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BONE TO IMPLANT SURFACE CONTACT AS A CRITERION FOR IMMEDIATE IMPLANT PLACEMENT WITH SIMULTANEOUS SINUS AUGMENTATION IN THE UPPER MOLARS INTERRADICULAR BONE: A RADIOLOGICAL CBCT STUDY

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Objectives: The aim of this study is to determine which type of vertical relationship (between molar apices and the sinus floor) is correlated with the most favorable bone to implant contact (BIC).

Methods: The CBCT database of the Faculty of Dental Medicine was used for datasets. For each dataset, a prosthetically-driven virtual implant placement was placed in the remaining interradicular bone. Potential BIC was measured using two different implant macrogeometries (straight and tapered).

Results: The study included 20 maxillary molars with divergent root anatomy: 90% of the molars had a type II vertical relationship with the sinus floor, while only 10% had type III. Mean pBIC surface for second molars was significantly higher for straight implants compared to tapered implants. However, no significant differences in BIC% means between straight and tapered implants for any of the comparisons was found.

Conclusions: Implant macrogeometry was found to have an impact on achieving higher pBIC values in certain situations, such as for second molars and type II relationship with the sinus floor. The study highlights the need for incorporating 3D software analysis in pre-operative surgical planning.

Keywords: Bone to implant contact, CBCT, immediate implant, internal sinus lift, interradicular bone, implant macrogeometry, sinus classification.

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Conflicts of interest:
The authors declare no conflicts of interest.

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Periodontology */ Parodontologie*

LA SURFACE DE CONTACT OS-IMPLANT COMME CRITÈRE POUR LA POSE IMMÉDIATE D'UN IMPLANT AVEC AUGMENTATION SIMULTANÉE DES SINUS DANS L'OS INTERRADICULAIRE DES MOLAIRES SUPÉRIEURES: UNE ÉTUDE RADIOLOGIQUE SUR CBCT

Objectifs: Le but de cette étude est de déterminer quel type de relation verticale (entre les apex molaires et le plancher sinusien) est corrélé avec un contact os-implant (BIC) le plus favorable.

Méthodes: La base de données CBCT de la Faculté de médecine dentaire a été utilisée pour les ensembles de données. Pour chaque ensemble de données, une pose d'implant virtuel prothétique a été placée dans l'os interradiculaire. Le potentiel BIC a été mesuré au niveau de deux macrogéométries d'implants différentes (droites et coniques).

Résultats: L'étude a inclus 20 molaires maxillaires présentant une anatomie radiculaire divergente : 90 % des molaires avaient une relation verticale de type II avec le plancher sinusien, tandis que seulement 10 % avaient une relation verticale de type III. La surface moyenne de pBIC pour les secondes molaires était significativement plus élevée pour les implants droits que pour les implants coniques. Cependant, aucune différence significative dans les moyennes BIC% entre les implants droits et coniques pour aucune des comparaisons n'a été trouvée.

Conclusion: La macrogéométrie de l'implant s'est avérée avoir un impact sur l'obtention de valeurs pBIC plus élevées dans certaines situations, comme pour les secondes molaires et la relation de type II avec le plancher sinusien. L'étude met en évidence la nécessité d'intégrer l'analyse logicielle 3D dans la planification chirurgicale préopératoire.

Mots clés: Contact os-implant, CBCT, implant immédiat, élévation sinusienne interne, os interradiculaire, macrogéométrie implantaire, classification des sinus

Introduction

The placement of dental implants in the upper molar region presents challenges mainly due to the complex anatomy and lack of bone density. To overcome these challenges, several surgical approaches have been proposed, such as lateral sinus floor elevation with simultaneous or delayed implant placement, transcrestal sinus floor elevation with or without graft, and transalveolar approach using the osteotome technique [1-3]. Immediate implant placement in molars fresh extraction sockets is also an alternative to the delayed protocol, but achieving primary stability can be challenging due to poor bone quality and anatomical limitations such as the maxillary sinus [4]. Immediate implant placement with simultaneous internal sinus floor elevation can help reduce the surgical steps and patient discomfort [5]. The success of this procedure, estimated to be between 50 and 80%, is influenced by implant macrogeometry and the type of vertical relationship between molar apices and the sinus floor [6-8]. A new classification proposed by Zhang et al. in 2019 helps evaluate the vertical relationships between the root apices of the maxillary molars and the maxillary sinus floor to plan implant placement and tooth extraction [9]. The aim of the study is to determine which type of relationship is correlated with the most favorable bone-implant contact on a presurgical CBCT to allow the immediate placement of implants. The differences in potential bone to implant contact surface (pBIC) will be investigated between straight and tapered dental implants placed in maxillary molars with different root anatomy and varying vertical relationships with the maxillary sinus floor according to Zhang 2019 [9].

Material and Methods

CBCT Datasets and images

The CBCT database of the Faculty of Dental Medicine were searched for CBCT datasets that meet the inclusion criteria (NEWTOM VGI large field of view, by CEFLA dental equipment- Imola, Italy,). Scan data were saved in DICOM (Digital Imaging and Communications in Medicine) format and the image analysis, segmentation and virtual planning were performed using the BlueSky Plan® (Blue Sky Bio, LLC, Grayslake, IL, USA) which provides axial, coronal and sagittal views through multiplanar reconstructions of 0.15mm slices. Axial images were reoriented to occlusal plane as a horizontal reference. A panoramic curve was created and cross-sectional images perpendicular to that curve were reconstructed at a 1 mm interval.

Classification According to Zhang

Two custom cross-sections each of 1mm thickness were used in order to classify each molar according to Zhang classification. The first one was a section passing through the mesial and palatal root and the second through the distal and palatal root. Molars with complete root fusion were excluded. These sections were also used with a third one passing through the buccal roots in order to check the separation of the roots: buccal mesial and buccal distal, distal and palatal, mesial and palatal (Figure 2). Type I, the MSF is located above the connection between the buccal and palatal root apices; this class was not taken into consideration in our study. Type II, the MSF is located below the connection between the buccal and palatal root apices, without an apical protrusion over the MSF; Type III, an apical protrusion is observed over the MSF at the buccal root apex; Type IV, an apical protrusion is observed over the MSF at the palatal root apex; and Type V, apical protrusions are observed over the MSF at the buccal and palatal root apices.

Study Population

Inclusion criteria

- Upper molars with no vertical bone between the root apices and the maxillary sinus floor
- Upper molars with an apical protrusion observed over the MSF at the buccal root apex, at the palatal root apex or at the buccal and palatal root apices (Types II-III-IV-V, Zhang 2019)
- Upper molars with divergent MB, DB and P roots
- Upper molars with fusion of the mesial and palatal roots

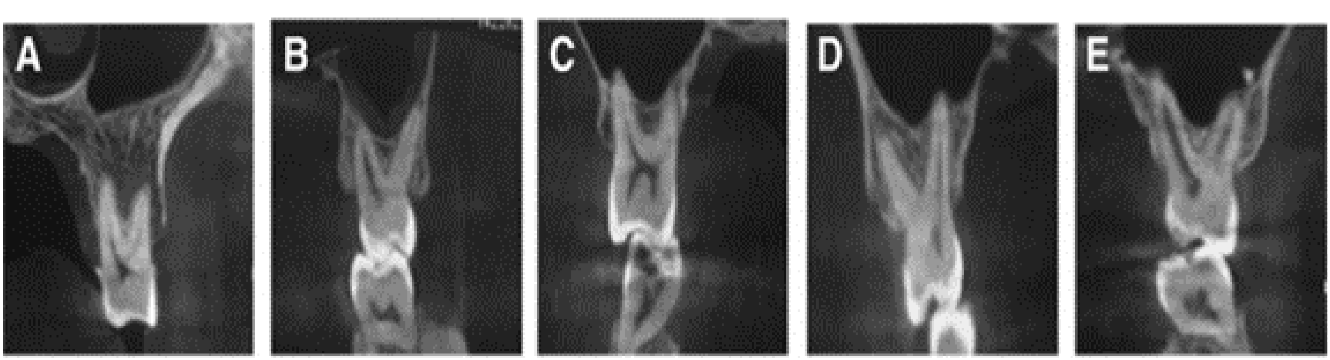

Figure 1. Different relationships between MSF and molar root apices according to Zhang 2019.
(A): Type I: the MSF is located above the connection between the buccal and palatal root apices.
(B): Type II: the MSF is located below the connection between the buccal and palatal root apices without an apical protrusion over the MSF.
(C): Type III: An apical protrusion is observed over the MSF at the buccal root apex.
(D): Type IV: An apical protrusion is observed over the MSF at the palatal root apex.
(E): Type V: Apical protrusions are observed over the MSF at the buccal and palatal root apices.

- Upper molars with fusion of the distal and palatal roots
- Upper molars with fusion of mesial and distal roots

Exclusion criteria

- Upper molars where the maxillary sinus floor is located above the connection between the buccal and palatal root apices (Type I, Zhang 2019)
- Upper molars with fusion of the mesial, distal and palatal roots
- Upper molars presenting bone loss due to a periodontal disease
- Upper molars presenting endodontic lesions or endo-periodontal lesions
- CBCTs with visible maxillary sinus pathologies or sinus membrane thickening
- The study was approved by the Ethical Committee of the Dental Faculty of Saint-Joseph University of Beirut: approval number USJ-2021-93.

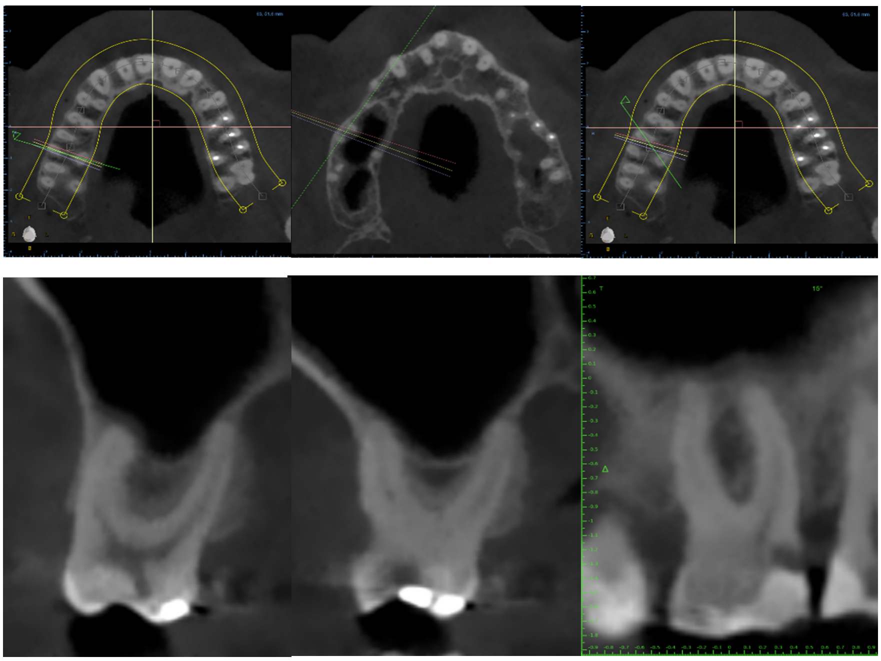

Figure 2. Two cross sections to classify each molar according to Zhang 2019

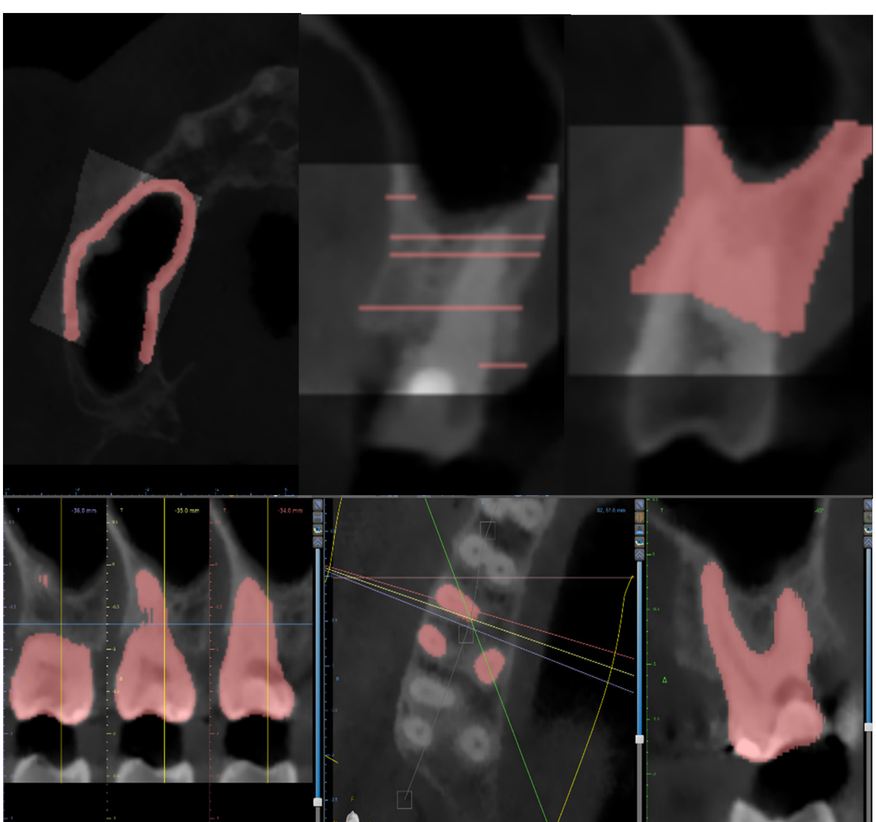

Figure 3. Segmentation of the maxillary bone at the upper molar site (semi-automated).

Segmentation of Maxillary Bone and Molars

The maxillary bone at the molar site was first segmented using a semi-automatic segmentation technique using a contour interpolation algorithm (Figure 3). The region of interest was one tooth mesial and a tooth distal to the site in the sagittal direction and up to 15mm from the bone level apically to the maxillary sinus. Trabecular bone was also highlighted during the segmentation in order to form a solid model. The bone contour was traced manually by the first operator and then verified by the second operator. A similar approach was used to segment the tooth with the advanced tooth segmentation method. To isolate the tooth the visible part of it was highlighted on each cut in order to form a solid model. A 3D model of each segmentation was created inside the software and the models outline was rechecked on the 2D slices with custom rotating 360 degrees section around the models to make sure it follows the proper bone and tooth/roots outline. In case of any mismatch, the model outline modifier tool was used to adjust the model edges in 2D (Figure 4)

Virtual implant placement

For each dataset, a virtual prosthetically-driven implant placement was performed with a 4.1 x 10mm Straumann® implant (Bone Level straight or Bone Level tapered) in the remaining interradicular bone. A

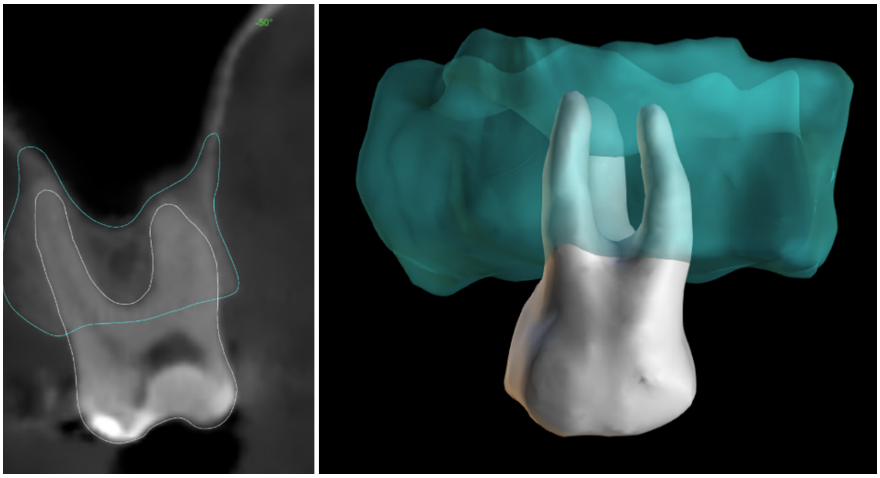

Figure 4. Outline of models in 2D and the 3D view of the segmentation.

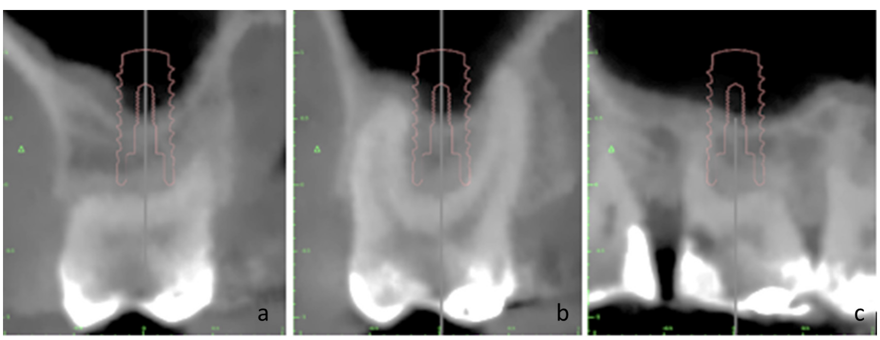

Figure 5. A 360-degree rotation around the implant axis to make sure of the proper implant position 5.a: Implant position in a vestibulo-palatal section. 5.b: Implant position in a custom section passing by the vestibular and palatal root. 5.c: Implant position in a mesio-distal section.

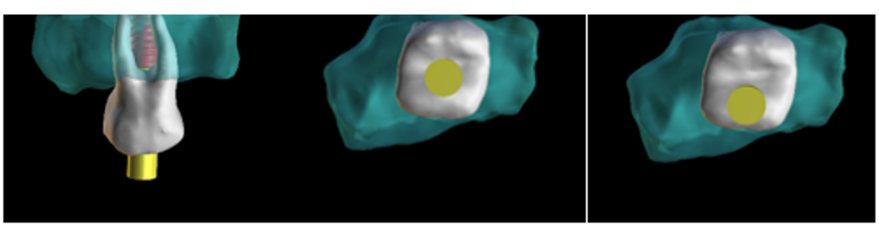

Figure 6. Virtual planning of the proper implant position. 6. a. (upper left), vestibular view simulation; 6. b. (upper middle), occlusal view with prosthetically driven implant axis; 6. c. (upper right), simulation with an abutment outside the prosthetic space

360-degree rotation around the implant axis was used to make sure of the proper implant position (Figure 5). A virtual abutment of 4.1mm in diameter and 15mm in length was used in order to check the implant axis and the emergence through the crown. The abutment must not touch the line joining the two buccal cusps in the vestibular area and the line joining the palatal cusps in the palatal area, otherwise it is considered outside the prosthetic space. From a mesio-distal point of view, the implant should be parallel to the tooth axis (Figure 6).

When the final implant position was achieved, the position was locked and the implant was duplicated in order to preserve its position. The new duplicated implant was replaced by the second macrogeometry (Straight or Tapered) (Figure 7). This way, both implant macrogeometries could be compared to assess the one correlated with more BIC.

Data export and measures

The bone, tooth and the two implant models were exported in STL format and imported in the Autodesk Meshmixer software for further analysis (Figure 8). First, a Boolean operation to subtract the tooth from the bone was realized in order to have an accurate model mimicking the alveolar socket after tooth extraction (Figure 9). The second Boolean operation was between the bone and the implant to highlight the implant surface in contact with the bone (Figure 10). This surface was selected and measured using the model Stability tool inside the software to

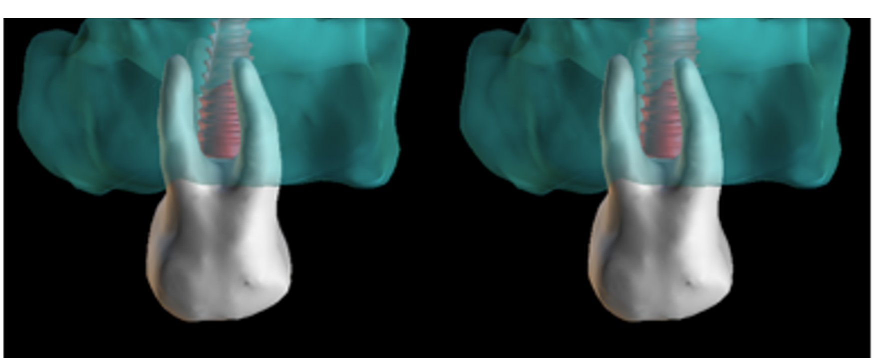

Figure 7. Implant locked in the right position and duplicated for both microgeometries. 7.a:3D view of the tapered implant,7.b:3D view of the straight implant.

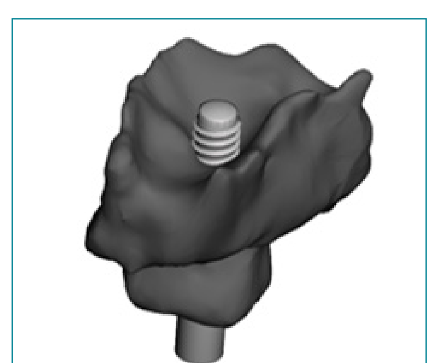

Figure 8. Models after import to Meshmixer.

obtain the pBIC value and compared to the total implant surface volume in order to generate a percentage of pBIC.

Using these operations, Zhang 2019 classification was analyzed to assess the type correlated with more pBIC. Implant macrogeometry was compared to assess if straight or tapered implants were more suitable for immediate implantation with simultaneous sinus floor elevation. Molar morphology prior to extraction was also compared to assess if root divergence, protrusion or fusion may influence the pBIC. All segmentations, simulations and measurements were performed by one operator (N. B.) and rechecked by an experienced operator in digital implantology and maxillo-facial radiology (N. G.). In order to study the intra and interobserver reliability of the measurements, two operators performed the measurements on 10 of the cases twice at a one-week interval (N. B. and N. K.). No major differences in measurements were observed between the operators.

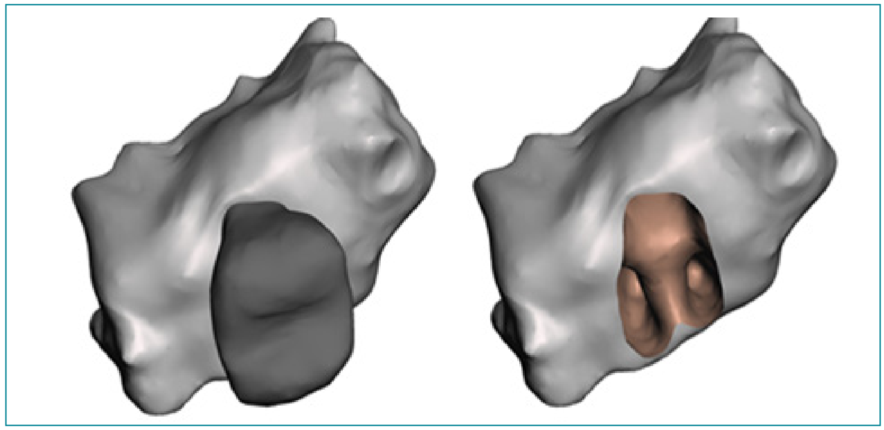

Figure 9. Initial model vs socket model after first boolean operation.

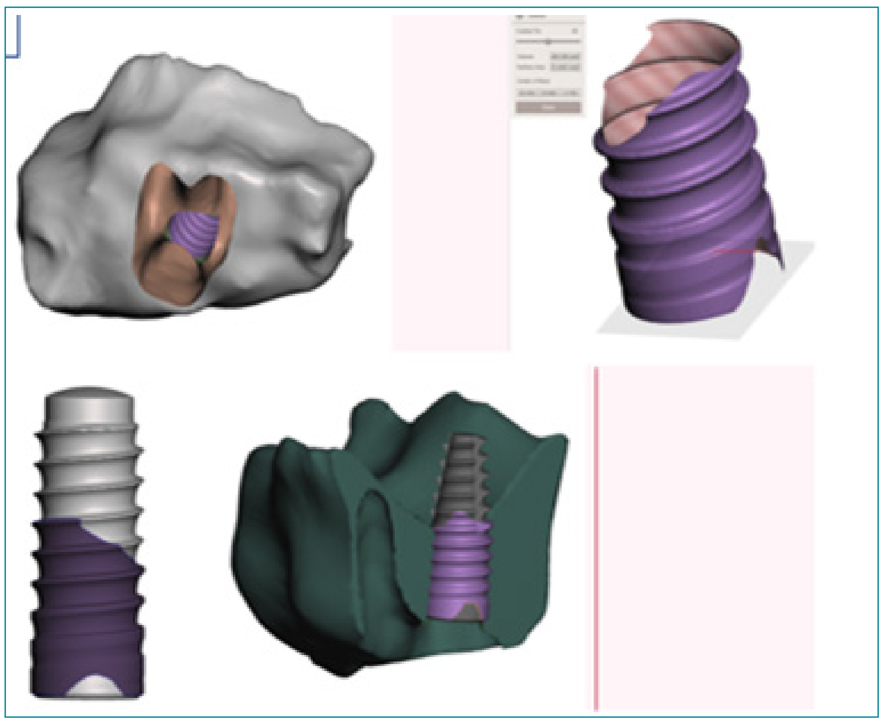

Figure 10. Socket model after second boolean operation + surface of implant in contact with bone in purple (with measurement in mm2).

Statistical analysis

The data was analyzed using IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated and presented as means (± standard deviations), and frequencies (percentages) for quantitative and qualitative variables respectively. The normality of the distribution of the quantitative variables (BIC parameters) was evaluated using the Shapiro-Wilk test, while the Levene's test was used to assess the homogeneity of variances. Paired-samples t tests were performed to compare the values of BIC parameters between straight and tapered implants within each type of vertical relationship between molar apices and sinus floor based on Zhang's classification and within each molar region (first/second), and independent Student's t tests were used to compare the values of BIC parameters for each implant's macrogeometry between first and second molar, and Zhang's types II and III. The significance level was set at 5% and all tests were two-sided.

Results

Twenty maxillary molars out of 210 were included in the study, from which ten were first molars. All included molars had divergent root anatomy, and only one had an adjacent extracted tooth. Regarding the vertical relationship between molar apices and the sinus floor according to Zhang's classification, 18 (90%) molars were classified as type II, and only two (10%) were classified as type III.

In addition, the results showed that for type II relationship based on Zhang's classification, the average pBIC surface was higher for straight implants (73.45 ± 28.94 mm^2) compared to tapered implants (68.02 ± 24.46 mm^2), with a significant difference between the two (p=0.015).

However, no significant difference in pBIC surface was found between straight and tapered implants for type III (p=0.228). Although type III molars showed greater pBIC values compared to type II molars for each implant's macrogeometry, these differences were not statistically significant (Table 1).

Regardless of the molar region and type of relationship with the maxillary sinus floor, pBIC surface mean was significantly higher for straight implant compared to the tapered one (p=0.008).

Table 2 presents a comparison of BIC percentage means between straight and tapered implants in relation to the molar type and type of vertical relationship with the sinus floor. It also shows the results of the comparisons between BIC% means of first and second molars for every implant macrogeometry, as well as the comparisons of BIC% between the two Zhang's types. Additionally, graphical representations are shown in Figures 18 and 19. The BIC% means did not differ significantly between straight (35.67 ± 13.33 %) and tapered implants (35.38 ± 12.13 %) (p=0.738), irrespective of the molar region or type of vertical relationship. Similarly, no statistically significant differences were observed in BIC% means between straight and tapered implants for each molar region and type of vertical relationship. Despite observing higher BIC% means for the first molar compared to the second, and for Zhang's type III compared to type II, for both implant macrogeometries, these differences did not reach statistical significance (Figures 11-14).

Table 1. Comparison of potential bone-to-implant contact surface (mm2) means based on implant macrogeometry, molar region, and type of vertical relationship between molar apices and the sinus floor as per Zhang's classification.

	Straight Implant pBIC surface (mm^2) Mean ± SD	**Tapered Implant pBIC surface (mm^2)** Mean ± SD	***p*-value**
Molar			
First (n=10)	78.17 ± 29.69	74.31 ±24.97	0.228
Second (n=10)	69.29 ± 26.04	62.46 ± 21.44	0.011*
***p*-value**	0.486	0.270	
Classification of Zhang			
Type II (n=18)	73.45 ± 28.94	68.02 ± 24.46	0.015*
Type III (n=2)	76.24 ± 13.42	71.67 ± 14.84	0.228
***p*-value**	0.896	0.841	
Total	73.73 ± 27.56	68.39 ± 23.45	0.008**

Table 2. Comparisons of bone-to-implant contact percentage (BIC %) means based on implant macrogeometry, molar region, and type of vertical relationship between molar apices and the sinus floor as per Zhang's classification.

	Straight Implant BIC% mean ± SD	**Tapered Implant BIC%** mean ± SD	***p*-value**
Molar			
First (n=10)	37.81 ± 14.36	38.45 ± 12.92	0.653
Second (n=10)	33.52 ± 12.60	32.32 ± 11.09	0.222
***p*-value**	0.486	0.270	
Classification of Zhang			
Type II (n=18)	35.53 ± 14.00	35.20 ± 12.66	0.720
Type III (n=2)	36.88 ± 6.49	37.08 ± 8.19	0.896
***p*-value**	0.896	0.841	
Total	35.67 ± 13.33	35.38 ± 12.13	0.738

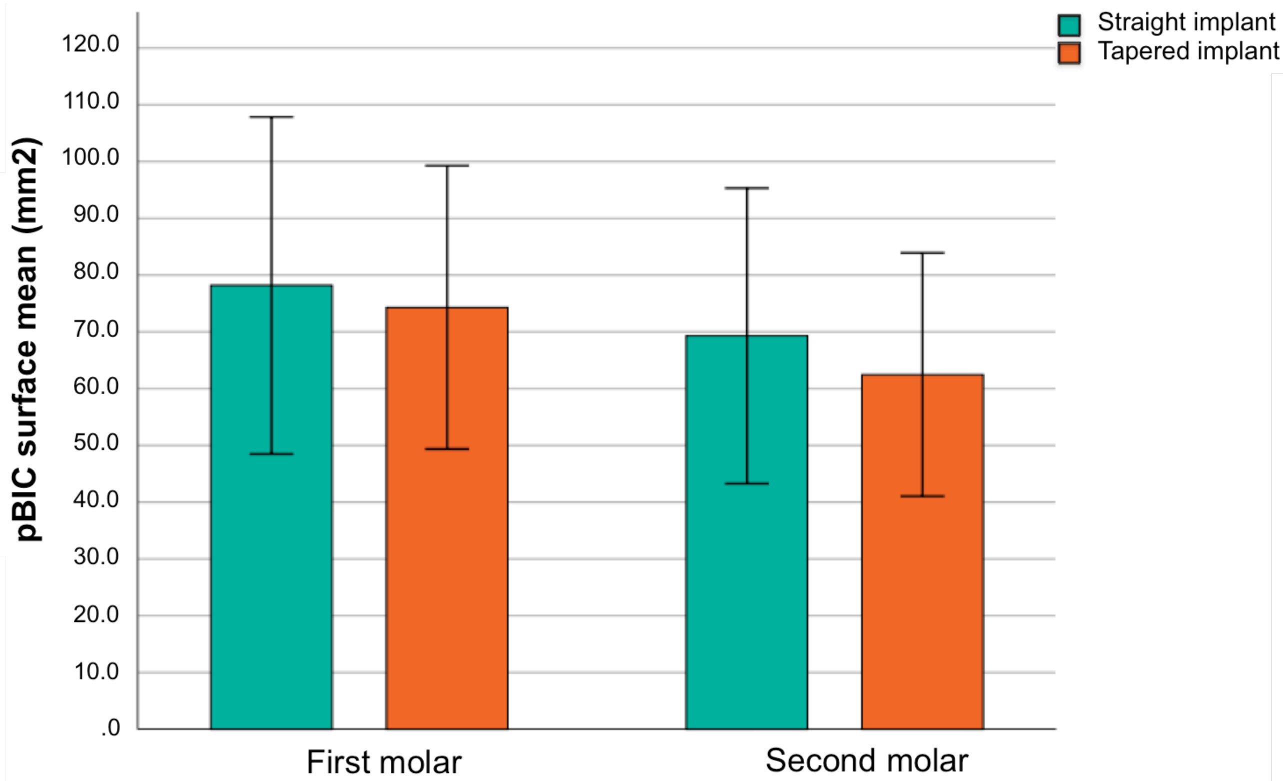

Figure11. Bar plots of the pBIC surface (mm2) according to implant's macrogeometry and molar region.

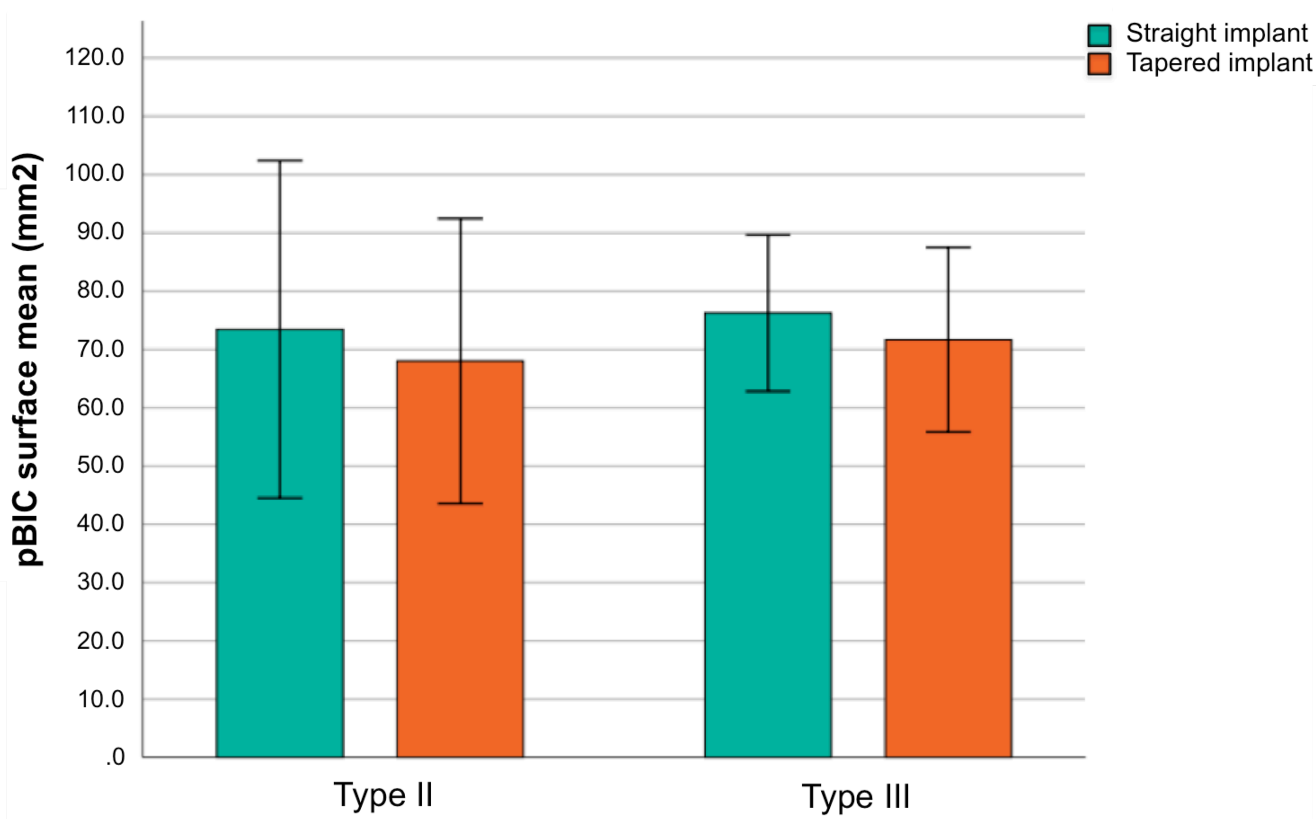

Figure 12. Bar plots of the pBIC surface (mm2) according to implant's macrogeometry and type of vertical relationship based on Zhang's classification.

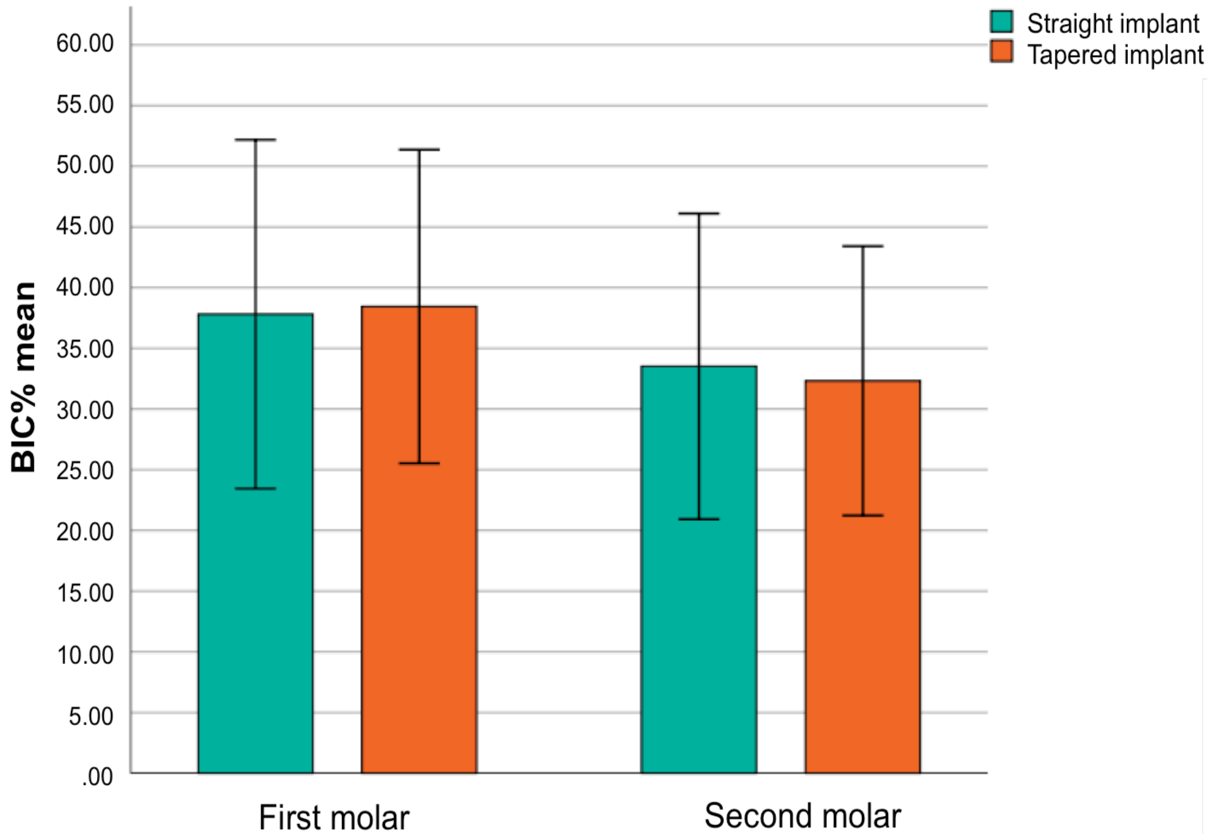

Figure 13. Bar plots of the BIC% according to implant's macrogeometry and molar region.

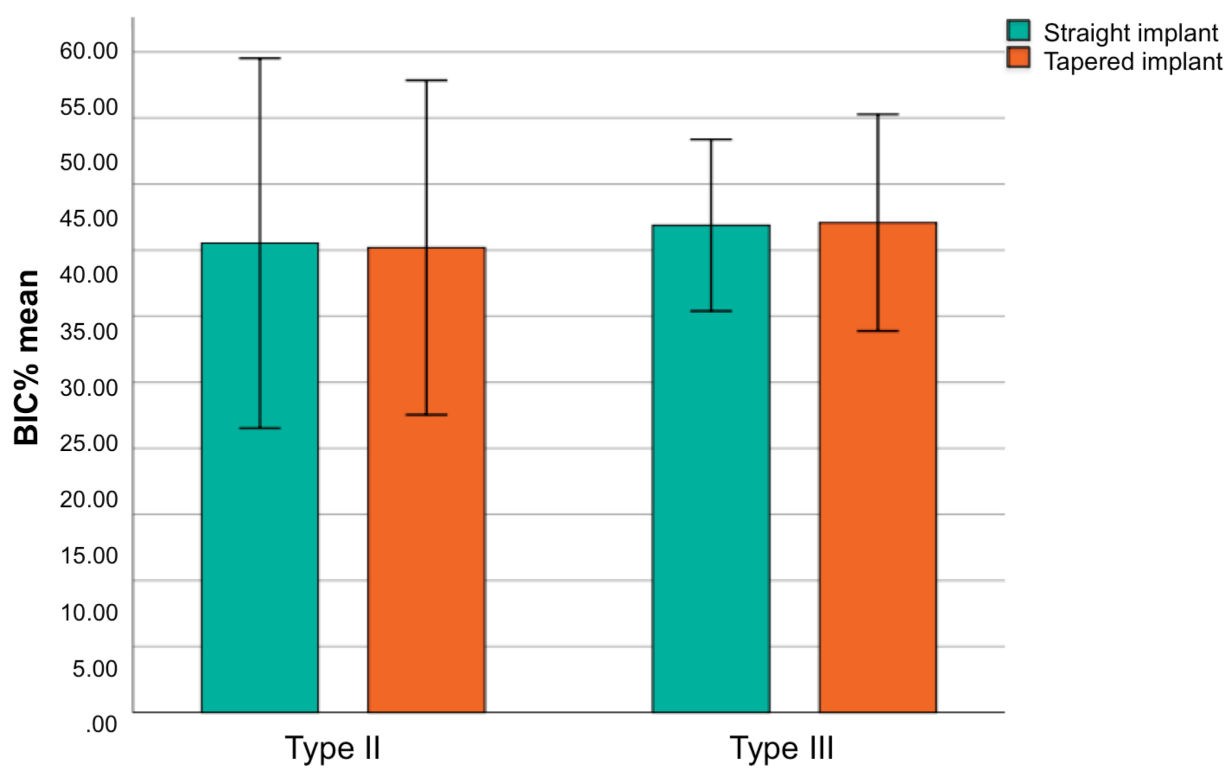

Figure 14. Bar plots of the pBIC surface (mm2) according to implant's macrogeometry and type of vertical relationship based on Zhang's classification.

Discussion

The study investigates the differences in potential bone to implant contact (pBIC) surface between straight and tapered dental implants placed in maxillary molars with different root anatomy and varying vertical relationships with the maxillary sinus floor. The results show that the mean pBIC surface for second molars was significantly higher for straight implants compared to tapered implants, but there was no significant difference for first molars. Furthermore, for type II relationship based on Zhang's classification, the average pBIC surface was higher for straight implants compared to tapered implants with a significant difference between the two. These findings are in line with previous studies that reported higher bone-to-implant contact and bone volume around straight implants compared to tapered ones, reflecting that straight implants may have advantages over tapered implants in terms of osseointegration and long-term stability. Shokri et al. (2021) conducted a systematic review and meta-analysis of 12 studies comparing BIC and bone volume around straight and tapered implants [10]. The study found that the pooled mean BIC value was significantly higher for straight implants (65.1%) compared to tapered implants (60.3%).

In a randomized controlled trial by Grandi et al. (2018), the mean BIC value was significantly higher for straight implants (64.5%) compared to tapered implants (57.3%) [11]. Similarly, Shibli et al. (2010) found in a histologic study in humans that straight implants had significantly higher mean BIC values (74.4%) and bone volume (45.7%) compared to tapered implants (62.4% and 35.8%, respectively) [12]. Lee et al. (2015) also found in a histomorphometric study in dogs that straight implants had significantly higher mean BIC values (63.7%) compared to tapered implants (47.8%) [13]. Additionally, Trisi et al. (2016) found in a histomorphometric study in dogs that straight implants had significantly higher mean BIC values (63.6%) and bone volume (44.3%) compared to tapered implants (54.2% and 35.6%, respectively) [14]. However, some studies found no significant difference between the two implant macrogeometries or reported a better outcome for tapered implants. For example, a systematic review and meta-analysis by Al-Khateeb et al. (2021) evaluated the implant survival rates and BIC values of straight and tapered implants in partially edentulous patients with a minimum follow-up of 12 months [15].

Similarly, a randomized controlled trial by Al-Thobity et al. (2019) compared the BIC values of straight and tapered implants in the posterior maxilla [16]. The study found that there was no significant difference in BIC values between the two implant types at 3- and 6-months post-implantation. However, a study by Shalabi et al. (2006) evaluated the BIC and biomechanical behavior of straight and tapered implants with different implant-abutment connections [17]. The study found that the tapered implants with internal connections had higher BIC values and better biomechanical behavior than straight implants with external connections. Another study by Sakka et al. (2012) compared the BIC values of straight and tapered implants in the posterior maxilla and mandible [18]. The authors found that the BIC values were significantly higher for tapered implants in both maxillary and mandibular posterior regions.

Moreover, the study suggests that the type of vertical relationship with the maxillary sinus floor may play a role in the potential bone to implant contact surface and may affect the choice of implant type. Previous studies have also reported that the vertical relationship with the maxillary sinus floor can affect implant success rates, as implants placed in close proximity to the sinus may lead to complications such as sinusitis or implant failure due to insufficient bone support. For example, Hwang and Lee (2012) conducted a retrospective study in humans to evaluate the influence of the vertical distance between implants and the maxillary sinus floor on implant survival rates. The study found that implants placed closer to the sinus floor had lower survival rates compared to those placed at a greater distance from the sinus floor. The authors concluded that the vertical distance between the implant and the maxillary sinus floor is an important factor in implant survival rates [19]. Also, Aghaloo et al. (2010) conducted a systematic review of the literature to evaluate the impact of sinus augmentation on implant survival rates. The review included 16 studies and found that the survival rates of implants placed in grafted sinuses were comparable to those placed in non-grafted sinuses. However, the authors noted that the success of the implant was dependent on the quality and quantity of the available bone, the type of grafting material used, and the surgical technique employed [20].

Overall, within the limitations of our study like the small sample size, the majority of the sample belonging to the same sinus classification and molar anatomy, the findings of this study emphasize the importance of considering the vertical relationship with the maxillary sinus floor when choosing implant type and assessing potential bone to implant contact surface. Moreover, our study is the first one to compare the radiological BIC on a presurgical scan in the different types of Zhang's recent classification of 2019, to check which one will be the most favorable for immediate implant placement with simultaneous sinus lift procedure in the upper molars interradicular bone. It uses a new digital three-dimensional (3 D) technique using CAD software in order to calculate the pBIC (potential bone to implant contact). However, more studies are needed to better understand the complex relationship between implant type, vertical relationship with the maxillary sinus floor, and long-term implant success with bigger sample size and more diversity regarding the molar anatomy and sinus classification.

Conclusion

The placement of immediate implants in fresh extraction sockets of molars can be challenging due to complications like lack of primary stability and sinus floor elevation. The success of this treatment depends on bone quality and quantity, and a new 3D digital technique using CAD software can help calculate potential bone-to-implant contact (pBIC) before surgery. Implant macrogeometry can play a role in achieving higher pBIC values, especially for second molars and type II relationship with the sinus floor where straight implants showed significantly more pBIC. However, more research is needed to fully understand the impact of implant type on success rates in maxillary molars with varying root anatomy and sinus floor relationship. Future research should aim to correlate 3D software analysis with clinical outcomes and incorporate the software into pre-operative surgical planning.

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