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Accuracy of dental models fabricated by CAD/CAM milling method and 3D printing method.

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Abstract: The purpose of this study was to evaluate the accuracy of a dental model fabricated using the CAD/CAM milling method and the 3D printing method. Materials and Method: This study was conducted in sequence of the digitization of the master model using an intraoral scanner, the manufacturing of working models (milling model, Multi-jet printing model and Color-jet printing model) by using the scan data of the master model, the digitization of the working model by using a laboratory scanner, the superimposition of the digital data of the master model and working models using inspection software, and 3-dimensional analysis. Ten measurements per group were done by one practitioner. One-way ANOVA and Tukey's post-hoc test were performed to compare the difference between the three groups. Results: The overall difference in models caused by the manufacturing method was measured as 73.05µm±9.64µm, 84.52µm±4.78µm, and 96.05µm±5.43µm in the milling group, Multi-jet printing group and Color-jet printing group, respectively. The difference according to the shape of the teeth, the abutment teeth among the three parts was recorded with the lowest values as 19.18±2.08µm, 77.10±7.48µm, and 56.63±4.58µm. Conclusions: Dental models manufactured by the CAD/CAM milling method presented superior accuracy over the models manufactured by the 3D printing method. Therefore, the use of optimized CAD software and appropriate materials is crucial for the fabrication accuracy of dental models.

Keywords: Milling; 3D printing; dental model; accuracy.

INTRODUCTION.

With the introduction of dental CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) system, impression taking using an oral scanner enabled rapid and effective fabrication of dental prostheses without the need for making physical models.[1,2] However, the disadvantage of dental prostheses that are fabricated without physical models is that fit between the abutment tooth and the prosthesis cannot be tested prior to the intraoral restoration.[3] The accurate fit of a prosthesis is one of the numerous requirements for a stable prosthesis and physical models are used during the process of prostheses fabrication, fit testing, and modifying the prosthesis. Physical models using CAD/CAM system are manufactured in two manners depending on the manufacturing methods. In other words, on the basis of the intraoral information taken by an intraoral scanner, the models can be manufactured by a subtractive manufacturing (SM) method using milling devices or by an additive manufacturing (AM) method using a 3D printer.[4] If a physical model is

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fabricated by using the CAD/CAM system, a number of steps can be omitted from the process for fabrication of a plaster model. Hence, lead time can be shortened and multiple copies that are free from distortion can be simply obtained due to exact 3D digital data.[5-7] Thermoplastic devices for orthodontic treatment, in particular, can be widely fabricated based on the physical model that is printed using a 3D printer.

Fabrication of dental restorations using the CAD/CAM system was enabled by high-performance computers and digitization. The first CAD/CAM system utilized in dentistry was based on the subtractive technique.[8,9] The advantage of this technique is that complex shapes and objects can be manufactured in a very short period of time, not possible through the traditional fabrication process in a dental laboratory. On the other hand, this technique carries limitations such as the considerable waste of raw material and the internal accuracy of the restorations that is dependent on the small size of the tools,[8] wear and tear and short life of the milling tools, and minute cracks on the surface of the ceramic due to the brittleness of this material.[9] Such disadvantages can be overcome by fabricating the object with additive manufacturing technique that constructs the object in a layer-by-layer manner. 3D printing is currently being used for fabrication of implant surgical guides, planning orthodontic treatment, fabrication of diagnosis model, and fabrication of customized orthodontic devices in dentistry. However, the accuracy and utility of current 3D printing are still insufficient to fabricate the models for prostheses.

One previous study evaluated the accuracy of the dental models that were fabricated by 3D printing and by the CAD/CAM milling and revealed somewhat higher accuracy for the model fabricated by the milling method over the one fabricated by 3D printing.[10] However, another previous study communicated that the stone models obtained by the traditional method were equivalent to the models obtained by 3D printing method after scanning the stone model.[1] Owing to the development of a dental CAD/CAM system, distribution of intraoral scanners has continuously increased. Impression taking using an intraoral scanner is the process for converting a patient's intraoral environment into a digital model, and prostheses can be fabricated based on the patient's intraoral information obtained in such way.[11-13] Impression taking is the conversion step of intraoral environment into a working model and is the most important step in fabrication of prostheses. The accuracy of the impression influences the fit of prostheses and is the most crucial element for the longevity of prostheses.[14-16] In addition, the accuracy of the working model that is fabricated from the impression is also an important element. The dental models produced with the intraoral scanning data are currently fabricated by a milling method and a 3D printing method. These dental models are used to study the accuracy in the field of dental orthodontics; however, the evaluation of accuracy of the models for fixed prostheses have rarely been done. Therefore, this study aimed to categorize the dental models that are fabricated based on the data obtained by using an intraoral scanner, according to the fabrication method and the shape of the teeth, and to evaluate the accuracy of the resulting models. The null hypothesis of this study was that there is no difference caused in a dental model by the manufacturing method and the shape of a teeth.

The null hypothesis of this study was that there is no difference in the shape of a teeth between the dental models manufactured using the different methods.

MATERIALS AND METHODS.

This study was conducted through the following steps: fabrication of the master model, digitization of the master model by using an intraoral scanner, fabrication of working models (using both milling and 3D printing) based on the scan data of the master model, digitization of the working models by using a laboratory scanner, superimposing the digital data of the master model and working model by using inspection software, and 3-dimentional analysis (Figure 1). The digital data from the master model and working models were assigned as CRM (CAD reference model) and CTM (CAD test model).

Fabrication and digitalization of the master model.

The left maxillary first molar on the full arch typodont model (AG-4, Frasaco, Germany) was assigned as the abutment tooth. A personal tray and polyvinylsiloxane (PVS) impression material were used for master model impression taking, and the master model was fabricated by pouring the Type IV dental modeling material (Fujirock, GC, Belgium) into the impression. The digital impression of the master model was obtained 10 times using a intraoral scanner (CS3500, Carestream Dental, USA) and these data were named and assigned to the CRM.

Fabrication of working models.

By using the CRM, which was obtained by scanning the master model, 10 models were fabricated with dental stone (Gypsum disc, Mungyo, Korea) by using the CAD/CAM (DWX-50, Roland, USA) milling method. At this point, a bur 2.0mm in diameter, an intermediate bur 1.0mm in diameter, and a smaller 0.5mm in diameter bur were used. Under the same conditions, 1 set of burs was used per disc. In addition, the twenty printing models were fabricated by using a printer with Multi-jet (MJ) technology (projet 3600 MP, 3D systems, USA) and a printer with Color-jet (CJ) technology (projet 260 plus, 3D systems, USA). The thickness of the additive layer was the minimum value that could be set in each printer; 16μm for the Multi-jet printing (MJP) method and 100 μm for the Color-jet printing (CJP) method. The working models that were fabricated by the milling method were classified into the MGM (milling gypsum model) group and the working models that were fabricated by the two types of printing methods were classified into the MJPM (Multi-jet printing model) group and CJPM (Color-jet printing model) group. In each group, corresponding numbers were given to the 10 models (Figure 1).

Digitization of working models.

A total of 30 working models were digitized using a desktop scanner (Identica Hybrid, Medit, Korea) and the scan data of these models were named as CTM and stored. A desktop scanner was used because that it is generally superior in terms of accuracy when a long region needs to be scanned compared to an intraoral scanner, and it allows for the acquisition of stable data compared to an intraoral scanner that may yield error in data collection depending on the proficiency and technique employed by the users during the scanning process.

Measuring the difference by using an inspection software.

Unnecessary and inaccurate parts of the digital data for all models were deleted. Each CTM was superimposed on the CRM of the same number by using an inspection software (Geomagic Control X, 3D systems, USA). The superimposition method was as follows: converting CTM into point cloud data, performing initial alignment with CRM that is the surface data, and realigning by using the best fit alignment function. Sampling ratio (100%) and the maximum repetition number (30 times) were assigned and the point cloud (CTM) was reflected on the surface of the CRM data. In addition, the difference between models was measured after selecting the relevant portion in CRM in order to produce the data for each part (Figure 2). The distance between CRM and every CTM was converted into a root mean square (RMS) value and their mean was calculated.[5]

$$\mathrm{RMS} = \frac{1}{\sqrt{n}} \cdot \sqrt{\sum_{i=1}^{n} \left(x_{1,k} - x_{2,k}\right)^2}$$

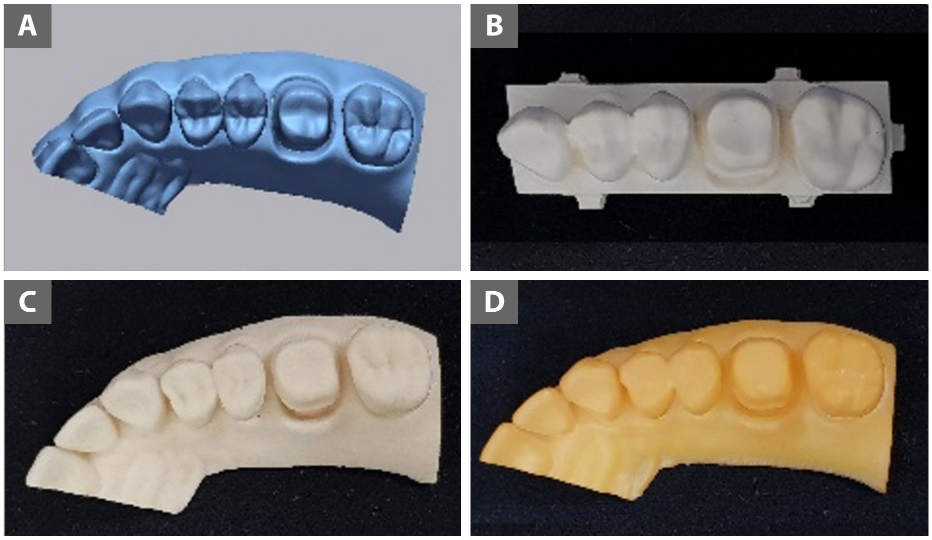
Where, $X_{1,k}$ is measuring point k on CRM, $X_{2,k}$ is measuring point k on CTM, and n is the total number of measuring points per specimen.

In addition, the result of the superimposition shown in the program is presented as the color difference map (Figure 2). In the color difference map, the range of tolerance between the maximum and minimum was +0.1mm ~ -0.1mm and the range of acceptable tolerance, which is indicated in green, was set as +0.01mm ~ -0.01mm. These numerical values were not acceptable values for prostheses restoration; however, the setting was done with these values in order to compare the accuracy between models fabricated by the milling and 3D printing methods easily.

Statistical analysis

Prior to comparing the difference between CRM that is the scan data of the master model, and CTM that is the scan data of the working models, normality of the data was tested. Technical statistics of RMS values were proposed and one-way ANOVA was performed to identify the intergroup difference. For comparison of the difference, Tukey's post-hoc test was conducted. IBM SPSS Statistics 23 (SPSS Inc, Chicago, USA) was used for statistical analysis (α= 0.05).

Figure 1. Digitization of the master model and working models that were fabricated by a CAD/CAM milling method and by a 3D printing method.

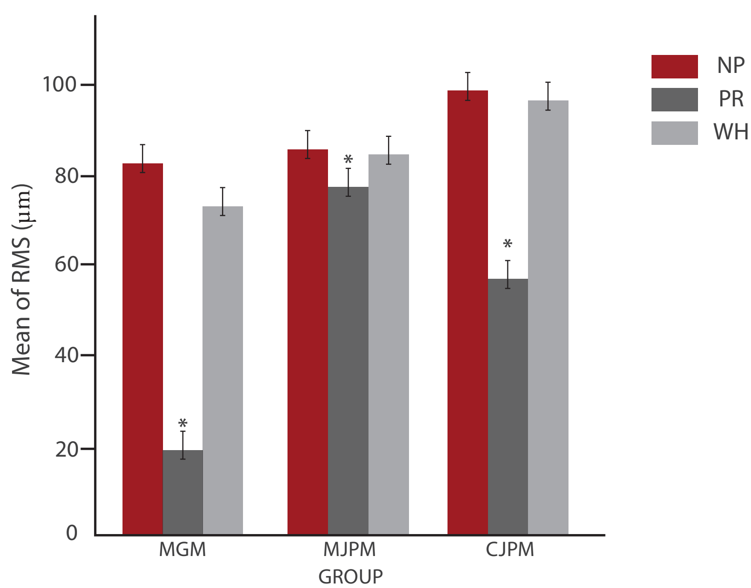


A. Digitization of the master model (CRM). **B.** Milling model (MGM). **C.** 3D printing model (MJPM). **D.** 3D printing model (CJPM).

Figure 2. Color difference map that represents the difference between models in different regions.

A. No preparation part. **B.** Preparation part. **C.** Whole.

Figure 3. Comparison of dental models according to teeth shape (unit= µm).



***:** Statistically significant by one-way ANOVA. Different letters indicate significant differences at *p*<.05. **MGM:** Milling gypsum model. **MJPM:** Multi-jet printing model. **CJPM:** Color-jet printing model. **NP:** No preparation part. **PR:** Preparation part. **WH**: Whole.

Table 1. Systems, methods, and materials used for model manufacturing in this study.

Group	Manufacturing system	Manufacturing method	Material
MGM	DWX-50	Milling	Gypsum
MJPM	Projet MJP 3600	3D printing	VisiJet M3 Pearlstone
CJPM	Projet CJP 260	3D printing	VisiJet PXL

MGM: Milling gypsum model. **MJPM:** Multi-jet printing model. **CJPM:** Color-jet printing model.

Table 2. Comparison of dental models according to manufacturing methods (unit= μm).

Group	No preparation part Mean ± SD	Preparation part Mean ± SD	Whole Mean ± SD
MGM	81.94 a ± 11.12	19.18 a ± 2.08	73.05 a ± 9.64
MJPM	85.30 a ± 4.72	77.10 b ± 7.48	84.52 b ± 4.78
CJPM	98.44 b ± 5.38	56.63 c ± 4.58	96.05 c ± 5.43
p-value	0.000 *	0.000 *	0.000 *

***:** Statistically significant by one-way ANOVA. Different letters indicate significant differences at *p*<.05. **MGM:** Milling gypsum model. **MJPM:** Multi-jet printing model. **CJPM:** Color-jet printing model. **S.D.:** Standard Deviation.

RESULTS.

The difference in accuracy beween the models manufactured by the different methods evaluated by inspection software (Geomagic Control X) is presented in Table 2, and the comparison between different tooth shape is presented in Figure. 3.

DISCUSSION.

The fabrication of dental prostheses using a CAD/CAM system, a milling manufacturing method and a additive manufacturing method have undergone continuous development with constant attention. In particular, intensive exploration of novel dental materials and equipment has established the rapid development of new technologies during the past 40 years. Dental prostheses are fabricated on hard plaster models or designed based on digital models obtained by an intraoral scanner and a desktop computer. Intraoral scanners allow for skipping the fabrication of a hard plaster cast or reduce the number of casts needed. This translates into the absence of an actual model during the fabrication of the prostheses when using an intraoral scanner. Most people are not familiar with working without dental models yet and are rather familiar with seeing prostheses mounted on the models, even though prostheses are fabricated using a digital method. Moreover, some people even regard dental models as essential during the checking and improving steps of the fit of the final prostheses.

To date, there is numerous literature on the accuracy of dental models through comparison according to the kind of impression materials,[17,18] method of impression taking,[19-21] the kind of impression tray used,[22,23] and the types of 3D printing technique.[5] Yau *et al.*,[10] stated that the model fabricated by the milling method presented better accuracy than the dental model fabricated by a 3D printing method. In addition, Kasparova *et al.*,[1] reported that both the plaster model obtained by the traditional method and the model obtained by 3D printing after scanning the plaster model presented the same result. In this study, the dental model manufactured by the milling method showed better accuracy than the two models manufactured by the two different 3D printing methods. The milling devices and CAM software that are widely used nowadays are optimized for the fabrication of dental prostheses, which require high accuracy. However, the CAM software (GMS v.2.0, Mungyo, Korea) used in this study, was initially developed for the purpose of dental plaster model fabrication; hence, it might be the most suitable for the milling of the model. In terms of materials, the gypsum blocks used in the milling process were prepared to reduce chipping of the margin and with the removal of porous air bubbles due to the high density and heat-resisting properties, through mixing during a special process. However, the materials used in 3D printing were not the resin used for the purpose of making dental models; and, the shape was achieved by adding layers of existing materials used for the fabrication of various products. The coherence of the materials and the shape of the surface have great influence on scan data. Such difference in materials and methods of forming the models reflected on the result of this study. Furthermore, the bur with the minimum diameter of 1 mm is used to process the details while milling the resin disk in general. This is because using a bur with the diameter smaller than 1 mm induces the its fracture during the manufacturing process as the resin melts and adsorbs onto the bur due to heat easily generated by the action of the bur. However, the accuracy of the model was able to be improved since a bur with a minimum diameter of 0.6mm was used in this study. The two models fabricated by 3D printing methods showed a statistically significant difference in all three parts. The minimum thickness of the layer produced by the equipment using MJP and CJP technique is 16µm and 100µm, respectively. In other words, the accuracy of the manufacturing equipment also influences the accuracy of the dental model.

This study was initiated based on the consideration that the model fabricated by a 3D printing method will be more accurate without having a preparation part whereas the model fabricated by the milling method will be more accurate in the preparation part. However, the result of this study reveal that the milled model was more accurate than 3D printed model in all parts. In this study, the CAD software and materials that are optimized for the fabrication of dental models were used to fabricate the model using the milling method. This indicates that our result is consistent with Moldovan *et al.*,[24] who reported that the process of CAD/CAM still needs to be improved in terms of standardization, reproducibility, and efficiency. This study presents the results obtained from the use of limited milling devices, printing devices, and materials. In the future, evaluation of the accuracy of the models fabricated by using more systems and evaluation of the models fabricated by using various materials should be conducted. Currently CAD/CAM systems are being continuously developed, as well as materials and equipment with better specifications. Therefore, application of a CAD/CAM system in the near future for dental models for the fabrication of prostheses requiring high accuracy is expected.

CONCLUSION.

The dental model manufactured by CAD/CAM milling method presented excellence in accuracy over the models manufactured by 3D printing methods. Hence, the use of optimized CAD software and suitable materials are important for the accurate fabrication of dental models.

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