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Evaluation of three-dimensional contraction of the volume of grafts after staged augmentation of the sinus floor, and an analysis of influential factors

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Abstract

Our aim was to evaluate the volume by which grafts contract after augmentation of the sinuses by three-dimensional analysis on cone-beam computed tomographs (CT), and to investigate the factors that influence the outcomes. The sinus floor was augmented with deproteinised bovine bone mineral in 58 patients with 123 edentulous sites related to 67 sinuses. The outcomes of augmentation were analysed by both linear and volumetric measurements on cone-beam CT images taken immediately after operation and six months later. Mathematical models were established to investigate the influence of anatomical characteristics of the sinuses and patient-related factors on contraction of the volume of the grafts. The mean reduction in the height of the grafts on site-based analysis was 17.8% after six months, and the contraction in volume on sinus-based analysis was 22.7 %. Of the edentulous sites 20/123 (16%) could not have implants 10 mm long inserted at the second stage operation because of insufficient bony height. Linear regression indicated that the type of edentulism (single or multiple teeth lost) was significantly associated with contraction in the volume of the grafts ($p = 0.006$). Mixed model regression showed that the reduction in the height of the grafts was significantly influenced by the width of the sinus floor and the angle between the lateral and the medial wall of sinus ($p = 0.001$, $p = 0.000$). The reduction in height of the grafts and contraction in volume on linear and volumetric measurements six months after augmentation were roughly 18% and 22%, respectively. A wide sinus, large lateromedial angle, and loss of multiple teeth under the same sinus strongly predict that large amount of grafts will resorb. The anatomy of the sinus and patients' characteristics should be taken into consideration before treatment.

Keywords: sinus floor elevation; bone augmentation; sinus anatomy; cone-beam computed tomography

Introduction

The posterior maxillary region is often a difficult place for clinicians to place dental implants, because of severe atrophy of the alveolar bone. Augmentation of the sinus floor by the lateral or transalveolar approaches has been developed to solve this problem.[1–3] Although plenty of studies have described predictable outcomes with the transalveolar technique,[4,5] the lateral window approach is still a preferred option because it gives direct vision of the sinus cavity and better control of the grafts.

However, the resorption of grafts and contraction of their volume postoperatively remain the major concerns about

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this technique. The rate of contraction reported elsewhere ranges from 20%–50% for both autogenous bone and bone substitute.[6–11] In some cases, the volume of bone after staged augmentation of the sinus floor is still not enough for proper placement of implants.[12] Previous studies have clearly indicated that contraction of the volume affects the positioning of the implants in two-stage lateral augmentation of the sinus floor and could result in future loss of implants.[7]

Augmentation of the sinus floor remains a complicated and expensive treatment, and both patient and surgeon want well-controlled use of bone or bone substitute during the procedure to satisfy the requirement for an adequate volume of bone for second-stage placement of implants.

Because sinus augmentation is an anatomy-dependent procedure,[13] the anatomical characteristics of the maxillary sinus and surrounding structures may have crucial roles in the contraction of grafts. Avila et al[14] investigated the influence of the buccopalatal distance on the outcome, and concluded that formation of vital bone at the endosinus tract is inversely proportional to the width of the sinus. However, we know of few if any studies that have focussed on the potential predictive value of anatomical variables on contraction of the volume of the grafts after staged augmentation.

Our aims were to evaluate the 3-dimensional contraction of grafts of staged augmentation of the lateral sinus floor on cone-beam computed tomography (CT), and to investigate the influence of anatomical variables in the sinuses, and patients' characteristics, on the outcome of augmentation, so that we could predict the requirements for substitute bone preoperatively in clinical practice.

Material and methods

Design of study

A prospective cohort design was used, and the study and clinical procedures were in accordance with the Helsinki Declaration, 2008 revision. The protocol was approved by the Ethics Committee of the Stomatology Hospital, School of Medicine, Zhejiang University, China. All patients gave their informed consent.

Selection of patients

Consecutive patients were selected who were treated at the Department of Oral Implantology, Stomatology Hospital, School of Medicine, Zhejiang University, Hangzhou, China, from January 2015 to January 2017. The inclusion criteria were: age 18 years or over, partial edentulism in the maxillary posterior region for at least three months, residual bone height 5 mm or less, sufficient width of bone in the edentulous region, healthy maxillary sinuses judged from radiographic and clinical examination, systemic and local conditions suitable for placement of implants and augmentation of the sinus floor, willingness to provide informed consent, and capable of compliance with the study protocol.

Exclusion criteria were: uncontrolled diabetes mellitus or other systemic disorders, uncontrolled periodontal conditions, endodontic lesions or other oral disorders, heavy smoking (10 cigarettes/day or more), acute or chronic sinus conditions, and previous installation of implants or bone grafting at the surgical site.

Treatment procedures

The two-stage augmentation technique was done under local anaesthesia in each case, and a standard, previously-described procedure was used.[15] The sinus membrane was raised, and deproteinised bovine bone substitute (DBBM, Bio-Oss®, Geistlich Pharma AG,) was grafted into the raised area. The amount of bone substitute grafted was governed by the surgeons' assessment of the membranous resistance. An absorbable collagen membrane (Bio-Gide®, Geistlich Pharma AG,) was used to cover the lateral window. Any patient with perforation of the sinus membrane was excluded from this study.

All patients returned for implants to be placed six months after the first stage of the operation. It was planned to put implants 10 mm long into the augmented area. If there was still insufficient bone for the designed implant, a short dental implant was used, or the sinus floor was raised with an osteotome without grafting. Oral panoramic radiographs or cone-beam CT images were taken after the implant had been put in place. Cone-beam CT images were taken on a NewTom 3 G cone-beam CT station (QR srl, Verona) at three time points: T0 – before operation, T1 – within one week after operation, and T2 – after a healing interval of six months.

Outcome measures

Linear measurements were made on a software program (NNT NewTom version 4.6, QR srl, Verona). The dimensions and related anatomical characteristics of the sinus were evaluated on cone-beam CT taken before augmentation of the sinus (T0) as follows (Fig. 1): (1) residual bone height, (2) height of sinus cavity, (3) width of sinus floor, (4) width of sinus cavity 12 mm above the alveolar crest, (5) thickness of sinus membrane, and (6) angle between lateral and medial sinus walls (Angle A).

The postoperative cone-beam CT images (at T1 and T2) were analysed to assess the reduction in the height of the graft by linear measurements. The height of available bone and the thickness of the sinus membrane after augmentation was also measured (Fig. 2). Differences in the height of available bone between T1 and T2 were defined as reduction in the height of bone grafts, and were expressed as percentages. Whether implants 10 mm long could be placed without any other augmentation during the second stage of the procedure

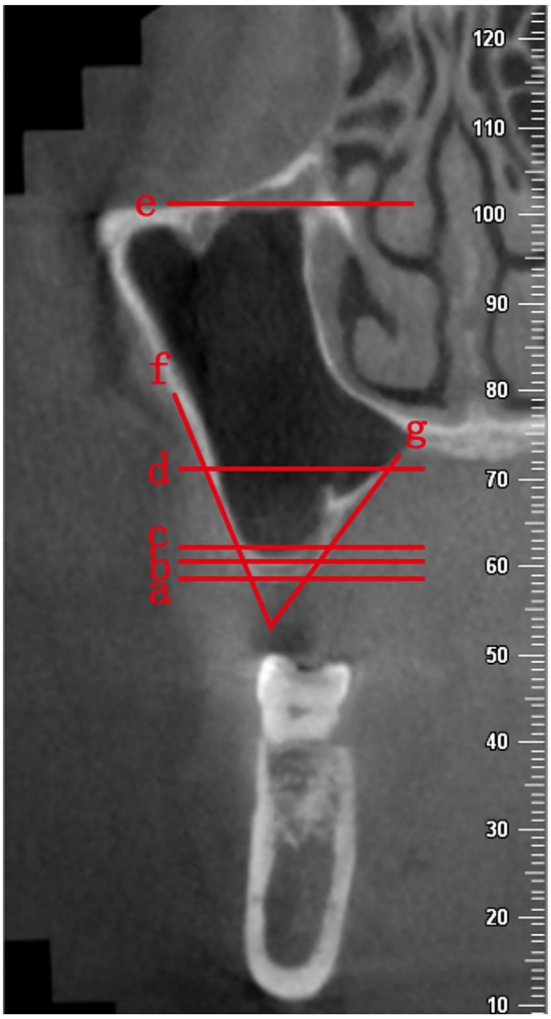

Fig. 1. Anatomical characteristics of the sinus cavity evaluated by linear measurements on NNT software at T0. residual bone height = vertical distance between lines a and b; height of sinus cavity = vertical distance between lines b and e; thickness of the sinus membrane = vertical distance between lines b and c; width of sinus floor = horizontal distance between the intersection of line c/f, and c/g; horizontal distance between the intersection of lines d/f, and d/g = width of sinus floor measured 12 mm above the alveolar crest; and Angle A = angle between lines f and g (lateral and medial sinus wall).

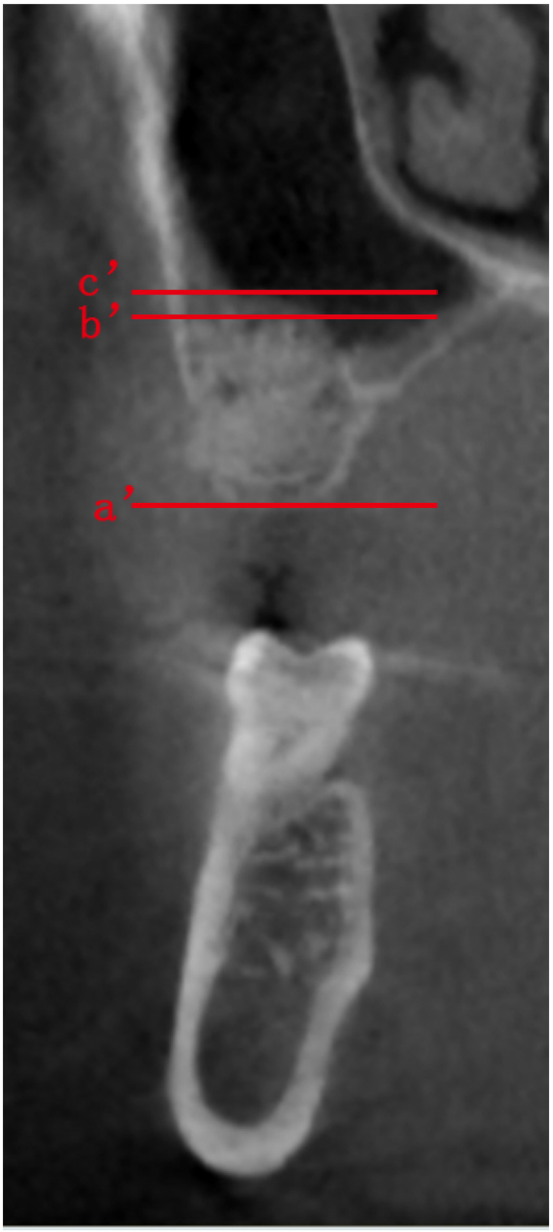

Fig. 2. The graft height reduction was evaluated by linear measurements on NNT software at T1 and T2:(1) ABH, vertical distance between line a' and line b' = available bone; (2) distance between line b' and line c' = thickness of sinus membrane 1/2.

was recorded. Any additional bone augmentation techniques (if any) were also recorded.

The volume of endosinus bone grafts was analysed using another image processing software (Mimics version 17.0, Materialise). The endosinus grafts were reconstructed in three dimensions (Fig. 3) and the 3-dimensional volume of bone grafts at T1 and T2 were calculated automatically. The contraction in the volume of the grafts was calculated using the formula (1 − volume at T2)/volume at T1. The volume of the cavity of the maxillary sinus was also measured by 3-dimensional reconstruction of cone-beam CT images at T0 using similar methods on the Mimics program. The presence of sinus septa was recorded on the 3-dimensional observations as well.

Statistical analysis

Data were collected by two independent examiners. The software SPSS Statistics for Windows (version 17.0, SPSS Inc.) was used for the statistical analyses. We recorded descriptive statistics, and absolute and relative frequency distributions were calculated for qualitative variables. Mean (SD) were calculated for quantitative variables. To bypass the problem of dependencies between multiple sites within one sinus, site-based statistics and sinus-based statistics were analysed separately. The normality of data was tested by the

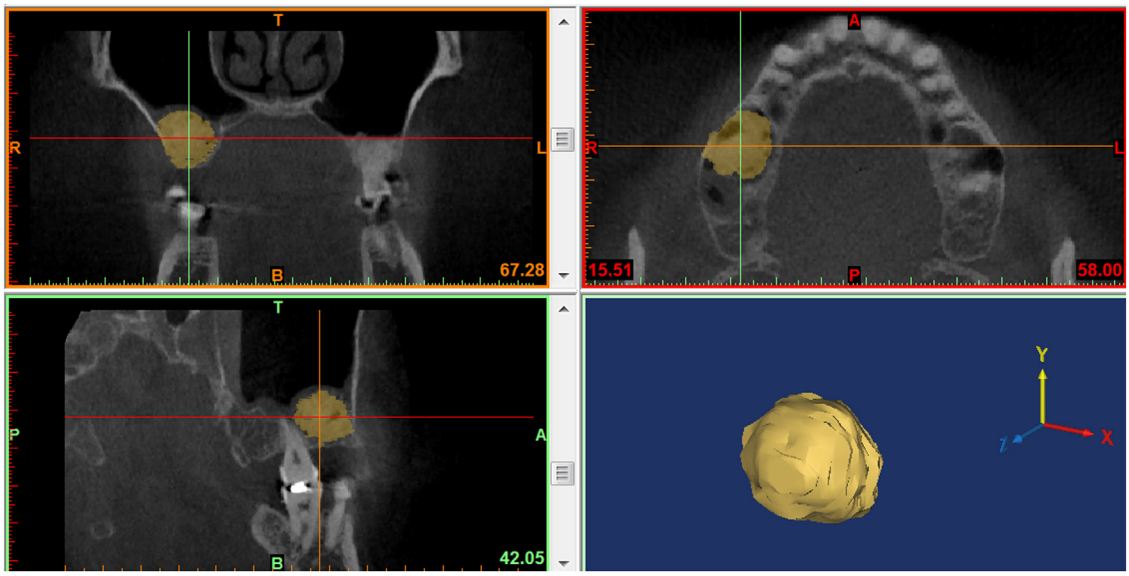

Fig. 3. Volumetric analysis using Mimics software (screenshot). A "yellow mask" of the endosinus grafts was created as the region of interest, and a 3-dimensional model constructed.

Kolmogorov-Smirnov test, and the homogeneity of variances verified.

For sinus-based statistics, we used generalised linear regression to detect factors that influenced the contraction in the volume of the grafts. The independent factors were patients' sex, age, periodontal status, smoking status, volume of the cavity of the maxillary sinus, and the edentulous type (single or multiple teeth lost in the same area). For site-based statistics, the potential influence of variables in the reduction in height of bone grafts was analysed by linear mixed model regression. The independent factors were height of residual bone, width of sinus floor, width of sinus floor 12 mm above the alveolar crest, thickness of the sinus membrane, and Angle A. Probabilities of less than 0.05 were accepted as significant.

Results

Fifty-eight patients with 123 edentulous sites in 67 sinuses were included initially, but three sinuses in three patients had to be excluded because of perforation of the sinus membrane during operation. Finally, the data of 55 patients (20 women and 35 men aged 20–73 (mean 52) years) with 118 edentulous sites in 64 sinuses were used for statistical analysis. Details of the patients and distribution of edentulous sites are shown in supplemental data (online only).

Table 1 shows the anatomical measurements of the maxillary sinus in the group studied, and Table 2 the results. At the second-stage operation, 19/118 of the edentulous sites could not have 10 mm implants inserted because of insufficient available bone.

The linear regression results indicated that type of edentulism (single or multiple teeth lost in the same area) was significantly associated with contraction of volume of the graft (Table 3). The mixed model regression results showed that the reduction rate of the height of the bone grafts was significantly influenced by the width of the sinus floor and Angle A (Table 3), but no other significant influences could be detected on both linear or volumetric measurements.

Table 2
Contraction of volume of grafts, reduction in height, and contraction of volume between the two time points.

	Mean (SD)	Range
Site-based statistics:		
ABH at T1(mm)	14.82 (2.72)	9.80–22.40
ABH at T2(mm)	12.19 (2.54)	7.23–18.90
BHR (%)	17.75 (8.10)	0.05–41.90
Sinus-bases statistics:		
GV at T1(cm^3)	3.280 (0.703)	2.106–4.618
GV at T2(cm^3)	2.510 (0.489)	1.581–3.588
GVC (%)	22.70 (8.15)	7.19–41.66

Bone ABH = available height of bone; BHR = reduction in height of bone grafts; GV = volume of grafts; GVC = contraction in volume of grafts.

Discussion

This study was designed to evaluate (using both linear and volumetric measurements) the contraction of grafts after staged sinus augmentation using deproteinised bovine bone mineral, and to investigate the possible influential factors. The results showed moderate contraction of grafts in general at six months after a staged sinus augmentation procedure. A wide sinus and multiple tooth loss in the same area might be associated with a large amount of contraction.

The stability of the volume of the graft is critical to the success of staged augmentation of the sinus. The reported

Table 1
Dimensions of sinuses and related anatomical characteristics measured by linear and volumetric measurements.

	Site-based		Sinus-based	
	Mean (SD)	Range	Mean (SD)	Range
RBH (mm)	2.82 (1.45)	0.47–5.60	–	–
HSC (mm)	34.66 (5.46)	11.93–49.43	–	–
WSF (mm)	8.60 (1.97)	4.33–14.30	–	–
WS12 (mm)	15.36 (3.88)	6.50–24.81	–	–
TSM (mm)	1.99 (1.85)	0–8.43	–	–
Angle A (°)	77.53 (19.02)	23.77–119.13	–	–
MSV (cm^2)	–	–	27.470 (3.589)	20.033-35.820
No. of septa	–	–	6/64	–

RBH = residual bone height; HSC = height of sinus cavity; WSF = width of sinus floor; TSM = thickness of sinus membrane; and MSV = maxillary sinus cavity.

Table 3
A and B. Analysis of influence of factors on reduction in the volume of grafts (sinus-based analysis) and reduction in the height of grafts (site-based analysis).

Part A: Linear regression for detecting factors influencing contraction of volume of grafts (sinus-based analysis).

Model summary $R^2 = 0.154$

	Sum of squares	df	Mean square	F	p value
Regression	489.690	1	489.690	8.260	0.006
Residual	3700.007	62	59.678	–	–
Total	4189.697	63	–	–	–

Coefficients and excluded variables

	B	SE	t	p value
Coefficients				
Constant	11.169	4.139	2.698	0.009
Edentulous type (single or multiple)	6.530	2.280	2.865	0.006
Excluded variables				
Sex	−0.600	–	−0.498	0.620
Age	0.064	–	0.482	0.631
Periodontal status	−0.157	–	−1.322	0.191
Smoking status	−0.037	–	−0.306	0.761
MSV	−0.050	–	−0.417	0.678

Part B. Linear mixed model regression for detecting variables influencing bone grafts height reduction (site-based analysis)

Variable	Estimate	SE	F	t	p value
Intercept	−10.866	3.882	7.834	−2.799	0.006
RBH	−0.262	0.404	0.422	−0.649	0.517
WSF	1.052	0.299	12.406	3.522	0.001
WS12	0.111	0.166	0.447	0.668	0.505
TSM0	0.146	0.283	0.267	0.516	0.607
Angle A	0.236	0.032	54.310	7.370	0.000

−2 Restricted Log Likelihood of mixed model: 744.230.
RBH = height of residual bone, WSF = width of sinus floor, WS12 = width of sinus cavity at the level of 12 mm above the alveolar crest, TSM0 = thickness of sinus membrane, Angle A = angle between lateral and medial sinus wall, and MSV = volume of maxillary sinus cavity.

3-dimensional resorption of bone substitute after augmentation was about 10%–26%.[7,8,11,16] The present study confirms the results of previous studies, in that the contractions of bone grafts on linear and volumetric measurements six months after lateral augmentation were 17.75% and 22.70%, respectively. Several papers also suggested that there were no significant differences in contraction of grafts among different kinds of bone or bone substitutes.[16,17] Regardless of the type of bone substitute, contraction of grafts is inevitable.

In 2008, Kirmeier et al[8] reported shrinkage in the volume of grafts of about 26% after sinus augmentation by 3-dimensional assessment on CT images. They discussed the pattern of contraction of different grafting materials, but did not consider different anatomical characteristics among populations. Several other studies suggested that the sinus anatomy is correlated with remodelling of bone grafts.[18–21] Avila et al[14] in a histomorphometric study, showed that the vital bone formation was inversely proportional to the buccopalatal distance of the sinus cavity. Similarly, based on

analysis of cone-beam CT images, we found that, on mixed model regression, the reduction in bony height was significantly influenced by the width of the sinus floor as well as the angle between the lateral and medial sinus walls. The reason for this might be the difficulty of completely raising the membrane in cases with wide sinuses.

The tension of the sinus membrane might provide additional pressure on the graft, which could accelerate the resorption process. In the cases with narrow sinuses and a sharp angle, the grafts might not compact well during augmentation. The gap between the bony particles and between grafts and the native bone wall were relatively wider so that, during the healing of the bone, the coagulum in these gaps would be progressively substituted with newly-formed bone, which would partly offset the contraction of the graft's volume.

According to the sinus-based results, the type of edentulism could also be associated with contraction of the graft's volume. There was more contraction in the sinus with multiple tooth loss than that with a single tooth lost. This result has not to our knowledge been reported by any previous studies. The phenomenon might be explained by the pneumatisation of the sinus after the teeth were lost. When multiple teeth were lost under the same sinus, the area of pneumatisation could be enlarged as well as the width of the sinus floor, to influence remodelling of endosinus grafts.

Klijn et al[9] found that the height of the alveolar crest and the patients' age could significantly affect bony resorption after staged maxillary sinus augmentation using autogenous bone. However, the results of the present study failed to confirm this, possibly because of the difference in the remodelling pattern between autogeneous bone and bone substitute. The osteoconductive properties of different bone substitutes could also influence the grafts' contraction.

Simultaneous placement of implants during sinus augmentation could also affect the grafts remodelling. Cricchio et al[22] indicated that placement of implants could help to resist the pressure of endosinus air flow and contribute to the maintenance of the raised area and the volume of the grafts. However, Mazzocco et al[23] failed to find significant differences in contraction of the volume of the graft between delayed and simultaneous placement of implants in a small sample. Future study is needed to explain these inconsistent findings.

Conclusion

Within the limitations of the present study, the results showed a reduction of about 18% and 22% in bone grafts on linear and volumetric measurements, respectively, six months after lateral sinus augmentation. The regression results indicated that a wide sinus, large lateral-medial angle, and multiple teeth lost under the same sinus, are related to a large amount of contraction of bone grafts postoperatively. These results could be used to predict the outcomes of augmentation of sinuses preoperatively, and to well-controlled calculations of different materials for sinus augmentation in different anatomical conditions. The anatomy of the sinus and the characteristics of the sites that affect bony contraction should be fully considered before treatment with sinus augmentation.

Funding

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Ethics statement/confirmation of patients' permission

The study design and clinical procedures were in accordance with the Helsinki Declaration revised in 2008, and it was approved by the Ethics Committee. All patients signed the informed consent form before treatment.

Conflict of interest

We have no conflicts of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.bjoms.2019.03.006.

References

1. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. *J Oral Surg* 1980;**38**:613–6.
2. Tatum Jr H. Maxillary and sinus implant reconstructions. *Dent Clin North Am* 1986;**30**:207–29.
3. Summers RB. A new concept in maxillary implant surgery: the osteotome technique. *Compendium* 1994;**15**, 152, 154–6, 158, 162.
4. Tan WC, Lang NP, Zwahlen M, et al. A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. Part II: transalveolar technique. *J Clin Periodontol* 2008;**35**:241–54.
5. Si MS, Zhuang LF, Gu YX, et al. Osteotome sinus floor elevation with or without grafting: a 3-year randomized controlled clinical trial. *J Clin Periodontol* 2013;**40**:396–403.
6. Hallman M, Sennerby L, Zetterqvist L, et al. A 3-year prospective follow-up study of implant-supported fixed prostheses in patients subjected to maxillary sinus floor augmentation with a 80:20 mixture of deproteinized bovine bone and autogenous bone. Clinical, radiographic and resonance frequency analysis. *Int J Oral Maxillofac Surg* 2005;**34**:273–80.
7. Wanschitz F, Figl M, Wagner A, et al. Measurement of volume changes after sinus floor augmentation with a phycogenic hydroxyapatite. *Int J Oral Maxillofac Implants* 2006;**21**:433–8.
8. Kirmeier R, Payer M, Wehrschuetz M, et al. Evaluation of three-dimensional changes after sinus floor augmentation with different grafting materials. *Clin Oral Implants Res* 2008;**19**:366–72.

9. Klijn RJ, van den Beucken JJ, Bronkhorst EM, et al. Predictive value of ridge dimensions on autologous bone graft resorption in staged maxillary sinus augmentation surgery using Cone-Beam CT. *Clin Oral Implants Res* 2012;**23**:409–15.
10. Kim ES, Moon SY, Kim SG, et al. Three-dimensional volumetric analysis after sinus grafts. *Implant Dent* 2013;**22**:170–4.
11. Umanjec-Korac S, Wu G, Hassan B, et al. A retrospective analysis of the resorption rate of deproteinized bovine bone as maxillary sinus graft material on cone beam computed tomography. *Clin Oral Implants Res* 2014;**25**:781–5.
12. Tepper G, Haas R, Zechner W, et al. Three-dimensional finite element analysis of implant stability in the atrophic posterior maxilla: a mathematical study of the sinus floor augmentation. *Clin Oral Implants Res* 2002;**13**:657–65.
13. van den Bergh JP, ten Bruggenkate CM, Disch FJ, et al. Anatomical aspects of sinus floor elevations. *Clin Oral Implants Res* 2000;**11**:256–65.
14. Avila G, Wang HL, Galindo-Moreno P, et al. The influence of the bucco-palatal distance on sinus augmentation outcomes. *J Periodontol* 2010;**81**:1041–50.
15. Kopecka D, Simunek A, Brazda T, et al. Relationship between subsinus bone height and bone volume requirements for dental implants: a human radiographic study. *Int J Oral Maxillofac Implants* 2012;**27**:48–54.
16. Cosso MG, de Brito Jr RB, Piattelli A, et al. Volumetric dimensional changes of autogenous bone and the mixture of hydroxyapatite and autogenous bone graft in humans maxillary sinus augmentation. A multislice tomographic study. *Clin Oral Implants Res* 2014;**25**:1251–6.
17. Nkenke E, Stelzle F. Clinical outcomes of sinus floor augmentation for implant placement using autogenous bone or bone substitutes: a systematic review. *Clin Oral Implants Res* 2009;**20**:124–33.
18. Schmitt CM, Doering H, Schmidt T, et al. Histological results after maxillary sinus augmentation with Straumann®, BoneCeramic, Bio-Oss®, Puros®, and autologous bone. A randomized controlled clinical trial. *Clin Oral Implants Res* 2013;**24**:576–85.
19. Chan HL, Suarez F, Monje A, et al. Evaluation of maxillary sinus width on cone-beam computed tomography for sinus augmentation and new sinus classification based on sinus width. *Clin Oral Implants Res* 2014;**25**:647–52.
20. Kang SJ, Shin SI, Herr Y, et al. Anatomical structures in the maxillary sinus related to lateral sinus elevation: a cone beam computed tomographic analysis. *Clin Oral Implants Res* 2013;**24**:75–81.
21. Shanbhag S, Karnik P, Shirke P, et al. Cone-beam computed tomographic analysis of sinus membrane thickness, ostium patency, and residual ridge heights in the posterior maxilla: implications for sinus floor elevation. *Clin Oral Implants Res* 2014;**25**:755–60.
22. Cricchio G, Sennerby L, Lundgren S. Sinus bone formation and implant survival after sinus membrane elevation and implant placement: a 1- to 6-year follow-up study. *Clin Oral Implants Res* 2011;**22**:1200–12.
23. Mazzocco F, Lops D, Gobbato L, et al. Three-dimensional volume change of grafted bone in the maxillary sinus. *Int J Oral Maxillofac Implants* 2014;**29**:178–84.