Three-Dimensional Volume Change of Grafted Bone in the Maxillary Sinus

Fabio Mazzocco, DDS, MS[1]/Diego Lops, DDS, PhD[2]/Luca Gobbato, DDS, MS[3]/
Alessandra Lolato, BMT[4]/Eugenio Romeo, DMD[5]/Massimo Del Fabbro, BSc, PhD[6]

Purpose: *The purpose of this study was to evaluate the three-dimensional radiographic changes of 100% anorganic bovine bone xenograft volume in a grafted maxillary sinus, based on a computerized analysis of cone-beam computed tomography (CBCT) scan.* ***Materials and Methods:*** *A maxillary sinus augmentation procedure done with a lateral approach using 100% anorganic bovine bone was performed in 20 patients. A CBCT scan of the grafted area was taken immediately after the procedure (T1) and 8 to 9 months later (T2). CBCT scan data were analyzed with image processing software to evaluate differences in the volume of grafted material between T1 and T2. Residual ridge height and width were also measured at T1.* ***Results:*** *The mean residual bone height and width at the implant sites was 4.40 ± 0.87 mm and 7.9 ± 2.22 mm, respectively. The mean graft volume was 1,432 ± 539 mm^3 and 1,287 ± 498 mm^3 at T1 and T2, respectively. A significant difference in graft volume was found between T1 and T2 data by paired* t *test (*P *= .01). The mean ratio between the volume at T2 and the volume at T1 was 0.90 ± 0.12, meaning a graft volume contraction of 10%.* ***Conclusion:*** *Within the limits of the present investigation, good stability of anorganic bovine bone graft volume up to 8 months after the grafting procedure was demonstrated. Three-dimensional computed tomographic volumetric assessment seems to be a promising approach to quantify long-term changes in the regenerated area.* INT J ORAL MAXILLOFAC IMPLANTS 29;2014:178–184. doi: 10.11607/jomi.3236

Key words: *bone graft, maxillary sinus, three-dimensional radiographic changes*

Augmentation procedures before dental implant placement are often required for the rehabilitation of the edentulous posterior maxilla in cases of enlarged maxillary sinus and reduced residual bone height. Bone grafting in the maxillary sinus was first introduced in the 1980s in order to provide a sufficient amount of bone for implant placement, and became widely accepted as a routine method to improve the amount of bone volume before implant placement.[1–5] Graft volume stability must be considered critical to the success of the procedure. In fact, due to repneumatization of the maxillary sinuses and resorption of the bone graft,[6] grafted areas may adapt considerably in shape and volume. Grafting techniques that initially only used autogenous bone showed similar results[7,8] when different bony substitutes were used, reducing the need for a second surgical site for harvesting the bone graft. The use of different bony substitutes as grafting materials has, however, introduced another variable in evaluating volume change.[9] Different radiographic techniques for assessment of the augmented bone volume have been described. Periapical or panoramic radiographs allow an estimation of the vertical dimension of grafts, but do not provide information about volume and three-dimensional (3D) changes.[10,11]

Cone-beam computed tomography (CBCT) seems to be a reliable method[12–14] to analyze bone volume by presenting the opportunity to perform not only linear measurements, but also 3D evaluations. The use of CBCT, due to its lower cost, smaller device size, reduced acquisition time, and lower radiation dose as compared to CT[12,15,16] is becoming more and more common in

[1]Resident, Department of Periodontology, University of Padua, Padua, Italy.
[2]Assistant, Department of Prosthodontics, Dental Clinic, School of Dentistry, University of Milan, Milan, Italy.
[3]Postgraduate Periodontology Faculty, Department of Oral Medicine, Infection and Immunity, Harvard School of Dental Medicine, Boston, Massachusetts, USA.
[4]PhD Student, Department of Biomedical, Surgical and Dental Sciences, University of Milan, Milan, Italy.
[5]Professor and Chairman, Department of Prosthodontics, Dental Clinic, School of Dentistry, University of Milan, Milan, Italy.
[6]Researcher, Department of Biomedical, Surgical and Dental Sciences, CRSO, IRCCS Galeazzi Orthopedic Institute, University of Milan, Milan, Italy.

Correspondence to: Dr Diego Lops, Department of Prosthodontics, Dental Clinic, School of Dentistry, University of Milan, Via Beldiletto 1/3 20142 Milano, Italy. Fax: 0250319040. Email: diego.lops@guest.unimi.it

oral-maxillofacial practice in multiple applications such as orthodontics,[17] implant dentistry,[14,18] endodontic surgery,[19] and periodontics.[20] Furthermore, its accuracy and precision for both linear measurements and 3D reconstructions has been demonstrated to be similar to that of CT,[14] as well as to micro-CT for dental research applications.[21] Therefore, CBCT can be a useful tool for diagnostics, planning, and follow-up evaluation of the dentomaxillofacial region.

Several computer-based software programs for elaboration of data from Digital Imaging and Communications in Medicine (DICOM) images are currently available. Previous studies on the estimation of volumetric changes of grafted maxillary sinus from CT scan in patients[22] and animals[23] have been reported, showing that this type of 3D evaluation may be a helpful predictive tool regarding graft prognosis. It could also help to decide the optimal time for implant placement as well as in the choice of the proper implant size. Based on two-dimensional evaluation, it has been reported that sinus grafts composed of 100% Bio-Oss tend to have minimal resorption over time.[24]

The purpose of this prospective single cohort preliminary study was to evaluate the 3D radiographic changes of 100% anorganic bovine bone graft volume in grafted maxillary sinus, based on a computerized analysis of CBCT scan.

MATERIALS AND METHODS

A prospective single cohort design was used to address the aim of this study. All patients were treated according to the principles of the Helsinki Declaration of 1975, as revised in 2000. The study was approved in 2009 by the Review Board of the Galeazzi Orthopedic Institute, University of Milan, Italy. All surgery and data acquisition in our study population took place between 2009 and 2011. Patients were included if the posterior region of the maxilla was edentulous and lacked sufficient bone for the placement of implants with a minimum length of 8 mm. Further inclusion criteria were: *(1)* ability to undergo surgical and restorative procedures (ASA-1 or ASA-2 according to the American Society of Anaesthesiologists classification), *(2)* older than 18 years of age, *(3)* absence of local inflammation, *(4)* absence of oral mucosal disease, *(5)* absence of sinus pathology, *(6)* adequate oral hygiene (full-mouth plaque score < 20%), and *(7)* availability to undergo CBCT examination soon after graft surgery and 8 months after the graft healing period, at the time scheduled for implant surgery as required by the study protocol. Patients scheduled for maxillary sinus augmentation and signing an informed consent form were consecutively included in the study.

Exclusion criteria were: *(1)* patients with systemic diseases (such as heart, coagulation, and leukocyte diseases or metabolic disorders), *(2)* history of radiation therapy in the head and neck region within 12 months prior to grafting phase, *(3)* current treatment with steroids, *(4)* neurological or psychiatric condition that could interfere with good oral hygiene, *(5)* immunocompromised status, including infection with human immunodeficiency virus, *(6)* smoking habit (more than 10 cigarettes/day), *(7)* drug or alcohol abuse, and *(8)* inadequate compliance.

The study group comprised 20 patients (7 women with a mean age of 47 years and 13 men with a mean age of 55 years) treated by a single operator (FM) in a single private dental clinic in Padova, Italy. A maxillary sinus augmentation procedure with a lateral approach was planned for all patients. No patients displayed symptoms of sinus or intraoral diseases, as confirmed by clinical examination and radiographic assessment immediately prior to maxillary sinus floor augmentation. The augmented maxillary sinus of each patient was examined radiographically by taking a CBCT scan within the first hour after maxillary sinus lift (T1) and after a scheduled interval of 8 to 9 months (T2). All scans were made in the same dental clinic using the same CBCT device (Kodak 9000, Kodak Dental System).

Surgical Procedure

A modified Caldwell-Luc sinus elevation procedure was performed as described by Kent and Block[2]: The posterior part of the maxilla was exposed via a crestal incision and a mucoperiosteal flap was elevated. An osteotomy was performed at the lateral aspect of the sinus wall using piezoelectric instrumentation (Mectron). The mucosa was carefully lifted using appropriate instruments. If any perforation of the sinus membrane occurred, the lesion was repaired using a bioresorbable collagen membrane (Bio-Gide, Geistlich). Anorganic bovine bone (Bio-Oss, 0.25 to 1 mm granules; Geistlich) was inserted in the space between the floor of the sinus and the sinus membrane. When the residual amount of bone was more than 3 mm, simultaneous placement of dental implants (4 mm NT Osseotite 3i) was attempted. If during implant placement, the insertion torque did not reach 20 Ncm, implants were reverse torqued and placement was postponed until after the healing period of 9 months.

The lateral window was closed using a bioresorbable collagen membrane (Bio-Gide). The full-thickness flap was then repositioned and sutured. Immediately after the surgical procedure (T1), a CBCT of the grafted area was taken. After a healing period of 8 to 9 months (T2), a scan of the area was taken. All patients received fixed partial dental prostheses based on cast gold-alloy frameworks.

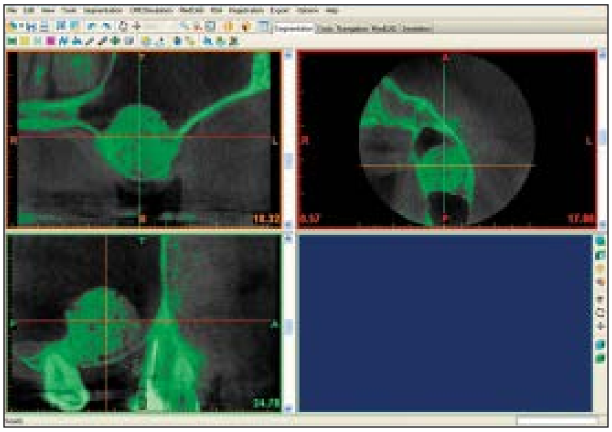

Fig 1 The modeling software's first segmentation mask. The displayed green mask produced the best representation of the bone graft by adjusting the optical density threshold value. On the screen, the images are displayed in three views: *(upper right)* the axial view, *(upper left)* the coronal view, and *(bottom left)* the sagittal view.

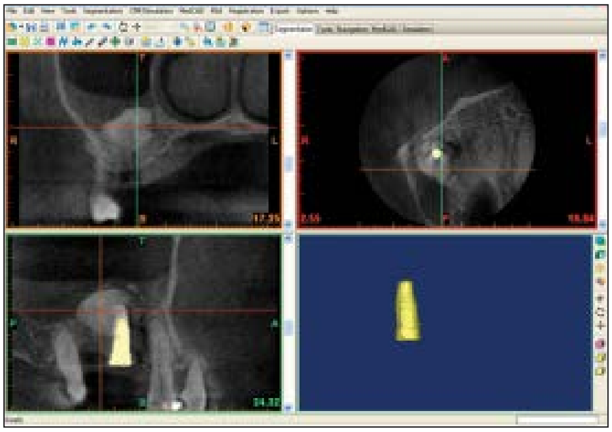

Fig 2 When the implant was present, a distinct mask was created to distinguish the implant from the other structures, based on the implant's different optical density. The images are displayed in three views as specified in Fig 1. In addition, the 3D reconstruction of the implant calculated on the basis of this mask is shown on the bottom right.

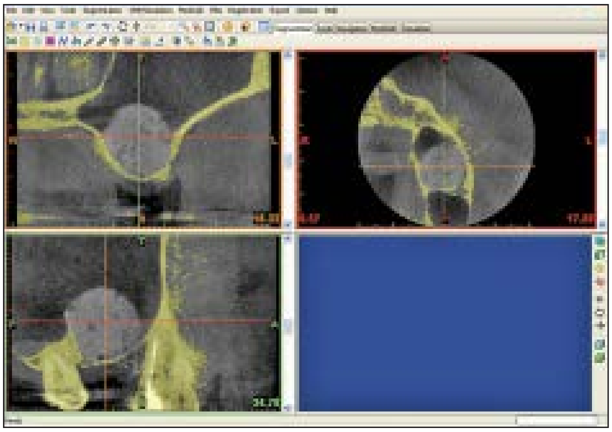

Fig 3 After the first segmentation mask step, the sinus bone graft region was deselected from each slice of each view on the yellow mask. At the end of this passage, the yellow mask is characterized by the presence of the uncolored bone graft region.

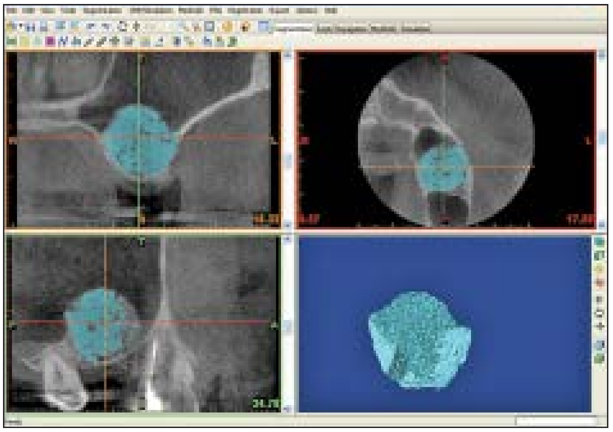

Fig 4 The bone graft selecting blue mask is created through the software's editing tool, working on the green and the yellow mask. In addition to the three views defined in Fig 1, the 3D reconstruction of the bone graft is shown on the bottom right.

Volumetric Analysis

Upper jaw CBCT scan data were analyzed using image processing software dedicated to 3D reconstruction of body components (Mimics version 12.1, Materialise). Sinus bone grafts were reconstructed in 3D to evaluate the volume at T1 and T2. Finally, the ratio of volumes (T2/T1) was calculated for each patient, in order to normalize volume changes.

Digital reconstruction was accomplished by importing the DICOM data set into the modeling software. The segmentation process was performed to select only the bone graft and was carried out manually by establishing a first optical density threshold value that produced the best representation of the graft (Fig 1). When an implant was present, a second threshold was established to distinguish the bone graft reconstruction from the implant itself (Fig 2).

The segmentation mask is a collection of pixels that constitutes the object of interest. Once the segmentation mask was created, the 3D reconstruction was achieved through a 3D calculating tool. Several segmentation masks were created, with each one displayed in a distinctive color, in order to select different parts of the images. After the segmentation mask step, the 3D model was constructed and the graft volume evaluation was performed (Figs 3 to 4). In the presence of one or more implants, a separate 3D object representing the implant(s) was also created (Fig 2).

Once the images were loaded, the orientation parameters were set up for a correct display. On the screen, the images were displayed in three views as shown in Fig 5. The next step consisted of adjusting the contrast, a process called windowing. Since different parts have different intensity depending on the optical density of the bone, the contrast adjustment allows a better visualization of the different structures.

The following segmentation masks were then created: a green mask representing the maxilla along with the bone graft, teeth, and implants when inserted; the soft yellow mask representing the maxilla not including the bone graft; the blue mask representing the bone graft alone; and the bright mask representing the inserted implants. A threshold value was set up to create the segmentation mask for the selection of the graft region; only those pixels with a value higher than or equal to the threshold value were contained. A second threshold was established to select only the implants.

The region-growing tool made possible the removal of the floating pixels (pixels with the same optical density of the graft but isolated and separate from it) from the segmentation mask. The editing procedures were as follows: Two identical segmentation masks were created, with the bone and graft structures highlighted in green and yellow, respectively. An editing tool consisting of a circle or square with adjustable size was used, and this tool was used in an erase mode to remove floating pixels from the active mask. Hence, the sinus bone graft region was deselected from the yellow mask and isolated. This step was done for each slice separately and on the three views: axial, coronal and sagittal. The yellow segmentation mask was then characterized by the absence of the colored bone graft. Next, a segmentation mask selecting only the sinus bone graft was obtained by means of a software tool (the Boolean procedure), allowing the subtraction of the yellow mask from the graft from the green mask showing the entire image.

Therefore, the mask that selects only the sinus bone graft was used to develop the 3D object. In case of implants insertion, a 3D object of the implants was also created. Once the 3D image was loaded, the model could be rotated and it was also possible to select different views: top, bottom, front, and back; and left, right, and isometric views. After the 3D object was developed, a 3D representation of the sinus bone graft was visualized at the bottom right of the screen. All information regarding the volume (in mm^3) of the 3D object was displayed.

The same software was also used to measure residual ridge height and width at the intended implant sites or adjacent to implants, using the CBCT scan taken at T1. Ridge width was measured at a level corresponding to mid-height. A single value of ridge height and width was considered for each patient.

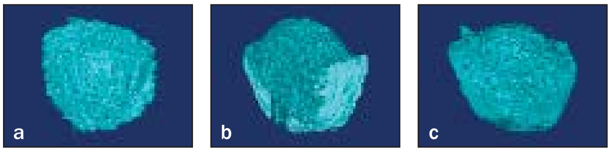

Fig 5 The bone graft 3D reconstruction shown in a higher resolution: *(a)* top view, *(b)* front view, and *(c)* isometric view.

Statistical Analysis

These procedures were performed for all CBCT data sets taken at T1 and T2 for all patients. In order to evaluate the significance of changes, a paired Student *t* test was used to compare the graft volume measurements at T1 vs T2 for both the distinct subgroups (simultaneous and delayed implant placement) and for the overall data. An unpaired Student *t* test was used to compare data from the two subgroups at T1 and T2. The Shapiro-Wilk test was used to assess normality of the distributions. Since the initial graft volume for different patients could differ significantly, depending on the anatomy and the individual needs of the patients, and such variability could affect the results of the comparative test, normalized values were calculated by dividing the volume at T2 by the volume at T1. Normalization also allows an easier interpretation of the data trend. Values lower than 1 indicate graft resorption. Normalized data of the two subgroups were compared by using the unpaired Student *t* test. The significance level was set at $P = .05$.

RESULTS

Two out of 20 treated patients were not included in the analysis because the CBCT at follow-up (T2) was not of adequate quality for the computer-based evaluation. Hence, the 3D reconstruction analysis was conducted on 18 patients who were treated for sinus lift augmentation. In eight cases, implants were placed simultaneously to the sinus grafting procedure. The mean residual bone height and thickness at sites for the implant placements were 4.40 ± 0.87 mm and 7.92 ± 2.22 mm, respectively.

Delayed Implant Placement Subgroup

In cases of delayed implant placement (n = 10), the mean graft volume was 1570 ± 717 mm^3 (range, 706 to 2,497 mm^3) and 1,441 ± 547 mm^3 (range, 525 to 2,592 mm^3) at T1 and T2, respectively. No significant difference in absolute values was found between T1 and T2 data by paired Student *t* test ($P = .13$). In this subgroup, an increase of the graft volume was recorded in two cases. The mean ratio between the volume at T2 and the volume at T1 was 0.93 ± 0.14. The mean graft volume contraction after 8 months of healing amounted to 7% (range from –29% to 18%).

Simultaneous Implant Placement Subgroup

In the 8 cases where one or two implants were present (n = 8), the mean graft volume was 1,259 ± 438 mm^3 (range 501 to 1,672 mm^3) and 1,093 ± 376 mm^3 (range 446 to 1,482 mm^3) at T1 and T2, respectively. The volume of the implants was not considered. Borderline significant difference was found between T1 and T2 data by paired Student *t* test ($P = .05$). The mean ratio between the volume at T2 and the volume at T1 was 0.87 ± 0.07. The mean graft volume contraction after 8 months of healing amounted to 13% (range from –24% to –3%). No significant difference between graft volume estimation in cases of delayed and simultaneous implant placement was found by unpaired *t* test at T1 ($P = .23$) and T2 ($P = .10$).

There was no significant difference in volume ratio (T2/T1) between cases of delayed and simultaneous implant placement with the unpaired *t* test ($P = .35$).

Overall Data

For the sample of 18 patients the mean graft volume was 1,432 ± 539 mm^3 and 1,287 ± 498 mm^3 at T1 and T2, respectively. A significant difference was found between T1 and T2 data by paired *t* test ($P = .01$). Overall, the mean ratio between volume at T2 and volume at T1 was 0.90 ± 0.12, meaning an average 9.8% contraction of the bone grafting volume. Using the Shapiro-Wilk test, all groups and subgroups of data proved to be significantly drawn from a normal distribution.

Complications

Perforation of the sinus membrane occurred in four cases and no implants were lost at the time of prosthetic loading. No perforation was wide enough to cause the abortion of the procedure. No further surgical complications occurred, and no other adverse events were reported during the follow-up period. However, during the healing period, four patients reported an important reduction of the mastication function and comfort while wearing a removable temporary prosthesis.

DISCUSSION

In the present prospective single cohort preliminary study, CBCT was used to evaluate quantitative analysis of bone.[25] The use of CBCT radiographic technology allowed a very precise measurement of the bone grafting volume[19] and consequently an accurate evaluation of the 3D variation of the grafting material during the healing period.

Regarding the bone grafting materials, it has been observed that a 100% autogenous bone graft tends to resorb considerably over time, especially if the graft is harvested from the iliac region.[26,27] Many bone substitutes have been developed and tested during the last 20 years, in order to reduce morbidity of the sinus augmentation procedure and possibly avoid the need for a second surgical site for bone harvesting. Among these materials, the most popular is anorganic bovine bone particulate, whose properties have been demonstrated to provide excellent support and duration. In fact, several histologic long-term studies have shown that these anorganic particles may be present even more than 10 years after the grafting procedure.[28] This confirms the view that a complete substitution of the graft material by newly formed bone is not necessary for the success of the augmentation procedure. Instead, if graft particles become well-integrated and do not cause any damage or adverse reaction, they can remain in place and maintain their support function.

Several studies suggested that resorption of grafts composed of anorganic bovine bone alone or mixed with autogenous bone is very slow, and minimal changes over time have been reported using two-dimensional radiographic techniques.[29–31] Nevertheless, there is a lack of data on the 3D evaluation of anorganic bovine bone volume changes after the healing phase.

An average contraction of 26% of the initial volume with a mean decrease of 0.74 cm^3 was seen when comparing maxillary CT scans taken within 2 weeks after augmentation and after a minimum postsurgical period of 6 months, as reported by Kirmeier et al[9] in 2007. However, the overall decrease was rather inconsistent with a minimum of 0.4% and a maximum of 54%. According to the authors, the reasons for this phenomenon were probably correlated with the different stability and resorptive patterns of the different grafting materials that were used in the study. Some patients were treated with autogenous bone harvested from tibia or iliac crest, while other patients were treated with a combination of autogenous bone and bone substitute and some others with bone substitute alone. The results of the study by Kirmeier and colleagues[9] are similar to those of several authors who used autogenous bone or a combination of autogenous bone with different bone substitutes: Wanschitz et al[32] reported an average volume loss of 13.9% about 6 months postoperatively using autogenous bone in combination with a bone substitute (phycogenic hydroxyapatite). Similarly, Smolka et al[33] used 100% calvarial bone for alveolar ridge augmentation and showed a mean volumetric reduction of 16% after an observation period of 6 months, and 19% after 12 months (on a reduced sample size).

In the present study, the results were more consistent, ranging from 13% to 7% of graft volume change in cases with and without implants, respectively; the reason for this may be due to the investigation of only one grafting material that is characterized by a very slow resorption pattern.

In the subgroup of delayed implant placement, two cases of increased graft volume after the healing period were found. Although this may appear unusual, indeed the two cases had a peculiar anatomical situation that could make a precise estimation of the boundaries between the graft and the native bone difficult, especially at the 8-month follow-up. At that time, the newly formed bone at the graft periphery was almost indistinguishable from the surrounding native bone, and it is possible that the actual volume size was overestimated. Furthermore, in these cases rather large spaces were present at T1 within the graft that, due to the peculiar anatomy, might not have been compacted well. Such spaces were no longer present at T2. We may assume that at T1 these spaces were filled with coagulum and that after 8 months a progressive substitution with newly formed bone occurred, causing an actual larger estimation of the bone graft volume than at baseline. The authors decided not to leave out these two cases since they minimally affected the overall trends observed in the present study.

A reduction of the graft during the healing phase is to be expected on the basis of previous reports.[9,32,33] The grafted area apical to the sinus floor and beneath the sinus membrane normally undergoes remodeling and shrinking, with the extent depending on the osteoconductive properties of the graft material and on the degree of vascularization and mineralization.[34] In the present study, the difference in the estimated graft volume between T1 and T2 was statistically significant and amounted to 9.8% of the baseline volume. While such a contraction is not clinically relevant at the observed stage, it would be interesting to perform an analog evaluation after a longer follow-up period to assess the long-term graft volume change.

CONCLUSION

Within the limits of the present investigation, good stability in bone volume after the grafting procedure using anorganic bovine bone was demonstrated. Three-dimensional computed tomographic volumetric assessment seems to be a promising approach to quantifying long-term changes in the regenerated area.

Further prospective studies are needed to investigate the volumetric changes of this bone substitute over a longer period of time to confirm the long-term bone stability and appropriate implant function.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

REFERENCES

1. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg 1980;38:613–616.
2. Kent JN, Block MS. Simultaneous maxillary sinus floor bone grafting and placement of hydroxylapatite-coated implants. J Oral Maxillofac Surg 1989;47:238–242.
3. Jensen J, Simonsen EK, Sindet-Pedersen S. Reconstruction of the severely resorbed maxilla with bone grafting and osseointegrated implants: A preliminary report. J Oral Maxillofac Surg 1990;48:27–32.
4. Olson JW, Dent CD, Morris HF, Ochi S. Long-term assessment (5 to 71 months) of endosseous dental implants placed in the augmented maxillary sinus. Ann Periodontol 2000;5:152–156.
5. Geurs NC, Wang IC, Shulman LB, Jeffcoat MK. Retrospective radiographic analysis of sinus graft and implant placement procedures from the Academy of Osseointegration Consensus Conference on Sinus Grafts. Int J Periodontics Restorative Dent 2001;21:517–523.
6. Araújo MG, Sonohara M, Hayacibara R, Cardaropoli G, Lindhe J. Lateral ridge augmentation by the use of grafts comprised of autologous bone or a biomaterial. An experiment in the dog. J Clin Periodontol 2002;29:1122–1131.
7. Tong DC, Rioux K, Drangsholt M, Beirne OR. A review of survival rates for implants placed in grafted maxillary sinuses using meta-analysis. Int J Oral Maxillofac Implants 1998;13:175–182.
8. Del Fabbro M, Testori T, Francetti L, Weinstein R. Systematic review of survival rates for implants placed in the grafted maxillary sinus. Int J Periodontics Restorative Dent 2004;24:565–577.
9. Kirmeier R, Payer M, Wehrschuetz M, Jakse N, Platzer S, Lorenzoni M. Evaluation of three-dimensional changes after sinus floor augmentation with different grafting materials. Clin Oral Implants Res 2008;19:366–372.
10. Fredholm U, Bolin A, Andersson L. Preimplant radiographic assessment of available maxillary bone support. Comparison of tomographic and panoramic technique. Swed Dent J 1993;17:103–109.
11. Reddy MS, Mayfield-Donahoo T, Vanderven FJ, Jeffcoat MK. A comparison of the diagnostic advantages of panoramic radiography and computed tomography scanning for placement of root form dental implants. Clin Oral Implants Res 1994;5:229–238.
12. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc 2006;72:75–80.
13. Veyre-Goulet S, Fortin T, Thierry A. Accuracy of linear measurement provided by cone beam computed tomography to assess bone quantity in the posterior maxilla: A human cadaver study. Clin Implant Dent Relat Res 2008;10:226–230.
14. Fatemitabar SA, Nikgoo A. Multichannel computed tomography versus cone-beam computed tomography: linear accuracy of in vitro measurements of the maxilla for implant placement. Int J Oral Maxillofac Implants 2010;25:499–505.
15. Ziegler CM, Woertche R, Brief J, Hassfeld S. Clinical indications for digital volume tomography in oral and maxillofacial surgery. Dentomaxillofac Radiol 2002;31:126–130.
16. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol 2004;33:291–294.
17. Kapila S, Conley RS, Harrell WE Jr. The current status of cone beam computed tomography imaging in orthodontics. Dentomaxillofac Radiol 2011;40:24–34.
18. Ritter L, Neugebauer J, Mischkowski RA, et al. Evaluation of the course of the inferior alveolar nerve in the mental foramen by cone beam computed tomography. Int J Oral Maxillofac Implants 2012;27:1014–1021.
19. Bornstein MM, Lauber R, Sendi P, von Arx T. Comparison of periapical radiography and limited cone-beam computed tomography in mandibular molars for analysis of anatomical landmarks before apical surgery. J Endod 2011;37:151–157.
20. Kehl M, Swierkot K, Mengel R. Three-dimensional measurement of bone loss at implants in patients with periodontal disease. J Periodontol 2011;82:689–699.
21. Maret D, Molinier F, Braga J, et al. Accuracy of 3D reconstructions based on cone beam computed tomography. J Dent Res 2010;89:1465–1469.

22. Sbordone C, Sbordone L, Toti P, Martuscelli R, Califano L, Guidetti F. Volume changes of grafted autogenous bone in sinus augmentation procedure. J Oral Maxillofac Surg 2011;69:1633–1641.
23. Jensen T, Schou S, Svendsen PA, et al. Volumetric changes of the graft after maxillary sinus floor augmentation with Bio-Oss and autogenous bone in different ratios: A radiographic study in minipigs. Clin Oral Implants Res 2012;23:902–910.
24. Ruoff H, Terheyden H. Retrospective radiographic investigation of the long-term stability of xenografts (Geistlich Bio-Oss) in the sinus. J Dent Implantol 2009;25:160–169.
25. Smolka W, Eggensperger N, Carollo V, Ozdoba C, Iizuka T. Changes in the volume and density of calvarial split bone grafts after alveolar ridge augmentation. Clin Oral Implants Res 2006;17:149–155.
26. Johansson B, Grepe A, Wannfors K, Aberg P. CT-scan in assessing volumes of bone grafts to the heavily resorbed maxilla. J Craniomaxillofac Surg 1998;26(suppl 1):85.
27. Johansson B, Grepe A, Wannfors K, Hirsch JM. A clinical study of changes in the volume of bone grafts in the atrophic maxilla. Dentomaxillofac Radiol 2001;30:157–161.
28. Iezzi G, Degidi M, Scarano A, Petrone G, Piattelli A. Anorganic bone matrix retrieved 14 years after a sinus augmentation procedure: A histologic and histomorphometric evaluation. J Periodontol 2007;78: 2057–2061.
29. Hallman M, Hedin M, Sennerby L, Lundgren S. A prospective 1-year clinical and radiographic study of implants placed after maxillary sinus floor augmentation with bovine hydroxyapatite and autogenous bone. J Oral Maxillofac Surg 2002;60:277–284.
30. Kim YK, Yun PY, Kim SG, Kim BS, Ong JL. Evaluation of sinus bone resorption and marginal bone loss after sinus bone grafting and implant placement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107:e21–e28.
31. Galindo-Moreno P, Hernández-Cortés P, Mesa F, et al. Slow resorption of anorganic bovine bone by osteoclasts in maxillary sinus augmentation. Clin Implant Dent Relat Res 2012 Feb 29 [epub ahead of print]
32. Wanschitz F, Figl M, Wagner A, Rolf E. Measurement of volume changes after sinus floor augmentation with a phycogenic hydroxyapatite. Int J Oral Maxillofac Implants 2006;21:433–438.
33. Smolka W, Bosshardt DD, Mericske-Stern R, Iizuka T. Reconstruction of the severely atrophic mandible using calvarial split bone grafts for implant-supported oral rehabilitation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:35–42.
34. Brägger U, Gerber C, Joss A, et al. Patterns of tissue remodeling after placement of ITI dental implants using an osteotome technique: A longitudinal radiographic case cohort study. Clin Oral Implants Res 2004;15:158–166.