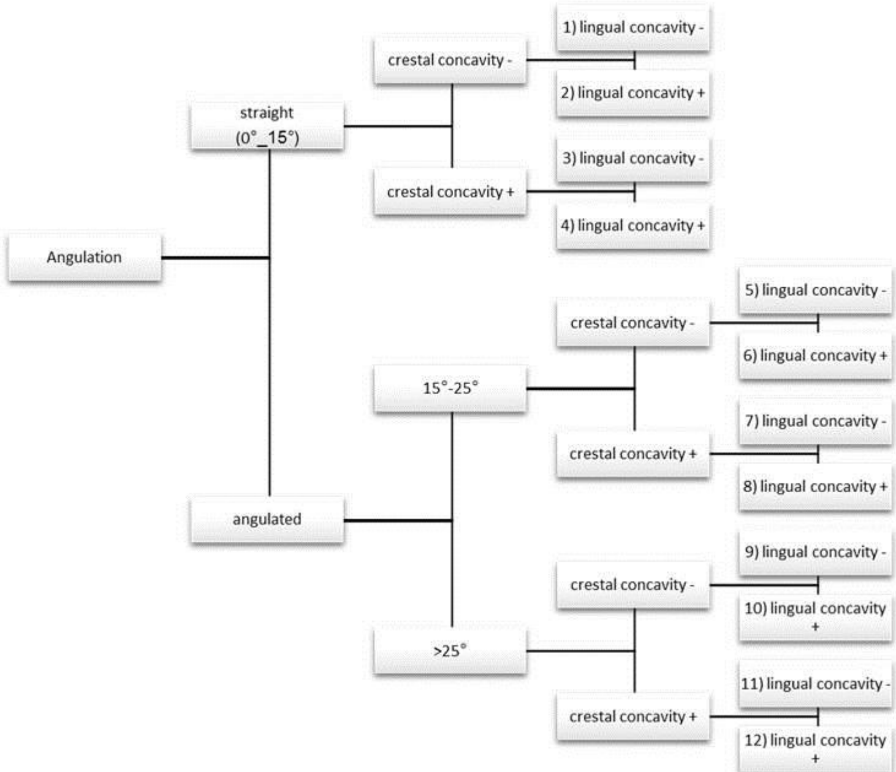
Table 2. Correlation of qualitative variables with age

	Variables	Age
Lingual concavity	Pearson Correlation	-0.045
	P value	.282
Crestal concavity	Pearson Correlation	-0.012
	P value	.776
Angulation limitation	Pearson Correlation	-0.101
	P value	**.015**
Vertical limitation	Pearson	-0.018

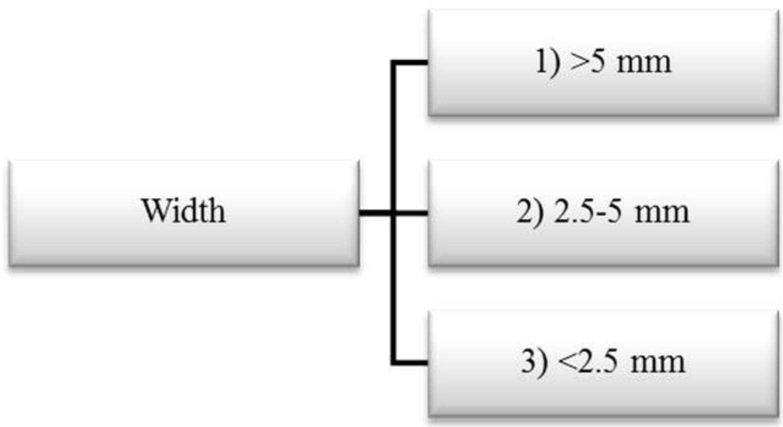
	Correlation	
	P value	٠.659٠
Horizontal limitation	Pearson Correlation	-0.121
	P value	**٠.004٠**

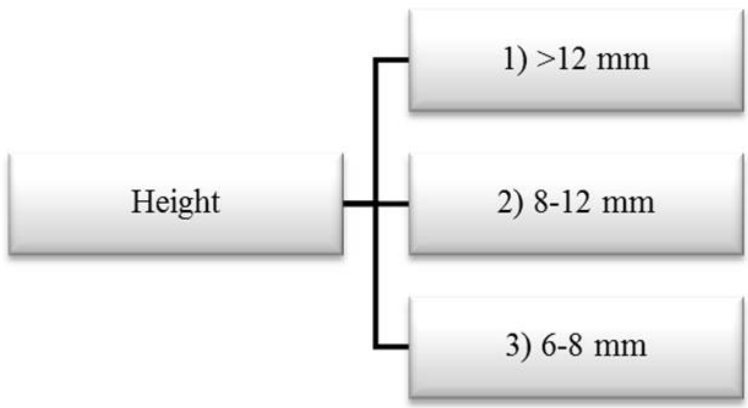
Table 3. Kappa values for the qualitative variables

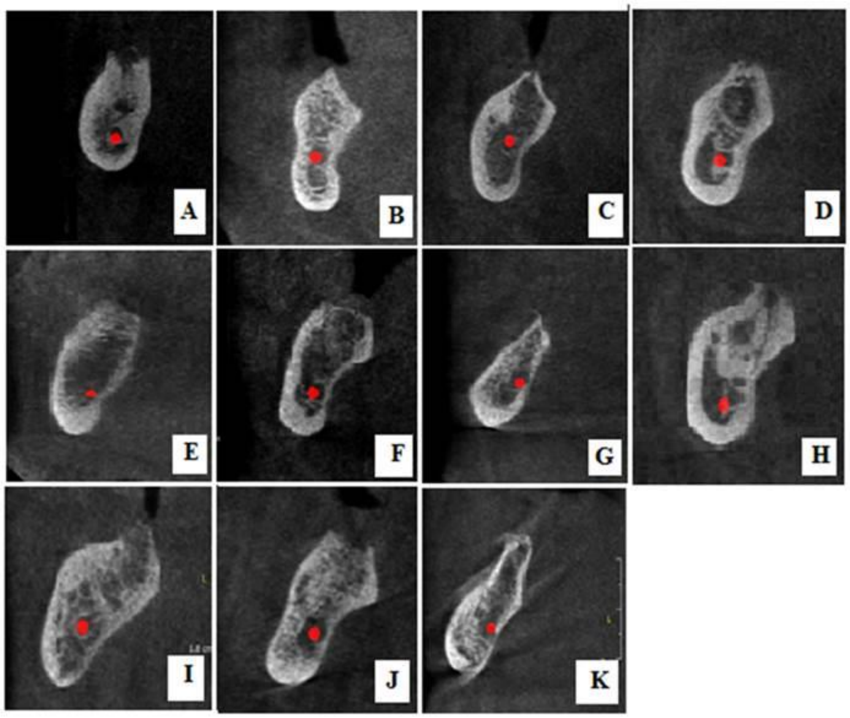
Variable	**Standard Deviation**	**Confidence Interval**	**Kappa**
Presence of lingual concavity	٠.٠٥	(٠.٣۶ ،١.٠٠)	0.81
Presence of crestal concavity	٠.١٧	(٠.۶١ ،١.٠٠)	٠.٧٢
Vertical limitation	٠.١١	(٠.٣۴ ،١.٠٥)	٠.٥٩
Horizontal limitation	٠.٢١	(٠.۴۴ ،١.٠٣)	٠.٧٨
Angulation limitation	٠.٠۶	(٠.۴4،0.95)	٠.٨٣

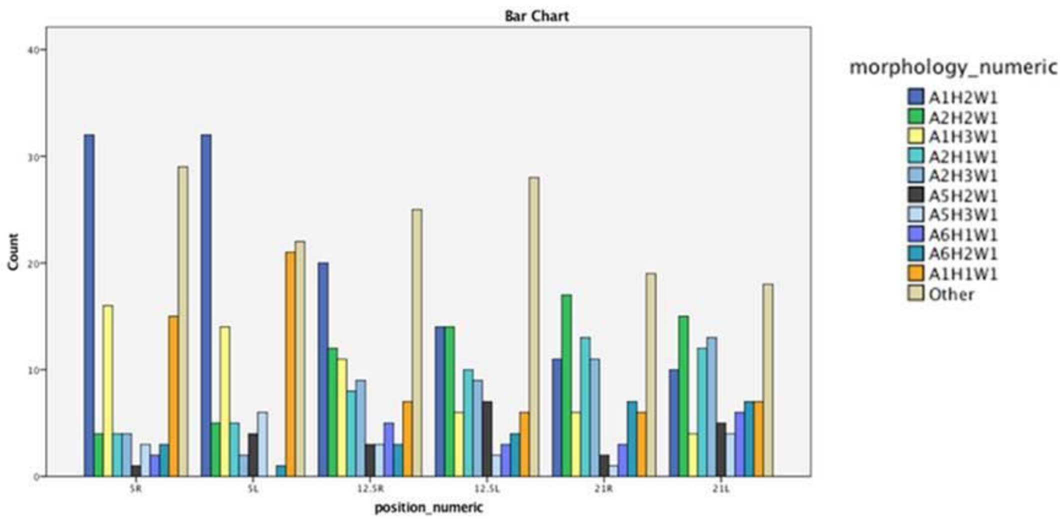


Angulation
straight
(0°_15°)
angulated
crestal concavity -
crestal concavity +
15°-25°
>25°
crestal concavity -
crestal concavity +
crestal concavity -
crestal concavity +
1) lingual concavity -
2) lingual concavity +
3) lingual concavity -
4) lingual concavity +
5) lingual concavity -
6) lingual concavity +
7) lingual concavity -
8) lingual concavity +
9) lingual concavity -
10) lingual concavity +
11) lingual concavity -
12) lingual concavity +

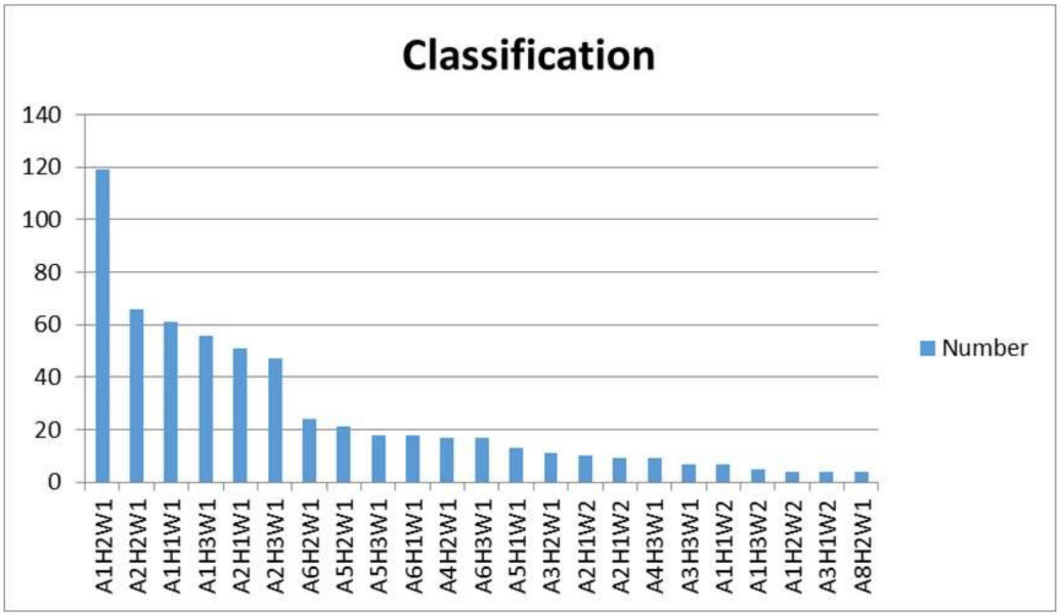

Width
1) >5 mm
2) 2.5-5 mm
3) <2.5 mm


Height
1) >12 mm
2) 8-12 mm
3) 6-8 mm


A
B
C
D
E
F
G
H
I
J
K



Bar Chart
40
30
20
10
0
Count
5R
5L
12.5R
12.5L
21R
21L
position_numeric
morphology_numeric
A1H2W1
A2H2W1
A1H3W1
A2H1W1
A2H3W1
A5H2W1
A5H3W1
A6H1W1
A6H2W1
A1H1W1
Other


Classification
140
120
100
80
60
40
20
0
Number
A1H2W1
A2H2W1
A1H1W1
A1H3W1
A2H1W1
A2H3W1
A6H2W1
A5H2W1
A5H3W1
A6H1W1
A4H2W1
A6H3W1
A5H1W1
A3H2W1
A2H1W2
A2H1W2
A4H3W1
A3H3W1
A1H1W2
A1H3W2
A1H2W2
A3H1W2
A8H2W1