

Virtual Implant Rehabilitation Of The Severely Atrophic Maxilla: A Radiological Study

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Abstract

Background : Advanced maxillary atrophy is often observed and implant placement could become difficult. Nevertheless, a volumetric evaluation using a proper diagnostic software could facilitate the implant planning. The purpose of the present study is to reveal the existence of a sufficient bone volume in the maxilla also in patients presenting a severely atrophic maxilla. Methods: A sample of CBCT images of 59 patients was evaluated. After a 3D anatomical evaluation, tilted implants has been virtually positioned in the retro-canine regions. All the implants were inserted with the same procedure at 30° and 45° degrees of tilting. The length, the palatal angulation and the diameter of the placed implant were identified. Results: 220 tilted implants were placed. An average implant measurement of 13,508 mm of length and 3,42 mm of diameter were calculated. Also, an average buccal-palatal angulation of 6° was identified. After the statistical analysis implant length was found significantly higher at 45° degrees than at 30° degree (<0.0001). Conclusions: A considerable amount of patients show a significant degree of bone atrophy. The implant-supported treatment plan can rely on the three dimensional imaging of the residual bone as a guiding tool to establish the most effective implant position for each specific case. In this study it is founded that in the majority of the maxillary atrophy the volumetric evaluation of the bone near the lateral wall of the nasal cavity could suggest the presence of an adequate basal bone volume for tilted implants placement.

Background

The growing ageing population and the psychosocial perception of tooth loss have both contributed to increase the implant-supported solutions¹⁻³. Throughout the past twenty years the use of osseointegration methods has grown more and more critical for oral rehabilitation, to completely regain functions and improve aesthetics⁴. This is also due to the frequency of disapproving patient outcomes with the use of removable partial or total dentures⁵. One of the most important requirements for dental implants osseointegration is the presence of a sufficient amount of basal bone⁶. Unfortunately, totally or partially edentulous maxillae often show a significant degree of sinus pneumatization and/or alveolar bone atrophy⁷. This lack of bone may complicate the implants placement and could influence the final results⁸. For these reasons, several aspects should be considered before the implant surgery and a 3D volume bone evaluation is essential to plan a proper implant rehabilitation⁹.

The cone beam computed tomography (CBCT) produces three-dimensional reconstructions of maxillary and mandibular anatomical structures using a single scan and offering multiple views with low radiations. A flat detector makes the capture. The X-ray diffusion is cone shaped. The CBCT scans permits to gain a better understanding of the jaws' morphology and to evaluate the volume of remaining bone in any given site. Furthermore, the scans allow interactive planning using 3D simulation software. To date, according to the American Academy of Oral and Maxillofacial Radiology, CBCT should be considered as the method of choice for the three dimensional evaluation of the maxillary bone to plan an implant treatment¹⁰. In particular, volumetric data acquired by CBCT showed a high accuracy of the

measurements with a relative error below 1% compared with the same measurements took in vivo as demonstrated by Veyre-Goulet et al¹¹.

Many surgical techniques are suitable to place and load implants in edentulous atrophic maxilla. Treatment plans may include bone grafting techniques to reconstruct the lost bone volume¹². For example procedures such as distracting osteogenesis, Le Fort osteotomy with inlay grafting, onlay bone grafts, maxillary sinus floor elevation or guided bone regeneration have been used to re-establish bone bulk before implant surgery¹³⁻¹⁷. However, these methods are all characterized by high morbidity and long duration of the therapy¹⁸⁻¹⁹. Widmark et al²⁰ found that implants inserted in native bone had a higher success rate than implants placed into grafted bone. The zygomatic implants are viable alternatives for treatment of the severely atrophic maxilla, nevertheless this procedure is operator-dependent²¹.

The aim of the present paper is to show the potential application of the maxillary retro-canine region as the designated place for tilted “iuxtameatal” implants. “iuxtameatal” means that the apex of the implants is surrounded by the cortical bone near the nasal inferior meatus. In particular, in this paper, iuxtameatal implants insertion is simulated on CBCT scans in order to show to clinicians how getting more implant stability also in patients presenting a severe maxillary atrophy. This virtual procedure could help surgeons to consider a tilted implant maxillary rehabilitation without the need of sinus lifts or invasive bone grafting operations and without facing post-operative complications.

Methods

Study Population

The radiological study was conducted in line with the TRIPOD reporting guidelines²² on patients referring to the Department of Dentistry, IRCCS San Raffaele Hospital, Milan, Italy, between 2015 and 2018.

Patients were included according to the following criteria:

- Age > 18 years old
- Edentulous area at least from the first molar to the canine
- Severely atrophic maxilla corresponding to class V of the Cawood and Howell's Classification²³. In particular, a residual flat ridge form, with less than 5 mm in height but without evident basilar loss, was categorized as class V of the Cawood and Howell's Classification

Patients were not included if they presented one of the following exclusion criteria:

- Contraindications to the CBCT exam
- Systemic diseases that influence bone metabolism
- Radiolucent or radiopaque images in the mid-maxilla area

- Implant or impacted tooth in the mid-maxilla area

Cbct Scan Acquisition

The CBCT scans were taken for diagnostic reasons. Each patient provided a written consent before undergoing the CBCT scan. All CBCT scans were acquired with a Field of View of 12 x 8 cm, at 90kV 10 mA 16 s and 0,2 mm Voxel size with a NewTom VGi evo Cone Beam 3D Imaging Device (Cefla SC, Imola Italy). The default position and orientation of the orthogonal sectional planes relative to the jaws were consistent in all the CBCT datasets of each patient. Thus, standardization of the site and orientation of the reformatted sample sites as achievable through measured shift and angulation of the orthogonal sectional planes.

To guarantee a stable head position, all CBCT scans were checked and re-orientated to place the scan view parallel to the Camper's plane.

Anatomical Landmarks

The "mid-maxilla" region is an anatomical district that belongs to the maxillary bone. It could be identified with the Retrocanine Bone Triangle²⁴ extended from the lateral border of the nasal cavity until the sinus cavity, including also the residual alveolar process below the sinus floor (Fig. 1).

Frontally, the antero-lateral side of the maxilla's body represents the external wall of the mid-maxilla. The residual alveolar crest represents the inferior margin, with a high thickness in the posterior section. The anterior wall of the maxillary sinus represents the posterior limit of the mid-maxilla and it's extremely concave due to the sinusal cavity. Medially, the mid-maxilla is limited by the lateral nasal cavity's wall, from the anterior external margin until the naso-lacrimal duct's emergency, under the inferior turbinate. The inferior medial border is represented by the alveolar process connected with the palatal process.

The bone polygon seems a truncated pyramid with a triangular base, described as follow.

The base: the inferior side of the pyramid is a sort of triangle with a posterior base. It represents the fixture's entry and allows a good stability to the implant. It belongs to the residual alveolar process. In very severe atrophy it includes also the lateral portion of the palatal process. The antero-lateral wall of the pyramid coincides with the antero-lateral face of the maxilla and includes also the canine pillar, the canine pit and the residual alveolar bone under the sinus floor. The medial alveolar portion, the palatal process and, superiorly, the lateral wall of the nasal cavity constitute the medial wall of the pyramid. Below the inferior nasal turbinate there is the emergency of the naso-lacrimal canal that limits the mid-maxilla.

The posterior wall is generally a large wall with a concavity due to the anterior wall of the maxillary sinus. It narrows apically following the shape of the frontal process of the maxilla²⁵.

Virtual iuxtameatal Implant Positioning

The residual bone of each patient was analyzed using the panorex image construction (Fig. 2). According to the software procedures the panorex image was obtained drawing a panoramic curve on the axial view of the maxillary segment above the residual alveolar crest. The cross sectional views perpendicular to the panoramic curve were automatically elaborated by the software.

In order to standardize the implant positioning, on the panoramic view a horizontal line "H" is drawn from the point "P0" (the lowermost point of the right or left maxillary sinus floor) parallel to the scan view.

Then a vertical line "V" is drawn tangent to the point "PV" (the most medial/anterior point of the right or left sinus cavity) and perpendicular to the line "H".

A line "1" was drawn with an angle of 30° from the line "V" and tangent to the antero-medial wall of the sinus cavity in the point "T30".

The meeting point of the line "1" with the line "H" is the point "P30".

From the point "T30" was drawn a segment "T30-A" with 3mm of length, perpendicular to line 1. This is the minimum distance of the implant axis from the sinus cavity. A line was drawn parallel to the line "1" and passing through point "A". This line corresponded with the long axis of the virtual iuxtameatal implant and crossed the line "H" in the point "Pe₃₀".

The distance from "P30" to "Pe₃₀" can be then calculated through the geometrical similarity.

Two triangles are similar if and only if corresponding angles have the same measure. This implies that they are similar if and only if the lengths of corresponding sides are proportional. It can be shown that two triangles having congruent angles (equiangular triangles) are similar, that is, the corresponding sides can be proved to be proportional. This is known as the AAA similarity theorem.

Then, in according to the trigonometry functions related to right triangles:

$$P30-Pe_{30} = T30-A / \cos 30^\circ = 3\text{mm} / \cos 30^\circ = 3,46 \text{ mm}$$

This result is the distance from the center of the implant to the point "P30". So that the initial drilling point of all the virtual iuxtameatal implants is the projection of the point Pe₃₀ to the residual alveolar crest (Fig. 3).

An analogous procedure can be performed in the case of a 45° degrees angulation implant (Fig. 4).

In this latter case the distance from P45 and Pe₄₅ (the drilling entry point) shall be:

$$P45-Pe_{45} = T45-B / \cos 45^\circ = 3\text{mm} / \cos 45^\circ = 4,24 \text{ mm}$$

In the general case, with the use of an implant of generic diameter “x”, the distance from P45 or P30, shall be measured as follow:

$$P30-Pe_{\text{generic}} = (1+x/2) / \cos 30^\circ$$

$$P45-Pe_{\text{generic}} = (1+x/2) / \cos 45^\circ$$

In the most examined cases the extreme maxillary atrophy allowed the implants placement only in the mid-maxillary basal bone, between the lateral nasal cavity wall and the anterior wall of the maxillary sinus.

For each patient, two iuxtameatal cone shape implants were virtually placed in tilted position in each side, according to the All-on-four procedure described by Malò et al²⁶ trying to maximally exploit all the bone volume offered (Fig. 5). All the implants were placed in the same way at 30° and at 45° of mesio-distally angulation, because the majority of implant companies produces abutments which can correct an angle of 30° maximum. However, the prosthesis meso-structure can correct additional 15° of angulation with its conic component, so that the maximum of angulation could be 45°.

Implant insertions were simulated with the RealGUIDE 5.0 implant planning software (3DIEMME, Cantù, Italy).

Outcome measures

The iuxtameatal implants were positioned in the mid-maxilla with a sufficient amount of bone all around the fixtures. Then the length and the diameter of the implants were measured. The buccal-palatal angulation of each implant were analyzed too in the cross sectional views (Fig. 6). A negative angle indicated that the implant insertion went from the palatal side to the vestibular side of the residual alveolar crest (Fig. 7). With the dedicated software also the bone density around the implants' apex was measured in gray-scale. Different studies demonstrated how grey levels of CBCT can be used to derive Hounsfield units²⁷. Nevertheless among CBCT scans gray-scales vary widely due to different factors, such as the lack of grey level uniformity, the presence of artifacts, the effects of scatter and beam hardening²⁸⁻²⁹. So gray-scales are not equivalent among CBCTs, but the outcomes taken from the CBCT scans could suggest the presence or not of cortical bone around the fixtures.

Statistics

All statistical analyses were performed with a specific software (R, R Core Team, Foundation for Statistical Computing, Vienna, Austria). In particular, the Linear and Nonlinear Mixed Effects models package was used to estimate the Linear Mixed Effects model³⁰.

To evaluate the effect of the tilting degree (30° vs. 45° degrees) on the implant length, a linear mixed-effects model was estimated. The modelling approach here applied allows to properly account for repeated measure data and for unobserved heterogeneity among patients. Actually, along with fixed effects, the model allows to specify in the model random components. An initial complete model was estimated including position and tilting degree as fixed effects along with their interaction. Subject-specific random effect was specified. Hence, a random intercept model was considered. Assumptions for the correct application of the model were checked. A backward stepwise procedure was applied to select a more parsimonious model.

In all the analyses, the significance threshold was set at 0.05.

Results

A total of 59 subjects were included in this study according to the inclusion criteria. They were selected among the patients referring to the Department of Dentistry, IRCCS, San Raffaele Hospital, Milan, Italy. There were 28 male and 31 females with an age range of 64,5 years old. In according to the inclusion criteria the alveolar crest height has to be lower than 5 mm in each case. It represents the distance between the lowermost point of the right or left maxillary sinus floor and the most coronal point of the residual crest.

Only 8 emi-maxillae showed an insufficient bone volume for an adequate implant placement. In particular, two patients showed a very severe maxillary atrophy in both right and left maxillae, one patient presented the right maxilla completely reabsorbed and three patients presented the left maxilla too narrow to place any implant.

In the CBCT scans of the other 57 patients 220 iuxtameatal implant insertions were simulated using a 3D software (see additional file 1). An average implant measurement of 13,508 mm of length and 3,42 of diameter were calculated (Tab. 1). Also, an average anterior-posterior angulation of 6° were identified. That means that in some simulations the implant axis was negative: the fixtures' most coronal point was palatal respect of the apex. The average bone density around implants was 570 gray-scale. It is not possible to compare the gray-scales among CBCT scans. However the average values calculated by the software in the tomographies included in this study established that the peri-implant bone density was greater than the average density of the cancellous bone, indicating that the apex of the iuxtameatal fixtures is effectively inserted in the cortical bone of the walls of the nasal meatus. After the statistical analysis implant length was found significantly higher at 45° degrees than at 30° degree (<0.0001). So, when considering tilting degree of the implant, significant effects of implant length were found (Fig. 8). Hence, a greater inclination of an implant could increase its length during the virtual surgical planning.

Discussion

Krekmanov et al.³¹ and Aparicio et al.³² presented the first papers in which a combination of tilted and axial implants was used in patients with severely reabsorbed posterior maxillae. The results indicate that the use of tilted implants is an effective and safe alternative to maxillary sinus floor augmentation or bone grafts procedures.

Peñarrocha-Oltra et al.³³ in 2013 wrote that tilted implants, both used alone and combined with axially placed implants and rehabilitated with different prosthetic options have high success rates, minimal complications and high patient satisfaction.

Also Balleri et al.³⁴ showed a very good outcome with 20 fixed partial dentures supported by two implants, one tilted and one axial, in the retro-canine bone triangle.

In a recent finite element study for two splinted implants, it appeared that tilting of the distal fixture does not stress the peri-implant bone as compared with the mesial axial fixture³⁵. It was also demonstrated that tilted posterior implants were mechanically more advantageous than distal cantilever units³⁶. The study of Barnea³⁷ demonstrates no effect of implant angulation on peri-implant bone loss in the posterior maxilla.

Gonda et al.³⁸ identified favorable implant placement positions in 10 edentulous maxillary bone using implant simulation software, clinical anatomical morphology and bone quality data obtained via CT. These data showed that premolar areas offer the most favorable scope in terms of bone height, width, angulation and quality. However, this study had a small sample size and did not consider the placement of tilted implant.

A similar study was conducted by Bertos Quilez et al.³⁹ but related to zygomatic implant. They investigated the malar bone volume and length that a zygomatic implant can engage using CBCT scans from 23 edentulous patients. The results suggested that the average volume of malar bone that a zygoma implant engaged did not vary regardless of the implant position and degree of alveolar bone atrophy. All of the cases evaluated showed enough bone volume at the zygoma level to allow for quadruple implant placement so it can be hypothesized that any malar bone is actually appropriate for the placement of two fixtures.

Pramstraller et al.⁴⁰ Evaluated the alveolar ridge dimensions of edentulous sites in the maxillary posterior sextants. CT scans from 127 patients with at least one missing tooth were analyzed with a dedicated software. The results indicated that second premolar as well as molar edentulous sites may call for bone augmentation procedures for proper implant placement due to the insufficient height of the alveolar ridge in a substantial amount of edentulous patients.

Also Nunes et al.⁴¹ Analyzed the width and the height of bone volume of the edentulous posterior maxilla using CBCT scans from 122 patients. They found that a high percentage (54%) of molar edentulous sites

exhibited a reduced bone height (less than 5mm) and do require a sinus floor elevation procedure if implant therapy is chosen as a treatment option but they did not take in consideration the possibility of tilted implants placement.

On the contrary, Tolstunov et al.⁴² measured the average bone volume of the edentulous maxilla with cone-beam computerized tomography scans from 30 patients and determined its suitability for implant treatment without additional bone grafting. The results indicated that in many maxillary edentulous cases the existing bone volume can be often enough for a full-arch maxillary implant treatment with also tilted implants, without an additional trauma or expense associated with bone grafting or sinus lift.

Candel Marti et al.⁴³ Evaluated soft tissue conditions and bone loss around palatal positioned implants supporting fixed full-arch prostheses to rehabilitate edentulous atrophied maxillae and compare them with conventional well-centered implants placed in non-atrophic maxillae after a minimum follow-up of 5 years. The results suggested that palatal positioned implants may be a good treatment alternative for patients with severe horizontal maxillary alveolar bone atrophy.

Ganz et al.⁴⁴ described the “Triangle of bone” and a decision-making tree to determine the ideal maxillary placement for an implant surrounded by the greatest amount of existing bone and alerted clinicians of the importance of a 3D anatomical view presented by the CT and CBCT technology.

Owing to mechanical and anatomic difficulties, implant treatment in the atrophic maxilla represents a challenge. The trabecular compartment of the canine/premolar region offered higher quality when compared with the posterior maxilla and the basal bone showed a higher density than the alveolar bone⁴⁵. So, in implant rehabilitations, clinicians should consider the amount of cortical bone around the nasal cavity in order to get more implant stability⁴⁶.

In the present study it was founded that it was possible to virtually insert fixtures also in patients with severely atrophic maxillae and the statistical analysis showed that an implant could be longer if its angulation is more accentuated. Hence, tilting implants could allow to insert the fixture apex in a high bone density area and consent more implant stability and, eventually, an immediate prosthetic load⁴⁷.

However the correct vestibular-palatal angulation of the implants cannot be planned in the ortho-panoramic radiography: only CBCT scans can suggest the ideal palatal angulation with extremely high precision. This is why the previously virtual implant plan is very important for clinical purpose.

No studies were found measuring the atrophic maxilla bone volume related to tilted implant treatment. The absence of similar studies in the scientific literature limits the founding of comparisons with other study.

Conclusions

Within the limits of the present study, it can be concluded that a good anatomical background and an accurate virtual plan before the implant surgery could help clinicians finding the best implant angulation and position, trying to take advantage from the retro-canine region, the maxillary area with the highest bone density, in order to increase the implant stability. This procedure could be also applied to patients with a severe atrophic maxillae, without any additional bone grafting or sinus floor elevation.

Further studies are needed to investigate the clinical use of iuxtameatal implants.

Abbreviations

CBCT: Cone Beam Computed Tomography

TRIPOD: Transparent reporting of a multivariable prediction model for individual prognosis or diagnosis

Declarations

Ethics approval and consent to participate

Written informed consent for publication of their clinical details and radiological images was obtained from all patients and the San Raffaele Scientific Institute ethical committee approved the study (number #11/INT/2014)

Consent for publication

Not applicable

Availability of data and materials

The dataset supporting the conclusions of this article is included within the article (and its additional file). All materials described in this manuscript, including all relevant raw data, will be freely available to any scientist wishing to use them for non-commercial purposes, without breaching participant confidentiality.

Competing interests

The authors declare that they have no actual or potential financial relationships with any companies whose products or services may be related to the subject matter of the article.

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Authors' contributions

MM conceived the idea;

BPdC approved the study protocol;

AM collected the data;

BPdC performed statistical analysis and drafted the manuscript;

PC and GT interpreted the data;

RV and PC revised the manuscript;

RV critical revisions, carried out the final revision of the text and approved the idea.

All authors read and approved the final manuscript.

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Tables

Table 1

RIGHT MAXILLA 30°	n	mean	sd	median	min	max	range
Alveolar.crest.height	56	4.57	0.42	4.6	2.5	5	2.5
Implant.lenght	56	13.22	2.97	13.38	7.07	19.26	12.19
Implant.diameter	56	3.44	0.33	3.35	2.76	4.26	1.5
Palatal.angle	56	5.93	8.04	6.23	-24.27	31.52	55.79
Bone.quality	56	566.57	124.74	567.5	274	822	548
RIGHT MAXILLA 45°	n	mean	sd	median	min	max	range
Alveolar.crest.height	56	4.57	0.42	4.6	2.5	5	2.5
Implant.lenght	56	14.31	2.91	14.27	9.21	22.63	13.42
Implant.diameter	56	3.41	0.32	3.38	2.62	4.02	1.4
Palatal.angle	56	5.2	7.6	5.72	-21.19	26.72	47.91
Bone.quality	56	565.91	125.51	567.5	274	822	548
LEFT MAXILLA 30°	n	mean	sd	median	min	max	range
Alveolar.crest.height	54	4.63	0.36	4.8	3.9	5	1.1
Implant.lenght	54	12.85	3.28	12.96	6.32	19.49	13.17
Implant.diameter	54	3.43	0.32	3.36	2.8	4.39	1.59
Palatal.angle	54	6.67	6.52	7.36	-10.44	23.33	33.77
Bone.quality	54	573.43	127.59	559.5	282	934	652
LEFT MAXILLA 45°	n	mean	sd	median	min	max	range
Alveolar.crest.height	54	4.63	0.36	4.8	3.9	5	1.1
Implant.lenght	54	13.65	3.01	13.86	8.34	20.86	12.52
Implant.diameter	54	3.37	0.31	3.34	2.63	4.07	1.43
Palatal.angle	54	5.29	6.66	6.01	-10.93	23.33	34.25
Bone.quality	54	571.8	130.92	559.5	282	952	670

Figures

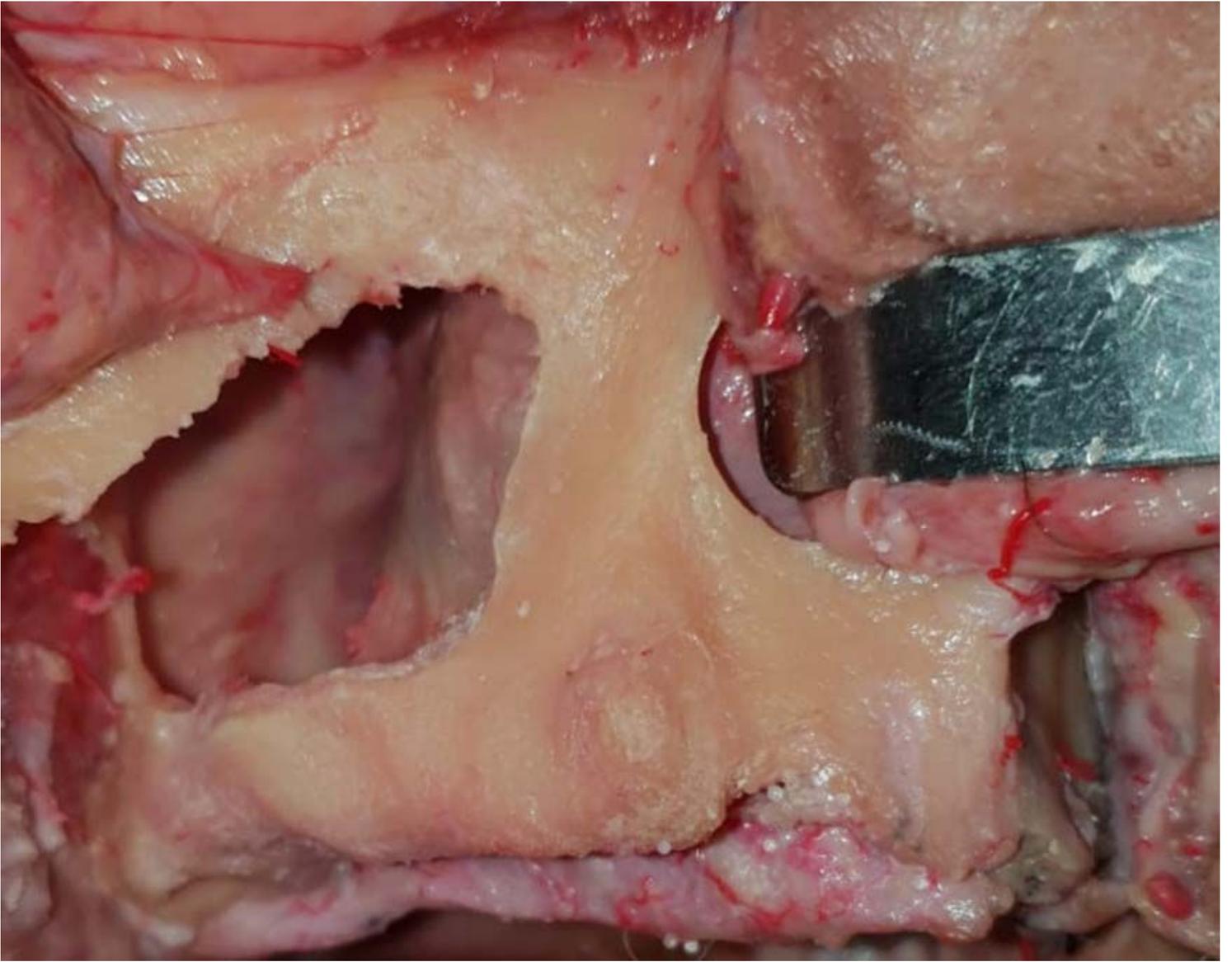


Figure 1

The mid-maxilla region is shown in this fresh frozen ex vivo fixed specimen. The vestibular wall of the right sinus has been removed in order to expose the extension of the paranasal cavity. The residual alveolar bone around the canine region is the area of interest for tilted implant positioning.

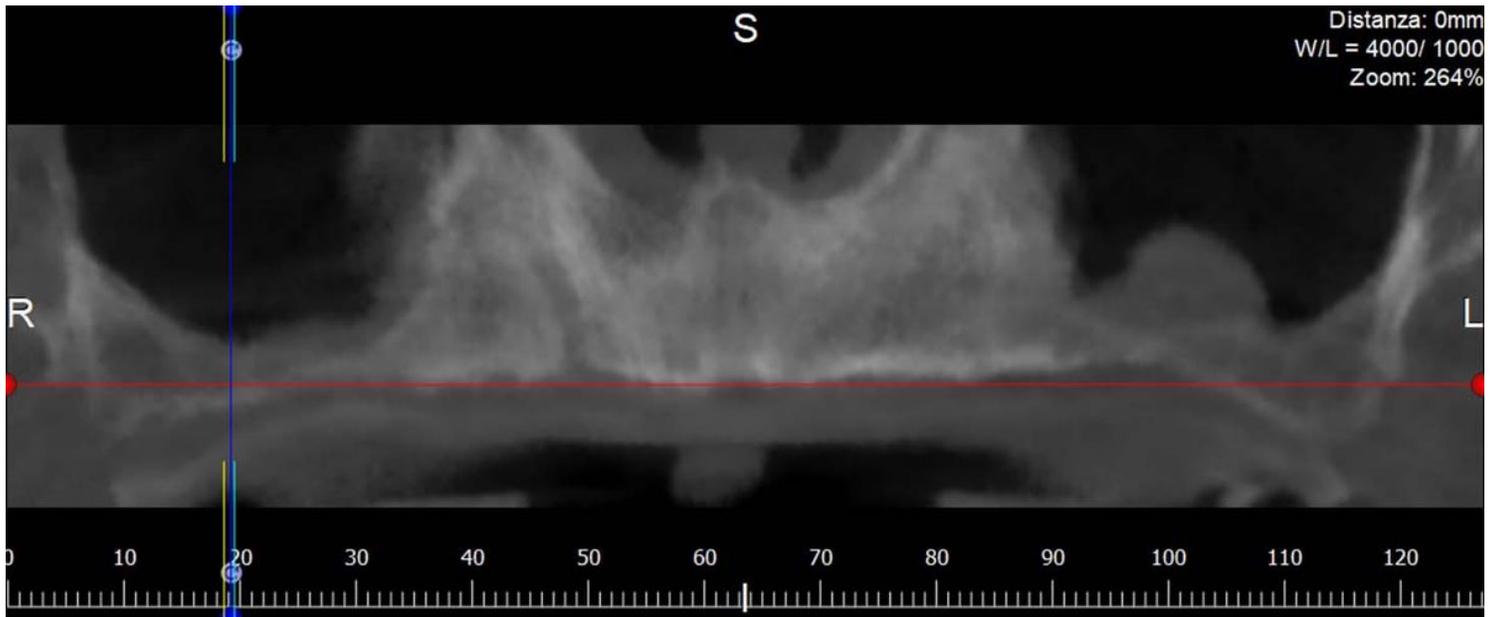


Figure 2

Panorex image elaborated by the software from a maxillary CBCT

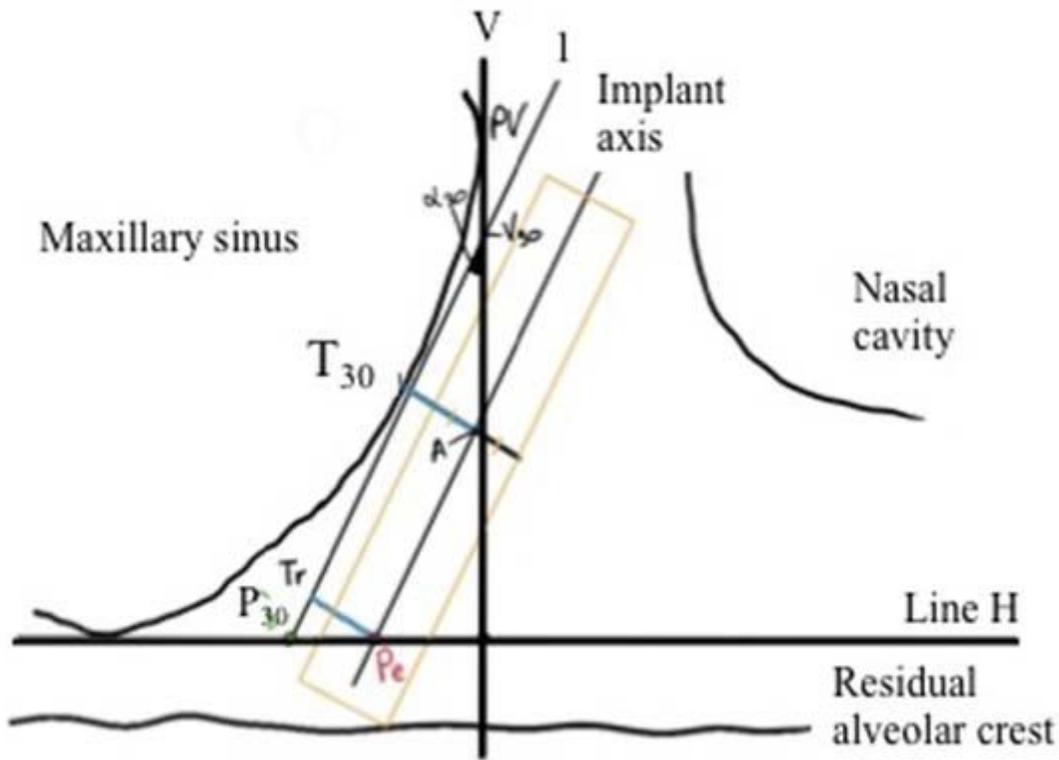


Figure 3

The initial drilling point of the virtual iuxtameatal implants with 30° of angulation is the projection of the point Pe30 to the residual alveolar crest.

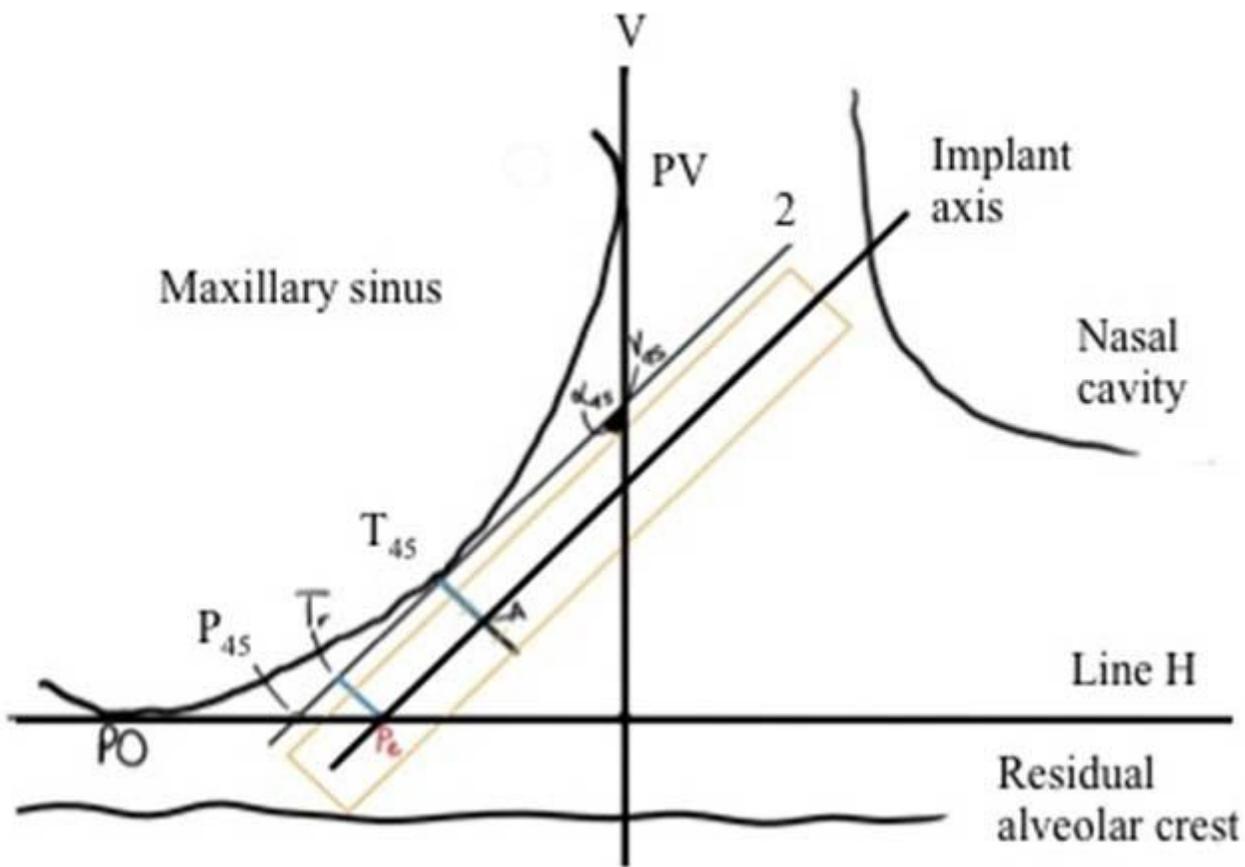


Figure 4

The initial drilling point of the virtual iuxtameatal implants with 45° of angulation is the projection of the point Pe45 to the residual alveolar crest.

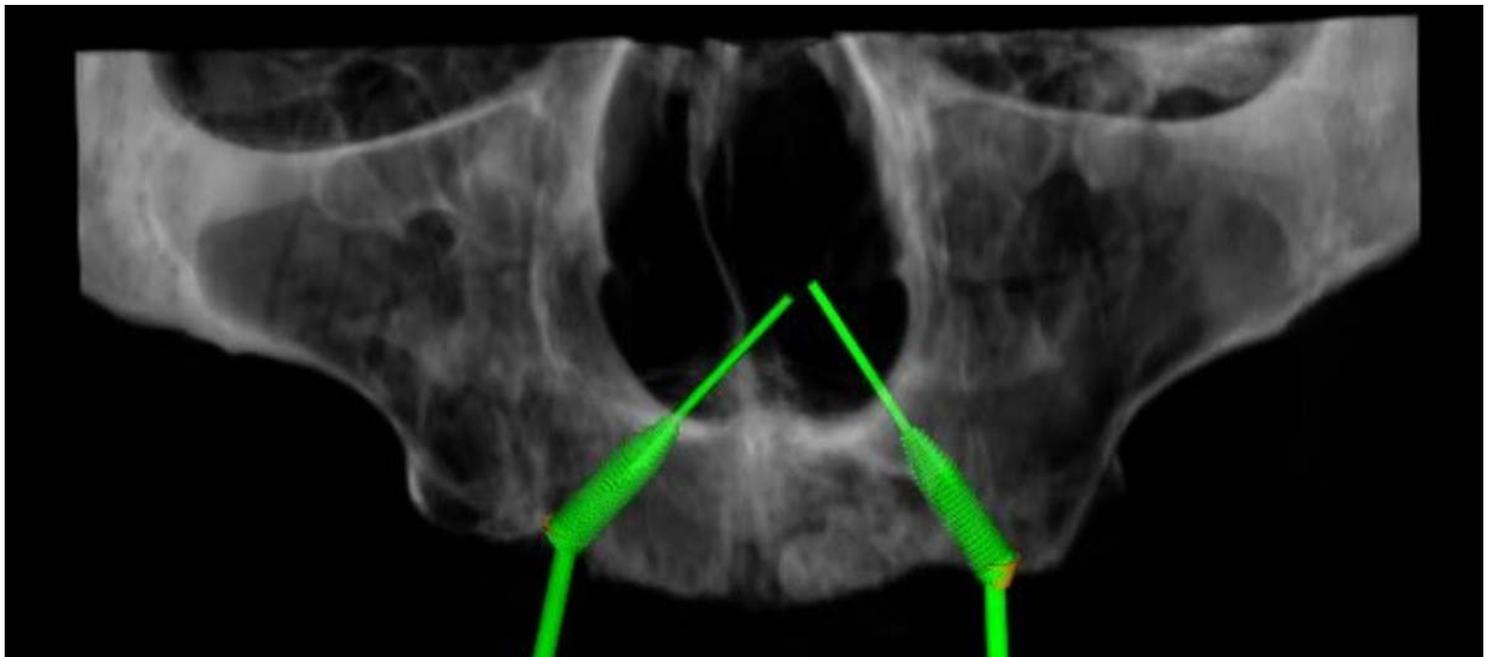


Figure 5

In this 3D reconstruction the iuxtameatal implant was placed in the right maxilla with 45° of angulation, in the left side with 30° of angulation.



Figure 6

Cross sectional view during the iuxtameatal implant positioning in the left side with a positive buccal-palatal angle.

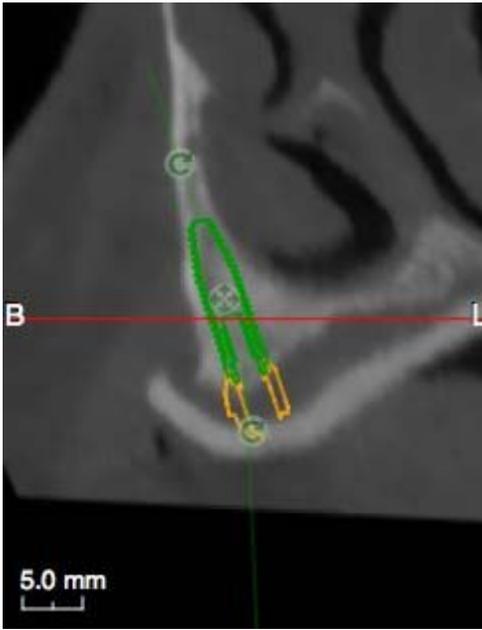


Figure 7

Cross sectional view during the iuxtameatal implant positioning in the right side with a negative buccal-palatal angle.

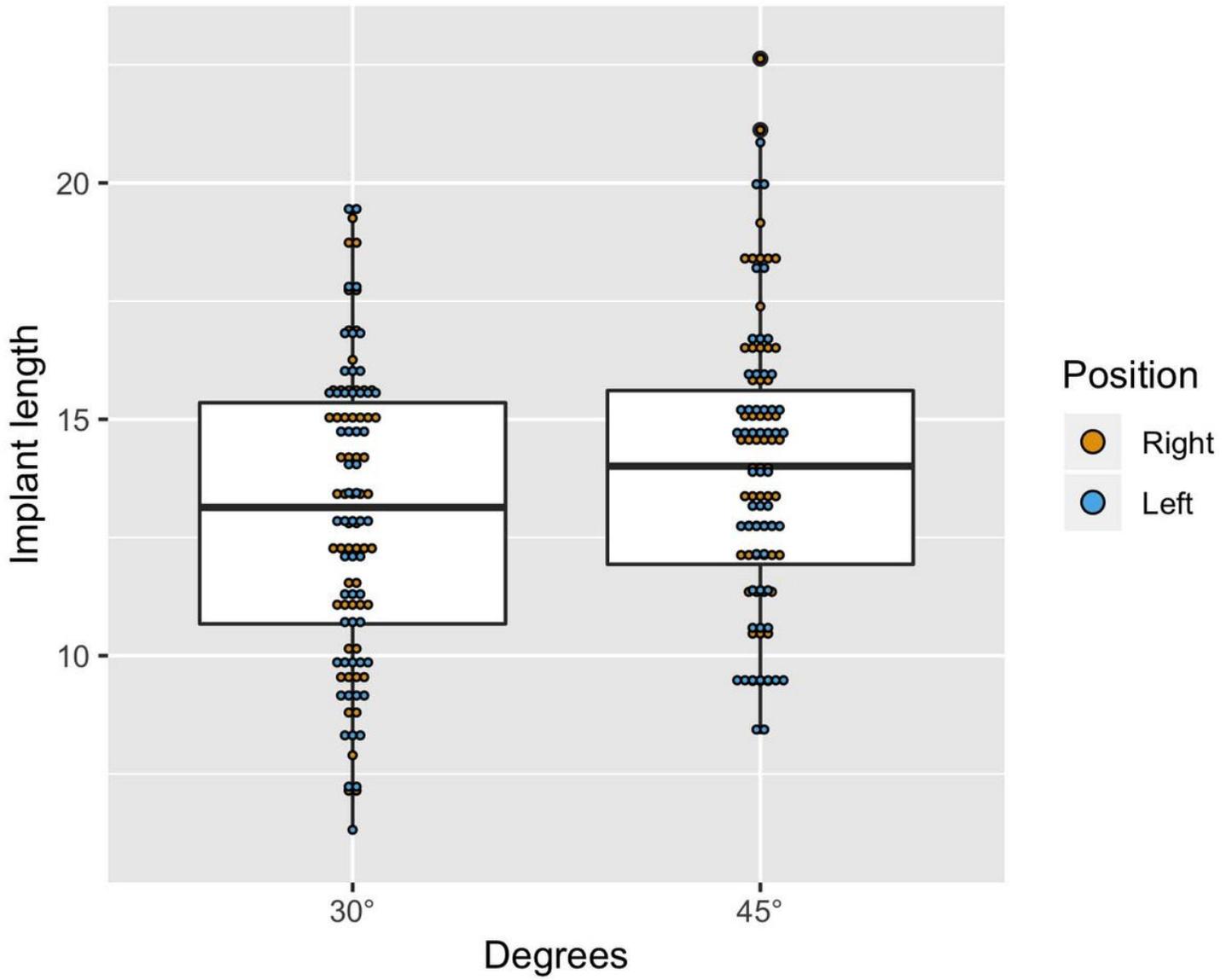


Figure 8

Boxplot showing the distribution of implant length by position and degrees.

Supplementary Files

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- [supplement1.xlsx](#)