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Evaluation of Aesthetic Zone of Maxilla for Ridge Augmentation: Human Cadaver Study and Status Review

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Abstract

Objectives: Functional outcomes of pre-implant ridge augmentation techniques have been a topic of controversy, especially in the anterior “aesthetic” zone of the maxilla. Reconstruction using bone grafts has focused on the restoration of cortical bone plates to provide primary stability for implants. This study examined the quality of interdental cancellous bone in this region and its significance for the evaluation of functional outcomes of pre-implant ridge augmentation in the aesthetic zone.

Methods: We harvested the anterior maxilla from six human cadaver donor bodies and scanned them with MicroCT. Architectural parameters were analyzed at three sagittal and three axial planes to identify areas of cancellous bone insufficiency. Parameters included percent bone volume, bone surface density, trabecular thickness, number, and separation, total porosity, and connectivity density.

Results: All areas included robust interdental cancellous bone, with percent bone volume ranging between 32% and 61%. Repeated-measures ANOVAs with post-hoc tests showed that bone at the gingiva had higher quality than at the root: the gingival plane had greater BV/TV (Tukey-adjusted p = 0.023) and Tb.Th (Tukey-adjusted p= 0.007), but lower BS/BV (Tukey-adjusted p = 0.047) and Po(tot) (Tukey-adjusted p = 0.023).

Conclusions: The aesthetic zone of the maxilla contains robust interdental cancellous bone that should be considered in planning alveolar reconstruction prior to implant placement, in addition to the buccal and palatal cortical plates.

INTRODUCTION

The anterior maxilla presents unique challenges for reconstruction. Anatomically, it has a complex three-dimensional configuration, limited subgingival space capacity, as well as inelastic gingival coverage. On top of these challenges, aesthetics of the of the canine-to-canine area of the maxilla is arguably the most critical determinant of patient satisfaction after dental rehabilitation, earning this anatomical location the label of “the aesthetic zone”.

Dental implants are commonly used to reconstruct the aesthetic zone. However, lack of bone coverage around implant margins often compounds the procedure due to lack of purchase, increased failure rate, and critical reduction of the interdental papilla and facial gingival height.[1] Restoration of vertical and horizontal bone dimensions is often required prior to implant placement, with two aims in mind: 1) providing adequate bony coverage of the implant at the time of insertion, both in volume and quality, and 2) securing sufficient gingival coverage.[2] Unfortunately, alveolar bone is uniquely susceptible to bone resorption following tooth loss, with the reduction of height, thickness, and quality progressively precluding implant placement. Bone grafting in this area is, therefore, the most critical step in the endeavour to achieve the desired aesthetic results.

The alveolar process of the jaws consists of alveolar bone proper (bundle bone) and supporting bone (Fig. 1).[3] The alveolar bone proper is the thin sheet bone that lines the tooth socket, where the Sharpey's fibers of the periodontal ligament (PDL) are inserted[3]. The remainder of the alveolar process is the supporting bone, which consists of the outer compact cortical plates of the jawbone and the cancellous or spongy bone in between.[3]

The integrity of the anterior maxilla has been evaluated based on the thickness of its buccal cortical plate.[4] The more prevalent *thin* bony phenotype has a thickness of less than 1mm, whereas the *thick* bony phenotype is 1mm or greater.[4 5] It has been shown that 90% of cases have a thin bony phenotype and 50% have 0.5mm or thinner maxillary facial bone.[6 7] It has been assumed that there is very little trabecular bone in this area. However, cone-beam computerized tomography (CBCT) imaging has shown that significant amount of trabecular bone could exist around the roots of maxillary incisors, especially in between the centrals (Fig. 1). This component of the alveolar bone is not given due consideration during implant planning. This study analyzed the qualitative and quantitative structural parameters of interdental cancellous bone in the anterior maxilla in human cadaver donors, followed by a discussion of how success of reconstruction could be assessed.

METHODS

Human Cadaver Donors

Six human cadaver donor bodies (4M, 2F, age range 47–96, median 76.5 y/o) were included. The anterior maxilla was harvested from each specimen. Cadaveric specimens were obtained through an institutional body donor program and were determined as exempt from human research guidelines by the institutional review board (IRB) at Western University of Health Sciences.

Micro CT Scanning

Specimens were imaged using a Bruker Micro CT scanner (Bruker, Billerica, MA) for high-resolution three-dimensional reconstruction. Region-of-interest segmentation and quantitative bone architecture analysis were performed using CTan software (Bruker). Following micro CT scanning and volumetric reconstruction, each specimen was systematically divided into anatomical regions of interest (ROIs) representing the interdental cancellous bone between adjacent teeth of the anterior maxilla (Fig. 2). For each interproximal space, cross-sections were organized into three axial levels: Gingiva (G): Occlusal level, Middle (M): Mid-root level Root, and (R): Apical root level (Fig. 3). For sagittal comparisons, three interdental sagittal cuts were compared: A: Midline, B: central-lateral, and C: lateral-canine (Fig. 3). For simplicity, measurements from the right and left B-planes were averaged, same with right and left C-planes.

Fifty sequential cross-sectional cuts were taken between each successive level. For level R, additional cuts beyond 50 were included if necessary to reach the apical extent of the root. Each ROI was manually delineated using the Volume of Interest (VOI) tool within CTan. Each delineated region was then independently analyzed for the following trabecular bone architectural parameters: percent bone volume (BV/TV), bone surface density (BS/BV), trabecular thickness (Tb.Th), trabecular number (Tb.N), trabecular separation (Tb.Sp), total porosity (Po(tot)), and connectivity density (Conn.Dn).

Statistical Analysis

We used repeated-measures analysis of variance (rmANOVA) to test for differences in the variables in each plane. We conducted a two-way rmANOVA that included the sagittal (A, B, C) and axial planes (G, M, R) as main effects, along with the sagittal × axial interaction effect. The two-way rmANOVA excluded two subjects for which we were unable to collect sagittal data owing to the lack of teeth and alveoli. Thus, for each variable, the sample for the two-way rmANOVA contained $n = 4$ subjects with nine measurements each, for total of 36 observations (four individuals × three sagittal planes × three coronal planes).

We also conducted a one-way rmANOVA on the variables in the axial planes, allowing us to include the full sample of $n = 6$ subjects. For this analysis, we averaged sagittal values in a given axial plane for the four subjects where we were able to collect such data. With six subjects and three axial planes (G, M, R), there are 18 observations per variable.

The rmANOVAs were computed using the *aov* function in R version 4.3.3 (R Core Team, 2024). When warranted, we conducted post-hoc comparisons among factors using the *emmeans* package (Lenth and Piaskowski, 2026), with a Tukey adjustment applied for multiple comparisons. To assess the robustness of our rmANOVAs, we used Friedman's test, a nonparametric version of rmANOVA. The Friedman's tests were performed using the *rstatix* package (Kassambara, 2023). The nonparametric tests provided the same overall signal as the rmANOVAs, indicating that our rmANOVA results are not distorted by violations of the model assumptions. We therefore only report the results of the rmANOVAs. All data visualizations were created using *ggplot2* (Wickham, 2016) and *ggpubr* (Kassambara, 2026).

RESULTS

The anterior maxilla had robust interdental cancellous bone throughout the aesthetic zone, with percent bone volume ranging from 32% to 61% across all sampled regions. No areas of significant bone deficiency were identified at the midline or interincisal planes at any axial level.

There were no statistically different differences among the sagittal planes (Fig. 4) in any of the architectural parameters. However, there is some evidence for differences among axial planes (Fig. 5). The main effects and interaction effects for the two-way rmANOVAs are mostly nonsignificant, with BS/BV being the only exception (Table 1). The one-way rmANOVAs performed on the full sample of six subjects indicate statistical differences among axial planes in four variables (Table 2): BV/TV ($p = 0.024$), BS/BV ($p = 0.039$), Tb.Th ($p = 0.009$), and Po(tot) ($p = 0.024$). Post-hoc comparisons indicate that, for

each of these variables, the G and R axial planes are significantly different. In comparison to the R plane, the G plane has greater BV/TV (Tukey-adjusted p = 0.023) and Tb.Th (Tukey-adjusted p = 0.007), but lower BS/BV (Tukey-adjusted p = 0.047) and Po(tot) (Tukey-adjusted p = 0.023). The fact that the M plane cannot be distinguished from the other planes suggests that there is a gradient in bone architecture from G to R for these four variables, but our sample size is not large enough to confirm this inference.

Notably, in the two edentulous samples, there was still robust cancellous bone (Fig. 6). These samples were included in the axial, but not the sagittal analysis, due to the difficulty in determining exact location of previous dental sockets.

Table 1
Two-way repeated measures ANOVA with sagittal × axial interaction

Variable	Effect	Df	*F*	*p*
BV/TV	Sagittal	2, 6	2.313	0.180
	Axial	2, 6	2.867	0.134
	Interaction	4, 12	0.460	0.764
BS/BV	Sagittal	2, 6	2.232	0.188
	Axial	2, 6	6.333	0.033*
	Interaction	4, 12	1.334	0.313
Tb.Th	Sagittal	2, 6	0.433	0.667
	Axial	2, 6	4.983	0.053
	Interaction	4, 12	1.155	0.378
Tb.N	Sagittal	2, 6	1.494	0.298
	Axial	2, 6	0.496	0.632
	Interaction	4, 12	0.844	0.524
Tb.Sp	Sagittal	2, 6	3.109	0.118
	Axial	2, 6	0.512	0.623
	Interaction	4, 12	0.528	0.718
Po(tot)	Sagittal	2, 6	2.313	0.180
	Axial	2, 6	2.867	0.134
	Interaction	4, 12	0.460	0.764
Conn.Dn	Sagittal	2, 6	0.222	0.807
	Axial	2, 6	0.208	0.818
	Interaction	4, 12	1.033	0.430

* $p < 0.05$.

Table 2
One-way repeated measures ANOVA of axial planes

Variable	Effect	Df	*F*	*p*
BV/TV	Axial	2, 10	5.519	0.024*
BS/BV	Axial	2, 10	4.572	0.039*
Tb.Th	Axial	2, 10	7.873	0.009**
Tb.N	Axial	2, 10	0.741	0.501
Tb.Sp	Axial	2, 10	0.712	0.514
Po(tot)	Axial	2, 10	5.519	0.024*
Conn.Dn	Axial	2, 10	0.087	0.917

* $p < 0.05$, ** $p < 0.01$.

DISCUSSION

The anterior alveolar process of the maxilla included robust interdental cancellous bone, with percent bone volume ranging between 32% and 61%. There was no focal deficiency in bone parameters in the midline or interincisal planes at any of the axial levels. However, the quality of interdental cancellous bone was highest at gingival plane, with a tendency to become less robust towards the roots. This finding is significant, since losing alveolar bone height, after tooth extraction or with aging, would result in losing bone with the highest value for osseointegration of implants. Analysis of this interdental cancellous bone should be considered in planning alveolar reconstruction prior to implant placement in the aesthetic zone, in addition to the buccal and palatal cortical plates.

Ridge atrophy after tooth loss has been shown to follow different patterns in the maxilla and mandible. In the mandible, the lingual wall tends to resorb before the buccal (centrifugal resorption). In the maxilla, however, the labial wall of the alveolar socket tends to resorb more rapidly after dental extraction and the ridge gradually becomes represented by the previous palatal wall (centripetal resorption). Importantly, in both jaws, the thickness of the alveolar bone ridge is believed to become compromised earlier than its height.[8 9] However, the thickness of the buccal cortical plates of the socket — not the mass of the interdental cancellous bone — is currently the main consideration during treatment planning.[4 5] It has been shown that 90% of candidate patients for implants have a thin bony phenotype, with 50% having 0.5mm or thinner buccal cortical plate.[6 7]

While the functional success and survival rates of dental implants in the aesthetic zone are comparable to those in other areas[10], there is no consensus as to what constitutes satisfactory aesthetic results or how to consistently achieve them. Patients typically have high expectations and low tolerance for

aesthetic imperfections when it comes to this area of dentition. It is imperative, therefore, that aesthetics remain the top consideration at every step of the treatment plan.

Autogenous bone grafts are considered the gold standard for bone reconstruction, largely since they uniquely offer osteoinductive, osteoconductive, and osteogenic properties.[11 12] They are osteoinductive since they provide in their matrix and marrow spaces inductive proteins, such as bone morphogenetic proteins (BMPs) that stimulate the differentiation of native osteoblast precursors at the recipient site into active bone-forming osteoblasts. Their osteoconductive property lies in the fact that new bone can form directly on the graft surface and through its spaces, while the graft is being resorbed by phagocytic cells. Their osteogenic property depends on how many active bone cells (osteoclasts, osteoblasts, and their precursor cells) are transported with the graft to the recipient site and contribute to jumpstarting the synthesis of new bone there. Finally, autogenous tissues do not have the limitation of graft rejection.

The goal of bone reconstruction using graft procedure is “graft incorporation”, whereby the grafted material is gradually replaced by newly formed native bone that is vascularized and accessible to systemic remodelling mechanisms. Ideally, the newly formed bone would have the same physical dimensions, shape, microscopic structure, and mechanical properties as the original bone. However, this ideal scenario remains more of a theoretical, rather than practical, benchmark. Implants have been shown to produce adequate functional outcomes even if the bone graft achieves a fraction of this goal. The achievement of primary stability of an implant in the anterior maxilla can be influenced significantly by the volume and quality of interdental cancellous bone, which could provide not only more bone-to-implant attachment, but also a source of osteogenic cells, which are essential for the osseointegration outcome.

Evaluation of reconstruction outcome in the aesthetic zone of the maxilla – current status:

Aesthetic outcome parameters have evolved to include both subjective (patient-mediated) and objective (dentist-mediated) quantitative outcomes. Several objective indices have been developed to assess clinician-mediated aesthetic outcomes for single-tooth implant restorations in the aesthetic zone, including the Pink Aesthetic Score (PES),[13] the Papilla Presence Index (PPI),[14] Peri-Implant and Crown Index (PICI),[15] PES/White Esthetic Score (PES/WES),[16] the Implant Crown Aesthetic Index (ICAI),[17] and a modified version of the ICAI (mod-ICAI).[18]

The survival rates of implants placed in augmented bone and those placed in native bone are comparable.[19] Autogenous bone blocks in the form of “Khoury plates” are recognised as one of the most reliable, predictable, and stable modalities for ridge augmentation, particularly when the vertical dimension is compromised.[20–23] Autogenous bone grafts, however, are associated with donor site morbidity, multiple treatment sessions, and prolonged operating and overall treatment time. There are claims that similar results can be achieved with simpler, less technically demanding methods. It is

important to critically examine the efficacy of autogenous bone augmentation in achieving adequate aesthetic results in the anterior maxilla.

As mentioned earlier, the maxillary alveolar process exhibits centripetal resorption after tooth loss, whereby the labial wall resorbs faster than the lingual wall,[24 25] while the lingual wall tends to resorb faster in the mandible. If these observed patterns are proven consistent, cortical bone grafts that aim to restore ridge thickness in elderly patients should be placed labially in the maxilla and lingually in the mandible.

Chappuis and colleagues demonstrated that, after 8 weeks of dental extraction, the mid-facial vertical bone loss of the anterior maxilla was greater in the thin bony phenotype, compared to the thick phenotype.[26] To date, no intervention has been successful in preventing alveolar ridge resorption following exodontia.[4 6] After single-tooth extraction, bone loss mainly causes reduction in ridge thickness, with minimal height loss, provided that healthy teeth are present on both sides.[6 7] Most radiographic bone resorption (0.75–1mm) occurs during the first year after extraction, with minimal bone loss during subsequent years.[1]

Little is known about the role of soft tissue management in the success of dental implant procedures in the anterior maxilla. At baseline, Chappuis and colleagues found that the soft tissue thickness was similar in both the thin and thick bony phenotypes.[4] Post-extraction, however, the soft tissue of the thin bony phenotype underwent spontaneous thickening (up to 7 times its original thickness) at 8 weeks.[4] Vertical soft tissue height also decreased by 1.6 mm in the thin bony phenotype, which had a 7.5 mm decrease in vertical bone height. On the other hand, the thick bony phenotype lost 1.4 mm of vertical soft tissue height, which was more congruent with the 1.1mm decrease in bone height. The study concluded that the significant thickening of soft tissue in the thin bony phenotype obscured the massive bone loss underneath.

Dental implants in the anterior maxilla seemed to preserve the vertical and horizontal dimensions of alveolar bone,[27 28] and had a high overall success rate[28]. Qiu and colleagues found bone resorption rate to be around 9% in the horizontal plane and 10.9% in the vertical plane, following reconstruction with autogenous bilaminar cortical bone, allogenic bone graft, and collagen membrane.[29] In a study evaluating implant outcomes in 38 patients over 52 months, implants placed in augmented autogenous bone blocks in the anterior maxilla were seven times less likely to have recession of overlying gingiva, compared to surrounding natural teeth.[30]

During growth, the development and maintenance of the alveolar bone is determined by two factors — the internal growth sites and the periosteal envelopes.[31] The teeth of the alveolar bone act as internal growth sites exerting stress and strain on the surrounding bone.[31] The periosteal surfaces are involved in periosteal molecule signalling and are important to prevent bone volume loss. The integrity of the cortical plates are essential in maintaining the morphology of the jawbone, as well as the integrity of the

alveolar process.[31] In osteoporosis, alveolar bone undergoes osseous involution involving cortical bone resorption[31].

Surgical Augmentation Techniques

Autogenous bone grafts for the reconstruction of defective alveolar ridges can be harvested from extra-oral sites, such as the iliac crest, skull, fibula, and ribs,[11] or intra-oral sites, such as the ramus of the mandible, maxillary tuberosity, and mandibular symphysis. Intra-oral sites have the benefit of a single surgical field performed under local anaesthetic and reduced morbidity. Based on observations in this study, building a robust interdental cancellous bone “cushion” before implant placement is an important consideration.

A number of studies have tested the efficacy of autogenous bone grafts harvested from the retromolar region of the mandible. Khoury and Hanser published a 10-year prospective clinical study, where a total of 3,874 bone blocks (from 3,328 patients) were harvested from the external oblique line using the Micro-Saw protocol and then split into 2 using the split bone block (SBB) technique.[11] The SBB technique splits the block longitudinally into 2 thinner blocks, which can then be used for grafting. Once split, one or both blocks can be grafted. Adding bone chips to the thin bone block from the SBB technique has a high success rate, perhaps because it increases the number of osteocytes and hence promotes osteogenic action, resulting in an increase in revascularisation and incorporation of the graft.[32–34] A cortico-cancellous graft is more advantageous than a cortical plate, as it combines the benefit of the mechanical stiffness of cortical bone and the osteoinductive and osteogenic potential of cancellous bone.[31]

Yu and colleagues used a bilaminar cortical grafting technique from the lateral aspect of the mandibular ramus.[29] Bone chips were used in between the blocks, which were then covered with an organic bone graft and collagen membrane. They reported a survival rate of 100% after seven years, with satisfactory aesthetic scores. A study also reported promising results of melatonin as adjuvant to autogenous bone grafting in the aesthetic zone. [35] That study showed that the test group had a higher bone density, less marginal bone loss, and a reduction in the peri-implant sulcus depth.

McCarthy and colleagues placed implants in the anterior maxilla with autogenous bone grafts, harvested from the mandibular symphysis, and found that the onlay grafts produced predictably satisfactory results.[36] On the other hand, Mounir and colleagues compared onlay verses inlay autogenous bone grafts from the symphysis with immediate implant placement and concluded that the inlay bone grafting technique had a statistically significant advantage in vertical bone gain[37].

Zhao and colleagues compared half-columnar bone grafts from the ramus with a rectangular bone graft from the symphysis to augment the horizontal ridge in the aesthetic zone.[38] Organic bovine bone or a collagen membrane were combined with the grafts. Both resulted in acceptable aesthetics. However, the

half-columnar graft from the ramus exhibited an increased stability at 4 months after augmentation and 1 year after loading.

Following dental extraction in the anterior region of the maxilla, the integrity of the alveolar ridge and mucosal morphology could be preserved with autogenous hard and soft tissue grafts.[39] In a 5-year consecutive clinical study by Khoury and Hanser, 58 extraction sockets from 49 patients were completely filled with autogenous bone chips, harvested from a variety of jaw sites. [39] These bone chips were crushed before placement and then covered with a gingival-connective tissue graft taken from the palate. Implants were placed 10–12 weeks post-extraction and at this time there was no collapse of the sockets. Clinically, 47 sockets (81%) had healthy bone structure while the other 11 sockets (19%) had superficial resorption. In the latter cases, bone spreading was used during implant placement to compensate for resorption. No additional regenerative materials were required. A histomorphological analysis showed osteocytic activity with a mean amount of vital bone 52% ± 8.6%. Upon clinical and radiographic examinations, all implants were osseointergrated at 3 months after implant placement and all implants survived at 5 years.

Another report confirmed that autogenous J-graft from the ramus could reconstruct both horizontal and vertical elements of the ridge[40]. A pedicled palatal connective tissue graft may be required if additional soft tissue is required.

Complications

Possible complications associated with harvesting autogenous bone blocks included neurosensory disturbances and post-operative pain, bleeding, swelling, and trismus[41]. Other complications that could render the graft unsuccessful included infection, wound dehiscence, and graft sequestration. Bone harvested from the mandibular ramus and retromolar area seemed to have fewer complications than those of the parasymphyseal region.[41–47] Cordaro et al. compared the complications arising from 2 different sites, the ramus and the chin,[41] and concluded that both result in excellent implant survival rates, with only mild complications that were well-tolerated by patients. There were a greater number of teeth that became sensitive after bone harvesting from the chin, infrequently requiring root canal treatment. When the chin was used as a donor site, it had more sensory disturbances of the skin and mucosa. Both results were statistically significant.

Khoury et al. demonstrated a low complication rate from harvesting a mandibular bone block in the retromolar region.[11] There was no permanent anaesthesia of the alveolar nerve. Temporary sensory problems occurred in 168 patients (4.33%) and 20 patients (0.5%) had hypoesthesia or paraesthesia lasting up to 1 year. Other complications included failure of primary healing (61 donor sites, or 1.58%), mainly (80.4%) in patients who smoked.

Aesthetic Outcome

Patients typically have high expectations for the aesthetic outcome of dental implants in the anterior maxilla. However, the prediction and evaluation of aesthetic success could be quite subjective. Combinations of scoring systems were developed in attempts to standardize the appraisal aesthetic outcomes, including patient questionnaires,[48] visual scales,[49] and various and objective scores such as Pink Esthetic Score (PES), PES/White Esthetic Score (PES/WES), implant aesthetic crown index (ICAI), Peri-Implant and Crown Index (PICI), Papilla Index (PI), Complex Esthetic Index (CEI) and Implant Aesthetic Score (IAS).

The PES has been a widely used index, whereby seven points of the peri-implant soft tissue are analyzed. It has been shown to produce adequate assessment of treatment success[47 50] and correlates to patients' subjective assessment.[2] However due to interobserver inconsistency, it is recommended to conduct repeated assessment by the same individual at different stages of the treatment.[2]

Noelken and colleagues performed immediate implant placement and simultaneous alveolar ridge augmentation with subperiosteal bone chips after complete loss of the facial bony lamella.[51] They achieved 100% functional implant success and assessed the aesthetics with PES of 12.5 and noted that oral hygiene had a significant role in regard to the aesthetics.[51] In another study, immediate implants were placed in combination with autogenous bone chips. After five-year of follow-up using PES, interproximal marginal bone levels, survival rates, and aesthetic results were shown to be stable,[52] except for a slight decrease in facial marginal bone that did not impact the PES score.

Naishlos and colleagues used PES/WES to assess aesthetic outcome after anterior atrophic maxilla augmentation with cancellous bone-block allograft and late restoration loading[53]. The mean value of PES/WES was 17.8 ± 2.78. All patients had a PES/WES value above 12, which was the threshold value defined as clinically acceptable aesthetics[53]. Ponton and colleagues assessed the aesthetic and functional outcome as well as the volume maintenance of autogenous block grafts in the aesthetic zone in patients with thin periodontal biotypes[54]. Pre- and post-CBCT showed that 97% of the augmented width was maintained after 3.3 years and there was a lack of implant transparency or mucosal recession around all implants. Therefore, the investigators concluded that a thin periodontal biotype did not affect the bone volume of the autogenous block grafts.

Wang and colleagues described a sandwich technique using two autogenous bone blocks to reconstruct severely deficient bone in the maxilla. They achieved a PES/WES of 12 and 8, respectively, at the one-year follow-up, and the patient's subjective assessment was positive. In another study, Parthasarathy reported optimal pink-and-white aesthetics and adequate stability of implant-supported fixed prosthesis in a case with severe advanced bone loss around a central incisor.[55] Socket preservation was carried out using autogenous cortico-cancellous block graft followed by a pedicled palatal connective tissue graft.

Raghoebar and colleagues utilized autogenous bone in combination with soft tissue graft from the maxillary tuberosity to reconstruct sockets after removing failed implants.[56] After a healing period of 3

months, new implants were placed. The investigators reported a 100% implant success rate at 1 year, with healthy peri-implant tissue and favourable PES scores. Herford et al used a split-thickness flap to cover the ridge and extending in a palatal direction, increasing the amount of soft tissue and resulting in enhanced aesthetics and implant maintenance.[57]

Hanser and colleagues used volumetric measurements with the aid of an acrylic stent[39]. Six reference points on the buccal alveolar contour were measured at baseline (prior to extraction) and at 1- and 5-year intervals. There were no significant changes to the buccal contour from baseline to 1 year and 5yrs. One of the six reference points had a significant change in the volume at 1 year and 5yrs.

Studies attempted to evaluate and compare certain indices. However, it has been difficult to discern which parameter is most reliable for assessing the aesthetics in the anterior maxilla. For example, Morton and colleagues found that PES and PI accurately assessed patients' opinions regarding the soft tissue aesthetics, while ICAI and mod-ICAI represented patient satisfaction. [49] Watzek concluded that the PES was reliable.[13] Wittneben compared ICAI, the PES/WES, and PICI, and found the latter two to be more reproducible.[15] Another study compared the PES, ICAI, mod-ICAI, and the index of the Californian Dental Association (CDA). They concluded the mod-ICAI combined the best objective and subjective assessment of aesthetics related to implant-supported crowns[18]. Raghoebar and colleagues assessed ICAI as an objective tool in rating aesthetics of implant-supported single crowns and adjacent soft tissues. Zegner and colleagues compared 8 different indices: PI, PES, ICAI, PES/WES, CEI, IAS, Subjective Esthetic Score (SES), and Rompen Index[50]. They found significant differences between the indices' reliability, validity and patient's assessment of the aesthetics[50]. However, a common feature noted in various studies was the effect of observer specialisation on the results of assessing the soft tissue aesthetics.[15 17 47 58]

CONCLUSION

The aesthetic zone of the maxilla contains robust interdental cancellous bone that should be considered in planning alveolar reconstruction prior to implant placement, in addition to the buccal and palatal cortical plates. The highest bone quality in the alveolar ridge seems to be at the gingival margin, which is lost early after tooth extraction. While autogenous bone graft remains the gold standard for alveolar ridge augmentation in the anterior maxilla, more research is required to compare different graft types and reconstruction strategies in specific scenarios, such as osteoporosis or post-traumatic bone loss.

Declarations

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Fig. 1 was created by Ms. Mariam Elsalanty

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Figures

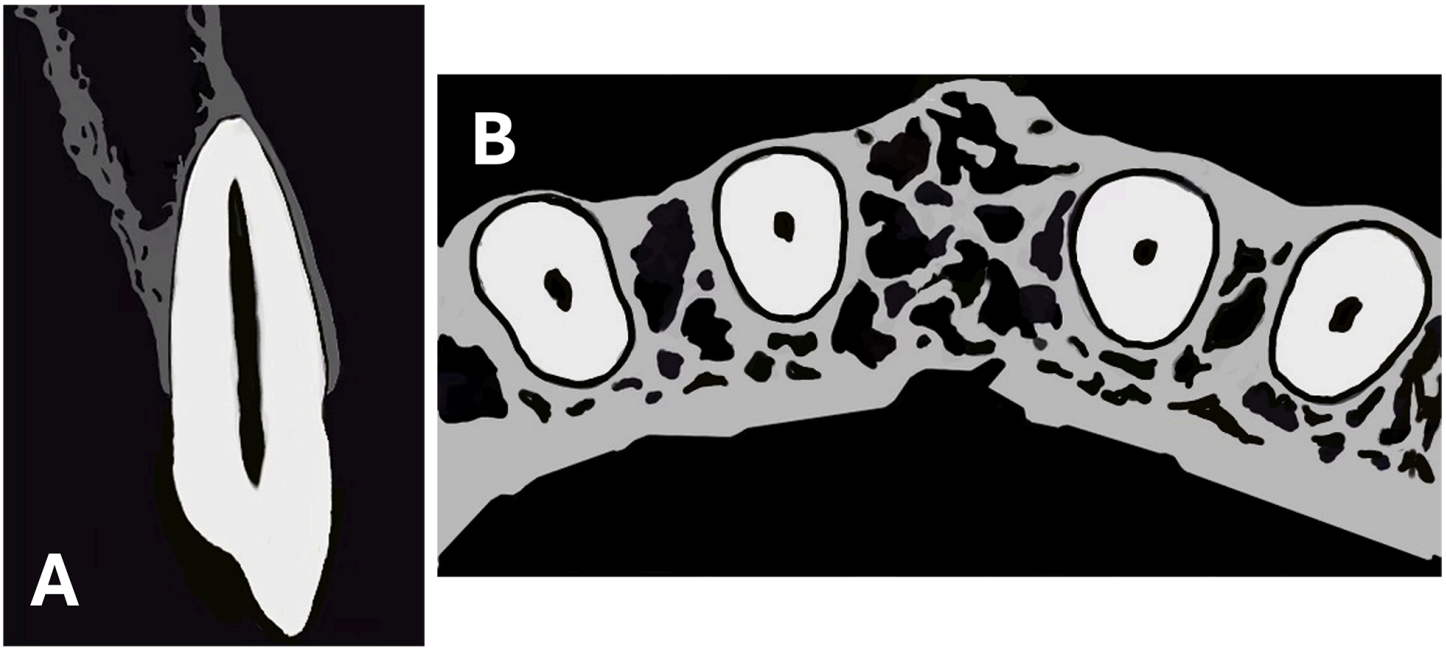


Figure 1

Representative graphical rendering of an axial (A) and a sagittal (B) sections in the anterior maxilla. It shows the distribution of trabecular bone on the labial, palatal, and interproximal areas.

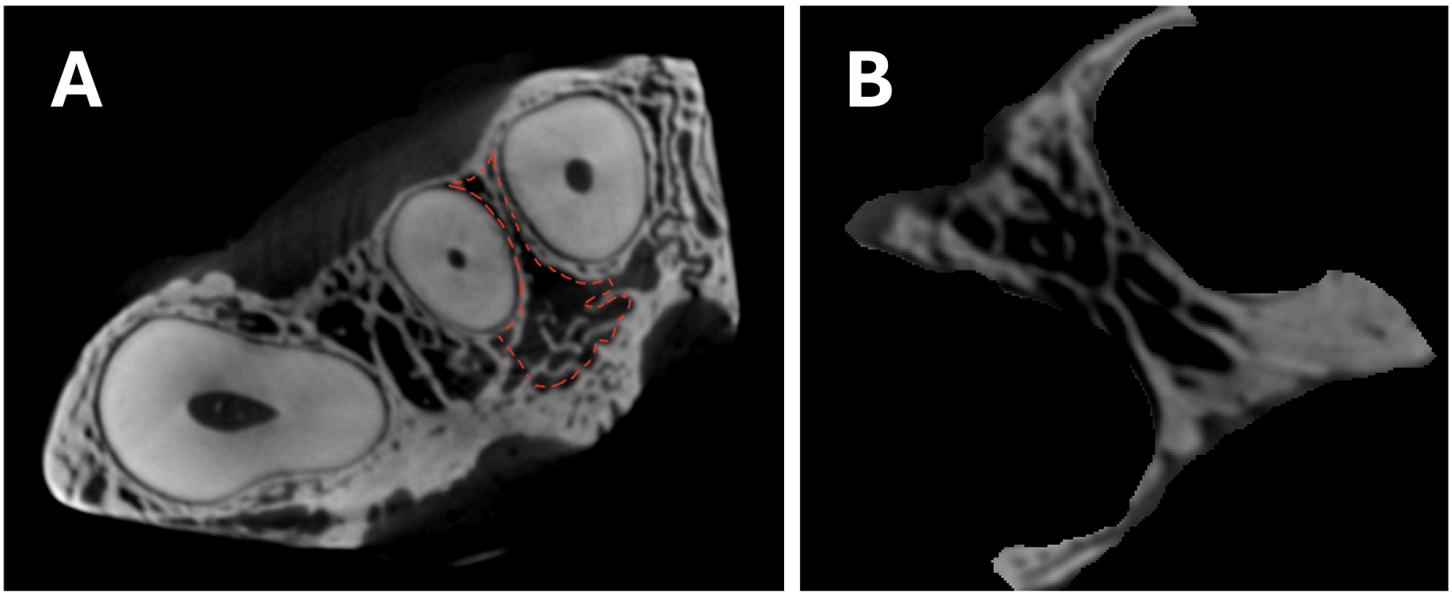


Figure 2

Volume of interest (VOI) segmentation: **A**: Axial slice of the anterior maxilla with the interdental cancellous bone region manually delineated in red. **B**: The corresponding isolated VOI region as extracted and independently analyzed by CTan software.

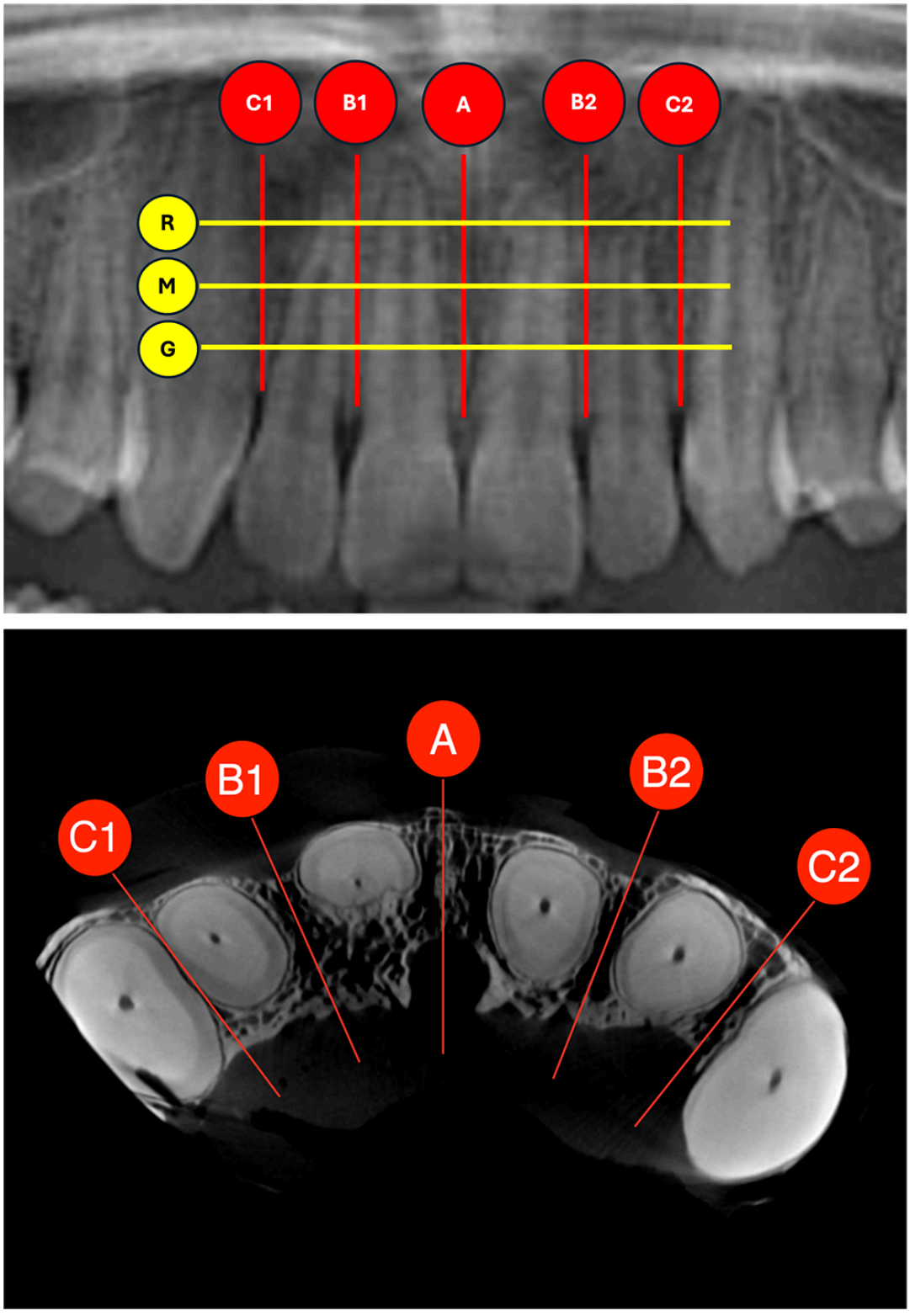


Figure 3

Measurement Planes Allocation: Three-Dimensional Division of Anterior Maxillary Interdental Spaces into Sagittal (A, B1, B2, C1, C2) and Axial (G, M, R) Zones

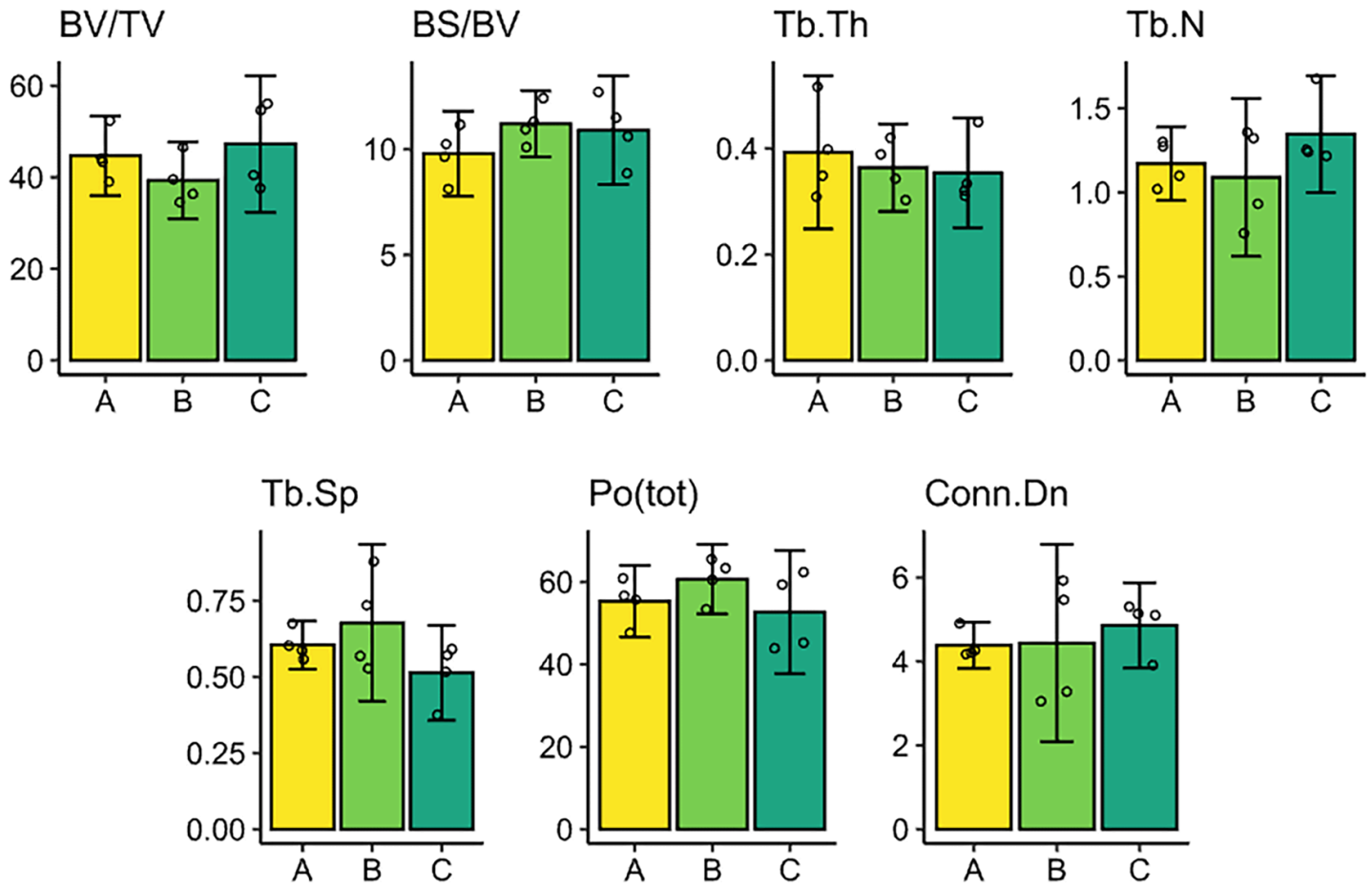


Figure 4

Bar plots illustrating trabecular bone architectural parameters of the interdental cancellous bone of the anterior maxilla (n = 4 subjects) across three sagittal interdental planes: midline (A), central-lateral (B), and lateral-canine (C). Percent bone volume (BV/TV) was highest at the occlusal level and declined gradually toward the apex, while total porosity exhibited the inverse trend, increasing at deeper levels. Bone surface density (BS/BV) showed a modest increase from occlusal to apical levels. The one-way rmANOVAs and post-hoc tests showed no statistically significant differences between the three planes in any of the architectural parameters. Bars indicate mean values. Whiskers show 95% confidence intervals. Circles are means for each subject.

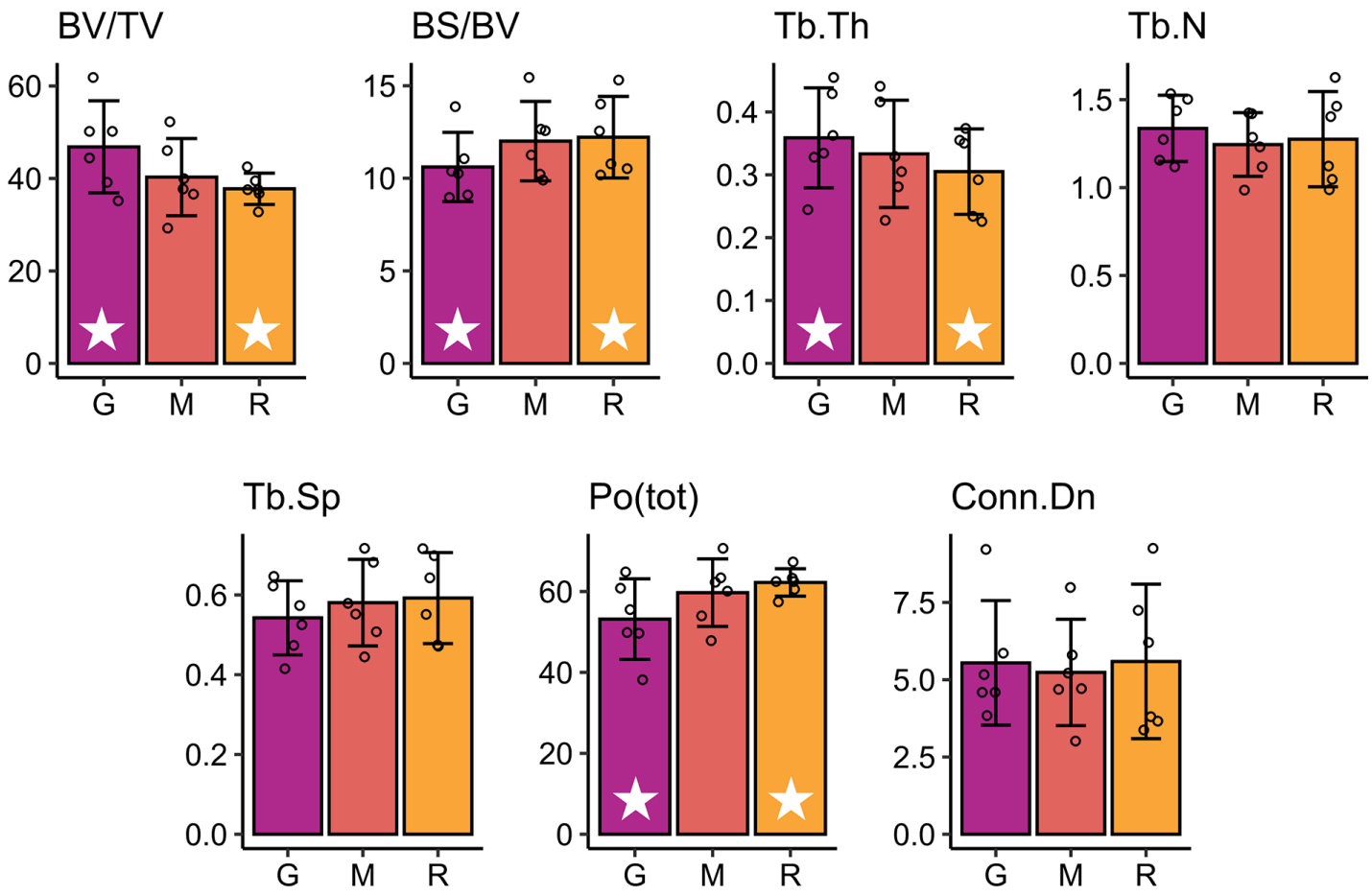


Figure 5

Bar plots illustrating trabecular bone architectural parameters of the interdental cancellous bone of the anterior maxilla (n = 6 subjects) across three axial levels: occlusal (G), middle (M), and apical (R). Percent bone volume (BV/TV) was highest at the occlusal level and declined gradually toward the apex, while total porosity exhibited the inverse trend, increasing at deeper levels. Bone surface density (BS/BV) showed a modest increase from occlusal to apical levels. The one-way rmANOVAs and post-hoc tests showed that bone at the gingiva had higher quality than at the root: G plane had greater BV/TV (Tukey-adjusted p = 0.023) and Tb.Th (Tukey-adjusted p = 0.007), but lower BS/BV (Tukey-adjusted p = 0.047) and Po(tot) (Tukey-adjusted p = 0.023). Collectively, these parameters indicate a robust, well-connected interdental cancellous bone network with no region of critical bone deficiency across the axial extent of the aesthetic zone. Bars indicate mean values. Whiskers show 95% confidence intervals. Circles are means for each subject. Within each plot, stars indicate planes that are significantly different.

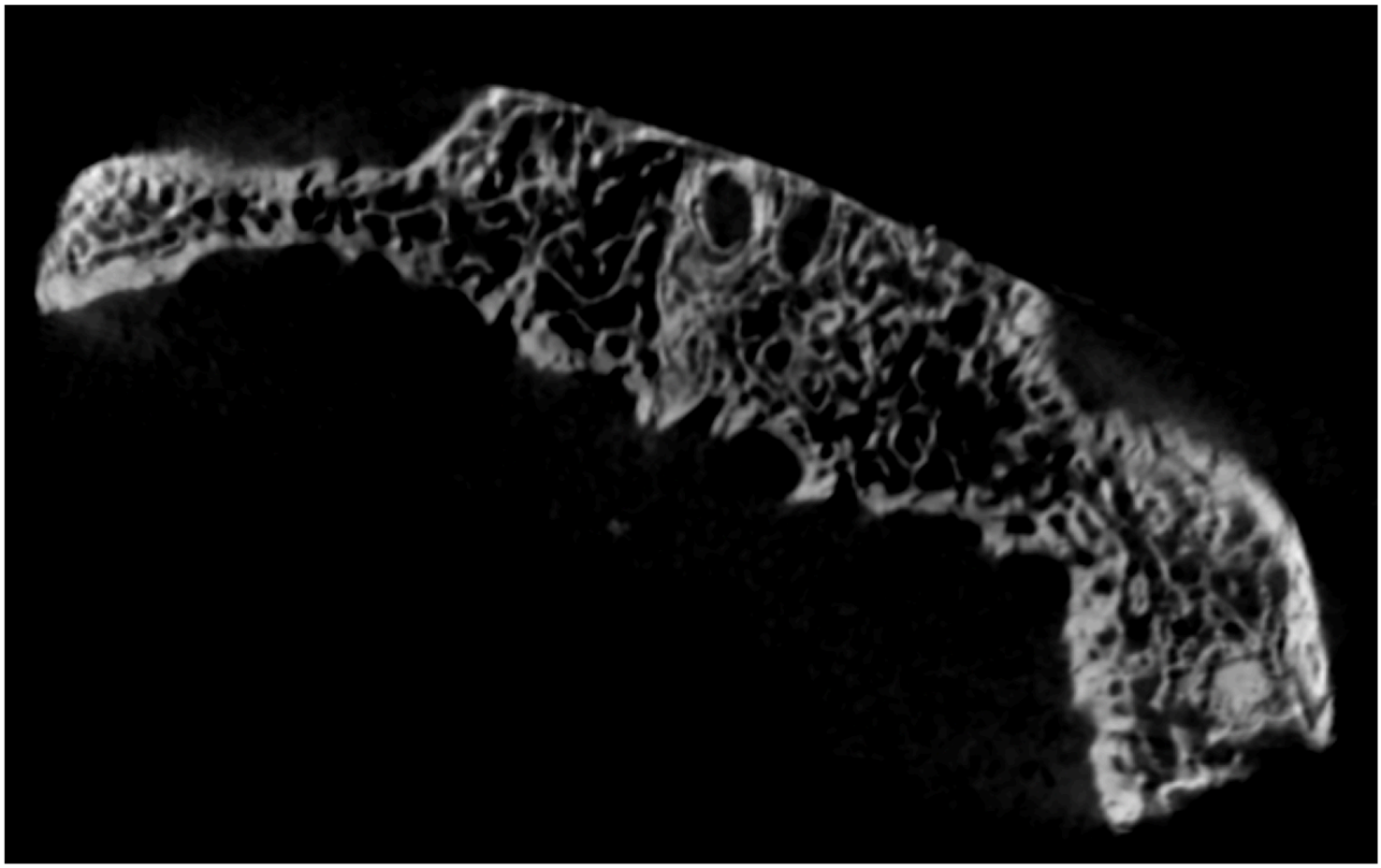


Figure 6

MicroCT reconstruction of the anterior maxilla demonstrating the trabecular bone network of the interdental cancellous bone throughout the aesthetic zone. This pattern of bone was detected even in edentulous samples