CONVENIENCE OF SEMI-AUTOMATIC SEGMENTATION PROTOCOL OF TWO FREE SOFTWARE PROGRAMS USING CONE BEAM COMPUTED TOMOGRAPHY (CBCT): A VALIDITY AND RELIABILITY STUDY

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1) Abstract:

Purpose: This study was conducted to assess semi-automatic segmentation time of the mandible using ITK-Snap and 3D Slicer software programs compared to ground truth manual segmentation.

Methodology: CBCT scans of twelve Egyptian patients were imported into three software programs to segment the mandible. Manual segmentation was accomplished by Mimics commercial software (version 21.0), which served as the gold standard of the present study. The semi-automatic segmentation was carried out using two open-source software packages, namely ITK-Snap (*version 3.8.0*) and 3D Slicer (*version 4.10.2*).

Numerical data were analyzed for intergroup comparisons using repeated measures analysis of variance (ANOVA) followed by Bonferroni post hoc test.

Results: There was a statistically significant difference ($p<0.001$) between different software programs. Region-growing semi-automatic segmentation using ITK-Snap and 3D Slicer software packages was significantly less than that of the manual segmentation ($p<0.001$), and 3D Slicer software being the fastest software.

Conclusions: There was a two- to three-fold reduction in segmentation time when comparing region-growing semi-automatic segmentation protocol of 3D Slicer and ITK-Snap software packages to manual segmentation. Moreover, 3D Slicer software showed less time to segment the mandible compared to the ITK-Snap software although it was statistically insignificant.

Keywords: Cone-Beam Computed Tomography, Mandible, Software.

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2) Introduction:

Over the past decade, dentistry has beheld amazing advances not only in diagnosis, yet also in pre-surgical planning, dental treatment, and post-surgical follow-up through a shift toward digital dentistry. Hence, it is important to utilize imaging modalities that provide detailed information that can ensure accurate diagnosis and good clinical outcomes [1]. Cone beam computed tomography (CBCT) was introduced into the dentistry field and has since made it possible to visualize teeth and skeletal maxillofacial structures in three dimensions with less ionizing radiation and a lower cost when compared to multidetector computed tomography (MDCT) [1, 2]. For tracking the effectiveness of treatments to the patients, CBCT can provide precise volumetric and linear measures [2, 3].

There are several software tools available for segmenting anatomical structures to generate 3D physical models that can be used to assist in pre-operative planning, surgical simulation, and patient management. Image segmentation is the initial stage of anatomical model preparation. Maxillary and mandibular 3D rendering is extremely useful for pre-operative surgical planning and post-operative follow-up evaluation in orthognathic surgery. Moreover, it can be used for the analysis of skeletal facial asymmetry, deformities, and temporomandibular joint (TMJ) asymmetry. In order to improve visualization and analysis, a certain element is segmented from its nearby structures of little relevance [3, 4, 5, 6].

There are a number of segmentation methods, including manual, semi-automated, and completely automatic. In comparison to all automated segmentation techniques, manual segmentation is frequently used as a reference. The automatic approach, on the other hand, is quick but occasionally produces wrong results. Because it combines the great efficiency and reproducibility of automatic approaches with the expertise of an operator, semi-automatic segmentation has been identified as the preferred methodology [6, 7].

Currently, CBCT data processing is frequently carried out using commercial software, which raises the cost of operation and patient administration. To deal with these problems, there is a wide variety of open-source medical imaging software available [8, 9]. The main advantage of open-source software is that it is free to use, which considerably lowers the initial entry barrier. Free software programs like ITK-Snap and 3D Slicer are frequently used for segmentation of the upper airways, maxillary sinuse, pulp cavity, and other structures [10, 11, 12, 13, 14].

Irrespective to the technique used, the calculation of segmentation time was one of the outcomes that we sought, which is a major concern to all software users undertaking in-office applications of anatomic 3D reconstruction. Therefore, the aim of this study was to assess the convenience of two free software packages in semi-automatic mandibular segmentation compared to manual segmentation using commercial software.

3) Materials & Methods:

According to the code of ethics, this study was undertaken after the approval of the Research Ethics Committee of the Faculty of Dentistry, Cairo University, Egypt (approval number 8721).

Sample size calculation was performed based on the primary outcome and was approved by the Medical Biostatistics Unit, Faculty of Dentistry, Cairo University, Egypt. According to the results of (Vallaeys et al. 2015)[15] assuming an alpha (α) level of 0.05 (5%), a Beta (β) level of 0.20 (20%) i.e., power= 80%, an effect size (dz) of 0.9078 the predicted sample size was found to be a total of (12) mandible. The sample size was calculated using G*Power version 3.1.

This is a prospective type of study, where the data collection was considered before the performance of index tests and reference standard. This study was conducted using 12 CBCT data sets from Egyptian Orthodontic patients who came to the Oral and Maxillofacial Radiology Clinic Department, Faculty of Dentistry, Cairo University, Egypt for CBCT imaging during the period from (11/2021 – 8/2022). Cone beam computed tomography images were taken from the workstation of the Oral and Maxillofacial Radiology Department, Cairo University as DICOM file format. CBCT scans with good quality and Field of view (FOV) including the whole mandibular bone were included. Scans with motion artifacts or traumatic injuries, craniofacial deformities, Temporomandibular Joint disorders, dental implants, and bony lesions were excluded.

This computerized database search was thoroughly performed by a maxillofacial radiologist to select cases matching the preset criteria for FOV and disease-free status. All scans were obtained using a Planmeca Promax 3D Mid machine (Planmeca Oy, Helsinki, Finland) with a voxel size of 0.4 Millimeter (mm), current of 8 Milliampere (mA), and peak kilovoltage of 90 kVp, and FOV 20 x10.2 cm.

Semi-automatic segmentation of the mandible was carried out with ITK-Snap software (version 3.8.0; www.itksnap.org) and 3D Slicer software (version 4.10.2; http://www.slicer.org) using the region-growing segmentation method. Segmentations were performed according to each software manufacturer’s recommendations. The initial seeds are located at the structure of interest to be segmented. These seeds selected manually (based on prior knowledge). Neighbors of the seed are compared with the seed using similarity criterion one by one, and if any of them satisfies the condition then that neighbor is also added to the region. The process iterates until no more pixels can be added to the region. Lastly, the segmentation result appear as a 3D model.

In ITK-Snap software CBCT scans were imported, then the region of interest was selected using the Snake Interaction Mode. Thereafter, the segment 3D button was selected to begin the three steps of segmentation namely pre-segmentation, initialization, and evolution. To finetune the segmentation process, the investigator adjusted the segment by erasing or adding areas to the highlighted mandible using the paintbrush mode (Figure 1 and Table 1). In 3D slicer software CBCT scans were imported, then the segment editor module was used to generate two segments (segment in and segment out). At that point, by using the paintbrush in the effects section, the seeds were placed in the three orthogonal planes. The two segments were highlighted by applying grow from seeds function, and the investigator adjusted the segment by erasing or adding to the highlighted mandible using the paintbrush tool (Figure 1 and Table 1).

A fully manual segmentation of the lower jaw was accomplished by Mimics commercial software (version 21.0), ((Figure 2 and Table 1) which served as the ground truth of the present investigation [8, 16, 17, 18]. In this method we manually paints the mandible.

The semi-automatic segmentation time of the two packages of open-source software was recorded in minutes to compare convenience and time efficiency in comparison to manual segmentation.

Statistical Analysis: Assessment of normal distribution and equality of variance of the data was performed with Shapiro–Wilk Normality Test. Since the data were normally distributed, parametric tests were used. Numerical data were presented as mean with 95% confidence intervals, standard deviation. They were analyzed for intergroup comparisons using (ANOVA) followed by Bonferroni post hoc test. Statistical analysis was performed with R statistical analysis software version 4.0.3 for Windows (R Core Team (2021).

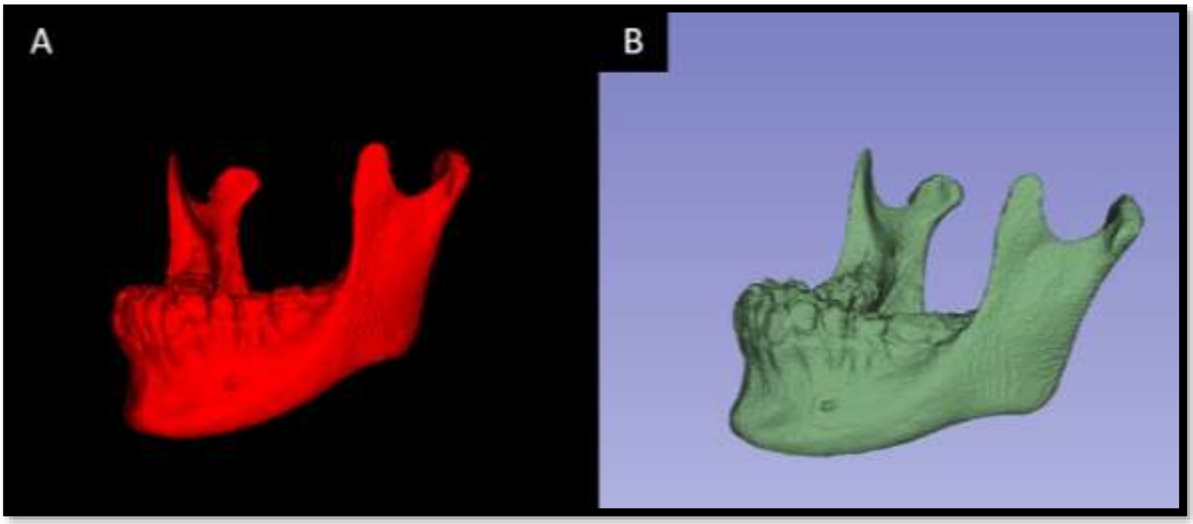

Figure (1) 3D reconstruction of the mandible with (A) ITK-Snap and (B) 3D Slicer software programs.

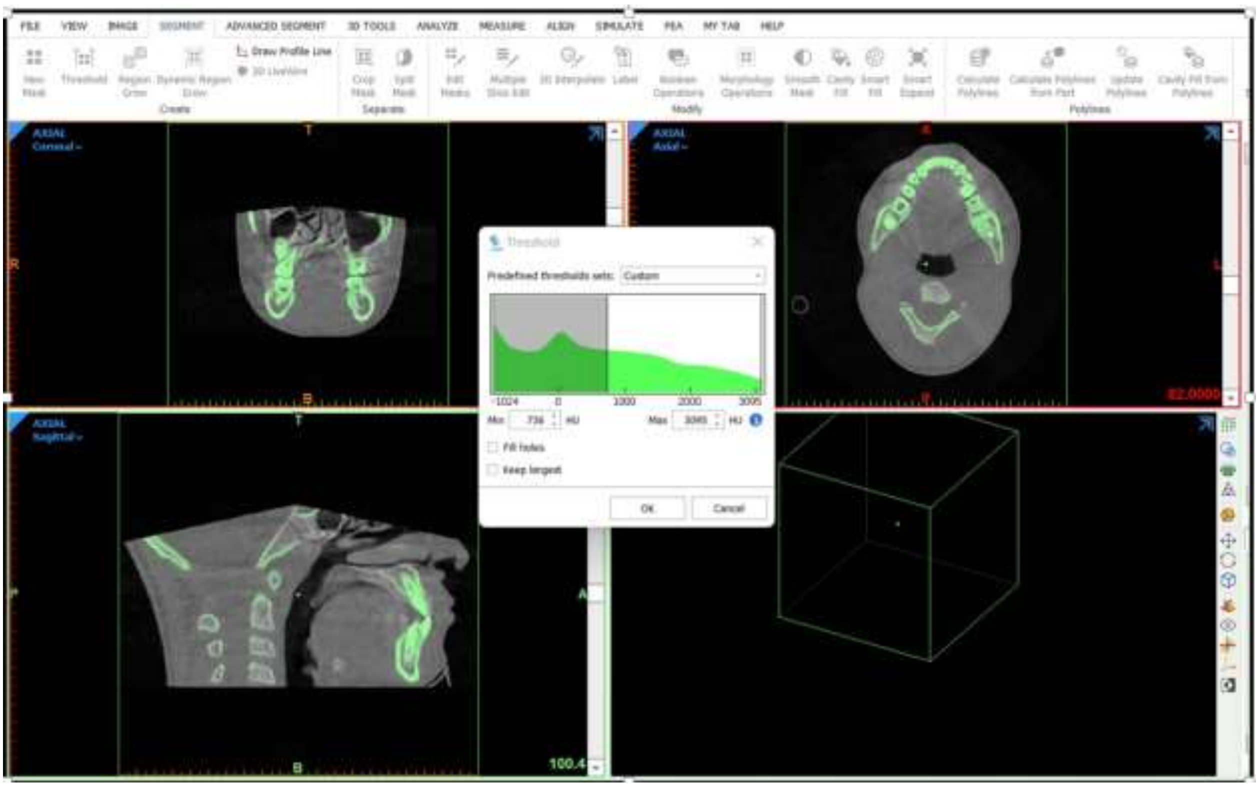

Figure (2) Manual segmentation of mandibular jaw (ground truth) using Mimics software.

Table (1): CBCT DICOM-Viewing Software Packages Description.

Software	Description	Operational system	
Mimics	**Version 21.0** Materialise, Leuven, Belgium	Windows	Not Free
ITK-Snap	**Version 3.8** University of Pennsylvania and Utah, USA	Windows, Mac OS X, Linux	Open-source
3D Slicer	**Version 4.10.2** Harvard University, USA	Windows, Mac OS X, Linux	Open-source

4) Results:

Results of repeated measures analysis of variance (ANOVA) test showed there was a significant difference between different methods ($p<0.001$). The highest value was found in Mimics (214.58±39.79), followed by ITK-Snap (86.25±9.91), while the lowest value was found at 3D Slicer (69.42±10.05) minutes (Table 2 and Figure 3). Post hoc pairwise comparisons revealed that the time for semi-automatic segmentation using ITK-Snap and 3D Slicer software packages was significantly less than that of the manual segmentation ($p<0.001$).

Table (2): Comparison of the segmentation time for the mandible with each software.

Software	Mean time (min)	SD	95% CI		p-value
			Lower	Upper	
Mimics	214.58^{A}	39.79	192.07	237.10	**<0.001***
ITK-Snap	86.25^{B}	9.91	80.64	91.86	
3D Slicer	69.42^{B}	10.05	63.73	75.10	

Means with different superscript letters within the same column are significantly different, SD: standard deviation, CI: Confidence interval,***; significant** ($p \leq 0.05$) **ns; non-significant** ($p>0.05$).

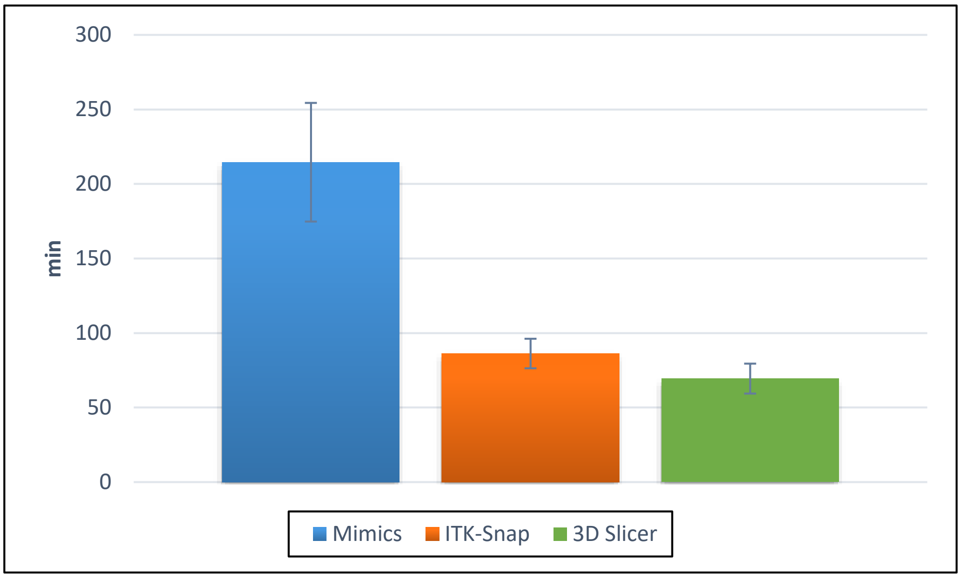

Figure (3) Bar chart showing mean and standard deviation values for segmentation time for each software.

5) Discussion:

The 3D reconstruction of anatomical models such as the mandibular jaw is important for pre-operative planning, surgical simulation, as well as for education and training. Image segmentation is one of the goals of digital image processing and computer applications that are considered to be among the most significant elements of clinical diagnostic tools [19, 20].

Segmentation is a significant step in many medical applications as 3D visualization of detailed patient anatomy, volumetric measurements, image-guided surgery to supply surgeons with a 3D model of patient-specific anatomy, and detection of anatomical changes over time. Furthermore, it plays a vital role in surgical planning and intra-surgical navigation [21, 22].

A wide variety of segmentation techniques or algorithms have been proposed in the literature. Unfortunately, there is no standard technique that can produce satisfactory results for all imaging applications, and as a result, segmentation remains a challenge. Clinical acceptance of segmentation methods depends on their computational simplicity and the degree of user supervision. Segmentation of medical image data has to be fast and accurate to be useful in a clinical setting [23, 24].

The availability and variety of post-processing software packages have grown with the digital revolution of dentistry which offer more options for further research to improve patient management [1, 2, 7].

Commercial software programs tend to have a much more user-friendly interface, but high purchase costs are an issue. In the last few years, many open-source software packages that can be obtained for free could open up opportunities for more general use of bone models, with obvious advantages for biomechanical research, and medical education. These software packages provide manual, semi-automatic, or automatic segmentation capabilities [1, 2, 8, 16, 18].

These software packages were chosen as they have several advantages, including being free-source programs with good threshold sensitivity, correction tools for segmentation mask, and compatibility with multiple operating systems (Windows, Mac OS X, and Linux) [25]. The region-growing segmentation method was selected as it is relatively simple and more immune to noise compared to other methods of segmentation. Moreover, (Verhelst et al. 2020) [26] advocated that the combination of semi-automated segmentation protocol with thresholding and region-growing algorithms helps achieve a high level of accuracy with a low chance of operator-dependent error in mandibular analysis.

It is noteworthy that the selection of the threshold is dependent on the software algorithm, the spatial and contrast resolution of the scan, the thickness and degree of cortication of the bony structure, and the technical skill of the operator [27]. Therefore, semi-automatic segmentation of the mandible in this study was performed by using the interactive threshold technique.

Although segmentation is very promising in the diagnostic field, nevertheless, we should bear in mind that the accuracy of the segmentation process can be affected by several factors that can significantly influence the quality of the segmented models such as metallic artifacts, patient motion, voxel size, field of view, and beam inhomogeneity of CBCT scanners. Therefore, all these factors should be adequately assessed to quantify the amount of error that might arise from such differences [7].

An old and more recent study performed by (Damstra et al. 2010) [28] and (Mukhia et al. 2021) [29], were undertaken to assess the accuracy of voxel size. Both found that the voxel size did not have a significant influence on the accuracy of 3D models derived from CBCT. Moreover, they recommended the use of 0.4 mm voxel protocol to compromise between accuracy and low radiation exposure. On the other hand, (Van Vlijmen et al. 2011) [30], and (Sang et al. 2016) [31] found that the scanner type had a significant influence on the accuracy of the segmented surface models. Accordingly, the collected CBCT scans in this study were obtained from the same CBCT machine, with the same acquisition parameters and voxel size 0.4 mm. Thus, all factors affecting the accuracy of the 3D model rendering were controlled before the segmentation process and differences were limited to the usage of different software. For that reason, we excluded CBCT scans with metallic or motion artifacts, craniofacial deformities, dental implants, or traumatic injuries.

The quality of life of patients is the main concern for clinicians in patient management. Despite the present abilities of freeware software packages, these cannot currently be used in clinical practice because of the lack of necessary certification. Therefore, in a clinical context, it is essential to understand which free software best fits the surgeon's expectations from different perspectives. Assessment of the processing time taken to fully develop a model is one of the main features that should be taken into consideration during anatomical reconstruction.

The time of segmentation may vary significantly depending on the ROI being segmented as well as depending on the speed of the software program used. The shorter the duration of this step, the more hassle-free and convenient the process will be for the users [32]. Since there is no sufficient evidence in the literature validating the time efficiency of open-source software programs in detecting the volumetric and morphological characteristics of mandibular bone [8, 12, 18]. Therefore, in this study we assessed the time for semi-automatic segmentation using free software packages compared to manual segmentation by Mimics software.

It is noteworthy by several research groups that the 3D reconstruction of the mandible has acceptable results helping to broaden the scope of its clinical applications, especially in orthodontics and maxillofacial domain [7, 8, 18, 33, 34]. Furthermore, semi-automatic segmentation of the maxilla is still questionable due to the notable inaccuracy presented. This was claimed to be due to the variations in cortical bone thickness and the presence of the maxillary sinus, which produce bone dehiscence and fenestration artifacts in the 3D model. Therefore, in this current study, we decided to assess the time efficiency of the semi-automatic segmentation of the mandible in comparison to the manual segmentation [7, 34].

According to our findings, there was a statistically significant difference between the time needed for manual segmentation by Mimics software, and semi-automatic segmentation by both the ITK-Snap and 3D Slicer open-source software packages. Mandibular manual segmentation takes an average time of 214 minutes (3.5 hours), as opposed to 86 minutes for semi-automatic segmentation using the ITK-Snap program and 69 minutes using the 3D Slicer software. There is a two to three-fold decrease in time when comparing manual to semi-automatic techniques. This significant reduction in time will ultimately improve the user experience and allow the process to be more hassle-free and user-friendly. Considering the comparative assessment of the efficiency of the two tested software packages, 3D Slicer software showed less time to segment the mandible compared to the ITK-Snap software although it was statistically insignificant.

Our results are consistent with (Argüello et al. 2019) [17] and (Lo Giudice et al. 2022) [25] who also found that the 3D Slicer software is faster than ITK-Snap software. The fast segmentation time in the 3D Slicer program is a consequence of the program's high threshold sensitivity for region-growing seeds, which enables accurate segmentation while maintaining a reasonable segmentation time.

6) Conclusions:

Regarding the mandible, comparison of the segmentation time for semi-automatic method using ITK-Snap and 3D Slicer open-source software packages was significantly less than that of the manual segmentation. Moreover, it can be inferred that the 3D Slicer software would represent the best alternative to manual segmentation in terms of time efficiency.

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8) Conflict of interest: Authors declared there was no conflict of interest.

9) Clinical recommendations:

Future studies should evaluate the performance of 3D Slicer and ITK-Snap open-source software programs in different anatomic regions and using different CBCT scanners. Using the same methodology, further studies are needed to assess the time efficiency of other open-source software packages and their built-in segmentation modules.

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