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# EVALUATION OF MANUAL CBCT SEGMENTATION TECHNIQUE ACCURACY IN THE VOLUMETRIC ANALYSIS OF BONE DEFECTS: INVITRO STUDY

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## ABSTRACT

**BACKGROUND:** Precise volume assessment of bone defects is crucial for planning reconstructive surgery involving bone grafting. Additionally, detecting the volume of a bone defect is a critical step in assessing its dimensional changes during the follow-up phase. CBCT (Cone Beam Computed Tomography) segmentation is about separating precise structural elements from adjacent anatomy to visualize certain anatomical structure or pathology.

**AIM:** To evaluate the accuracy of manual CBCT segmentation in the volumetric analysis of simulated bone defects.

Materials and methods: Twenty-one bone defects were created in bovine rib blocks. Osteolytic defects were made by perforating the buccal plate of the bone. The Blocks were scanned with an i-CAT CBCT machine. DICOM (Digital Imaging and Communication in Medicine) data were transferred to Mimics software for segmentation and volumetric analysis. To evaluate the accuracy of CBCT segmentation in volume analysis, the results were compared with the physical measurements (gold standard) of the defects using the Wilcoxon-Signed rank test. The intra-class correlation coefficient and Cronbach's alpha reliability coefficient were used to assess the examiners' agreement.

**RESULTS:** Wilcoxon-signed rank test comparisons showed no significant difference between the volumetric analysis of bone defects using CBCT segmentation and the gold standard measurements. The CBCT segmentation of the defects using MIMICS software showed good inter-examiner agreement, with an ICC value of (0.87).

**CONCLUSION:** CBCT segmentation using MIMICS software offers an accurate, user-friendly, and non-invasive option for assessing the volume of bone defects.

**KEYWORDS:** CBCT -segmentation- simulated bone defects- volumetric analysis.

**RUNNING TITLE:** Volumetric analysis by 3d segmentation.

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## INTRODUCTION

Volumetric analysis in dentomaxillofacial radiology unquestionably plays a vital role in evaluating and determining the volume of various structures including the maxillary antrum, tooth socket and bony defects including cysts and tumors (1). These measurements are crucial for assessing dimensional changes in bone defects during follow-up procedures and for determining the success of defect healing (2).

Additionally, volumetric analysis is highly valuable for the clinical assessment and monitoring of various surgical procedures. Following surgical intervention, bone remodeling, a complex process involving the resorption and formation of bone tissue, plays a crucial role in the observed dimensional changes. This process affects the volumetric dimensions of the bone tissue. The volumetric alterations should be thoroughly studied for a better treatment approach (3).

Two-dimensional radiographs cannot accurately depict the actual size of a bone defect. They also have limitations in showing the location of the defect in the three dimensions. Additionally, the bone defect may be obscured by the surrounding anatomical structures (4). CBCT technology was developed in the late 1990s and has since been integrated into dental radiology as a reliable and effective diagnostic tool. CBCT provides high-resolution 3D images of the teeth, jaws, and surrounding structures, offering dentists and oral surgeons valuable insights for accurate diagnosis and treatment planning (5).

Cavalieri principle is a technique for estimating the volume of an object. This method involves slicing the object into parallel slices that are spaced equally apart. The area of each slice is calculated and multiplied by a specific distance between the successive slices to obtain the volume. This technique is currently not used to quantify digital areas and volumes on CBCT images because it is time-consuming (6-8).

Today, with technological advancements, we have access to a time-saving computer-based CBCT technology known as segmentation. Image segmentation is the process of identifying and extracting specific structural data from several images to analyze and understand the anatomy or pathology. This technique utilizes 3D reconstruction to create detailed visual representations (9). Segmentation is the process of separating an image from its surrounding structures into regions with comparable characteristics, such as density (9-11).

CBCT segmentation, the technique of partitioning an image into multiple segments, is a complex task that can be influenced by human bias (12). CBCT segmentation poses specific challenges due to the proximity of various anatomical structures (13). These factors can make it difficult to delineate individual structures within the CBCT images accurately. Additionally, the general limitations in CBCT resolution and the absence of standardized segmentation methods further compound the complexity of the task (13). As a result, there is a need for in-depth investigations of various segmentation methods to address these challenges and improve the accuracy of CBCT image segmentation. Therefore, our study aimed to assess the accuracy of manual segmentation technique using MIMICS software to estimate the volume of simulated bone defects.

Our null hypothesis is that no significant difference exists between the volumetric measurements of simulated bone defects obtained through manual CBCT segmentation and the reference volumetric values.

## MATERIALS AND METHODS

The study was performed after gaining the approval of the Research Ethics Committee, Faculty of Dentistry, Alexandria University (IRB No. 0010556-IORG 0008839) before any research-related activities.

The alveolar bone was simulated by the bovine ribs in this study. They were obtained from a local butcher. The Soft tissue covering the ribs was removed. The rib ridge was flattened utilizing a surgical bur, and the ribs were cut into small blocks of equal size to obtain twenty-one bovine rib blocks. osteolytic defects were created with perforation of one cortical plate while keeping the other plate intact **(Figure 1)**. This was done by using spherical and cylindrical burrs.

**Physical volume measurements (gold standard)**

A silicon-based impression material (Silaxil, Lascod, Ultimate Dental Supply Pty Ltd), was used to fill the bone defects. After setting, the excess impression material was trimmed to keep it confined within the borders of the defect. The impression material was removed from the defect carefully in order not to be deformed. **(Figure 2)** shows the impression material within the defect and after its removal. Then, the impression weight was calculated by a sensitive balance (RADWAG Wagi Elektroniczne, Poland) **(Figure 3)** Using Archimedes' law, the impression's volume was computed by dividing each sample's mass by the Silaxil material's particular density. This method was the gold standard. It was used to determine the reference volume for each defect.

**CBCT scanning and image segmentation**

The Blocks were scanned with an i-CAT CBCT X-ray machine (Imaging Sciences International, Hatfield, PA, USA). The following acquisition parameters were used: 160 × 4 FOV, 0.125mm voxel, 18.54 mAs and 120 kVp. The highest resolution was selected to better visualize bone trabeculae and cortical plate defects and ensure the highest accuracy during manual segmentation.

CBCT DICOM data were transferred to Mimics software (Materialize NV, Leuven, Belgium) for segmentation and volumetric analysis. Manual segmentation was carried out by outlining the defect slice by slice and the defect border was color-delineated. The volume of the simulated bone defect was finally calculated using the 3D object function (properties tool). **(Figure 4)** shows the segmentation procedure and the final 3D volume of the defect on MIMICS software.

According to lindsay essig et al.(14) at least 25% of the cases should be included to assess the inter examiner reliability. To guarantee the reliability of the volume calculation process, about 50% of the defects (10 defects) were individually measured twice by two oral radiologists. with over 10 years of experience in handling CBCT software This rigorous approach was adopted to thoroughly evaluate the inter-observer reliability. For intra observer reliabilty each CBCT scan was segmented twice by the same observer with one week interval between both examinations.

To guarantee the reproducibility of the examination procedure and to confirm the accuracy of the analysis of the artificial lesions, the examinations were carried out utilizing a standardized manner. The examinations were conducted in accordance with the manufacturer's software recommendations. The two examiners were unaware of each other's results. Both examiners followed the same steps during manual segmentation, which was detailed previously. They both used laptops with the same screen size, 15.1 inches.

**Statistical analysis**

The data was inputted into the computer and analyzed using the IBM SPSS software package, version 20.0**.** **(**Armonk, NY: IBM Corp**)**. The Shapiro-Wilk test was used to check the normality of distribution. Quantitative data were described using inter-quartile range, mean, and standard deviation. The significance of the obtained results was judged at the 5% level. Wilcoxon signed-rank test was used to compare non-normally distributed quantitative variables between the two groups. The Bland-Altman plot was utilized to demonstrate the agreement between the analysis methods.

## RESULTS

Quantitative data were described using the minimum and maximum values, inter-quartile range, mean, and standard deviation **(Table1)**. For the CBCT segmentation, the minimum and maximum values were 590.8 mm3 and 1326.6 mm3, respectively. In comparison, the gold standard technique's minimum and maximum results were 747.1 mm3 and 1294.1 mm3, respectively. For the CBCT segmentation technique, the median and interquartile range were 1005.69 and (798.20, 1130.81), while for the gold standard technique, they were 1000.00 and (902.94, 1108.82). Furthermore, the gold standard technique's mean and standard deviation were 1012.25 and ± 162.61 while the CBCT segmentation technique's were 976.46 and ± 219.70.

Wilcoxon-Signed rank test comparisons showed no significant difference between the volumetric analysis of bone defects using the CBCT segmentation and the gold standard measurements (P value = 0.26) **(Table 2)**. The segmentation of the defects using MIMICS software showed good inter-examiner agreement, with an ICC value of (0.87). Furthermore, the intraexaminer agreement was very good, with an ICC value of (0.92) **(Table 3)**.

**Table 1:** Descriptive analysis of the volumetric measurements of bone defects using CBCT and gold standard techniques (N = 21).

| Analysis methods | Min. – Max. | Median (IQR) | Mean ± SD |
|---|---|---|---|
| CBCT segmentation | 590.8 – 1326.6 | 1005.69 (798.20, 1130.81) | 976.46 ± 219.70 |
| gold standard | 747.1 – 1294.1 | 1000.00 (902.94, 1108.82) | 1012.25 ± 162.61 |

*Min.:minimum*
*Max: maximum*
*IQR* :interquartile range,
*SD:* standard deviation

**Table 2:** Association between the CBCT segmentation and gold standard techniques in the volumetric analysis of bone defects (N = 21).

| Analysis methods | 95% CI | *p* value |
|---|---|---|
| CBCT segmentation and gold standard | (-81.06, 9.48) | 0.26 |

Wilcoxon-Signed rank test
*CI:* confidence interval

**Table 3:** Interobserver and intraobserver reliability in performing volumetric analysis of bone defects using CBCT segmentation technique.

| Reliability | ICC | 95% CI | *p* value |
|---|---|---|---|
| **Interobserver reliability** | 0.87 | (0.11, 0.96) | 0.01* |
| **Intraobserver reliability** | 0.92 | (0.23, 0.99) | < 0.001*** |

*ICC* intraclass correlation coefficient, *CI* confidence interval
*Statistically significant at $p < 0.01$
***Statistically significant at $p < 0.001$

The Bland Altman plot compares the disparities between the manual segmentation method and the gold standard technique to the mean of the two measures. The middle horizontal line depicts the mean difference between the two measurements, while the higher and lower horizontal lines represent the 95% bounds of agreement. It was discovered that there is no bias between the CBCT segmentation and the gold standard, with a mean difference (-35.8) **(Figure 5)**.

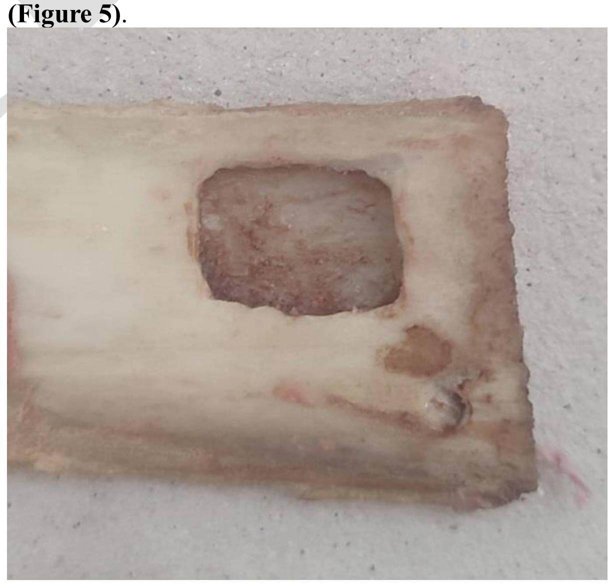

**Figure 1:** Simulated osteolytic bone defect in a bovine rib block.

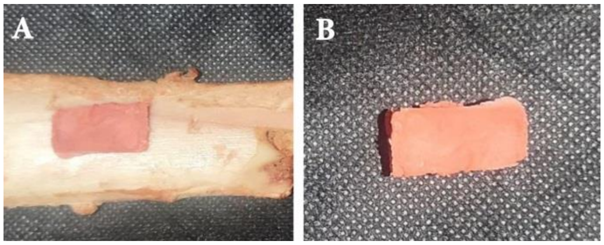


**Figure 2: A)** Impression material was inserted into the defect and left to set. **B)** The impression material was removed from the defect to be weighed.

**Figure 3:** Analytical balance.

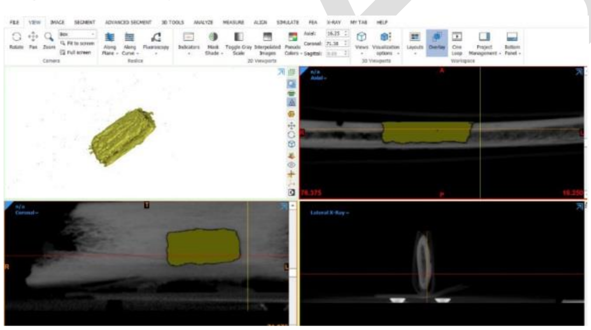

**Figure 4:** Manual segmentation of the defect and the resulting 3D volume on MIMICS software.

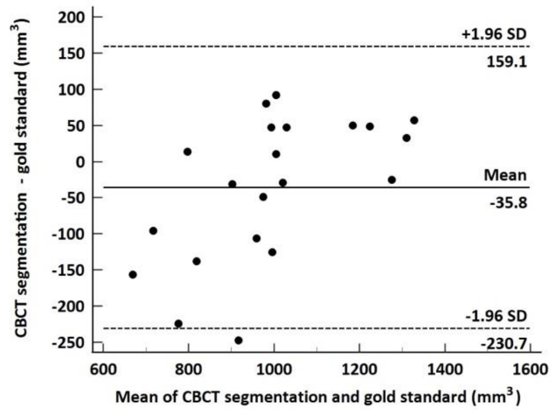


**Figure 5:** Bland-Altman plot for the difference between CBCT and gold standard segmentation methods in volumetric analysis of bone defects ($mm^3$).

## DISCUSSION

Segmentation using CBCT is a critical process in the evaluation of bone volume. This procedure is essential as it provides the surgeon with detailed and accurate information about the total volume and precise dimensions of a bone lesion. This information is vital for planning and carrying out surgical interventions and treatments, ensuring the best possible patient care (15). Manual segmentation was selected for volumetric measurements in this study as it is the most suitable technique for matching the defect's shape (16). It enables the examiner to precisely delineate boundaries in each slice, with the software performing the final volumetric calculation (17).

In our research, bovine rib bone was chosen as an alternative for human bone, despite variations in the density and mechanical properties (18, 19). It has been reported that the structure of cortical bone and bone marrow in bovine bone is sufficiently similar to that of human bone, making it a good alternative (18).

Concerning our study, we intentionally created defects by perforating the cortical wall to examine their impact on the accuracy of the volumetric analysis. After conducting the necessary analysis, we observed that the volumetric measurements of the defects obtained through CBCT segmentation did not exhibit any statistically significant differences when compared to those obtained through the gold standard technique (*P* value=0.26).

The results of our study confirmed a previous finding that assessed the accuracy of volume estimation of intrabony defects using CBCT images. The aforementioned study showed that the estimated volumes were similar to the actual volumes of the bony defects (20). These findings are also in line with a study by Sun et al. (21) which compared bone volume from

CBCT images and the results of a digital caliper method. They found that the measurements were accurate.
Similarly, Hatata et al. (22) compared actual volumetric measures of alveolar bone defects to CBCT measurements to assess their accuracy. The study found that CBCT-estimated volumes were comparable to actual volumes for bone defects. Elbelblawy et al. (23) assessed the accuracy of CBCT segmentation technique using MIMICS software in the volumetric analysis of cystic lesions and revealed no statistically significant difference between the results of the segmentation technique and that of gold standard.
On the other hand, another study compared extraction socket volumes using CBCT images and Archimedes' principle, revealing a significant difference between the two methods (24). The previous study utilized semi-automatic segmentation, whereas our study employed manual segmentation, which may explain the observed differences as semi automatic segmentation technique is prone to software errors. Lo Giudice et al. (4) also found that that the semi automatic segmentation using MIMICS software using threshold-based segmentation algorithms may result in under/ overestimation of boundaries. To accurately define an object's limits, trained doctors can refine manually.
Regarding the Inter-examiner reliability, our study demonstrated strong agreement between the measurements (ICC=0.87), supporting the accuracy of CBCT in volumetric measurement. Similarly, a previous study reported excellent interexaminer reliability. The researchers assessed the accuracy of the volumetric analysis obtained from the CBCT segmentation of induced bone defects and compared their measurements with the actual volumetric measurements. They reported that the CBCT segementation had an excellent agreement with the actual volume. This result aligns with the findings of our study. The researchers attributed the high agreement to the rigorous training program that all examiners underwent to ensure the use of an appropriate strategy (25).
Our current study has some limitations. Firstly, this is an in vitro study. The findings from this study need to be verified in vivo due to factors such as patient movement during x-ray exposure which can impact scan quality. Secondly, The Archimedes principle is useful for determining volume, but its accuracy is dependent on the material's flowability and stability after removal. Reference scanners, such as optical desktop scanners or MicroCT, can be good alternatives for providing precise volume and surface measurements. It would be very interesting to explore semi-automatic segmentation in future studies and compare its accuracy and time spent with those of manual segmentation.

## CONCLUSION

1) This study shows that CBCT manual segmentation is very accurate in determining the volume of a simulated bone defect.
2) The MIMICS software offers a precise, user-friendly, and non-invasive method for accurately assessing bone defect volume through CBCT segmentation manually.

### CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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