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Volumetric analysis of extraction sockets using cone beam computed tomography: a pilot study on ex vivo jaw bone

Jimoh Olubanwo Agbaje[1], Reinhilde Jacobs[1,2], Frederik Maes[3], Katleen Michiels[2] and Daniel van Steenberghe[2]

[1]Oral Imaging Centre, Faculty of Medicine; [2]Department of Periodontology, Faculty of Medicine; [3]Medical Image Computing, ESAT/PSI, Faculty of Engineering, Katholieke Universiteit Leuven, Leuven, Belgium

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Abstract

Aim: The aim of this study was to determine the accuracy of volumetric analysis of extraction sockets using cone beam computed tomography (CBCT).

Material and Methods: The volume of 40 dental alveoli in nine dry skull specimens (four mandibles and five maxillae) was determined by measuring the volume of the tooth socket impression using the water displacement technique. This was considered as the gold standard. Then, the tooth socket was scanned with CBCT and data were uploaded in the semi-automated Livewire® segmentation software. The software segments the tooth socket in consecutive 1 mm-thick two-dimensional slices. After segmentation, the total volume of the delineated socket was computed. The statistical difference between direct volumetric measurements and those obtained with CBCT imaging was assessed using the Student paired *t*-test.

Result: The mean socket volume of the skull specimens was $227 \pm 91\,mm^3$ when obtained by direct measurement and $225 \pm 90\,mm^3$ when obtained by CBCT imaging. Student paired *t*-test showed no significant differences between both volume measurements ($p > 0.1$).

Conclusions: CBCT permits imaging of anatomical structures in three planes and allows for reliable volume estimates. The results should be verified in clinical circumstances and might have potential applicability for evaluation of extraction socket healing under different conditions.

Key words: bone volume; cone beam CT; jaw; tooth socket; volumetry

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The introduction of cone beam computed tomography (CBCT) has initiated a new era in the field of dentomaxillofacial radiology. Owing to the acquisition of large data volume in a short scan time and at low radiation dose (Ziegler et al. 2002, Lascala et al. 2004, Scarfe et al. 2006), CBCT is well suited for imaging the dentomaxillofacial area. It provides clear images of high-contrasted structures and is extremely useful for evaluating bone pathology (Ziegler et al. 2002, Sukovic 2003, Hilgers et al. 2005).

The typical ''spiral'' CT scanner requires a separate scan of the maxilla and of the mandible. Each of these scans subjects the patient to 200–300 times the radiation required for a panoramic radiography (Cohnen et al. 2002, Loubele et al. 2006). When both jaws need to be scanned, the patient collectively receives 400–600 times the radiation dose for a panoramic radiograph. CBCT scanners use a narrow, collimated cone beam of radiation that scans both the maxilla and mandible at one time. This requires only two to eight times the amount of radiation used in a panoramic radiograph (Rustemeyer et al. 2004, Loubele et al. 2005). In terms of risks and benefits, CBCT is the better choice. Another advantage of CBCT is the increased accuracy. CBCT digital imaging is as accurate as the digital imaging produced by conventional medical CT units and it is not affected by head posture during acquisition unlike conventional CT (Hashimoto et al. 2006, Loubele et al. 2006). The distance

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of an anatomic structure (like the mandibular nerve) or thickness of cortical bone can be measured to one-tenth of a millimetre (Yajima et al. 2006, Ludlow et al. 2007).

CBCT scanners are based on volumetric tomography, using a two-dimensional (2D) extended digital array providing an area detector. This is combined with a three-dimensional (3D) X-ray beam (Danforth et al. 2003, Scarfe 2005, Scarfe et al. 2006). The cone-beam technique involves a single 360° scan in which the X-ray source and a reciprocating area detector synchronously move around the patient's head.

Software programs incorporating sophisticated algorithms including filtered back-projection are applied to these image data to generate a 3D volumetric data set. The latter can be used to provide primary reconstruction images in three orthogonal planes (axial, sagittal and coronal). CBCT imaging is useful in the assessment of growth and development (Aboudara et al. 2003, Maki et al. 2003, Sukovic 2003, Scarfe et al. 2006), oral implant planning (Hatcher et al. 2003, Sato et al. 2004), assessment of bone pathology, temporomandibular joint assessment (Honda et al. 2004, Tsiklakis et al. 2004) and pre- and post-operative assessment of craniofacial fractures (Ziegler et al. 2002, Sukovic 2003, Heiland et al. 2004). Perhaps the greatest practical advantage of CT in maxillofacial imaging is its ability to interact with the data and generate images replicating those commonly used in clinical practice. Until the advent of CT, linear measurements were typically used for pre-operative planning while volume measurements would have been more useful.

CBCT allows image reformat not only in the axial plane but also along 2D coronal, sagittal and even oblique and curved image planes, or curved reformation. Data acquired from CBCT are amenable to reformatting in a volume rather than a slice, providing 3D information (Scarfe et al. 2006). Because the CBCT volumetric data set is isotropic, the entire volume can be reoriented as such that the patient's anatomic features are realigned without introducing artefacts. CBCT can also be used to assess volumetric changes over a period of time. Hence this technique is considered well suited for diagnosis, treatment planning, patient follow-up and research in the dentomaxillofacial region (Ziegler et al. 2002, Sukovic 2003).

In order to make CBCT a useful tool in various aspects of patient management and research, the accuracy and reliability of volumetric measurements obtained with 3D image data sets should be checked. Data on the latter aspect are unfortunately lacking.

Therefore, the aim of this study was to determine the accuracy of the volume of extraction sockets as measured on CBCT images of the jaw bone. The objective of the study was to determine the accuracy of volume of extraction sockets measured on CBCT images as compared with physical measurement.

Material and Methods

Materials

Nine dry jaw bones (four mandibles and five maxillae) were provided by the Department of Anatomy of the Faculty of Medicine (Katholieke Universiteit Leuven). The study sample could not be identified, by either age, gender or ethnic group.

For the experiment, 40 extraction sockets in the nine jaws were selected. As a gold standard, the volume of each tooth socket was determined by taking a socket impression using a Xantopren H® (Bayer Dental, Germany) impression material and then quantifying the volume by means of the water displacement technique. Afterwards, each tooth socket was scanned using a high-resolution CBCT (Accuitomo®, Morita, Japan) and the volumetric data set was exported for volume quantification using the semi-automated analysis software known as Livewire® (Institute of Computing, State University of Campinas, Brazil).

Methods

Physical volume measurements

The volume of each tooth socket was measured physically using the following method: Xantopren H® impression material was mixed according to the manufacturer's instructions and injected into each selected socket with a syringe until the socket was completely filled to the level of alveolar crest. Excess impression material was then removed.

The impression material was allowed to set for at least 5 min. and then removed from the socket. A 5-ml measuring cylinder (Hirschmann Laborgeräte GmbH & Co., Eberstadt, Germany) with an accuracy of 0.1 ml was filled with water at room temperature (23.5°C) to a 3 ml mark. The tooth socket impression was completely immersed in the measuring cylinder. Following the water displacement technique, the new water level was recorded. The volume of the displaced water was then obtained by subtracting the initial water volume from the final volume obtained after immersing the socket impression in the water in the cylinder (Forbes et al. 1985, Peterfy et al. 1995, Jensen et al. 1998). To reduce error to an absolute minimum, five impressions were made for each tooth socket; the displaced water volume for the five impressions was then averaged for each single tooth socket (Fig. 1).

The volume of each tooth socket's impression was measured twice as described above by two independent observers. The average volume thus obtained was considered as the gold standard.

CBCT imaging of extraction sockets

CBCT images were acquired with the Accuitomo® CBCT scanner. The jaw bone was immobilized with the median sagittal plane perpendicular to the horizontal plane, as recommended by the scanner patient positioning protocol reference manual. The vertical and horizontal laser-positioning guides were used to guide the proper orientation and positioning of the skull sample. Lateral scout radiographs were taken for adjusting the position and orientation when deemed necessary.

The scan was made at 1 mA and 70 kV with a single 360° rotation and a total scan time of 17 s. The isotropic data set was 0.125 mm and reconstructed data set was $0.125 \times 0.125 \times 1.000$ mm. Upon completion, the projection data were reconstructed with Accuitomo® software to create a contiguous set of axial slices (primary reconstruction). The data set had a voxel size of $0.125 \times 0.125 \times 1.000$ mm and consisted of contiguous slices with respect to the Z-axis (Fig. 2a).

Data export and segmentation

The data set was then exported using the DICOM (Digital Imaging and Communication in Medicine) version 3 file

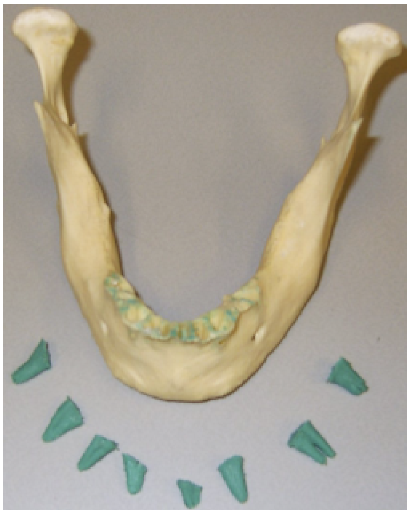

Fig. 1. Mandibular specimen and impression of corresponding tooth sockets.

format to a workstation for volume measurements using semi-automated segmentation software known as Livewire® (Institute of Computing, State University of Campinas, Brazil) (Barrett & Mortensen 1997). The DICOM format is not readily readable by LiveWire® software. Thus, the data set was first converted to the SCN (Scene node description) file format by conversion software implemented using Visualization toolkit (VTK) (Kitware Inc., New York, NY, USA) and Tool command language toolkit (TCL/TK). The SCN file was then imported into LiveWire®. The software allowed segmenting the tooth socket on consecutive 2D slices. AccuiTomo I-Dixel software® was used to show the socket view at each level of segmentation from radicular to coronal part of extraction socket. This was used as a guide during segmentation.

Each socket was colour coded to facilitate differentiation. After segmentation, the software computed the total volume of the stack of segmented 2D slices (Fig. 2b). This corresponded to the CBCT socket volume.

Barrett et al. showed that the Livewire® segmentation is much more efficient and accurate than manual tracing and that inter-observer variability is drastically reduced (Barrett & Mortensen 1997).

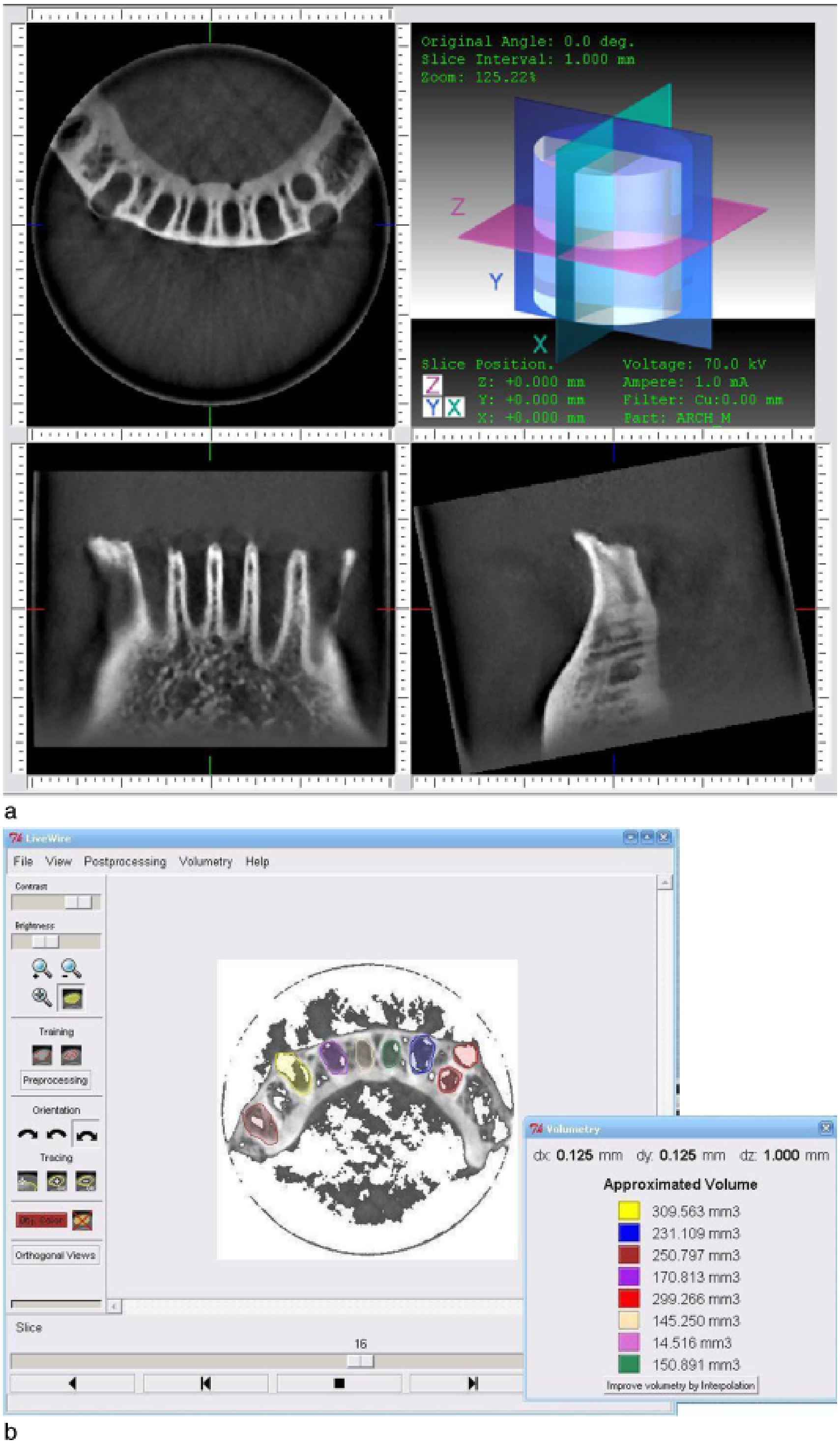

Fig. 2. (a) Screenshot from the Accuitomo® I-Dixel software illustrating the three orthogonal multi-planar reformatting (axial, coronal and sagittal) views with the cross-hair tool. (b) Screenshot from LiveWire® analysis software illustrating the segmentation process for volume quantification. Each socket is colour coded for ease of differentiation.

Data analysis

All data were entered into Excel 2003 (Microsoft, Redmond, WA, USA). Accuracy of the CBCT volume measurements was assessed by comparison with the direct volume measurement of the same skull using the paired Student *t*-test. The level of significance was set at 5% ($p \leqslant 0.05$).

Result

In the ex vivo series of tooth sockets ($n = 40$), 32 extraction sockets were intact, while the remaining sockets had

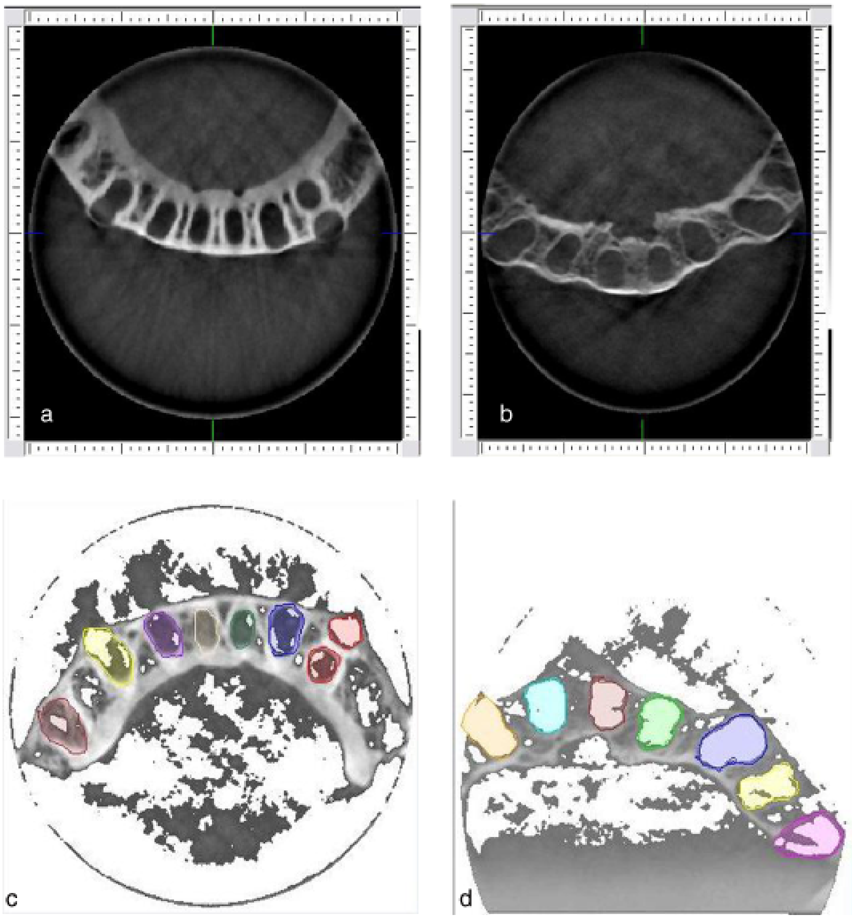

Fig. 3. This figure shows the axial images obtained on cone beam computed tomography. (a) mandible (b) maxillae. The mandible (a) shows a good cortical bone and better image quality than the maxillae (b), (c) and (d) show segmentation and volume quantification of teeth socket in (a) and (b).

minor defects on the vestibular side, representing a loss of bone between 1 and 3 mm.

Figure 3 illustrates the Livewire® segmentation for volume quantification on axial images of mandibular and maxillary dental sockets obtained with Accuitomo® CBCT.

The measurements obtained from dry skulls (physical measurements) as well as those from the Accuitomo® CBCT images are tabulated for the maxilla and the mandible (Table 1). Differences between the physical and the CBCT volume measurements are below 8% (range 0–8 mm^3) for the maxilla and below 7% (range 0–7 mm^3) for the mandible (Table 1).

The mean volume plus standard deviation of physical measurements ($227 \pm 91\ mm^3$) is slightly larger than that of CBCT measurements ($225 \pm 90\ mm^3$), but this difference is statistically not significant (Student paired t-test; $p > 0.1$).

Discussion

In this study no soft tissue simulation was used, because the primary aim of the study was to verify the accuracy of volume measurement on CBCT. Soft tissue is known to cause X-ray scatter with associated streak artefact. X-ray scatter reduces the contrast to noise ratio and makes reconstruction value less accurate (Siewerdsen & Jaffray 2001).

The purpose of this study was to test the accuracy of volume measurements derived from CBCT images.

The results show that the physical volume measured on dry skulls was hardly different from those obtained from the CBCT images and statistically insignificant.

The mean variation in volume between the physical- and CBCT-based volume measurements range from as low as 0.27% to 8.00%. CBCT underestimates the volume in 21 cases (range from −0.33% to −7.27%, mean: −3.82%, mode: −2.67%) and it overestimates it in the remaining 19 cases (range from 0.27% to 8%, mean: 3.50%, mode: 4%).

The mandible shows a better CBCT image quality than maxillae (Fig. 3a and b). This could be due to the greater contrast between the dental alveolus and the cortex surrounding it, giving it a clearer image. The lower image quality of the maxillae on CBCT results in difficulty in delineating the socket during segmentation. This is probably the reason as to why the CBCT measurements in the mandible are closer to the physical measurement than in the maxillae.

When considering the present results of accurate volumetric assessment together with the lowered radiation doses from this technique as reported by others (Mozzo et al. 1998, Ziegler et al. 2002, Mah et al. 2003, Sukovic 2003, Araki et al. 2004, Lascala et al. 2004, Guerrero et al. 2006, Scarfe et al. 2006), the CBCT technique seems useful for particular indications in diagnosis, therapy planning and follow-up in the orofacial region. The advantage is also that a CBCT can scan smaller jawbone parts than a regular CT scan. Considering the generation of very low-radiation doses, it can be justified to make a 3D image even for planning a solitary implant.

Nowadays, CBCT can be considered as the method of choice in preoperative diagnostics. It can be performed postoperatively as well as during follow-up (Pohlenz et al. 2007). Using mobile scanners, CBCT has also been described for intra-operative imaging after open reduction of zygomatic complex fractures, because during open reduction not all fracture sites are regularly exposed for direct visual control (Stanley 1999, Hoelzle et al. 2001)

Clinically CBCT can be used to estimate healing of extraction socket. During the healing process, bone is deposited and remodelling takes place causing a reduction in volume of the extraction socket. The diminution in socket volume corresponded to the amount of bone deposition during the healing process (Rajnay et al. 1997, Butler et al. 1998, Elsubeihi & Heersche 2004). The rate of extraction socket healing can therefore be assessed by this decrease in volume of the extraction socket over a period of time.

Based on the present results, one can conclude that the CBCT technique is reliable for the clinical assessment of bone volume measurements, such as

Table 1. The means of physical and CBCT measurements of maxillary and mandibular teeth socket

	Tooth socket	Mean real volume (mm^3)	Mean CBCT volume (mm^3)	Difference between real and CBCT volume (mm^3)	Percentage of difference in volume (%)
1	11	125	120	− 5	− 4.00
2	11	300	277	− 23	− 7.67
3	12	87	90	3	3.43
4	12	250	256	6	2.40
5	13	200	186	− 14	− 7.00
6	13	500	472	− 28	− 5.60
7	14	200	216	16	8.00
8	15	150	159	9	6.00
9	15	175	165	− 10	− 5.71
10	21	100	98	− 2	− 2.00
11	21	275	261	− 14	− 5.10
12	22	75	77	2	2.60
13	22	250	260	10	4.00
14	23	225	234	9	4.00
15	23	450	433	− 17	− 3.78
16	24	225	229	4	1.78
17	24	225	219	− 6	− 2.67
18	25	225	220	− 5	− 2.22
19	25	225	226	1	0.44
20	31	150	151	1	0.67
21	31	125	116	− 9	− 7.20
22	32	225	231	6	2.67
23	32	150	143	− 7	− 4.67
24	33	300	299	− 1	− 0.33
25	33	375	374	− 1	− 0.27
26	34	300	312	12	4.00
27	34	250	254	4	1.60
28	34	150	149	− 1	− 0.67
29	35	300	305	5	1.67
30	35	200	194	− 6	− 3.00
31	35	250	244	− 6	− 2.40
32	41	150	145	− 5	− 3.33
33	41	175	188	13	7.43
34	42	175	171	− 4	− 2.29
35	42	150	146	− 4	− 2.67
36	43	300	310	10	3.33
37	43	350	327	− 22	− 6.29
38	44	275	261	− 14	− 5.09
39	44	250	267	17	6.80
40	45	225	230	5	2.22

CBCT, cone beam computed tomography.

bone lesions (bone resorption, cysts or tumour dimensions) (Naitoh et al. 2006, Pinsky et al. 2006). It is useful in the post-operative assessment of bone healing of extraction wounds. The same may apply to the preoperative planning of periodontal surgery, the monitoring of bone grafting procedures, oral implant placement and orthognathic surgery; but this needs to be substantiated.

Conclusions

CBCT permits imaging of anatomical structures in three planes and allows accurate volume estimates. It offers potentials for assessment of extraction socket healing over time. Thus the impact of interfering or therapeutic factors may be monitored. CBCT has a low radiation dose and thus the clinical benefits will mostly outweigh the biologic risk.

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Address:
Reinhilde Jacobs
Oral Imaging Center
Faculty of Medicine
KU Leuven
Kapucijnenvoer 7, 3000 Leuven
Belgium
E-mail: Reinhilde.Jacobs@uzleuven.be

Clinical Relevance

Scientific rationale for the study: Few data are available in the literature on the accuracy of volumetric assessment using CBCT images of jaw bones.

Principal findings: A good match was found between the volumes of extraction socket measured physically and by CBCT. The latter offers a potential to monitor defective jaw bone healing.

Practical implications: These results should be verified in a larger clinical study. The CBCT holds potential applications for assessment of extraction socket healing and bony defects around teeth. The CBCT imaging indeed shows the 3D nature of bone defects at a fairly reasonable radiation dose.