

An Evaluation of Three-Dimensional Scans of the Time-Dependent Volume Changes in Bone Grafting Materials

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Abstract: Introduction: It is essential for the dental implantologist to be aware of the time-dependent volume changes that could occur in the augmentation material. Should the implant placement stage be delayed in time, the dental clinician must select the appropriate bone grafting material for the specific case. Materials and methods: 35 patients were eligible for inclusion, divided into 4 groups, who had a planned maxillary sinus floor augmentation procedure with different bone replacement materials: Group 1 (10 patients) - Bone Ceramic (a synthetic biphasic calcium phosphate material, consisting of hydroxyapatite and β -tricalciumphosphate in a ratio of 60:40). Group 2 (10 patients) – Cerabone (Xenogenic bone material from the mineral phase of bovine bone). Group 3 (10 patients) - Maxresorb inject (Calcium phosphate paste, composed of 80% nano-hydroxyapatite aquagel and 20% biphasic calcium phosphate granules). Group 4 (5 patients) - Collagen fleece absorbed in venous blood. Results: The various bone grafting materials applied demonstrated different volume loss over time following a maxillary sinus floor augmentation procedure. The least volume loss over time was found in the application of Xenogenic bovine hydroxyapatite material (XBHM), and most volume contraction was observed in the use of Biphasic calcium phosphate paste material (BCPPM). Conclusions: In maxillary sinus floor augmentation procedures the application of Xenogenic bone material from the mineral phase of bovine bone as an augmentation material has proven to maintain its volume the longest in comparison with other bone grafting materials.

Keywords: 3D computed tomography; sinus floor elevation; volumetric stability

1. Introduction

The clinical monitoring of the application outcome of bone grafting materials in oral surgery has been facilitated by the use of non-invasive diagnostic methods.[1]

Bone remodeling that occurs following a bone grafting procedure in the maxillary sinus was first studied using two-dimensional imaging.[2] In 1996 Nyström et al. [3] attempted to evaluate the volume loss of bone replacement material using panoramic radiographs, showing changes in the height and width of the bone graft. Computed tomography and three-dimensional imaging assist the oral surgeon in determining the individual anatomical structures - shape and volume, and evaluating the changes in the graft volume loss over time with high accuracy.[4, 5]

Baciu M. et al. [6] performed a pre- and postoperative assessment of the maxillary sinuses on 13 patients (16 sinuses) with a planned sinus augmentation procedure, using panoramic radiographs (OPG) and CBCT scans. The study comprised choice of treatment, timing of implant placement, sinus morphology, complication prediction and graft volume assessment. A preoperative planning based on CBCT provides better diagnostics and a more precise postoperative monitoring.

Shanbhag S. et al. [7] systematically reviewed the available literature on graft volume changes after sinus augmentation with different biomaterials using three-dimensional

images. Seven controlled and five uncontrolled studies (234 sinus lifts) were included and reported on a range of graft materials. Autogenous bone was used in the particulate or block form. Bone substitutes were used either alone or in combination with other materials as composite grafts. All studies reported reductions in bone graft volumes over time, generally after 6 months to 6 years. Substantial reduction of the bone graft volume (approximately 45% in 77 sinus lifts) was reported for autogenous bone grafts after 6 months and up to 2 years. Reductions in augmentation volumes over time for alloplastic materials were relatively lower (approximately 18% to 22% in 142 sinus lifts).

Nishida T. et al. [8] presented radiological findings of a CBCT study of trans-crestal sinus floor elevation, using autogenous bone as the augmentation material. 91 implants on 52 patients were subsequently placed in the regenerated bone. The 6-month follow-up CBCT study demonstrated resorption of the grafted augmentation material but at least 1 mm of grafted augmentation material was recognized around the implant fixtures.

Gorla L.F. et al. [9] carried out a study comparing the changes in bone volume after maxillary sinus lifting using 3 different bone replacement materials: autogenous bone (n=12), autogenous bone associated with beta-tricalcium phosphate (β -TCP) (n=9), and β -TCP alone. The change in bone graft volume was evaluated 6 months postoperative in each group. The results showed an average resorption of 45.7 ±

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18.6% for the first group, $43.8 \pm 18.4\%$ for the second group, and $38.3 \pm 16.6\%$ for the third group.

Berberi A. et al. [10] performed a detailed retrospective study to quantify volumetric bone graft changes over a two-year period in maxillary sinuses augmented with a mineralized cortical bone allograft material. 11 patients (6 males and 5 females) with mean age of 51.6 years underwent a maxillary sinus floor augmentation procedure. CBCT scans were taken within the first 2 weeks after the maxillary sinus lift, immediately before implant placement (4 months after grafting) and after 1 year of implant loading. Mean graft volume was $16.24 \pm 1.54 \text{ cm}^3$ at the first two weeks, $14.48 \pm 1.48 \text{ cm}^3$ after 4 months and $13.06 \pm 1.39 \text{ cm}^3$ after 2 years, i.e. the retrospective investigation demonstrated a 20.63% decrease in graft volume for the entire follow-up period.

Soardi CM. et al. [11] verified the diagnostic potential of CBCT on the evaluation of bone regeneration, comparing data from the 3-D scans and the data from microradiographic analyses of bone biopsy samples. The authors concluded that the data obtained from the CBCT scans did not differ statistically from the biopsy data.

Mazzocco F. et al. [12] performed a three-dimensional radiographic study of 100% anorganic bovine bone xenograft as a bone replacement material of good stability in time. A maxillary sinus augmentation procedure was done in 20 patients. A CBCT scan of the augmented site was taken immediately after the procedure and 8 to 9 months later. The mean graft volume was $1,432 \pm 539 \text{ mm}^3$ and $1,287 \pm 498 \text{ mm}^3$ respectively for the period right after surgery and the 8-9 months after surgery, demonstrating a significant difference in graft volume by paired t-test ($P = .01$), meaning a graft volume contraction of 10%.

Liu Y. et al. [13] conducted an elaborate research on maxillary sinus floor augmentations using Bio-Oss alone over a 6-month comparative period. The authors took CBCT scans right after grafting and 6 months later, revealing a bone height gain of $14.19 \pm 2.02 \text{ mm}$ immediately after augmentation, which stabilized at $13.68 \pm 1.95 \text{ mm}$ after the bone healing period.

Umanjec-Korac S. et al. [14] analyzed the resorption rate of deproteinized bovine bone material used alone as well as mixed with autologous bone chips as graft material. A retrospective analysis of 29 augmented sinuses in 19 patients was conducted and CBCT scans of the augmented sinuses were obtained pre- and post-operatively up to 2-year follow-up. The results indicated similar graft volume resorption for both groups of approximately $20 \pm 10\%$.

Ohe JY. et al. [15] applied biphasic calcium phosphate as augmentation material grafted in the maxillary sinus. The objective of the study was to confirm the stability of grafted volume over time by 3-D CT. From 2009 to 2011, 15 patients were included in the study, 8 male and 7 female of mean age 50.1 years. For the sinus floor augmentation procedure, biphasic calcium phosphate with local blood was packed loosely into the maxillary sinus and the grafted site was covered with a collagen membrane. For the evaluation of

volume change, 3D CBCT scans were taken pre-operatively, 1 week post-operatively, 1 month, 3 months, and 6 months later. 84.32% of the grafted biphasic calcium phosphate was maintained until 6 months later, and the average volume loss was 207.7 mm^3 , indicating a significant volume change (decreasing).

An interesting series of clinical cases have been presented by Atef M. et al. [16], investigating the use of a titanium micromesh for lateral-window sinus floor elevation without bone grafting. The 3-D scans showed that the initial residual ridge height was $3.6 \text{ mm} \pm 1.6 \text{ mm}$ prior to surgery, while 6 months postoperatively it reached $9.63 \text{ mm} \pm 1.47 \text{ mm}$. However, the study did not provide any follow-up results since the removal of the titanium micromesh.

Kim ES. et al. [17] suggested a more thorough investigation in an attempt to assess the efficacy of a bioabsorbable membrane to maintain the level of the augmented sinus floor of 14 patients. Using CBCT scans they carried out volumetric analysis of the augmentation volume of a sinus graft over time: before surgery, immediately after surgery, 6 months after surgery, and 1 year after surgery. Overall, the average percent volume of graft material that remained 6 months after implantation was 82.0%, and the average percent volume of graft material that remained 1 year after surgery was 60.4%. The reductions were shown to be statistically significant ($P = 0.002$ and $P < 0.001$, respectively).

The literature review above proves that CBCT is indeed a reliable method in preoperative planning. Based on numerous studies, the conclusion follows that when comparing OPG, segment radiology and computerized axial tomography with Cone Beam Computed Tomography (CBCT), the latter method is superior when analyzing the anatomical features of areas in the maxillofacial region.

Maxillary sinus floor augmentation is a surgical procedure requiring detailed preoperative diagnostic evaluation. First the clinician ought to establish the absence of inflammation in the maxillary sinus cavities which could eventually prevent the integration of the augmentation material. The clinician also has to analyze the morphology of the anatomical box and to locate the passage of critical vessels and organs which could in turn hinder the surgical intervention. It is also essential to consider the success of the surgery in long-term time perspective.

The dental literature available on the subject proves insufficient as there are many controversial issues that demand further investigation. Therefore, we carried out a study using CBCT which also included diagnostics of the anatomical features of the maxillary sinus, thus enabling the oral surgeon to prepare for the sinus floor augmentation procedure and follow up the results of surgery.

2. Materials and methods

A comparative study was performed of the volume of the bone graft material immediately after the maxillary sinus floor augmentation procedure and 3 years postoperatively.

35 patients were eligible for inclusion, divided into 4 groups, who had a planned maxillary sinus floor augmentation procedure with different bone replacement materials:

Group 1 (10 patients) - Bone Ceramic (a synthetic biphasic calcium phosphate material, consisting of hydroxyapatite and β -tricalcium phosphate in a ratio of 60:40)

Group 2 (10 patients) - Cerabone (Xenogenic bone material from the mineral phase of bovine bone)

Group 3 (10 patients) - Maxresorb inject (Calcium phosphate paste, composed of 80% nano-hydroxyapatite aquagel and 20% biphasic calcium phosphate granules)

Group 4 (5 patients) - Collagen fleece absorbed in venous blood

CBCT scans were taken on Day 12 after the maxillary sinus floor augmentation procedure to evaluate the state of the sinus and the bone graft. (Figures 1, 2, 3). The scans were acquired with a cone-beam computed tomography scanner

(Planmeca ProMax 3D Max), integrated with a computer hard drive and backup peripheral devices, software for reconstructing images (Planmeca Romexis) and a patients registration program. Scanning parameters were: scanning time 9-40 sec., image reconstruction time 2-55 sec. CBCT images were stored and read by Planmeca Romexis software, compatible with Windows XP, Windows 7 and Windows 8. Six to nine months following the maxillary sinus floor augmentation procedure, the dental implant area was identified and the implants were placed. Three or four months later the implant prosthetic loading took place.

Thirty-six months after the first surgery, all patients were referred for a follow-up scan (Figure 4) in order to evaluate the time-dependent volume maintenance and resorption of the bone augmentation materials most commonly used in dental implantology practice. The images were used to examine the state of the maxillary sinus and to determine the height of augmented subantral bone in the site of subsequent biopsy. The findings of the scans were compared and qualitative and quantitative analyses were performed.

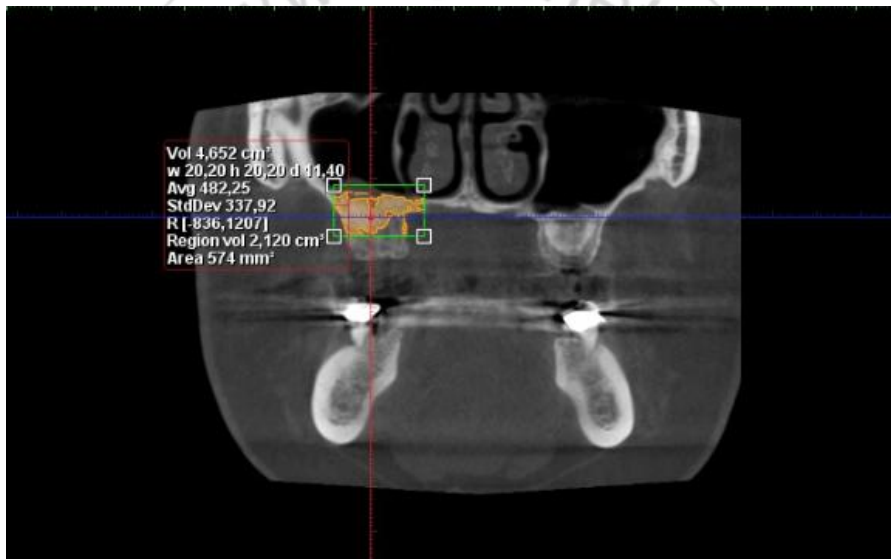


Figure 1: Measuring the bone graft volume following a maxillary sinus floor augmentation procedure

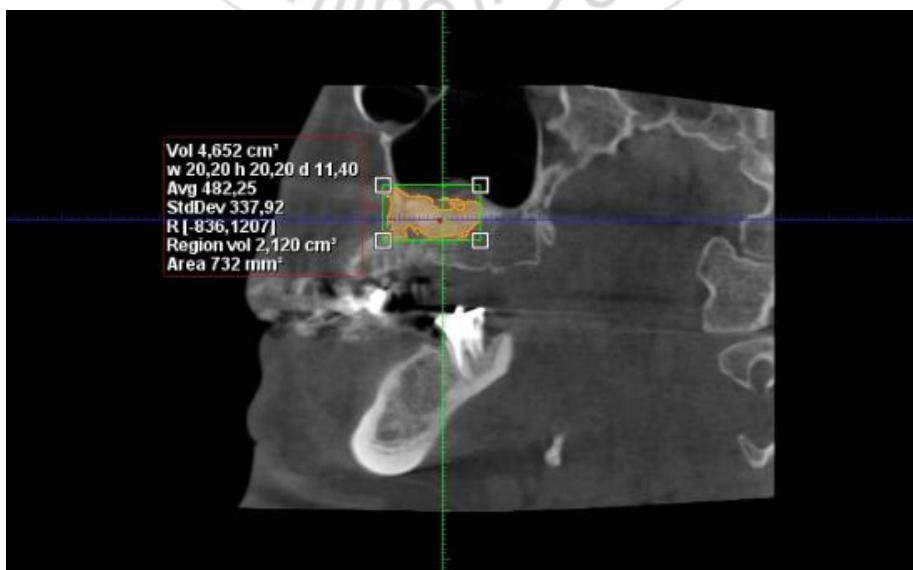


Figure 2: Measuring the bone graft volume following a maxillary sinus floor augmentation procedure

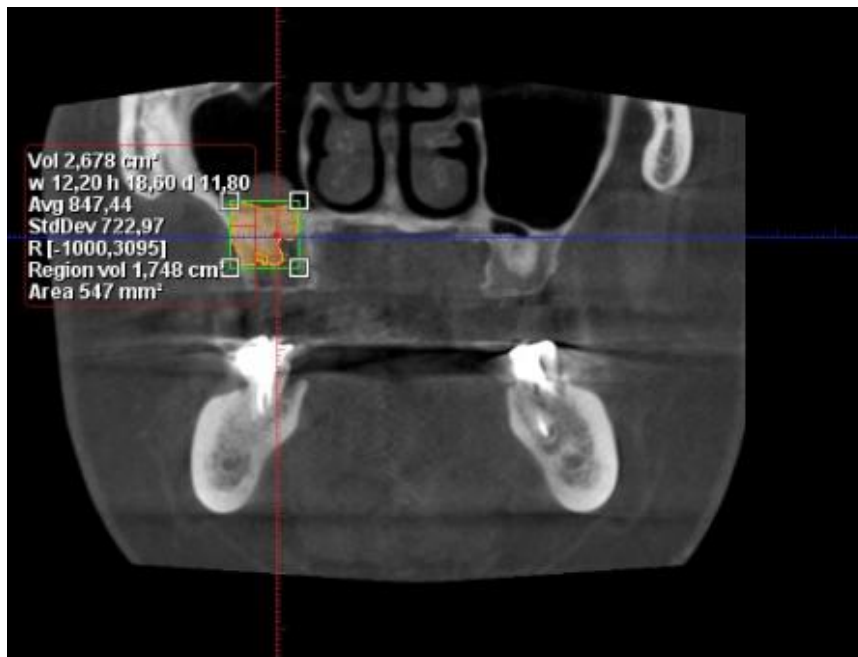


Figure 3: Measuring the bone graft volume 3 years after the maxillary sinus floor augmentation procedure

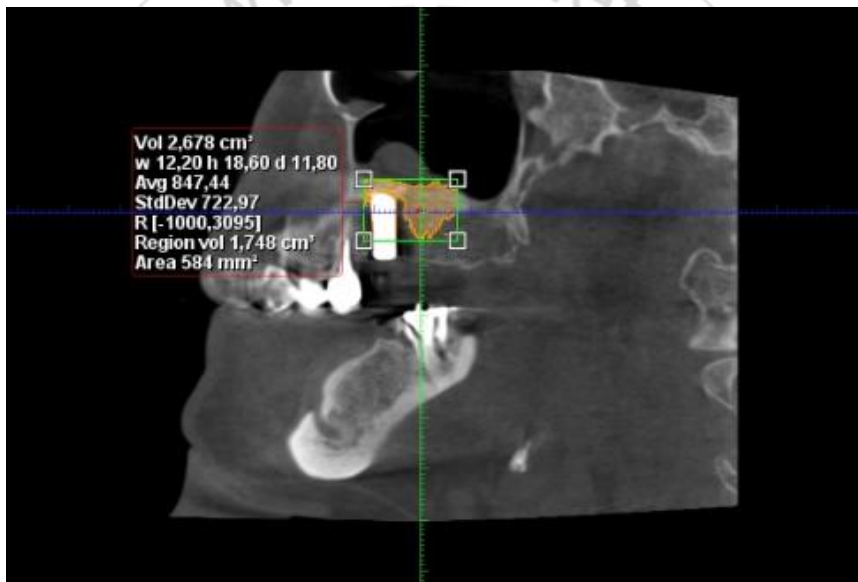


Figure 4: Measuring the bone graft volume 3 years after the maxillary sinus floor augmentation procedure

3. Results

The bone healing period following the maxillary sinus floor augmentation surgeries was uneventful and without complications. The patients had the usual complaints post surgery, namely swelling at the augmented site, dull pain over the first 2-3 days and occasional nosebleeds during the first 24 hours.

Haemorrhaging occurred during four of the surgical interventions due to affecting a.a.a., which was quickly managed as it had been expected. For three of the patients there was a minor sinus membrane perforation. Both types of complications did not affect the final result of the surgery and had no consequence for the study.

The bone grafting materials applied were as follows: Xenogenic bovine hydroxyapatite material (XBHM) - Cerabone of BotissDental, Berlin, Germany; synthetic biphasic calcium phosphate material (SBCPM) - BoneCeramic™ Straumann, Switzerland; and biphasic calcium phosphate paste material (BCPPM) - Maxresorbinject of BotissDental, Berlin.

Three years after the maxillary sinus floor augmentation procedures each patient was referred for a follow-up CBCT scan in order to evaluate any change in the bone graft volume over time.

The results obtained by comparing the volume change of XBHM bone grafting material over time, after surgery and 3 years later, are demonstrated in Figures 5 and 6 respectively.

T-testforDependentSamples										
Markeddifferencesaresignificantat p < ,05000										
	Mean	Std. Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p	Confidence -95,000%	Confidence - +95,000%
Cerabone after surgery	16,566	0,25								
Cerabone after 3 years	14,228	0,26	10	0,233	0,06	11,50	9	0,000001	0,1878	0,2797

Fig. 5The t-test for dependent samples revealed a statistically significant difference (p = 0.000001 <0.05) for the mean values of Cerabone, showing decreasing in graft volume after 3 years of approximately 0.2338.

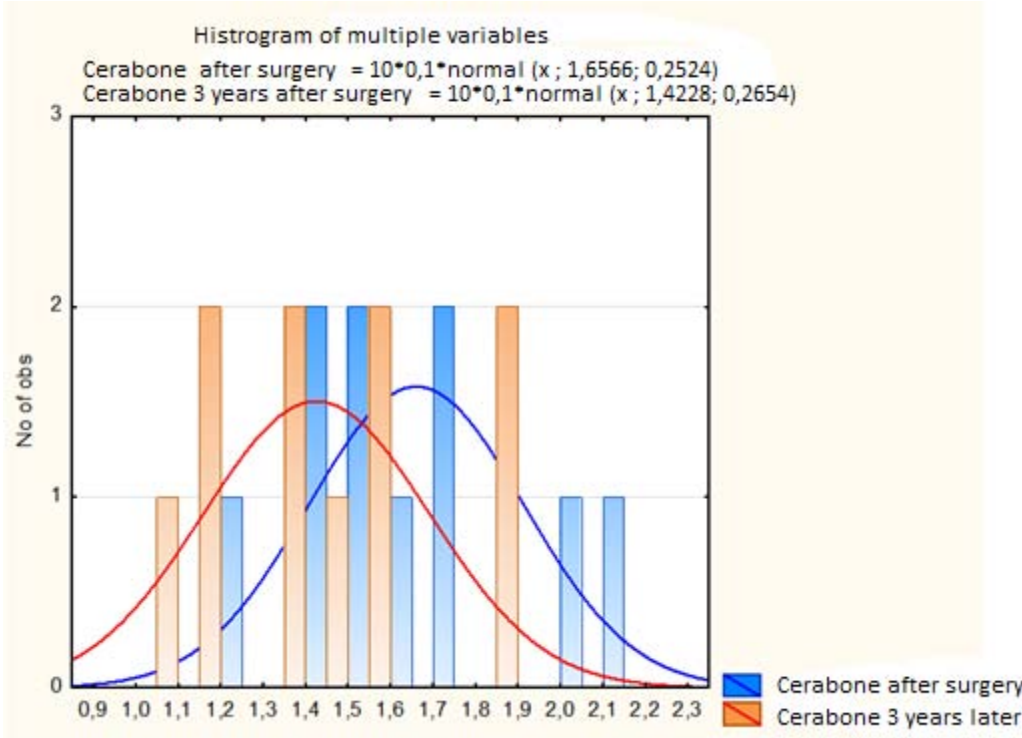


Fig. 6A histogram of the volume change of Cerabone graft material over time, 3 years after surgery. The results obtained by comparing the volume change of SBCPM bone grafting material over time, after surgery and 3 years later, are demonstrated in Figures 7 and 8 respectively.

T-testforDependentSamples (GEORGIEV.sta)										
Markeddifferencesaresignificantat p < ,05000										
	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p	Confidence - -95,000%	Confidence - +95,000%
BoneCeramic after surgery	1.6979	0.351627								
BoneCeramic after 3 years	1.3475	0.372375	10	0.3504	0.1022	10.8	9	0.000002	0.277283	0.423517

Fig. 7The t-test for dependent samples revealed a statistically significant difference (p = 0.000001 <0.05) for the mean values of BoneCeramic, showing decreasing in graft volume after 3 years of approximately 0.3504.

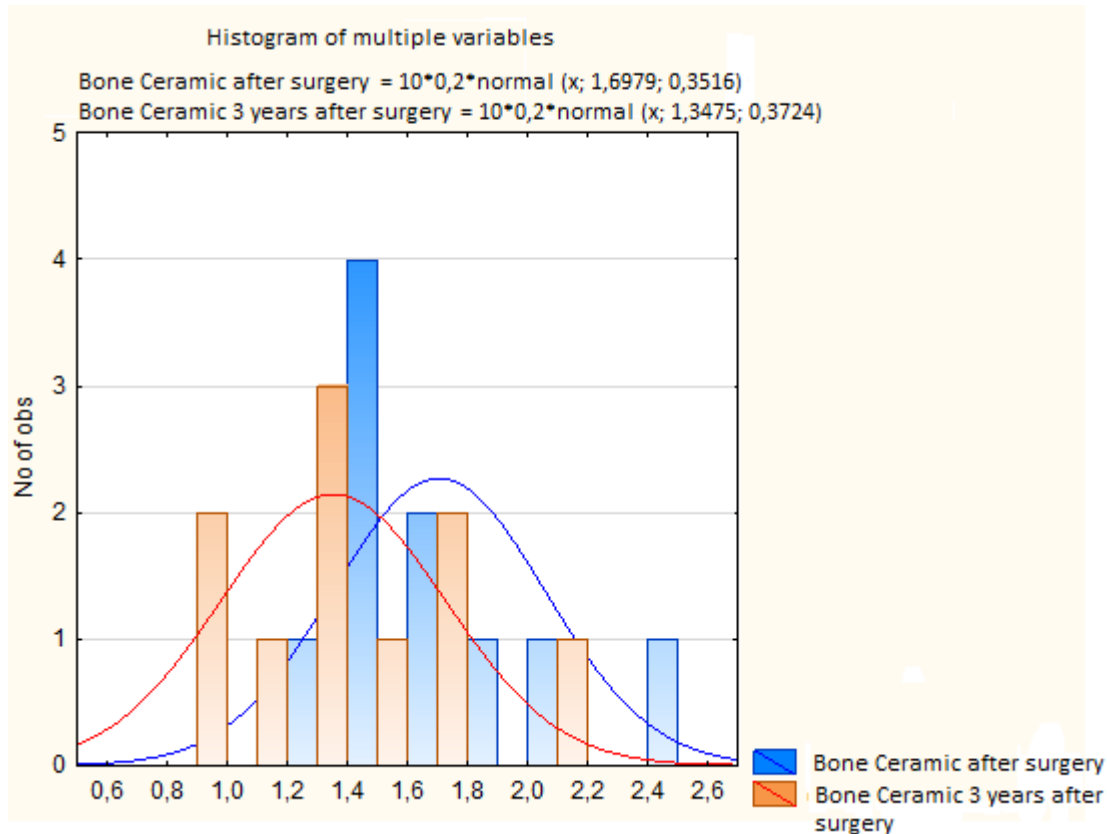


Fig. 8 A histogram of the volume change of Bone Ceramic graft material in time, 3 years after surgery.

The results obtained by comparing the volume change of BCPPM bone grafting material over time, after surgery and 3 years later, are demonstrated in Figures 9 and 10 respectively.

T-test for Dependent Samples (GEORGIEV.sta)										
Marked differences are significant at $p < ,05000$										
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95,000%	Confidence +95,000%
Maxresorb inj after surgery	1.3676	0.449091								
Maxresorb inj after 3 years	0.842	0.330356	10	0.5256	0.1527	10.884	9	0.000002	0.416361	0.634839

Fig. 9 The t-test for dependent samples revealed a statistically significant difference ($p = 0.000001 < 0.05$) for the mean

values of Maxresorb inject, showing decreasing in graft volume after 3 years of approximately 0.5256.

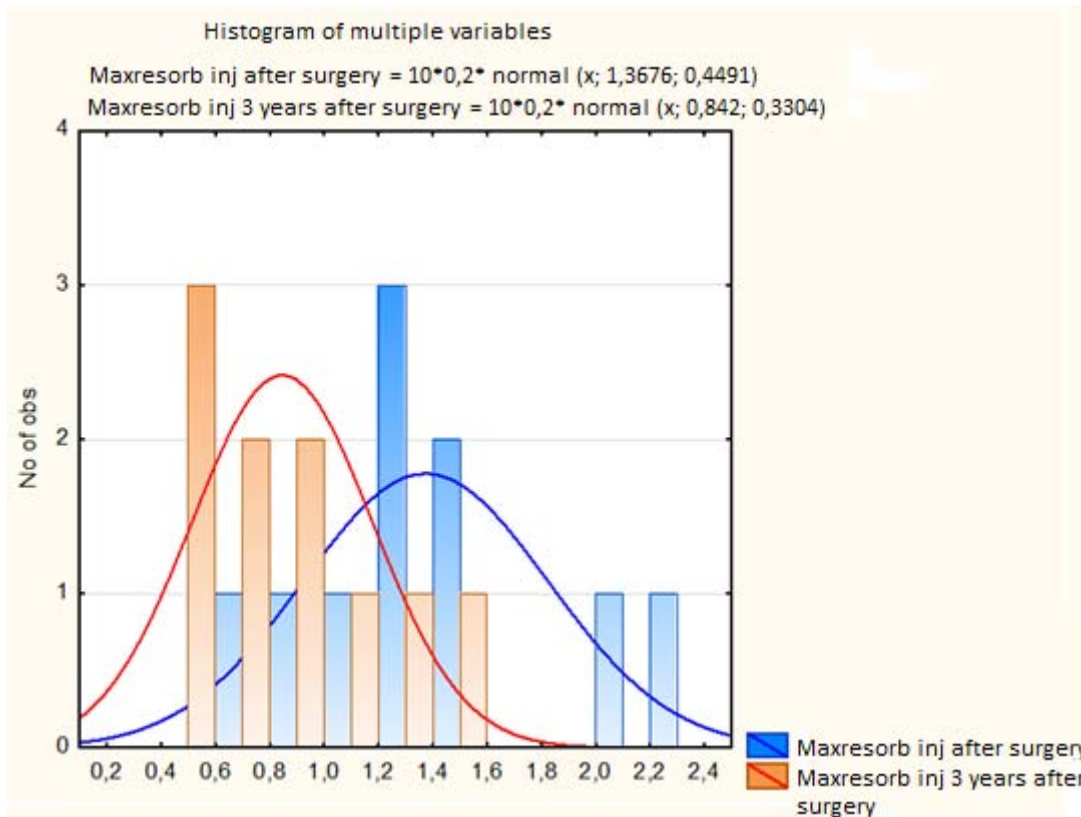


Fig. 10 A histogram of the volume change of Maxresorb inject graft material over time, 3 years after surgery. The results obtained by comparing the volume change of

Collagen fleece absorbed in venous blood used as bone grafting material over time, after surgery and 3 years later, are demonstrated in Figures 11 and 12 respectively.

T-test for Dependent Samples (GEORGIEV.sta)										
Marked differences are significant at $p < ,05000$										
	Mean	Std.Dv.	N	Diff.	Std.Dv. - Diff.	t	df	p	Confidence - -95,000%	Confidence - +95,000%
Collagen fleece after surgery	0.5894	0.116944								
Collagen fleece after 3 years	0.1794	0.026529	5	0.41	0.0951	9.6	4	0.000648	0.291901	0.528099

Fig. 11 The t-test for dependent samples revealed a statistically significant difference ($p = 0.000001 < 0.05$) for the mean values of Collagen fleece absorbed in venous

blood, showing decreasing in graft volume after 3 years of approximately 0.410.

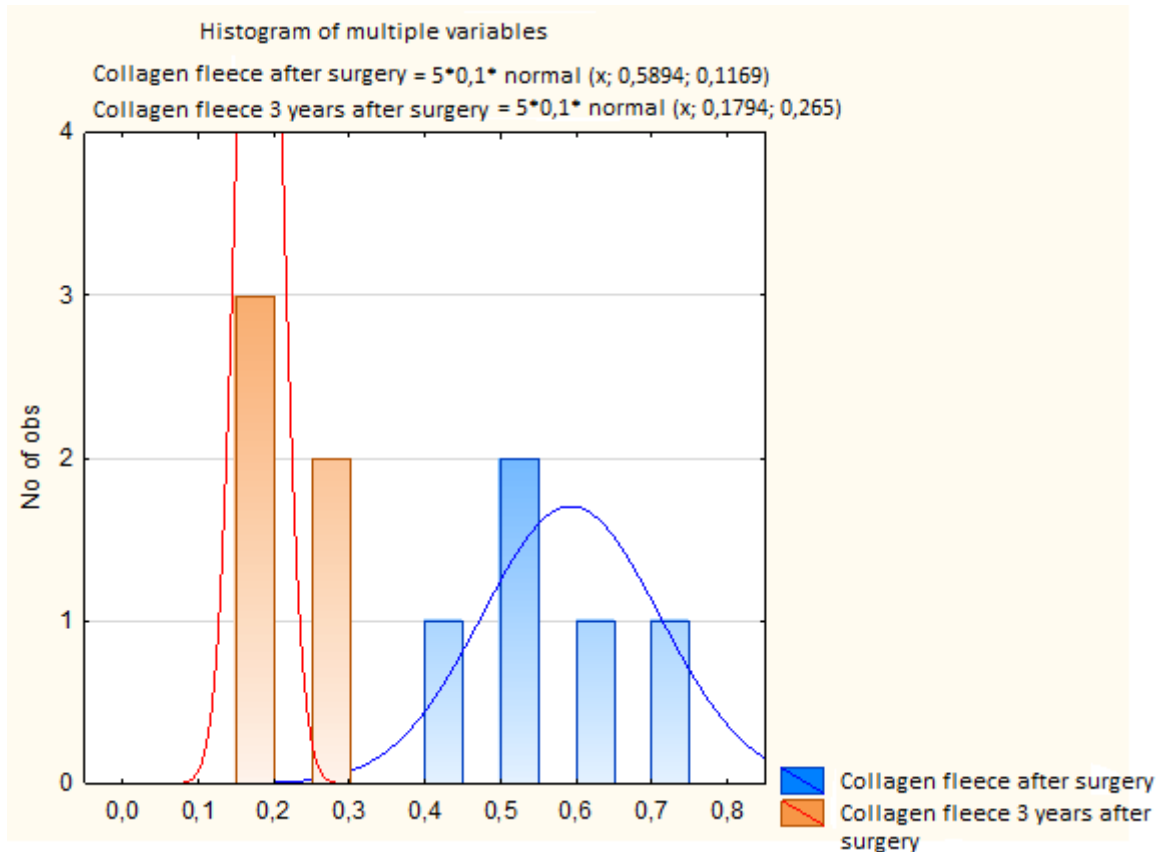


Fig. 12 A histogram of the volume change of Collagen fleece absorbed in venous blood over time, 3 years after surgery. The various bone grafting materials applied demonstrated different volume loss over time following a maxillary sinus floor augmentation procedure. The least volume loss over time was found in the application of Xenogenic bovine hydroxyapatite material (XBHM), and most volume contraction was observed in the use of Biphasic calcium phosphate paste material (BCPPM). (Figure 13)

Type of bone grafting material	Bone graft volume loss after 3 years
Cerabone	0.2338 cm ³
BoneCeramic	0.3504 cm ³
Maxresorbinject	0.5256 cm ³
Collagen fleece absorbed in venous blood	0.410 cm ³

Fig. 13 Comparison between bone grafting materials, applied in maxillary sinus floor augmentation procedures, and the volume loss of bone graft over a 3-year period.

4. Discussion

The volumetric changes of the maxillary sinus following a maxillary sinus floor augmentation procedure are of great importance for the outcome of surgery as well as for the right stage of placing dental implants in the augmented site. A number of authors have investigated the time-dependent changes in an augmented sinus.

Atef M.[16], Ohe JY.[15], Liu Y.[13], Berberi A.[10], Nishida T.[8], Dellavia [18] followed up the volumetric

changes occurring after a sinus floor augmentation procedure over a 6-month period.

Mazzocco F.[12] investigated the bone graft volume changes following surgery over a 9-month period.

Berberi A.[10], Kim ES.[17] followed up the bone graft volume changes following a sinus floor augmentation procedure over a 1-year period.

The time devoted by Umanjec-Korac S.[14] to explore bone graft volume changes after a sinus floor augmentation was 2 years.

Shanbhag S. et al. [7] performed a systematic literature review, observing no differences in the volume change of various bone grafting materials over time.

The present study set as an objective to follow up bone graft volume changes over a 3-year period, which had not been attempted or published yet.

The results obtained in this study displayed different values of bone graft volume with the application of various bone replacement materials. The best results proved to be achieved using Xenogenic bovine hydroxyapatite material (XBHM), and most resorption was observed when using Biphasic calcium phosphate paste material (BCPPM).

The data obtained from CBCT [19,20,21,22] would not be of any significance should the oral surgeon decide to perform a sinus floor lift and dental implant placement in one stage or to carry out both procedures within a relatively short time. It

is not uncommon to have patients who for some reasons after the sinus floor augmentation procedure take a long time before the implant placement stage. In those cases it is essential to select the proper augmentation material that would maintain its volume as long as possible over time.

5. Conclusions

Based on a comparison of different bone replacement materials for a maxillary sinus floor augmentation procedure, the bone grafting material that maintained its volume the longest over time proved to be Xenogenic bovine hydroxyapatite material.

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