Comparison of 3D reconstruction of mandible for pre-operative planning using commercial and open-source software

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Comparison of 3D reconstruction of mandible for pre-operative planning using commercial and open-source software

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Abstract. 3D printing of mandible is important for pre-operative planning, diagnostic purposes, as well as for education and training. Currently, the processing of CT data is routinely performed with commercial software which increases the cost of operation and patient management for a small clinical setting. Usage of open-source software as an alternative to commercial software for 3D reconstruction of the mandible from CT data is scarce. The aim of this study is to compare two methods of 3D reconstruction of the mandible using commercial Materialise Mimics software and open-source Medical Imaging Interaction Toolkit (MITK) software. Head CT images with a slice thickness of 1 mm and a matrix of 512x512 pixels each were retrieved from the server located at the Radiology Department of Hospital Universiti Sains Malaysia. The CT data were analysed and the 3D models of mandible were reconstructed using both commercial Materialise Mimics and open-source MITK software. Both virtual 3D models were saved in STL format and exported to 3matic and MeshLab software for morphometric and image analyses. Both models were compared using Wilcoxon Signed Rank Test and Hausdorff Distance. No significant differences were obtained between the 3D models of the mandible produced using Mimics and MITK software. The 3D model of the mandible produced using MITK open-source software is comparable to the commercial MIMICS software. Therefore, open-source software could be used in clinical setting for pre-operative planning to minimise the operational cost.

INTRODUCTION

Three-dimensional (3D) model is a physical object that is created using 3D printing process through successive material layering. The technology is known as rapid-prototyping (RP) because its main use is to quickly create cost-effective prototypes during the design process. RP is also known as 3D printing [1] or additive manufacturing [2, 3]. The printing of patient-specific 3D models has been used for pre-operative planning [4], surgical guide [3], as well as for medical education [5].

3D printing of mandible is important for pre-operative planning, diagnostic purposes, as well as for education and training [6]. In the absence of a 3D model, plates are bent intra-operatively in to conform to the patient's mandibular structure. Then, bone graft from fibula free flap and fixation plates have to be reshaped during the operation by trial and error, which is often a time-consuming procedure. Additionally, the cost for operation would be higher, as more time is spent in the operation theatre.

3D model of the mandible can be used in a variety of ways to improve medical education and patient management. One way to produce 3D model is to convert Digital Imaging and Communications in Medicine (DICOM) data, obtained during the acquisition of computed tomography (CT) radiographs, into a file that can be read by a 3D printer.

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The ability to efficiently and accurately 3D print patient-specific anatomic details improves surgical education and preoperative planning [5].

The 3D printer can fabricate the 3D models directly from a 3D virtual model with very complex geometry [7]. It provides a new concept for the clinical treatment in orthopaedics and maxillofacial surgery.

Currently, the processing of CT data is routinely performed with commercial software [8] which increases the cost of operation and patient management for a small clinical setting. Articles addressing the 3D reconstruction of mandibles were searched in PubMed using the following three keywords: 3D model, reconstruction, and mandible. The search yielded 65 results. All papers were studied; 28 were published before year 2010, 2 were not in English, and 14 did not match the criteria—they were focused on unrelated studies, or does not mention the type of software used, or were not available—and were thus excluded. Out of the 21 related papers, 20 used commercial software and one with open source software. However, this open source software is a lighter version of an actual licensed version, and applicable to Mac operating system (OS) only.

The use of open-source software as an alternative to commercial software for 3D reconstruction of the mandible from CT data is scarce. The aim of this study was to compare two 3D models of the mandible reconstructed using commercial and open-source software.

MATERIALS AND METHODS

This was a preliminary study to produce patient specific physical models of mandible for pre-operative planning. Sample population was obtained randomly from the Picture Archiving and Communication System (PACS) server at the Radiology Department, Hospital USM. Ethical application was approved by the Ethics and Research Committee USM (FWA Reg. No: 00007718; IRB Reg. No: 00004494), reference number USMKK/PPP/JEPeM (259.3[2]) dated 15th January 2013. Patients were scanned using the Siemens Somatom Definition AS+ 128-slice (Siemens, Erlangen, Germany) housed at the Radiology Department, Hospital USM.

Head CT images with a slice thickness of 1 mm and a matrix of 512x512 pixels each were retrieved from the server were retrieved from the PACS Server to a Dell Precision T7500 workstation in DICOM format. Five scans were processed using both commercial MIMICS software, version 17.0 (Materialise NV, Belgium) and open source Medical Imaging Interaction Toolkit (MITK) software, version 2015.05.2 (German Cancer Research Centre, Germany). Both MIMICS and MITK use the existing axial view to create cross-sections in the sagittal and frontal views for the 3D image segmentation.

MITK software [9-11] was first utilised as an in-house medical image analysis solution for the German Cancer Research Centre, Germany, and later published in 2005 [11]. It started primarily as a toolkit, focusing on support for interactive multi-view applications. This software is an open source medical image processing framework that fulfils a specific and pressing need of craniofacial imaging research by providing a combination of manual and semi-automatic tools for extracting structures of interest. It allows interactive segmentation [9] with simultaneous image viewing and outlining of regions in axial, sagittal, and coronal orientations

The sequence of the CT images, representing the various sections the anatomical structures, can be identified on the basis of the grey scale of the pixels. The Hounsfield Unit (HU), which expresses the gray scale, was adjusted accordingly using threshold method to separate hard tissues and soft tissues. Then, region growing method was employed to separate the skull from other parts. Another segmentation process was performed to separate the mandible from maxilla by separating the embedded teeth, as well as mandibular condyle from mandibular fossa of temporal bone. Finally, region growing method was applied again to produce only the mandible for further assessment as shown in Figure 1. The virtual 3D surface models of the mandible can then be saved in STL format for 3D printing of the physical 3D model.

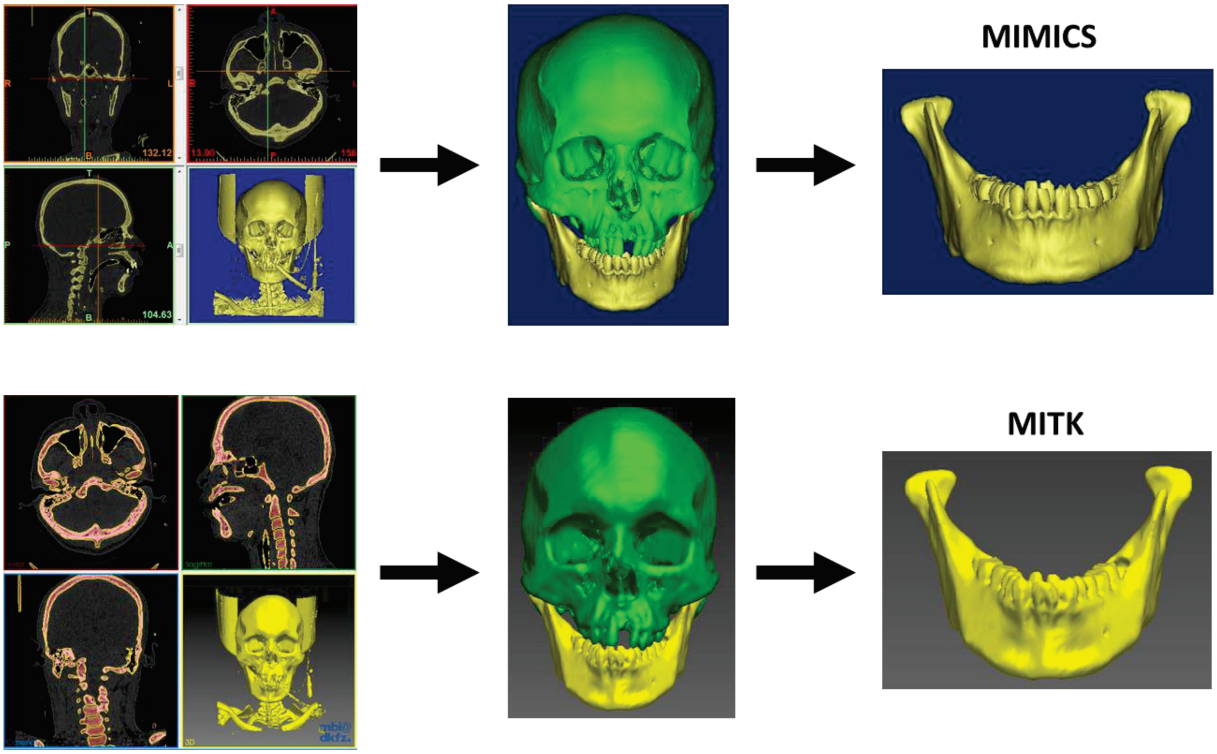

FIGURE 1. SEGMENTATION OF THE HARD TISSUES AND MANDIBLE USING MIMICS AND MITK SOFTWARE. 1(A): CT DATA IN DICOM FORMAT VISUALISED IN MIMICS AND MITK SOFTWARE 1(B): EMBEDDED TEETH BETWEEN MAXILLA AND MANDIBLE 1(C): THE FINAL 3D MODEL AFTER SEPARATION OF MANDIBLE FROM THE SKULL

The STL format of the 3D models of mandible produced by MIMICS and MITK software were imported into 3Matic modelling software (Materialise NV, Belgium) for morphometric analyses as shown in Fig. 2. The mandibular models were assessed for the following distance between identified landmarks: infradentale-gnathion, mental foramen to mandibular crest, mental foramen to inferior mandibular border [12, 13], bicondylar breadth [14] and distance over the surface from left mental foramen to right mental foramen.

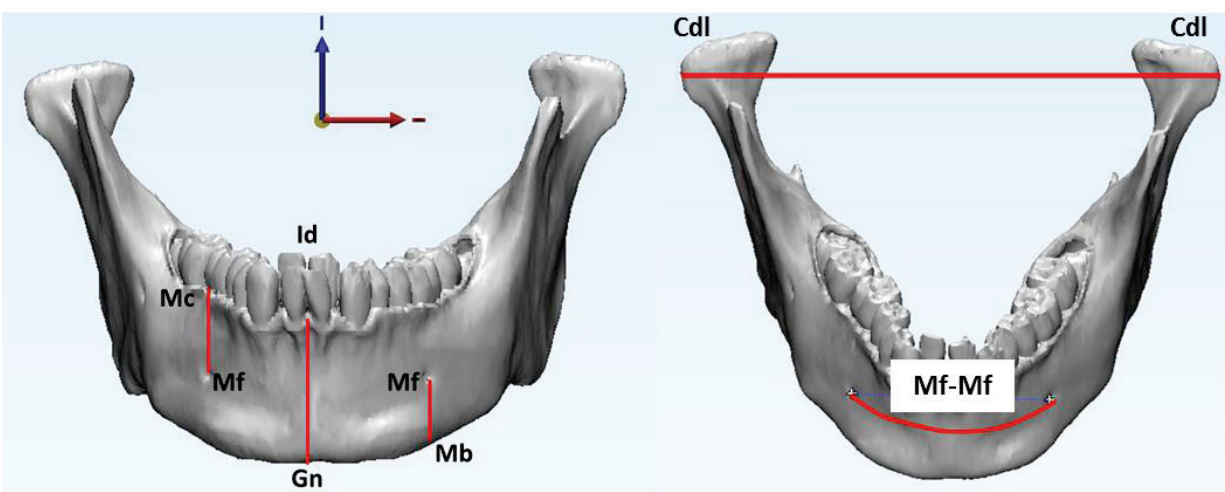

FIGURE 2. 3D VIEWS OF THE MANDIBLE WITH LANDMARKS FOR MEASUREMENTS IN 3MATIC MODELLING SOFTWARE.

Measurement of five distance between landmarks on 3D models of mandible of five patients was carried out by one researcher, and repeated three times. After the first measurements were completed, the results were blinded to the researcher before trying the second measurements a week later. Following completion of the landmarks measurement the first time, all data were saved and the program was reset. The researcher then carry out the procedure again for the second time, and then the third, to get three sets of measurement. The blinding was carried out to minimize the examiner's bias. The average of the three readings of each measurement was considered for the final statistical analysis in order to minimize the intra-examiner variation.

The IBM SPSS Statistics version 22 (IBM, Armonk, NY, USA) was used for statistical analyses. Statistical significance was set at $p < 0.05$. A Wilcoxon Signed Rank Test was conducted to compare between the measurements of MIMICs software and MITK software.

The five sets of 3D models produced using MIMICS and MITK were then compared to analyse the differences and similarities of the results obtained using Hausdorff Distance. This was achieved by calculating point by point, the distance between two geometry objects and then measuring the actual dimension in millimetres. The smaller the distance between the two points, the greater the similarities between the two models at that point. To compute the geometric difference between the two 3D models of the mandible, MeshLab software was employed to calculate the Hausdorff Distance. After calculating the Hausdorff Distance, to better visualize the error, the values were represented by colours in red-green-blue colour map. In this colour map, the red colour is minimum and the blue colour is maximum, therefore, red means zero error (good) and blue means high error (bad) as shown in Fig. 3.

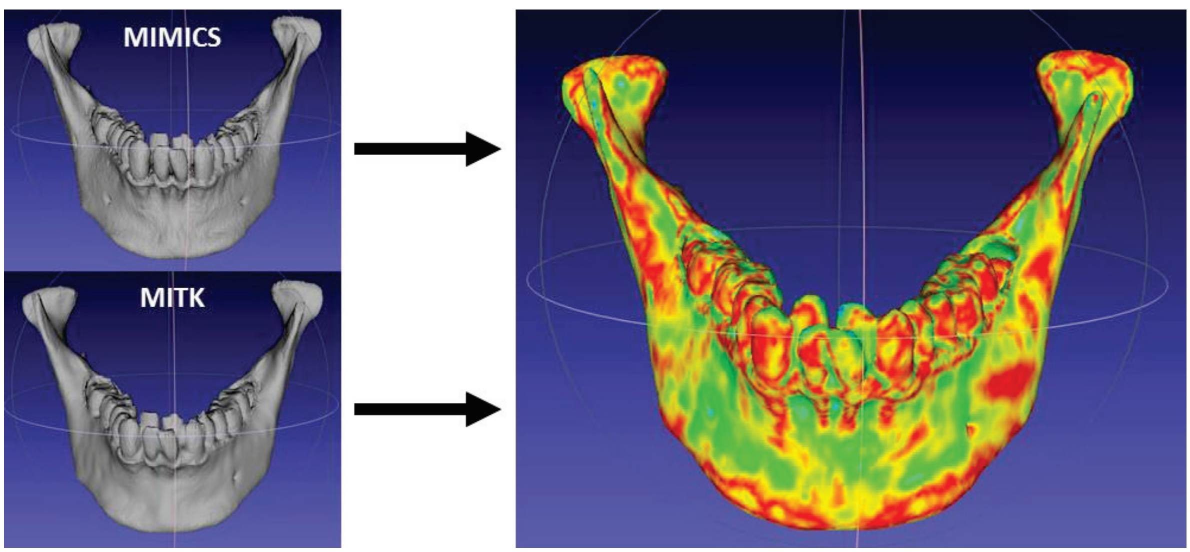

FIGURE 3. THE GEOMETRIC DIFFERENCE BETWEEN 3D MODELS OF MIMICS AND MITK COMPUTED IN MESHLAB SOFTWARE.

RESULTS AND DISCUSSIONS

Results of the landmark measurements are shown in Table 1. A Wilcoxon Signed Rank Test was conducted to compare between the measurements of MIMICs software and MITK software.

TABLE 1. THE MEASUREMENTS OF LANDMARKS ON MANDIBLE (n = 5)

Patient's No.	Landmarks	Median (IQR) of measurement (mm)			
		p	MIMICS	MITK	Difference
1	infradentale-gnathion (Id-Gn)	0.1	29.06 (5.34)	30.53 (5.30)	1.47
2	mental foramen–mandibular crest (Mf-Mc)	0.5	14.62 (3.12)	14.43 (2.02)	-0.19
3	mental foramen–mandibular border (Mf-Mb)	0.7	14.32 (1.87)	14.3 (2.44)	-0.02
4	bicondylar breadth (Cdl-Cdl)	0.2	122.43 (15.65)	122.03 (14.4)	-0.40
5	mental foramen–mental foramen (Mf-Mf)	0.1	59.53 (4.12)	57.65 (5.12)	-1.88

Significance level was set at 5%

There was no significant difference ($p > 0.05$) between the two groups for all five measurements. The three times blinded measurement were applied which helped to reduce error, as the average of three measurements were used. The results demonstrate that both 3D models produced by MIMICS and MITK software are comparable.

TABLE 2. THE GEOMETRIC DIFFERENCE (HAUSDORFF DISTANCE) BETWEEN THE TWO 3D MODELS OF THE MANDIBLE

Patient's No.	Maximum error (%)	Average error (%)
1	0.7	0.16
2	0.6	0.15
3	0.7	0.16
4	2.3	0.15
5	1.0	0.16

Results of the geometric differences applying Hausdorff Distance are shown in Table 2. The maximum error between the two meshes is approximately 2%, but on average the errors of two 3D models are less than 1%. Therefore, the two 3D models are geometrically very similar.

Research in the medical imaging has become increasingly complex over the years. The availability and variety of modalities has grown; for example, the advancement in MR and CT images offers more options for further research to improve patient management but at the same time the researchers will be faced with more challenges. These are in the form of cost and expertise to deal with the software.

Many open-source software exist for medical imaging to solve these challenges. This software may provide manual, semi-automatic, or automatic segmentation capability, but they tend to be either very broad or very specific in the scope of functionality that they provide. For instance, 3D Slicer [15] and MIPAV [16] software provide large-scale packages/functionalities; however, they carry a steep learning curve, due to the large number of features that they provide. Some software is specialized, created by a small team or even by a single person as the result of a research project, an example is the ITK-SNAP [17]. This software streamlined towards one specific task which uses user-guided 3D active contour segmentation [18].

Out of the 21 related papers that applied the use of software to segment and produce 3D model of the mandible, 20 studies applied commercial software, where 12 of them were using MIMICS software [3, 4, 19-28], another 8 studies were using different type of commercial or in-house software [29-36] and one adopted open-source software [37].

Arzi et al. [37] employed OsiriX software to view and segment CT images of the rostral mandible to produce 3D models. However, OsiriX software is only available for Apple computer using Mac OS, and they are divided into free version (OsiriX Lite) and commercial version (OsiriX MD 64-bit) as stated in OsiriX website at http://www.osirix-viewer.com/Downloads.html. In Malaysia, Microsoft(R) Windows® OS is more popular and widely adopted by the researchers as well as the surgeons. Therefore, it is preferable for the software to be compliant with Microsoft® Windows® OS, or cross-platform. The OsiriX software is well accepted by some researchers for some studies [38-40]. However, it is not cross-platform as it is confined to Mac OS. According to Nolden et al.[10], the OsiriX software locks the user and its licensing policy limits the developer. The free version of OsiriX offers less capabilities compared to the commercial version, which is a disadvantage if further assessment is needed.

Research in medical imaging has become increasingly challenging over the past decades due to the introduction of new imaging modalities and more demanding clinical needs [10]. The MITK software offers flexible user interface with a powerful and robust framework. It provides an extensible application framework for creating custom medical image applications. Its flexible and customizable user interface makes it well suited for usage in different clinical settings. This software has a growing number of users and contributors of various backgrounds and experience levels. It is established and has been accepted by the open-source community [9-11]. MITK is available for Windows, Linux, and Mac operating systems. They have also a few versions of software which are all free for download from their website.

The quality of life of a patient is the main concern for clinicians in patient management. The use of open-source software in a clinical setting reduces the overall cost incurred by the clinician and the benefit is passed down to the patients.

CONCLUSION

The 3D model of the mandible produced using MITK open-source software is comparable to the commercial MIMICS software. Thus, open-source software should be employed in clinical setting for pre-operative planning for minimising the operational cost.

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