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The accuracy of three-dimensional fused deposition modeling (FDM) compared with three-dimensional CT-Scans on the measurement of the mandibular ramus vertical length, gonion-menton length, and gonial angle

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Abstract. Presurgical treatment planning plays an important role in the reconstruction and correction of defects in the craniomaxillofacial region. The advance of solid freeform fabrication techniques has significantly improved the process of preparing a biomodel using computer-aided design and data from medical imaging. Many factors are implicated in the accuracy of the 3D model. To determine the accuracy of three-dimensional fused deposition modeling (FDM) models compared with three-dimensional CT scans in the measurement of the mandibular ramus vertical length, gonion-menton length, and gonial angle. Eight 3D models were produced from the CT scan data (DICOM file) of eight patients at the Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, University of Indonesia, Cipto Mangunkusumo Hospital. Three measurements were done three times by two examiners. The measurements of the 3D CT scans were made using OsiriX software, while the measurements of the 3D models were made using a digital caliper and goniometry. The measurement results were then compared. There is no significant difference between the measurements of the mandibular ramus vertical length, gonion-menton length, and gonial angle using 3D CT scans and FDM 3D models. FDM 3D models are considered accurate and are acceptable for clinical applications in dental and craniomaxillofacial surgery.

1. Introduction
The reconstruction and correction of defects in the craniomaxillofacial region require careful preoperative planning. This is because the anatomy in this region is very complex, involves sensitive systems and, most of all, affects facial appearance [1,2]. Even a small deformity can greatly affect functionality and aesthetics [2-7]. Conventional preoperative planning uses cephalometric analysis based on a two-dimensional radiograph and a study model mounted on an articulator [3]. However, technological advances in computed tomography (CT) have had major impacts in the world of craniomaxillofacial surgery [1,8]. The development of CT has been fast, creating new approaches and treatments and enabling practitioners to obtain a 3-dimensional (3D) model of the skull using the solid free-form fabrication (SFF) technique. Its clinical applications include orthognathic surgery, post-traumatic reconstruction or tumor ablation, and implantology [5,8-13].
Soon after its discovery in 1986, the SFF technique was developed to create prototypes in the design of new industrial products. This technique changed the method of making prototypes, which initially required a long time. New design and rapid prototyping (RP) techniques [4], including selective laser sintering (SLS), fused deposition modeling (FDM), 3D printing (3DP), and stereolithography (SL), shortened the time frame for creating prototypes [8,14,15].

The SFF technique has evolved significantly and has affected many areas, including the medical field. With this technique, structures can be replicated with precise geometry from 3D medical imaging data, such as information from CTs and MRIs in the form of Digital Imaging and Communications in Medicine (DICOM) files. In craniomaxillofacial surgery, CT imaging is chosen because it provides the best 3D data of the bone structure. The DICOM file is then processed with software and converted into a file with the Standard Tessellation Language (STL) format. Some of the available software platforms include OsiriX, MIMICS, CT-Modeller, Simplant, NobelGuide, AMIRA, iPLAN 3.0, and MagicsRP [1,13,16,17]. An STL format file can be used to create a model of the skull in 3D [4,5,8]. The potential for errors exists in each stage of the process, and they can produce a distorted final model [18].

Several studies have examined the accuracy of 3D models made by using the SFF technique. Huotilainen et al. analyzed a 3D skull model and reported inaccuracies that were caused by the process of converting a DICOM file into the STL format [8]. In 1996, Kragskov et al. compared 3D CT-scans with a stereolithography model in four patients with craniofacial anomalies and obtained deviation results that were large enough to be problematic [16]. However, other studies have had different results. It was reported that the accuracy of a paper-based 3D model that was made using a 3D printer [15]. Nizam et al. compared the dimensions of a 3D skull model with four dry skulls and showed a very small difference, which was deemed acceptable for clinical applications in oral and maxillofacial surgery [17].

CT examination with 3D reconstruction is the current gold standard of examination and is often used in the Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, University of Indonesia, especially in tumor cases, complex trauma, or congenital defects. In such cases, the role of 3D modeling has grown. In addition to help with making the diagnosis and determining the treatment plan, the 3D model is also used for pre-bending the reconstruction plate. This study was conducted to determine the accuracy of 3D models by comparing the vertical length of the ramus of the mandible, the length of the gonion-menton, and the gonial angle on the model with measurements on a 3D CT reconstruction. This kind of tracing was chosen because the structures are highly calcified, so they can be properly captured and documented by the CT scanner and duplicated by RP machines [17]. In addition, the selection of this tracing was based on measurements that have been statistically validated [19].

2. Materials and Methods

This study involved a laboratory experimental test to assess the accuracy of a 3D model by comparing the results of measurements of the vertical length of the ramus of the mandible, the gonion-menton length, and the gonial angle in the model with 3D CT reconstruction. The study was done at the Laboratory of Biomedical Technology, Post Graduate Program, Universitas Indonesia. The study was conducted from June 2015 until July 2015. The subjects of this study were taken from the CT scan data of patients of Oral and Maxillofacial Surgery, Faculty of Dentistry, University of Indonesia, Cipto Mangunkusumo Hospital, Jakarta.

The study sample was calculated using formula from Dahlan [20], it was determined that the number of samples was 8. Subjects of the study had the following inclusion criteria: the digital data were in DICOM format, the data were not corrupted and readable, and the data were obtained from patients aged over 18 years old who had intact mandibular segments. Exclusion criteria of the study subjects included any defects on one side of the mandible past the midline.
2.1. The Study Stages.
Data from CT scans and DICOM were converted into 3D CT reconstruction data. By using the OsiriX application, some of the data were converted into the STL format for 3D models. The reference points of the condylion, gonion, and menton on the 3D CT image were determined. The lengths of the ramus of the mandible and the gonion-menton were measured using a digital caliper. The gonial angle was measured using VRC series collection with a sagittal view. The measurements were performed three times by two examiners, with the interval between each measurement within 1 week. They were performed in the morning to avoid eyestrain. The level of detail was set to the fine position, and the surface rendering and data were saved in the STL format. The STL format file was then opened with the DS Catia program for correcting and smoothing until the data were ready to print. In the Catalyst program, which is associated with the FDM printer, the amount of material required and the estimated time for the printing process can be estimated. The data was then uploaded to the FDM printer to produce the 3D model.

2.2. Data Management and Analysis.
The primary data from the measurements that were collected were recorded and entered into a computer for analysis using SPSS 17.0 software. Measurements of the vertical length of the ramus of the mandible, the length of the gonion-menton, and gonial angle on 3D CT and 3D models were carried out by two examiners three times. The measurement results were calculated to determine the technical error of measurement (TEM) value. The results of the measurements of the examiner with the lowest TEM value was then tested by an ANOVA repeated test. After the ANOVA repeated test, a paired t test was conducted to compare the results of measurements on the 3D CT and 3D models.

3. Results and Discussion
3.1 Results
All measurements were performed by two examiners. Both examiners did all the measurements three times in a span of 1 week. To obtain the most accurate measurement and objective, calculation of the TEM value was established. A normality test of data distribution in each group was done. The Shapiro-Wilk normality data test was used because the number of samples in each group was less than 50. A p-value > 0.05 was obtained for all measurement variables, so the data distribution was normal. The statistical analysis indicate that the comparisons of measuring the vertical length of ramus of the mandible, length of gonion-menton, and gonial angle on the 3D CT and 3D models have significant differences where p > 0.05. (Table 1)

| Measurements                      | Means of 3D CT Measurement (SD) | Means of 3D Models Measurement (SD) | Difference (SD) | p-value |
|----------------------------------|---------------------------------|------------------------------------|-----------------|---------|
| Length of ramus of the mandible  | 58.33 (6.18) mm                 | 58.21 (6.26) mm                    | 0.12 (0.33) mm  | > 0.05  |
| Length of gonion-menton         | 80.49 (7.34) mm                 | 80.61 (7.52) mm                    | 0.12 (1.72) mm  | > 0.05  |
| Gonial angle                    | 122.17° (12.24°)                | 122.59° (8.82°)                    | 0.42° (4.05°)   | > 0.05  |

3.2 Discussion
The success of a reconstruction treatment and correction of defects in the craniomaxillofacial region is greatly influenced by careful preoperative planning. One of the technological advances that are now widely used in preoperative planning in the medical field is specific 3-dimensional modeling for each patient. This 3D model plays a very important role in complex cases where supporting examinations in
the form of 2D and 3D imaging is not adequate, so it requires a high level of accuracy. Regardless of the technique used, errors can occur at any of the multiple stages of making a 3D model, including DICOM data processing, the conversion phase into STL data, the 3D model production process, and the finishing process.

This study compared measurements of the vertical length of the ramus of the mandible, the gonion-menton length, and the gonial angle using 3D CT, which is the gold standard in supporting the examination of patients with 3D models using FDM technology at the Department of Oral & Maxillofacial Surgery, Faculty of Dentistry, University of Indonesia, Cipto Mangunkusumo Hospital. Several researchers have used 3D CT as a control group because a very high level of accuracy has been demonstrated in previous studies, without distortions in the shape, size, and spatial aspects. In fact, several studies have confirmed the accuracy of the surface landmarks of the skull on 3D CT [17, 21].

The selection of the anatomical structure that is used as the reference point affects the accuracy of measurement. According to Nizam, the selected anatomical structure should be well captured by CT imaging, and the structure should be highly calcified, such as bones and teeth [17]. Preferably, the reference point should have been previously validated statistically [19]. Therefore, the condyion, gonion, and menton were selected as the reference points for the measurements in this study.

The software packages used in this study, OsiriX MD and DS Catia, were selected because they could be obtained at no cost, but were certified for use in the medical field. The 3D printer used in this study was the U Print Plus, which is made by Stratasys, a pioneer in the manufacture of 3D printers using the FDM technique.

Distortion in a model may occur due to gantry tilt on the CT imaging. But in some cases, gantry tilt is required to obtain the optimal orientation of the pieces. Improper segmentation can also cause distortion. Therefore, the selection of data that was included as a sample in this study was very important. Errors can also be caused by the process of refining the surface at the time of 3D imaging reconstruction [16].

Residue polymerization, the finishing process, the thickness of each layer, and the removal of the support structure can also cause errors. Ozwelski stated that the post-production process, even if it is done with care, can also cause errors, especially when using certain software packages. However, previous studies have claimed that the distortions that occur as a result of this process can be within acceptable limits [17].

The difference that is obtained between the measurements on 3D CT and 3D models can also occur due to errors in determining the reference point. When measuring anatomical points on the human body, it is difficult to determine the definitive reference point due to the generally smooth surface. Therefore, Salmi suggested the use of a measuring ball to help measure more accurately [18]. However, it was not possible in this study because the samples were taken from an existing database, as the DICOM data was obtained from the patient CT scans with the standard rule. The orientation at the time of the measurements should also be noted. The measurement orientation on 3D CT and 3D models should be consistent. For example, when a gonial angle is measured with 3D CT and performed on the sagittal view, the 3D model measurement should also be performed on the sagittal view. The same consistency in orientations should be applied to measuring the lengths of the ramus of the mandible and the gonion-menton.

The results in this study indicated a 0.48% difference in the vertical length measurement of the ramus of the mandible, a 1.85% difference in the length of the gonion-menton, and a 2.84% difference in the gonial angle, but these differences were not considered significant. These results were in line with several previous studies that examined the accuracy of biomodels. In those studies, the differences in both external and cortical bone thickness measurements were up to 6%. However, the differences obtained were generally equivalent to the thickness of the surgical saw used in craniomaxillofacial surgery and much smaller than the thickness of the surgical bur [17]. Therefore, it can be concluded that the accuracy of the biomodel in our study was satisfactory, or minimally acceptable on a clinical basis [8]. In its application as a model for pre-bending preoperative
reconstruction plates, the 3D model using FDM techniques will require a bit of adjustment in intraoperative situations. As suggested in other studies, further research is needed on biocompatible materials and the role of 3D models using FDM technology in craniomaxillofacial surgery. The use of 3D models is clearly useful in the preoperative planning process, and it is possible that they could also be applied directly in other facial bone scenarios and act as a tissue-engineering scaffold.

4. Conclusion
Differences in the results of measurements of the vertical length of the ramus of the mandible, the length of the gonion-menton, and the gonial angle were found between 3D models and 3D CT reconstruction, but these differences were not statistically significant. Therefore, the 3D model using FDM techniques is assessed as accurate and therefore clinically acceptable.

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