RESEARCH ARTICLE

Accuracy of cone beam computed tomography in following simulated autogenous graft resorption in maxillary sinus augmentation procedure: an *ex vivo* study

¹Sanja Umanjec-Korac, ²Azin Parsa, ¹Aria Darvishan Nikoozad, ¹Daniel Wismeijer and ¹Bassam Hassan

¹Department of Implantology and Prosthetic Dentistry, Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands; ²Department of Oral Radiology, Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands

Objectives: Maxillary sinus augmentation is a well-documented procedure with long-term success in implant dentistry. Assessing graft volume changes over time is crucial, since resorption remains a major concern. CBCT is commonly employed to assess the quantity and quality of the available bone at the implant receptor site. However, its applicability in following graft volume changes is yet to be determined. The study aimed to assess CBCT accuracy in following simulated graft resorption *ex vivo*.

Methods: 4 differently sized autogenous bone blocks harvested from the zygomatic buttress were bilaterally placed in the maxillary sinus of 12 human cadavers. The Accuitomo (J Morita, Kyoto, Japan) CBCT system was employed to scan each one of the 4 grafts in each of the 12 cadavers using identical settings. Gold standard graft measurements were obtained using micro-CT. One independent observer assessed the volume of each graft on CBCT images twice. Intraobserver reliability was assessed using Cohen's kappa and one-sample *t*-test was used to compare CBCT with micro-CT volumetric measurements.

Results: The mean micro-CT graft volumes were 97.12 ± 1.4 , 197.32 ± 3.4 , 361.41 ± 4.2 and $1040.11 \pm 3.2 \text{ mm}^3$ for Grafts 1–4, respectively, and the mean CBCT volumes of the corresponding grafts were 115.39 ± 7.01 , 205.97 ± 9.91 , 404.05 ± 16.81 and $1138.04 \pm 20.98 \text{ mm}^3$. CBCT measurements were statistically significantly different from micro-CT measurements ($p = 0.001$). Intraobserver reliability was good ($r = 0.78$).

Conclusions: In every case, CBCT overestimated the maxillary graft volume in comparison with micro-CT. However, the measurement differences were limited and might not influence clinical performance.

Dentomaxillofacial Radiology (2016) 45, 20160092. doi: 10.1259/dmfr.20160092

Cite this article as: Umanjec-Korac S, Parsa A, Darvishan Nikoozad A, Wismeijer D, Hassan B. Accuracy of cone beam computed tomography in following simulated autogenous graft resorption in maxillary sinus augmentation procedure: an *ex vivo* study. *Dentomaxillofac Radiol* 2016; 45: 20160092.

Keywords: CBCT; dental implants; sinus floor augmentation

Introduction

Resorption of the alveolar bone as well as ageing will result in pneumatization of the maxillary sinus and is considered to be an indication for augmentation

procedures.¹ Various bone-grafting materials are used for grafting procedures. Autogenous bone is considered to be the gold standard owing to its osteoinductive and osteoconductive properties, although the requirement of a donor-site surgery for bone harvesting and the potentially exacerbated patient morbidity have been commonly cited as major disadvantages of autogenous

Correspondence to: Dr Azin Parsa. E-mail: a.parsa@acta.nl

The Department of Oral Implantology and Prosthetic Dentistry internally funded the study with no external funding.

Received 2 March 2016; revised 4 May 2016; accepted 9 May 2016

bone grafting.^{2,3} Therefore, various alternative materials including alloplastic and xenoplastic grafts have been used as substitutes or supplements to the autologous bone.^{2,4} However, resorption following grafting procedures remains a major disadvantage in maxillary sinus augmentation.⁵ In a recent systematic review involving clinical trials assessing sinus graft changes using tomographic radiography, it was reported that significant resorption in the first 12 months could be expected irrespective of the graft type.⁶ It is therefore crucial to accurately measure and monitor the volume of the augmented bone. Monitoring was previously performed with the aid of panoramic radiographs, which had the disadvantage that resorption could be assessed only in two dimensions and also that overprojection of the artefacts of the adjacent anatomical structures could lead to less accurate radiographic measurements.⁷ To accurately monitor and follow up graft volume changes over time, a tomographic radiographic technique is required. Now that CBCT is more common, three-dimensional (3D) assessment of the graft volume has become available. Compared with panoramic radiography, CBCT has a high spatial resolution, thus making it more suitable for true volumetric measurements. However, the accuracy of CBCT is limited by the system type, scan settings and reconstruction parameters.⁸ Therefore, the accuracy of CBCT in following the resorption rate of the grafted bone needs to be assessed. Two reports could be identified assessing the accuracy of CT in following graft volume changes in one study Paris was used as a simulation material, while in the other study radiopaque impression material was applied.^{9,10} The aim of the study was to assess CBCT accuracy in measuring changes in the autogenous bone graft volume in human cadavers.

Methods and materials

Sample preparation and CBCT scans

The institutional review board (NL56221) of the dental faculty approved the use of human remains for this study. 12 human cadavers not identified by age, sex or ethnic group were obtained from the Functional Anatomy Department. Cadavers were cut with a band saw (MBS 240/E; Proxxon GmbH, Föhren, Germany) transversally at the infraorbital foramina level to expose both maxillary sinuses. In addition, four autogenous bone blocks were harvested from the zygomatic buttress of a cadaver. The bone blocks were manually shaped so that the size of each sample was roughly half the size of the next sample. This was performed in order to mimic maxillary sinus graft resorption. The bone blocks were shaped to clinically applicable sizes (Figure 1). Subsequently, they were congruously adapted to the maxillary sinus floor to simulate clinical procedure. The augmented sinuses with the largest bone block were submitted to a CBCT scan to establish the original graft

volume. Subsequently, the remaining smaller blocks replaced the largest bone blocks to simulate graft resorption and at each step, a CBCT scan with identical settings was obtained. The CBCT scanner (Accuitomo 170; J Morita, Kyoto, Japan) was used, and the scanning parameters were (90 kVp, 5 mA, 17.5-s scan time and 0.125-mm isotropic voxel size with a scan field of view of 100 × 50 mm). Prior to each CBCT acquisition, a scout scan was made to verify the scan position.

CBCT graft volume measurements

Data obtained from the CBCT scanner were converted into digital imaging and communication in medicine format and imported into the image analysis software (Amira v. 4.2; Visage Imaging, San Diego, CA). In the segmentation mode of the software, axial and coronal slices were created and a region of interest limited to the borders of the graft was traced using a 3D selection tool (Figure 2). The 3D lasso tool attempts to automatically trace the border of the graft based on density contrast with the surrounding region. The user could then adjust the border tracing as required. On each slice, the surface area of the selected region was subsequently automatically calculated. The volume of the graft was obtained by summing up all the graft surface areas for all the segmented slices.

Micro-CT scanning procedure and graft volume measurements

In order to establish gold standard measurements of graft volumes, the autogenous bone blocks were submitted for scanning with a micro-CT system (mCT 40; Scanco Medical AG, Bassersdorf, Switzerland). The scan settings were 70 kVp, 15 mA, 45-min scan time, 2 megapixel scan resolution and voxel size 0.018 mm. The scan field of view was 30 × 40 mm. The resulting slices were of high spatial resolution (Figure 3). The data sets were also exported as digital imaging and communication in medicine files and imported into the Amira software. An interactive threshold-based segmentation algorithm was applied to select the outer contour of the bone blocks (Figure 4). The volumes were then automatically obtained in cubic millimetre.

Statistical methods

To assess the measurement validity of the CBCT tracing procedure, one observer independently traced the graft volumes twice with a 4-week separation between the first and second measurement, and Cohen's kappa was

Figure 1 The four harvested bone blocks ranging in size from small to large.

Figure 2 An example of the segmentation procedure with CBCT. The selected graft area on both coronal cuts (left) and axial cross-sections (right) can be noticed.

calculated.¹¹ One-sample *t*-test (SPSS® v. 22; IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL) assessed the statistical significance of the differences between CBCT and micro-CT measurements. Mean and standard deviation measurements were calculated for the bone grafts assessed by both CBCT and micro-CT. The significance level was set to $\alpha = 0.05$.

Results

A total of 12 cadavers were augmented with 4 autogenous bone blocks of various sizes to simulate sinus graft resorption. Volumes of the bone samples as assessed on CBCT and micro-CT are demonstrated in [Tables 1 and 2](#), respectively. The mean CBCT graft volumes were 115.39 ± 7.01 , 205.97 ± 9.91 , 404.05 ± 16.81 and $1138.04 \pm 20.98 \text{ mm}^3$ and the corresponding micro-CT

graft volumes were 97.12 ± 1.4 , 197.32 ± 3.4 , 361.41 ± 4.2 and $1040.11 \pm 3.2 \text{ mm}^3$ for Grafts 1–4, respectively. Intraobserver agreement was good (Cohen’s kappa 0.78). There were statistically significant differences between the volumetric CBCT and micro-CT measurements ($p = 0.001$). In every case, CBCT overestimated the amount of the remaining sinus graft.

Discussion

The study was conducted to assess the accuracy of CBCT in following up simulated graft resorption in the maxillary sinus *ex vivo*. The results demonstrated that CBCT measurements overestimated the remaining graft volume. There are several explanations for this phenomenon. First, the voxel size of the CBCT scan was 0.125 mm and this means that the CBCT voxel was significantly larger than the micro-CT voxel (0.018 mm). Second, human error cannot be ignored during any manual segmentation approach, since accurately distinguishing the sinus floor from the added graft material can be difficult for observers. A third reason could be the artefacts and patient positioning associated with a CBCT scan. Relevant in this case could be beam hardening, the partial volume effect and aliasing artefacts.¹² However, even when adding the combined effect of all errors and the statistically significant difference, the observed deviations were limited in their magnitude, although it remains to be investigated whether the differences could be considered as within clinically acceptable limits. It has to be emphasized although that the deviations between micro-CT and CBCT measurements are in cubic millimetre— $1000 \text{ mm}^3 = 1 \text{ cm}^3$; so, there is an overestimation of $90 \text{ mm}^3 = 0.09 \text{ cm}^3$, which can prove to be a limited difference in a clinical situation. The applicability of CBCT for assessing and following

Figure 3 A cross-sectional slice of the micro-CT scan of the bone graft. The rich trabecular bone pattern can be noticed.

Figure 4 The segmented bone grafts from micro-CT represented as three-dimensional surfaces.

bone graft volumes is a recent development and therefore clinicians need to adapt to thinking in 3D and looking at volume differences rather than the familiar crestal height measurements in millimetre. When interpreting differences, a 1-mm³ volume reduction on CBCT is considerably <1 mm crestal height reduction as assessed on a panoramic radiograph.

Few studies attempted to assess the accuracy of CBCT in following up volumetric changes of graft materials in the maxillary sinus. In a comparable *ex vivo* study, plaster of Paris was used as a simulation material for bone grafting.⁹ However, this highly radio-opaque material is

readily easily distinguishable on radiographs and can therefore be considered an unrealistic simulation, leading to overestimation of the accuracy of CT tomographic measurements. In another recent study, the researchers used a radio-opaque dental impression material to simulate the bone graft and they reported that CBCT was a reliable assessment tool to follow up incremental changes in graft volumes.¹⁰ However, that study suffered essentially from the same limitation that the impression material was not a realistic simulation of bone grafting. In this study, autogenous bone blocks were used, which were essentially harvested from the same cadavers.

Table 1 CBCT measurements of bone block volumes (labelled from the smallest Block 1 to the largest Block 4)

Sample	Block 1		Block 2		Block 3		Block 4	
	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2
Cadaver 1	116.001	110.251	201.625	199.013	436.011	420.187	1108.8125	1111.651
Cadaver 2	123.251	130.011	200.125	202.062	395.062	399.078	1138.6875	1135.752
Cadaver 3	118.4375	115.501	200.8125	203.252	413.375	405.031	1125.25	1118.001
Cadaver 4	111.1875	121.341	209.25	201.625	384.875	385.951	1128.9375	1130.125
Cadaver 5	120.253	115.125	217.6875	220.254	391.062	385.187	1132.375	1129.501
Cadaver 6	117.1875	122.625	223.001	225.436	418.187	420.725	1136.25	1140.012
Cadaver 7	123.875	130.901	219.753	215.751	399.750	390.185	1165.001	1164.175
Cadaver 8	111.5625	105.151	201.875	205.001	421.001	420.750	1189.437	1185.125
Cadaver 9	116.875	118.875	201.5625	200.503	401.187	405.185	1131.375	1133.875
Cadaver 10	118.751	109.125	203.8125	208.902	410.375	413.25	1133.437	1135.625
Cadaver 11	109.012	114.812	204.125	209.752	375.250	385.00	1123.187	1120.151
Cadaver 12	98.505	95.375	188.011	195.754	402.501	408.78	1143.752	1145.812

Rep 1 and Rep 2 are repeated measurements.
All measurements reported are in cubic millimetre.

Table 2 Micro-CT measurements of bone block volumes (labelled from the smallest Block 1 to the largest Block 4)

Sample	Rep 1	Rep 2
Block 1	95.72	98.52
Block 2	200.72	193.92
Block 3	365.61	357.21
Block 4	1036.91	1043.31

Rep 1 and Rep 2 are repeated measurements.

All the measurements reported are in cubic millimetre.

An increasing number of clinical studies using CBCT to follow graft volume changes have demonstrated the potential for applying this technique to assess not only the quantity but also the quality of the osseointegrated graft.^{13–16} And it has recently been reported to be the best clinically available tool for assessing graft volume changes *in vivo*.¹⁷ CBCT was

additionally found to be equally valid to multislice CT in following up osseous volumetric changes in a cleft palate model.¹⁸ The study was limited as just one type of CBCT scanner was used; therefore, findings could be different with other CBCT systems. In addition, the samples were stationary and therefore no effects of motion artefacts could be simulated. The effect of this artefact is expected to be significant because motion artefacts are frequently observed in CBCT scans.¹⁹

Conclusions

Within the study limitations, it was found that CBCT overestimates the amount of remaining graft volume compared with micro-CT. However, the overestimation could be of limited clinical significance.

References

1. Pramstraller M, Farina R, Franceschetti G, Pramstraller C, Trombelli L. Ridge dimensions of the edentulous posterior maxilla: a retrospective analysis of a cohort of 127 patients using computerized tomography data. *Clin Oral Implants Res* 2011; **22**: 54–61. doi: <http://dx.doi.org/10.1111/j.1600-0501.2010.01984.x>
2. Galindo-Moreno P, Avila G, Fernández-Barbero JE, Mesa F, O'Valle-Ravassa F, Wang HL. Clinical and histologic comparison of two different composite grafts for sinus augmentation: a pilot clinical trial. *Clin Oral Implants Res* 2008; **19**: 755–9. doi: <http://dx.doi.org/10.1111/j.1600-0501.2008.01536.x>
3. Nkenke E, Radespiel-Tröger M, Wiltfang J, Schultze-Mosgau S, Winkler G, Neukam FW. Morbidity of harvesting of retromolar bone grafts: a prospective study. *Clin Oral Implants Res* 2002; **13**: 514–21. doi: <http://dx.doi.org/10.1034/j.1600-0501.2002.130511.x>
4. Cordaro L, Bosshardt DD, Palattella P, Rao W, Serino G, Chiapasco M. Maxillary sinus grafting with Bio-Oss or Straumanns Bone Ceramic: histomorphometric results from a randomized controlled multicenter clinical trial. *Clin Oral Implants Res* 2008; **19**: 796–803. doi: <http://dx.doi.org/10.1111/j.1600-0501.2008.01565.x>
5. Umanjec-Korac S, Wu G, Hassan B, Liu Y, Wismeijer D. 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. doi: <http://dx.doi.org/10.1111/clr.12174>
6. Shanbhag S, Shanbhag V, Stavropoulos A. Volume changes of maxillary sinus augmentations over time: a systematic review. *Int J Oral Maxillofac Implants* 2014; **29**: 881–92. doi: <http://dx.doi.org/10.11607/jomi.3472>
7. Hatano N, Shimizu Y, Ooya K. A clinical long-term radiographic evaluation of graft height changes after maxillary sinus floor augmentation with a 2:1 autogenous bone/xenograft mixture and simultaneous placement of dental implants. *Clin Oral Implants Res* 2004; **15**: 339–45. doi: <http://dx.doi.org/10.1111/j.1600-0501.2004.00996.x>
8. Liang X, Jacobs R, Hassan B, Li L, Pauwels R, Corpas L, et al. A comparative evaluation of cone beam computed tomography (CBCT) and multi-slice CT (MSCT) Part I. On subjective image quality. *Eur J Radiol* 2010; **75**: 265–9. doi: <http://dx.doi.org/10.1016/j.ejrad.2009.03.042>
9. Johansson B, Grepe A, Wannfors K, Aberg P, Hirsch JM. Volumetry of simulated bone grafts in the edentulous maxilla by computed tomography: an experimental study. *Dentomaxillofac Radiol* 2001; **30**: 153–6. doi: <http://dx.doi.org/10.1038/sj.dmf.4600600>
10. Platzer S, Wildburger A, Lorenzoni M, Jakse N, Riedl R, Weiglein A, et al. Human cadaver study evaluating a new measurement technique for graft volumes after sinus floor elevation. *Clin Implant Dent Relat Res* 2014; **16**: 212–22. doi: <http://dx.doi.org/10.1111/j.1708-8208.2012.00472.x>
11. Landis JR, Koch GG. The measurements of observer agreement for categorical data. *Biometrics* 1977; **33**: 159–74. doi: <http://dx.doi.org/10.2307/2529310>
12. Hassan B, Nijkamp P, Verheij H, Tairie J, Vink C, van der Stelt P, et al. Precision of identifying cephalometric landmarks with cone beam computed tomography *in vivo*. *Eur J Orthod* 2013; **35**: 38–44. doi: <http://dx.doi.org/10.1093/ejo/cjr050>
13. Dellavia C, Speroni S, Pellegrini G, Gatto A, Maiorana C. A new method to evaluate volumetric changes in sinus augmentation procedure. *Clin Implant Dent Relat Res* 2014; **16**: 684–90. doi: <http://dx.doi.org/10.1111/cid.12058>
14. Sbordon C, Toti P, Guidetti F, Califano L, Bufo P, Sbordon L. Volume changes of autogenous bone after sinus lifting and grafting procedures: a 6-year computerized tomographic follow-up. *J Craniomaxillofac Surg* 2013; **41**: 235–41. doi: <http://dx.doi.org/10.1016/j.jcms.2012.09.007>
15. Berberi A, Bouserhal L, Nader N, Assaf RB, Nassif NB, Bouserhal J, et al. Evaluation of three-dimensional volumetric changes after sinus floor augmentation with mineralized cortical bone allograft. *J Maxillofac Oral Surg* 2015; **14**: 624–9. doi: <http://dx.doi.org/10.1007/s12663-014-0736-3>
16. Ohe JY, Kim GT, Lee JW, Al Nawas B, Jung J, Kwon YD. Volume stability of hydroxyapatite and β -tricalcium phosphate biphasic bone graft material in maxillary sinus floor elevation: a radiographic study using 3D cone beam computed tomography. *Clin Oral Implants Res* 2016; **27**: 348–53. doi: <http://dx.doi.org/10.1111/clr.12551>
17. Mazzocco F, Lops D, Gobbato L, Lolato A, Romeo E, del Fabbro M. Three-dimensional volume change of grafted bone in the maxillary sinus. *Int J Oral Maxillofac Implants* 2014; **29**: 178–84. doi: <http://dx.doi.org/10.11607/jomi.3236>
18. Albuquerque MA, Gaia BF, Cavalcanti MG. Oral cleft volumetric assessment by 3D multislice computed tomographic images. *Int J Oral Maxillofac Surg* 2011; **40**: 1280–8. doi: <http://dx.doi.org/10.1016/j.ijom.2011.05.015>
19. Zhang Q, Hu YC, Liu F, Goodman K, Rosenzweig KE, Mageras GS. Correction of motion artifacts in cone-beam CT using a patient-specific respiratory motion model. *Med Phys* 2010; **37**: 2901–9. doi: <http://dx.doi.org/10.1118/1.3397460>