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Comparative evaluation of the accuracy of linear measurements between cone beam computed tomography and 3D microtomography

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Abstract
Objective. The aim of this study was to evaluate the influence of artifacts on the accuracy of linear measurements estimated with a common cone beam computed tomography (CBCT) system used in dental clinical practice, by comparing it with microCT system as standard reference.
Materials and Methods. Ten bovine bone cylindrical samples containing one implant each, able to provide both points of reference and image quality degradation, have been scanned by CBCT and microCT systems. Thanks to the software of the two systems, for each cylindrical sample, two diameters taken at different levels, by using implants different points as references, have been measured. Results have been analyzed by ANOVA and a significant statistically difference has been found.
Results and Discussion. Due to the obtained results, in this work it is possible to say that the measurements made with the two different instruments are still not statistically comparable, although in some samples were obtained similar performances and therefore not statistically significant.
Conclusion. With the improvement of the hardware and software of CBCT systems, in the near future the two instruments will be able to provide similar performances.

Key words
- cone-beam CT
- microCT
- linear measurements
- artifacts

INTRODUCTION

Radiographic images are, in odontostomatological clinical practice, basic instruments for diagnostic and therapeutic processes. With particular respect to oral surgery, conventional orthopantomography and periapical radiographs represent reliable modalities of visualization. Nevertheless, bidimensional imagines, in most complex cases, can not provide sufficiently detailed information for the clinicians. In fact, bidimensional imaging presents not negligible limits such as the superimposition and lacking of definition of important anatomical structures, the incapability of visualization of mandibular cortical lingual plate and the unreliability of bone crest morphological characterization. Volumetric imaging is an important visualization medium of maxillo-facial area and a lot of innovations have been reported in order to obtain high quality of images including a considerable reduction of x-ray dose for the patient [1-3]. Since 1998 with Mozzo's publication, cone beam computed tomography (CBCT) has known an exponential diffusion in dental practice thanks to high resolution of images and to radiant dose much lower than conventional multi-slice tomography [4]. However, conic shape of X-ray beam and the processing of acquisition and reconstruction of images are at the same time responsible for the persistence of artifacts able to provide decreasing of image quality. Thus, fine-tuning of this technology has provided an important scientific production about the accuracy of linear measurements with particular respect to the influence of image artifacts on these kind of evaluations. Several studies have been based on the comparison among different CBCT devices or with multi-slice tomography by varying parameters of

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acquisition and classifying evaluations with different protocols [5-8]. Scientific literature on CBCT has reported a lacking use of *in vitro* microCT as reference [9-11]. In fact, this technology, even though finalized to the *in vitro* analysis, thanks to its high resolution and its nondestructive nature, is considered an instrument of evaluation and comparison. The aim of this study has been to evaluate the influence of artifacts on linear measurements, made by CBCT on heterologous bone, comparing with *in vitro* microCT.

MATERIALS AND METHODS

Ten samples have been obtained by inserting ten dental implants (13 mm x 4 mm) in the bone tissue of the proximal epiphysis of tibia extracted from the fresh cadaver of an 18 months old bovine. By using a coring bur with the internal diameter of 10 mm, ten bone cylinders containing one implant each have been prepared and stored in a solution of 10 % concentration of formalin.

The presence of implants has had the aim to provide points of reference, thanks to known morphology and dimensions, and, at the same time, to decrease image quality, because of the production of artifacts due to the metallic nature. To obtain sample immobility during processes of acquisitions, each cylinder has been stabilized by connecting its internal implant with a healing abutment linked with resin to a plastic base. Cylindrical samples have been scanned with CBCT device ProMax 3D (Planmeca Oy, Helsinki, Finland) and microCT device Skyscan 1072 (BRUKER-MICROCT, Kontich, Belgium). In order to obtain reliable and uniform measurements, the same parameters of acquisition have been applied for each sample *(Table 1)*. Once the acquisition has been completed, for each sample, central coronal section has been selected, within images provided by dedicated software Romexis (Planmeca Oy, Helsinki, Finland). By activating "angle measure" command it has been drawn a 90° angle delimited by the straight line tangent to the external surface of cylinder and by the segment D1, corresponding to cylinder diameter tangent to the implant apex. By "line measure" command the segment D1 has been measured five times *(Figure 1)*. Replacing the predefined angle caudally, the segment D2, corresponding to diameter of the cylinder tangent to the base of the implant collar, has been identified. Segment D2 has also been measured five times. The same procedure has been applied to the corresponding microCT sections on the images provided by Cone-Rec v.1.6.6, the SkyScan 1072 dedicated software *(Figure 2)*.

Results have been compared by one-way analysis of variance (ANOVA).

RESULTS

Measurement mean values with relative standard deviations, corresponding to D1 and D2 segments obtained from CBCT and microCT instruments, have been reported in *Table 2*.

By means of ANOVA analysis, D1 and D2 segment measurements of all samples obtained by CBCT and microCT have been compared. Results have shown a statistically high significant difference ($p \leq 0.001$). Then, by means of ANOVA analysis, D1 and D2 measurements of each sample has been compared. Results *(Table 2)* have pointed out a statistically significant difference of all samples for D1 measurements ($p \leq 0.05$).

For measurements of D2, almost all the samples showed a statistically significant difference ($p < 0.05$), only 3, 6 and 7 samples showed values of comparison not statistically significant.

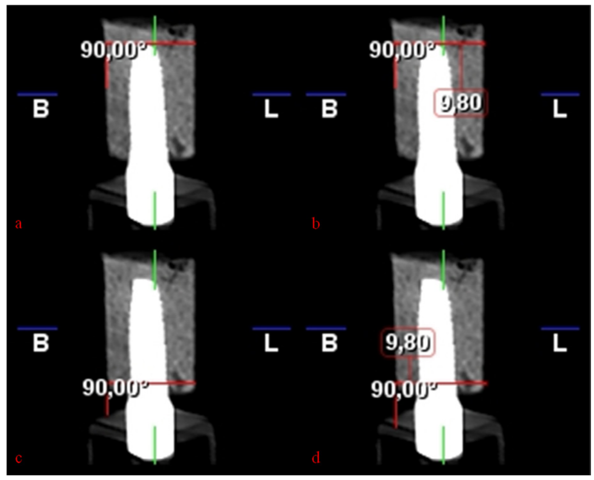

Figure 1
CBCT measurements: a) 90° angle drawn; b) measurement of D1; c) 90° angle moved caudally; d) measurement of D2.

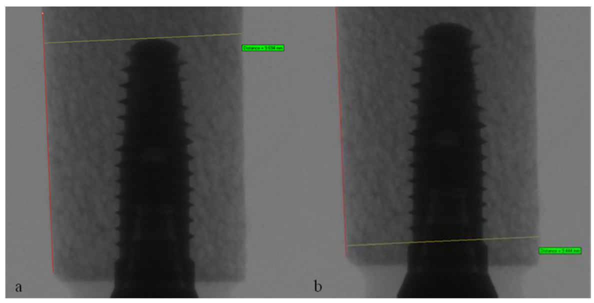

Figure 2
microCT measurements: a) 90° angle drawn and measurement of D1; b) 90° angle moved caudally and measurement of D2.

DISCUSSION

Since Mozzo's work publication in the late 90's, the application of CBCT in dental practice has known an amazing increase. In fact, though in many clinical situations the images provided by bidimensional radiographies are sufficient to an accurate diagnostic process, pre-operatory evaluations can be simplified by multiplanar reconstructions. With CBCT technology is possible to obtain high quality images with fewer radiant dose and exposition time than conventional multislice CT scan (MSCT), thanks to the X-ray beam collimation to the interested area. Respect to conventional CT, cone-beam technology provides less noise affected images.

With particular respect to oral surgery and oral implantology, literature agrees with the accuracy and the reliability effectiveness in CBCT use for diagnosis

Table 1
Acquisition parameters of the CBCT and microCT systems used

CBCT		MicroCT	
Tension	90 kV	Tension	100 kV
Current	8 mA	Current	98 µA
Magnification	401 x 401 x 401 µm	Magnification	15 X
Voxel size	200 µm	Pixel size	19.1 x 19.1 µm
X-ray emission	12 s	Exposure time	5.9 s
Rotation angle	200°	Rotation step	0.45°
FOV dimension	80 x 80 mm	Rotation angle	180°

and treatment planning, thanks to proved reliability of linear measurements in different studies too. Many studies have shown also that linear measurement accuracy is not influenced by metallic artifacts [12-20].

Anyway, partial volume and beam hardening effects don't allow a reliable use of CBCT for post-implant and post-regenerative evaluations [1].

Many studies [8, 10-12] on CBCT measurement accuracy were published in the last few years; most of them are focused on the comparison with multislice CT, while many others are based on evaluation and comparison between different CBCT instruments or on same CBCT but by changing only acquisition parameters.

Usually, accuracy of linear measurements has been evaluated by three different protocols: use of geometrical hardware phantoms, use of anthropomorphic phantoms and by comparison with an existing established imaging modality, such as MSCT. For each method a guideline protocol needs to be identified for a correct comparison of image data [5].

Less numerous is the production of papers based on comparative evaluation with microCT. In fact as affirmed by Szabo *et al.*, Maret *et al.* and Wang *et al.*, microCT was used as reference standard for the evaluation of CBCT 3D image reconstructions. The 3D microCT technique, considered the reference standard for volumetric evaluations, could be successfully used for estimation of accuracy of CBCT linear measurements. Such a technology provides images with a spatial resolution of at least 5 micron and allows to study internal structure of little radiopaque objects with a non destructive and non invasive investigation [9-11].

In this work, microCT was used as reference standard for the evaluation of influence of artifacts on accuracy of linear measurements made with CBCT on cylindrical heterologous bone samples.

ANOVA results showed a high statistically significant difference between values obtained from CBCT and microCT analysis of D1 and D2 segments ($p \leq 0.001$) for all samples processed by dedicated software.

The statistical comparison between CBCT and microCT measurements applied to every sample for each segment has demonstrated significant difference ($p < 0.05$) for almost all samples.

For samples 3, 6 and 7, the difference between CBCT

Table 2
Mean values with relative standard deviations of linear measurements

Sample	D1 CBCT	D1 microCT	p (D1)	D2 CBCT	D2 microCT	p (D2)
1	9.81 ± 0.14	9.65 ± 0.02	0.035	9.65 ± 0.09	9.42 ± 0.02	0.000
2	9.83 ± 0.00	9.57 ± 0.01	0.000	9.63 ± 0.00	9.44 ± 0.01	0.000
3	9.57 ± 0.09	9.74 ± 0.02	0.003	9.49 ± 0.11	9.60 ± 0.02	0.059
4	9.69 ± 0.09	9.84 ± 0.02	0.007	9.55 ± 0.08	9.68 ± 0.02	0.008
5	9.82 ± 0.00	9.78 ± 0.01	0.000	9.78 ± 0.09	9.52 ± 0.00	0.000
6	9.80 ± 0.00	9.72 ± 0.01	0.000	9.56 ± 0.22	9.44 ± 0.01	0.258
7	9.79 ± 0.09	9.68 ± 0.01	0.026	9.75 ± 0.11	9.68 ± 0.01	0.259
8	9.82 ± 0.00	9.57 ± 0.01	0.000	9.82 ± 0.00	9.49 ± 0.10	0.000
9	9.88 ± 0.11	9.19 ± 0.01	0.000	9.80 ± 0.00	9.56 ± 0.02	0.000
10	9.97 ± 0.09	9.64 ± 0.01	0.000	9.81 ± 0.00	9.60 ± 0.01	0.000
Tot.	9.80 ± 0.12	9.64 ± 0.17	0.000	9.68 ± 0.15	9.54 ± 0.10	0.000

and microCT measurements has not been statistically significant only for D2 segment.

The meaning of such results can be due to different factors. First of all CBCT provides images with a lower degree of resolution than microCT and this could be responsible of a more difficult observe and focus reference point selected by the user; in fact, as observed by Cremonini *et al*., bone tissue could not appear clearly and could show discontinuity on CBCT image, in presence of metallic artifacts [21].

Furthermore, the points corresponding to apex and collar base of the dental implants are showed in the areas of images in which metallic nature of implant increases beam-hardening and scattering radiation effects. Also, the points delimitating segments D1 and D2 are displayed on the two lines of *Figure 2*, so that, in the areas in which partial volume effect is more evident. Low contrast of images of samples is also due to the absence of soft tissue within the bone, as observed by Ganguly *et al*. [22, 23].

Moreover, considering segments D1 and D2 as evaluation of cylindrical bone samples thickness, results of the study agree with Timock *et al*. which found out that bone thickness measurements have lower reliability than bone height on CBCT images [24].

It must be observed also that all points of reference selected for the experimental protocol carried out in this work, relapse in cranial and caudal portions of cylinders, areas in which the most important bone deformation could have been present. It could be plausible that almost the whole trabecular bone has been distorted due to biopsy modalities requested by use of a coring bur and in particular by the pressing action needed for the initial cut and the traction action functional to the complete avulsion of samples from the bone tissue.

Therefore, the irregular shape of bone cylinder samples, together with a lower resolution of image and the artifacts influence, have made the identification of reference points on CBCT images difficult for the user and consequently have compromised the accuracy of the linear measurements obtained. The difference between CBCT and microCT measurements of about 0.20 mm, obtained in this work, agrees with many studies based in comparison with MSCT in which a sub-millimetric overestimation in CBCT measurements has been reported [24-26]. Nevertheless, observing the standard deviation values obtained by the measurements of D1 and D2 segments for each sample on CBCT images, it is possible to verify that they are very small even including device and user's mistakes which could always affect measurements accuracy.

CONCLUSIONS

Cone-beam computed tomography is one of the most traditional techniques for diagnostic imaging in clinical dental practice. This study has evaluated applicative possibilities of this technology with a comparative evaluation of *in vitro* microCT as standard reference for linear measurement accuracy.

The comparison with microCT, that is a technology used only for *in vitro* analysis, based on the same geometrical shape of X-ray beam but with a higher resolution than CBCT, has the only aim to quantify the mistakes in CBCT measurements.

ANOVA has shown a statistically significant result between mean values of measurements obtained by CBCT and microCT systems which always shows a mathematical difference of about 0.20 mm of overestimation in CBCT ones.

The nature of this comparison has obviously underlined the limits of tomography with cone-beam technology. Anyway, if the real terms of measurement scales needed for an accurate diagnostic evaluation are taken into account, CBCT confirms its role of reliable instrument for diagnosis due to its sufficiently precise measurements, the high power of communication of the tridimensional visualization and the undoubted biological advantage for the patient in terms of low radiation dose absorption.

Although the two instruments examined in this work have been built to make different observations, one *in vivo* and the other *in vitro*, and to obtain images with different resolutions, the linear measurements carried out provide encouraging results, even though statistically different.

In the near future, we will need to improve the reconstruction algorithms used in CBCT *in vivo*, to obtain performance similar to those provided by microCT *in vitro* investigations, perhaps working on a huge amount of comparisons, in order to compensate for the statistically significant difference of their performance in measurement evaluation and image reconstruction.

Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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