The impact of regional bone dimensions on the selection of pterygoid implant directions: a radiographic study

Abstract

Aims
This investigation sought to delineate the bone morphology of the pterygomaxillary complex across various vertical planes and, furthermore, to clarify the extent to which anatomical bone characteristics inform the choice of pterygoid implant orientation.

Materials and methods
Cone-beam computed tomography scans were analysed using specialised software. Measurements related to bone dimensions, density, and implant direction were recorded in the panoramic and multiple axial planes.

Results
A total of 188 pterygoid sites were analyzed. The mean vertical bone height of the pterygomaxillary complex was 13.6 ± 2.7 mm. Bone width and thickness were significantly lower in the superior plane than in the inferior plane (width: mean difference 1.7 mm, 95% CI: 1.4–2.0, d = 0.9; thickness: mean difference 1.0 mm, 95% CI: 0.8–1.3, d = 0.7; both $p < 0.001$). Bone density in the pterygoid region was significantly higher than in the tuberosity (mean difference 526.5 GSD, 95% CI: 475.0–577.9, d = 1.5, $p < 0.001$). Most sites (80.9%) allowed implant placement in both low and high orientations. In contrast, 16.5% of sites permitted only the low orientation due to insufficient superior bone. Sites limited to low-orientation placement exhibited significantly reduced bone thickness compared with sites permitting both orientations (inferior plane: mean difference −1.9 mm, 95% CI: −2.3 to −1.5, d = −1.3; superior plane: mean difference −1.9 mm, 95% CI: −2.3 to −1.4, d = −1.1; both $p < 0.001$).

Conclusions
Bone dimensions of the pterygomaxillary complex decrease progressively at more superior levels. Most sites accommodate both low- and high-orientation implant trajectories, whereas insufficient superior bone restricts placement to a low-orientation pathway.

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Keywords

pterygomaxillary complex, pterygomaxillary junction, pterygomaxillary pillar, pterygoid implants.

INTRODUCTION

Severe maxillary atrophy following tooth loss remains a challenging clinical scenarios (1, 2). Full-arch rehabilitation supported by implants is a reliable solution for this condition, and the all-on-4 concept has been widely accepted (3). In this approach, two conventional implants are placed in the anterior region, along with two distal implants positioned along the anterior wall of the maxillary sinus (4). There are some disadvantages to this treatment, such as the appearance of distal cantilevers, which can lead to biomechanical complications (4, 5). To overcome this issue, additional implants can be placed either in the residual molar bone below the sinus with sinus elevation and grafting or in the posterior wall of the sinus without requiring sinus procedures (6, 7). A graftless solution may eliminate complications associated with grafting and sinus involvement (8, 9).

A potential option for implant placement in the posterior sinus wall involves the use of pterygoid implants (10). These implants pass through two different bone zones: the softer bone of the maxillary tuberosity and the denser bone of the pterygoid process. Pterygoid implants can achieve good primary stability due to their engagement with high-quality bone (6, 11). Nevertheless, the placement of these implants is a sensitive procedure because of limited surgical access, the requirement for the mouth to remain open, and the complexity of the regional anatomy (12). Therefore, it is essential for clinicians to evaluate the bone dimensions at the pterygomaxillary junction and the surrounding anatomical structures, such as the descending artery and nerve medially, the pterygopalatine fossa superiorly, and the infratemporal fossa laterally (13, 14).

It is essential to perform virtual implant placement on CBCT-based planning software during the treatment planning phase to determine the appropriate angulation, position, and trajectory of the implant, as well as its relationship to adjacent anatomical structures that must be preserved. There are two placement directions of pterygoid implants: low direction (downward) and high direction (upward) (15). Low-direction implants traverse three areas: the tuberosity, the pyramidal process of the palatine bone, and the pterygoid process of the sphenoid bone. In contrast, high-direction implants are positioned at a more upright angle with the apex directed towards the pterygopalatine fossa. Consequently, high-direction implants engage only the tuberosity and the pterygoid process, without passing through the pyramidal process.

Previous studies (14, 16) have measured the dimensions and bone density of the pterygomaxillary complex; however, they have not assessed these parameters across different vertical planes. Moreover, prior investigations have been limited to describing implant direction without evaluating the relationship between bone morphology and the selection of pterygoid implant orientation (15). Therefore, the present study was undertaken to characterize the bone dimensions of the pterygomaxillary complex across multiple vertical planes and, additionally, to elucidate how anatomical bone parameters influence the selection of pterygoid implant orientation.

MATERIALS AND METHODS

A cross-sectional study was conducted involving 100 participants seeking treatment for tooth loss through dental implants at a private hospital in Ho Chi Minh City, Vietnam, from June 2023 to December 2024. Ethical approval for this research was obtained from the Research Ethics Committee in Medical Sciences at Can Tho University of Medicine and Pharmacy, under approval number 23.010.NCS/PCT-HDDD. Cone-beam computed tomography (CBCT) scans of these patients were collected for diagnostic and planning purposes.

Patients were included if they had a hemimaxilla that was completely missing all molar teeth, accompanied by varying degrees of sinus enlargement, and had unlimited residual bone height below the sinus floor. Patients were excluded if their radiographs were unclear or distorted, had artefacts from previous prosthetic treatments or implants, and/or did not include the pterygoid area. Additionally, patients with impacted wisdom teeth, the presence of various diseases (such as cysts, tumours, or traumatic lesions), any bone deformities in the investigated area, and bone deficiency in the pterygomaxillary region due to previous posterior maxilla resections were excluded.

Sample size calculation

Prior to beginning the study, the sample size was determined using the formula in figure 1.

According to the outcomes of a previous study (16), the estimated standard deviation for the pterygomaxillary bone height parameter (σ) is 1.82, and the desired margin of error (d) is 0.26. With a 95% confidence level, the calculated sample size (n) was 188.

$$n = \left(\frac{(z_{1-\alpha/2} \cdot \sigma)^2}{d} \right)$$

Fig. 1 Sample size calculation formula.

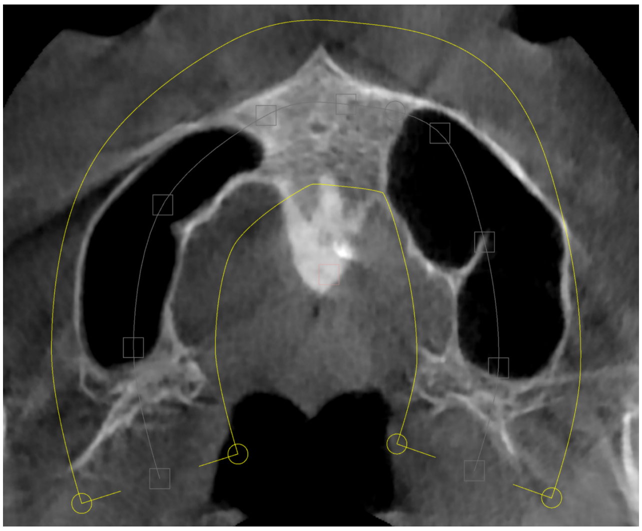

Fig. 2 The panoramic curved line was drawn in the axial plane.

CBCT

A CBCT device (NewTom GiANO HR, Cefla, Italy) was used to obtain radiographs for all patients. The Frankfort plane was positioned precisely parallel to the floor, serving as the standard reference for the radiographic examinations. The CBCT parameters were set to 90 kVp, 15 mA, and an exposure time of 16.8 seconds to obtain high-quality images. The field of view was 10 × 10 cm and the voxel size was 160 µm. The obtained Digital Imaging and Communications in Medicine (DICOM) files were imported into Blue Sky Bio version 4.13 (Blue Sky Bio, Libertyville, IL, USA). All study parameters were measured and analysed by a single trained investigator (T.L.D).

Measurements of bone dimension parameters

The panoramic curve should be drawn in the axial plane, reaching the level of one-third of the apex of the maxillary teeth or more upper level. At this plane, the medial and lateral pterygoid plates, as well as the pterygoid fossa, can be observed (figure 2).

In the paranoramic view, the vertical bone height of the pterygomaxillary complex was measured from the lowest point of contact between the tuberosity and the pterygoid pillar to the highest point in the vertical direction. These points were further corroborated on the axial plane. The bone width and thickness of the pterygomaxillary complex was measured at two different axial planes: the intersection between the upper and middle thirds, and the intersection between the middle and lower thirds along the vertical axis. To determine the bone density of the tuberosity and the pterygomaxillary pillar, the mean density was calculated from three different areas at each bone site. Fig. 3 provides images with these bone dimension and density measurements.

Selection of the pterygoid implant direction

Before measuring the parameters related to virtual implants, virtual pterygoid implants were inserted based on the following requisites. The implant apex and collar had to be entirely within the bone, avoiding the descending palatine artery and the pterygopalatine fossa. The implants had a maximum length of 24 mm and could invade the sinus. The implant axis could be in either the high or low direction. In the high direction, the implant axis is generally more upright with the apex directed towards the pterygopalatine fossa.

For high-direction implants, the initial drill point was located more distally compared with the drill point for low-direction implants. This point was not positioned less than 4 mm from the end of the tuberosity to ensure there was adequate distal bone around the

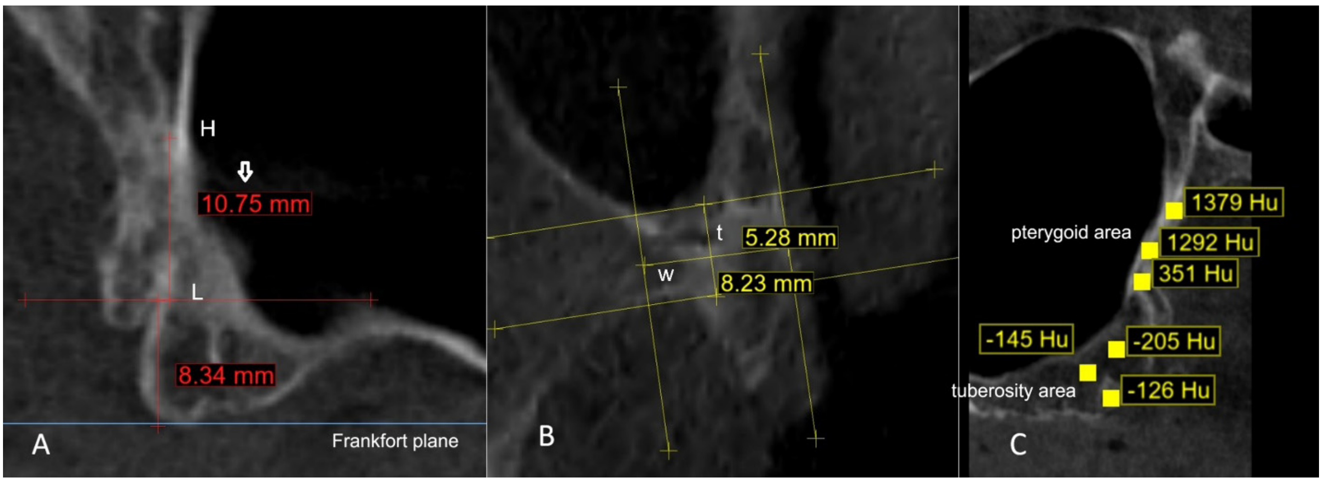

Fig. 3 Measurement of the bone dimension parameters: (A) the vertical bone height (arrow): the vertical distance from the highest point (H) to the lowest point (L) of pterygomaxillary complex, (B) the bone thickness and width were measured follow the curved line, and (C) the bone density of tuberosity and pterygomaxillary junction.

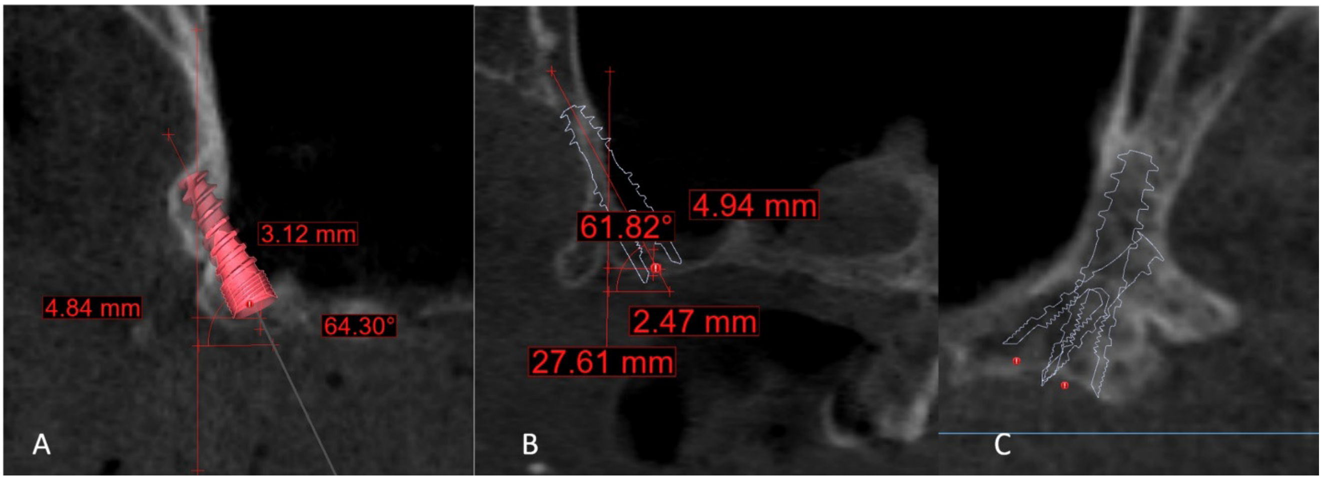

Fig. 4 Selection of pterygoid implant directions: (A) only the low direction, (B) only the high direction, and (C) both directions.

pterygoid implants. The initial point for low-direction implants was determined by either a residual bone height of >3 mm below the sinus floor at that position or a distal angulation of the implant of <45 degrees. Additionally, the low-direction virtual implants were not placed more than 12 mm mesially from the end of the tuberosity.

Within the same pterygomaxillary region, three scenarios may dictate the selection of pterygoid implant orientation: (1) low-direction only, in which the implant can be placed exclusively along a low trajectory because a high trajectory is precluded by insufficient bone volume; (2) high-direction only, where placement is feasible only along a high trajectory and a low trajectory is not anatomically possible; and (3) both directions, where the implant can be placed along either trajectory. Fig. 4 illustrates these three scenarios.

To evaluate the reliability and consistency of the measurements taken by the same investigator for each subject, 30 randomised study sites were selected to calculate the intraclass correlation coefficient (ICC). In each study region, the height of the pterygomaxillary complex was measured three times. The ICC was 0.94, indicating excellent reliability among the three repeated measurements for each subject.

Data analysis

The data were analysed with Stata 14 (StataCorp LLC, College Station, IL, USA). The Shapiro-Wilk tests and Q–Q plots were used to determine whether the vertical bone height, bone width, bone thickness, the distance from the first tuberosity-pterygoid contact to the lowest tuberosity, and bone density followed a normal distribution using. Paired t-tests were used to compare bone dimensions across the different axial planes and the bone density of two different areas. To compare bone dimensions between the two groups defined by implant orientation, Welch's t-test was employed, given the unequal sample sizes between groups.

RESULTS

The bone dimensions of the pterygomaxillary complex

Table 1 shows the bone dimension parameters of the pterygomaxillary complex based on a total of 188 pterygoid regions from 100 CBCT scans. The mean

Parameter	Mean ± SD	Minimum to maximum
Vertical bone height, mm	13.6 ± 2.7	6.5 to 23.6
Bone thickness (inferior plane), mm	4.9 ± 1.7	1.4 to 10.0
Bone thickness (superior plane), mm	3.8 ± 1.8	1.0 to 11.1
Bone width (inferior plane), mm	9.4 ± 1.6	3.6 to 13.9
Bone width (superior plane), mm	7.7 ± 1.6	3.4 to 11.7
Density of the tuberosity, GSD	273.2 ± 282.1	-205.0 to 1465.0
Density of pterygoid region, GSD	795.4 ± 308.6	128.3 to 1565.3

Tab. 1 The bone dimension parameters of the pterygomaxillary complex.

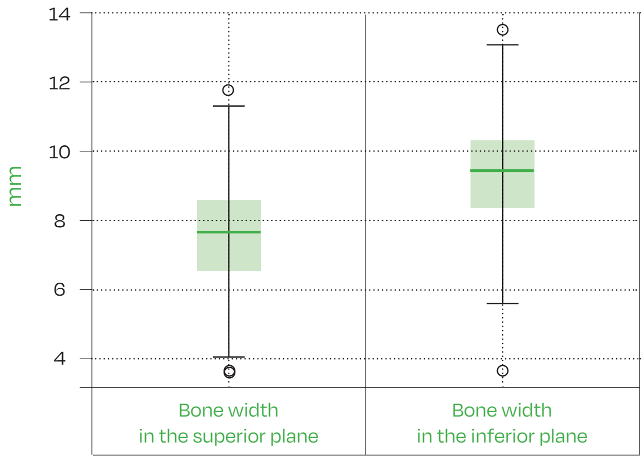

Fig. 5 Boxplot comparison of bone width in the superior and inferior planes, highlighting the dimensional variation between the two evaluated planes.

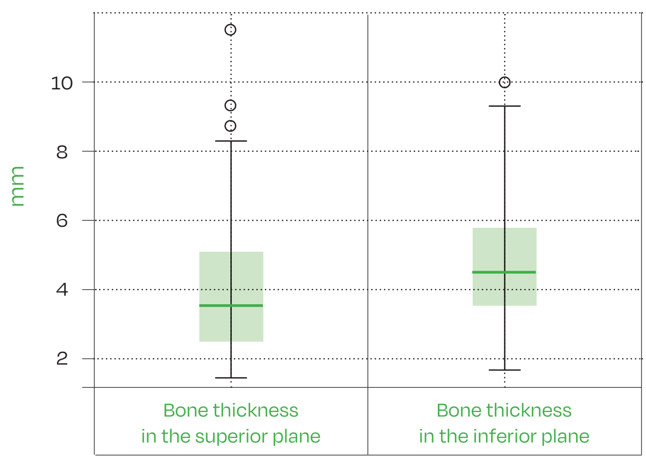

Fig. 6 Boxplot comparison of superior and inferior plane bone thickness, depicting the variation in measurements between the two planes. .

	Variable (mm)	Low-direction only (G1) (n = 31)	Both directions (G2) (n = 152)	Mean difference (G1 – G2)	95% CI	Effect size (Cohen's d)	P-value*
Superior plane	Bone width	8.3 ± 1.3	7.5 ± 1.6	+ 0.8	+0.3 to +1.3	0.5 (medium)	0.004
	Bone thickness	2.3 ± 0.9	4.2 ± 1.7	–1.9	–2.3 to –1.4	–1.1 (large)	<0.0001
Inferior plane	Bone width	9.6 ± 1.7	9.3 ± 1.6	+0.3	–0.4 to 0.9	0.2	0.436
	Bone thickness	3.3 ± 1.0	5.2 ± 1.6	–1.9	–2.3 to –1.5	–1.2 (large)	<0.0001
	Vertical bone height	13.5 ± 3.0	13.6 ± 2.6	–0.1	–1.3 to 1.1	–0.04	0.869

(*) The Welch's t-test was used to compare each variable between the groups.

Tab. 2 Comparison of the bone dimension parameters between the group that allowed only low-direction implants and the group that allowed implants in both directions.

± SD vertical bone height of the pterygomaxillary complex was 13.6 ± 2.7 mm (range: 6.5 to 23.6 mm).
At the intersection between the middle and lower thirds of the axial plane (the inferior plane), the mean ± SD bone width and thickness of the pterygomaxillary complex was 9.4 ± 1.6 mm and 4.9 ± 1.7 mm, respectively. At the intersection between the upper and thirds of the axial plane (the superior plane), the mean ± SD bone width and thickness of the pterygomaxillary complex was 7.7 ± 1.6 mm and 3.8 ± 1.8 mm, respectively.
The mean bone width in the superior plane were significantly lower than that in the inferior plane (mean difference: 1.7 mm, Cohen's d = 0.9 (95% CI: 1.4 – 2.0), paired t-test, $p < 0.001$). Similarly, bone thickness measured in the superior plane was substantially less than the corresponding measurements obtained in the inferior plane (mean difference: 1.0 mm, Cohen's d = 0.7 (95% CI: 0.8 – 1.3), paired t-test, $p < 0.001$). Figures 5 and 6 illustrate these findings.
The pterygoid region showed a significantly higher mean density than the tuberosity area (mean difference: 526.5 Grey scale density (GSD), Cohen's d = 1.5 (95% CI: 577.9 – 475.0), paired t-test, $p < 0.001$).

Virtual pterygoid implant directions

Overall, 183 low-direction virtual implants and 157 and high-direction virtual implants were considered. In nearly 81% of the pterygoid regions, virtual implants were inserted in both the low and high directions. There were 31 pterygoid regions (16.5%) where implants were placed exclusively in the low direction, while 5 regions (2.6%) permitted only high-direction implants.

The impact of the bone dimensions on the selection of virtual implant directions

Table 2 shows a comparison of the bone dimension parameters between the group that only permitted low-direction implants and the group that allowed implants in both directions. In the inferior axial plane, the mean bone thickness for the group with only low-direction implants was significantly lower compared with the group with implants oriented in both directions (mean difference: −1.9 mm, Cohen's d = −1.3 (95% CI: −2.3 to −1.5), Welch's t-test, $p < 0.001$). Similarly, for the superior plane, the group with only low-direction implants had a significantly lower mean bone thickness than the group with implants in both directions (mean difference: −1.9 mm, Cohen's d = −1.1 (95% CI: −2.3 to −1.4), Welch's t-test, $p < 0.001$). In the inferior axial plane, the group with only low-direction implants had a lower mean bone width (mean ± SD = 9.6 ± 1.7 mm) compared with the group with implants in both directions (mean ± SD = 9.3 ± 1.6 mm), but the difference was not significant (mean difference: +0.3 mm, Cohen's d = 0.2 (95% CI: −0.4 to 0.9), Welch's t-test, $p < 0.001$). In contrast, for the superior axial plane, the group with only low-direction implants showed a significantly higher mean bone width compared with the group with implants oriented in both directions (mean difference: +0.8 mm, Cohen's d = 0.5 (95% CI: 0.3 to 1.3), Welch's t-test, $p < 0.001$). Finally, the mean vertical bone height of the complex did not differ between the group directions (mean difference: −0.1 mm, Cohen's d = −0.04 (95% CI: −1.3 to 1.1), Welch's t-test, $p < 0.001$)

DISCUSSION

The pterygoid implant was first introduced as an effective method for implant-supported full-arch rehabilitation in cases of partial maxillary and total tooth loss associated with sinus enlargement. This study sought not only to characterize the bone morphology of the pterygomaxillary junction, but also to compare bone dimensions across multiple axial planes along the vertical axis. Additionally, it examined how various anatomical factors of the bone affect pterygoid implants based on measurements from CBCT scans.

The mean vertical bone height in this study aligns with the findings of previous studies conducted by Lee et al. (17) and Kim et al. (18) (approximately 13 mm). However, our values are slightly higher than those reported by Salinas-Goodier (16) and Sahoo (14). Those authors employed a similar measurement method to ours: they calculated the vertical bone height from the first (lowest) point of contact between the tuberosity and pterygoid process to the final (highest) point of contact between these two bone regions along the vertical axis. In contrast, Motiwala et al. (19) utilised a different measurement approach. They defined the vertical bone height as the vertical distance from the highest point of the pterygomaxillary complex to the lowest position of the pterygoid process, which usually lies below the first contact measured in our study. Nonetheless, they reported a mean bone height of approximately 12 mm, smaller than what we calculated. In summary, the slight differences in these results may be attributed to variations in the investigated samples and methods.

To the best of our knowledge, this study is the first to measure the bone width and thickness of the pterygomaxillary junction in two axial planes: the higher plane, which is where the upper and middle thirds intersect along the vertical axis, and the lower plane, where the middle and lower thirds intersect. Based on the findings, when the axial plane is positioned higher, the bone thickness and width decrease.

In a similar previous investigation, Sahoo et al. (14) calculated the width for only one axial plane, where the first complete fusion of the tuberosity and pterygoid process occurs. They reported a mean bone width of 8.15 mm for the dentulous group and 8.13 mm for the edentulous group. These values are lower than our bone width of 9.4 mm for the inferior plane but higher than the 7.7 mm for the superior plane. This finding is consistent with a previous study that reported a mean bone width of 8.8 mm for the pterygomaxillary complex (19). The authors of another study used a similar measurement method and reported a mean bone width of 7.51 mm, which is smaller than our measurements for both planes (16). The main reason for this difference may again be attributed to differences in the investigative methods used.

The thickness of the pterygomaxillary complex in the present study is approximately the same as reported in a previous study (mean = 5 mm) (18), but lower than that of another study (17). In the study with the lower mean bone thickness, the authors measured directly from the skull and noted that bone thickness decreases with higher vertical positions. Given that the mean bone thickness we measured is only 3.8 mm, clinicians should avoid using large implants (>4 mm in diameter) (20) and instead opt for implants with a smaller apex to accommodate the limitations of the available bone (15, 21).

In terms of bone quality of the tuberosity area, Rodriguez et al. (13) reported a mean bone density of 307.4 GSD while Salinas-Goodier et al. (16) reported a mean bone density of 370.3 GSD. We recorded a notably lower mean of 273.2 GSD. Conversely, we recorded a higher mean bone density in the pterygoid region compared with what was reported in past studies. Overall, previous studies and our research have consistently demonstrated that the pterygoid region exhibits significantly better bone quality compared with the tuberosity area. Therefore, the pterygoid region should be the preferred site for implant placement in this area. Implants need to be long enough to penetrate the softer bone of the tuberosity and engage with the denser bone of the pyramidal and pterygoid processes, thereby improving primary stability (6, 12).

In more than 80% of the regions, we found that the pterygoid implants could be positioned in either

direction. However, in five regions we could not place the implant in a low direction due to limitations related to the virtual implant length (< 10 mm) and the residual bone height (RBH) below the sinus floor. It can be challenging to achieve high primary stability for the implant in these areas. Due to the severe enlargement of the sinus, low-direction pterygoid implants could not be placed in certain areas because of the RBH at the initial drilling position. This is similar to trans-sinus implants, which require a minimum RBH of 3-5 mm for initial stability during placement (2). We found that 31 regions (16.5% of the total) could only receive a low-direction implant due to limited bone volume in the middle and superior vertical parts of the complex. The average bone thickness in these sites was 3.3 mm in the lower plane and 2.3 mm in the higher plane. As a result, a virtual implant could not be placed in the high direction. We found significant differences in the mean bone width and thickness between the group that could only receive low-direction implants and the group that could receive implants in both directions. This suggests that the choice of implant direction could be influenced by the bone dimensions of the pterygomaxillary complex.
In addition to evaluating and comparing the bone dimensions of the pterygomaxillary complex at superior and inferior levels, this study also identified the influence of reduced bone volume on the preoperative selection of implant orientation during the treatment planning phase for pterygoid implants. These represent notable strengths of the present investigation. The findings may provide valuable guidance for selecting the most appropriate and clinically favorable implant trajectory.
However, this study has several limitations. Its cross-sectional design and single-center sampling limit the generalizability of the results to broader populations, and it does not account for variables such as age, sex, or duration of edentulism, all of which may influence bone morphology.

CONCLUSIONS

The anatomy of the pterygomaxillary region varies considerably among individuals; therefore, a tailored radiological evaluation is required before planning the placement of a pterygoid implant. Bone dimensions within the pterygomaxillary complex differ markedly between lower and higher vertical levels, with a progressive reduction in bone volume observed as the assessment moves superiorly. In most cases, implant placement is feasible along both low- and high-orientation trajectories. In cases where the superior segment of the pterygomaxillary complex provides inadequate bone support, virtual pterygoid implant placement becomes feasible solely along a low-orientation pathway.

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