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The Evaluation of Working Casts Prepared from Digital Impressions

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Clinical Relevance

In general, the iTero scanner system displayed excellent extraoral performance. However, the polyurethane casts of the iTero system showed relatively low reproducibility, which indicated that the system should be used with caution for working cast fabrication.

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SUMMARY

Objective: The aim of this study is to evaluate the reproducibility of working casts of a digital impression system by comparing them with the original, virtual, and rapid prototyping casts.

Materials and Methods: A total of 54 cast sets in clinically stable occlusion were used. They were scanned by an iTero intraoral scanner and converted into STL format virtual casts. Rapid prototyping casts and polyurethane casts were fabricated from the iTero milling system based on the virtual casts. Several horizontal and vertical measurements were performed from the four types of casts, that is, original stone casts, virtual casts, rapid prototyping casts, and polyurethane casts of iTero. Measurement error, intraclass correlation coefficient (ICC), and differences among the casts were calculated and compared.

Results: Casts from iTero milling machines exhibited greater dimensional differences and lower ICC values than did other casts. In addition, many of the measurements of the iTero working casts showed statistically sig-

nificant differences in comparison to the three other types of casts. In contrast, there were no statistically significant differences between the virtual and original casts.

Conclusion: Virtual casts made by the iTero intraoral scanner exhibited excellent reproducibility. However, the casts from the iTero milling machine showed greater dimensional differences and lower reproducibility compared to other types of casts.

INTRODUCTION

More than 20 years have passed since digital dentistry emerged as a computer-assisted design/computer-assisted manufacturing (CAD/CAM) system for the fabrication of indirect dental restorations.[1,2] At the initial launch, the restorations created by the system were rather rudimentary from the contemporary perspective. However, with the advancement of digital technology, the field of digital dentistry continues to expand.[3]

Digital dentistry in restorative fields includes primarily two types of equipment, acquisition media and manufacturing media.[3] Presently, several systems are equipped with chair-side intraoral scanner units to function as acquisition media during in-office restorative procedures,[4] while many CAD/CAM systems are still limited to the realm of dental technicians and bench-tops.[5] The digital impression technologies of in-office systems have their own unique working principles, light sources, and imaging types. Some systems require a coating powder over the scanning area.[6]

Among the imaging systems, the iTero system (Cadent, San Jose, CA, USA) is based on a parallel confocal imaging principle. For this imaging technique, parallel beams of light are sent through a small hole before contacting the object that is to be scanned. The beams hit the object at the perfect focal length, bounce off of the object, and return through a small hole. Ultimately, these beams of light hit a sensor and are converted to a digital image.[7] This system can capture 100,000 beams of parallel red laser light at 300 focal depths that are spaced approximately 50 μm apart. This spacing allows for an approximate scanning depth between 13 and 15 mm. In total, the system captures approximately 3.5 million data points for each scanned arch.[3] In addition, the acquired image data can be saved as unencrypted STL (Stereo Lithography interface) files that can be used with many other CAD/CAM systems, in contrast to other in-office systems that use proprietary encrypted files for specific platforms.[4]

Another noted feature of this system is the lack of a requirement for a dedicated coating before scanning, which is a clinical advantage. In fact, the iTero system can be used solely as a digital impression system for traditional crown and bridge dentistry. After confirming the scanned virtual cast, the file is sent to a center for cast fabrication. This system uses a subtractive technique for the fabrication of the cast and die, which utilizes a computer numerical-controlled five-axis milling system.

To achieve an accurately fitting prosthesis, precision must be maintained in every step involved in conventional casting: impression, die, wax pattern, investment, and casting.[8] Although CAD/CAM systems do not require all of these steps, obtaining an accurate impression is the critical part of prosthesis fabrication. Whether it is digital or conventional, the overall goal of a dental impression is to produce an exact negative three-dimensional (3D) replica of the hard and soft tissues of the oral cavity.[9] In addition to the impression, accurate working casts are also essential for precisely fitting restorations. The reproducibility of die and casts from the prepared and antagonist sides is one of the decisive factors of not only the fit of definitive restorations, but also for chair-side intervention time.

While digital impressions have recently become more widely used, the accuracy of working models made from digital impressions has not been thoroughly evaluated. Therefore, the aim of this study is to evaluate the accuracy of working models of the iTero system by comparing them with the original, virtual, and rapid prototyping (RP) models.

MATERIALS AND METHODS

Type IV gypsum (Neoplumstone, Mutsumi Chemical Industry Co Ltd, Yokkaich, Japan) cast sets were prepared following alginate impressions taken by 100 first-year students at the School of Dentistry, Seoul National University, Korea (Figure 1a). Casts with missing teeth other than the third molars or those having more than 3 mm of crowding or arch length discrepancies were excluded from the study. In addition, casts with any kind of restorations or carious defects in the posterior segment, which includes the second premolar, first molar, and second molar, on either the preparation or antagonist side were also excluded. After this selection occurred, a total of 54 cast sets judged to be in clinically stable occlusions were used in the present

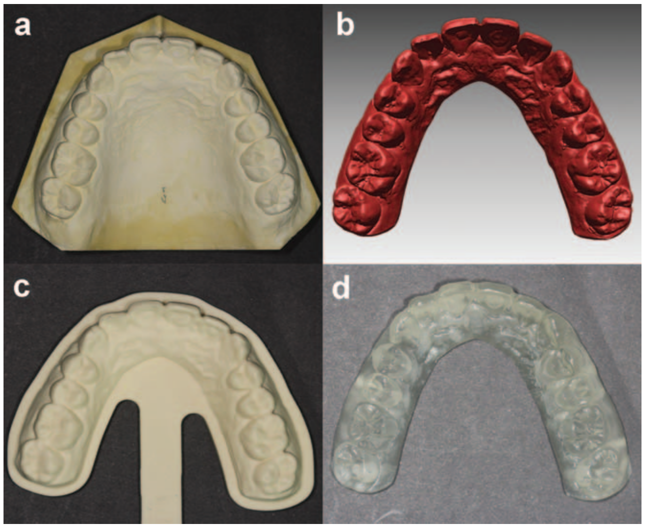

Figure 1. *Comparison of four types of casts: (A) original stone casts; (B) virtual casts in the form of a STL file; (C) polyurethane casts created using the iTero system; and (D) casts prepared by rapid prototyping.*

study. The ages of the participants ranged from 23 to 26 years, with a mean age of 24.3 years. All of the subjects provided written informed consent. This study was approved by the institutional review boards of the College of Dentistry at Seoul National University.

All of the casts selected were scanned by an iTero intraoral scanner. To make the diagnostic model, the digital image capture mode was selected to "Reference model" type to acquire the image of the full arch without the selection of any abutment. Each individual tooth was then scanned on both the buccal and lingual aspects. The anterior, right, and left posterior bites were captured to determine the occlusal relationship. Any undercut area of the cast that failed to produce a clear image was filled using the "Add scans" tool. After the scan process was completed, the captured image was sent to the iTero center for image adjustment and conversion to a STL file (Figure 1b). On the basis of STL data, a polyurethane block was milled by a five-axis milling machine (VF-2TR, Haas Automation Inc, Oxnard, CA, USA). The axes federate, repeatability accuracy, and positioning accuracy of the milling machine were 1000 ipm (25.4/min) on the X, Y, and Z axes; 0.00001 inch; and 0.00002 inch, respectively (Figure 1c).

The STL file was also imported into a prototyping software (Clinet Software) and submitted to a RP machine (Project HD 3000, 3D Systems, Rock Hill, SC, USA) for the fabrication of the actual sized model. The accuracy of a RP machine ranges between ±0.001 and 0.002 inches (0.025~0.05 mm) per inch. This system works with the 3D System's patented Multi-Jet Modeling (MJM) technology and uses two materials (part and support material). A transparent acrylic photopolymer (VisiJet® EX200 Plastic, 3D Systems) was developed specifically as the build material, and a white, nontoxic wax material (VisiJet® S100 Wax, 3D Systems) was used for hands-free melt-away support. The 3D model was built by overlaying in HD mode of resolution of a 32 μm layer of resin polymerized with ultraviolet light curing. The completed RP cast was placed into an oven to burn out the support wax at a temperature of 60°C (Figure 1d).

Horizontal and vertical measurements were performed to evaluate the reproducibility of the working casts. For the horizontal parameters, measurements were made between the distal incisal tips of the bilateral central, lateral incisors, and bilateral canine tips, and the bilateral buccal cusp tips of the premolars and bilateral mesiobuccal cusp tips of the molars (Figure 2a). For the vertical parameters, the distances between the most cervical points and cusp tips of the canine and buccal cusp tips of the second premolars were measured (Figure 2b). The virtual 3D casts were measured and analyzed using specialized software (Rapidform 2004, ver PP2, INUS Technology, Seoul, Korea), and the original casts and two kinds of working casts were measured using digital point calipers with a resolution of 0.01 mm (Mitutoyo, Kawasaki, Japan). Measurements of each cast were made three separate times by a single observer over a three-week period. To test the reliability, 10 virtual casts and 10 actual casts were randomly selected and measured again one month after the initial measurement.

The technical errors of measurement using the original Dalberg formula and intraclass correlation coefficients (ICCs) were calculated among the measurements using language R. With the measurements from original cast sets as a reference, the

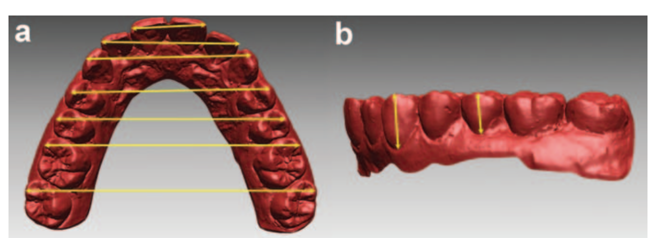

Figure 2. *Examples of measured parameters. (A) Horizontal parameters and (B) vertical parameters.*

differences and percentage differences of measurements from the other three casts were calculated. SPSS software (SPSS for Windows, version 12.0, Chicago, IL, USA) was used to perform paired-sample *t*-tests to determine the significant differences of the measured parameters among the casts. Significance was predetermined at the 0.05 and 0.01 levels of confidence.

RESULTS

Intraexaminer reliability coefficients ranged from 0.994 to 0.999 for virtual measurements and from 0.989 to 0.997 for real measurements. In terms of root mean square values, the random errors of estimation were less than 0.03 mm for virtual measurements and 0.07 mm for real measurements. None of the variables were significantly different between test and retest measurements.

Errors of measurements and the ICCs among the measurements from the four types of cast are summarized in Table 1. In general, casts from iTero milling machines exhibited greater root mean square errors and lower ICC values than other casts. The comparison of iTero casts with the other three types of casts showed errors in terms of the Dalberg formula ranging from 0.033 mm to 0.261 mm, with ICC values ranging from 0.912 to 0.999. In contrast, the comparison among the other three casts exhibited error that ranged from 0.002 mm to 0.040 mm, with ICC values ranging from 0.997 to 1.000. Most of

Table 1: *Errors of Measurement Calculated Using Dahlberg Formula and Intraclass Correlation Coefficients (ICCs)*

	PU vs RP		PU vs OC		PU vs VC		RP vs OC		RP vs VM		OC vs VM	
	rmse, mm	ICC	rmse, mm	ICC	rmse, mm	ICC	rmse, mm	ICC	rmse, mm	ICC	rmse, mm	ICC
Horizontal distance measurements between maxillary teeth												
11 to 21	0.149**	0.954	0.146**	0.957	0.146**	0.956	0.008*	1.000	0.008*	1.000	0.004	1.000
12 to 22	0.201**	0.980	0.203**	0.98	0.203**	0.98	0.007	1.000	0.006	1.000	0.005	1.000
13 to 23	0.169**	0.984	0.169**	0.984	0.170**	0.984	0.004	1.000	0.004	1.000	0.003	1.000
14 to 24	0.169	0.992	0.168	0.992	0.168	0.992	0.009	1.000	0.009	1.000	0.003	1.000
15 to 25	0.257	0.985	0.260	0.985	0.261	0.985	0.007	1.000	0.007	1.000	0.004	1.000
16 to 26	0.182**	0.998	0.182**	0.998	0.184**	0.998	0.006	1.000	0.007	1.000	0.003	1.000
17 to 27	0.200**	0.998	0.198**	0.998	0.198**	0.998	0.007	1.000	0.007	1.000	0.003	1.000
Subtotal average	0.190	0.984	0.214	0.985	0.215	0.958	0.007	1.000	0.007	1.000	0.004	1.000
Horizontal distance measurements between mandibular teeth												
31 to 41	0.116**	0.912	0.115**	0.912	0.115**	0.912	0.008	1.000	0.008	1.000	0.002	1.000
32 to 42	0.152**	0.974	0.154**	0.974	0.151**	0.975	0.007	1.000	0.008	1.000	0.010	1.000
33 to 43	0.129**	0.998	0.125**	0.998	0.225*	0.994	0.008*	1.000	0.008*	1.000	0.039	0.999
34 to 44	0.133*	0.998	0.135*	0.998	0.134*	0.998	0.004	1.000	0.004	1.000	0.003	1.000
35 to 45	0.119**	0.999	0.124**	0.999	0.126**	0.999	0.007*	1.000	0.008*	1.000	0.003	1.000
36 to 46	0.191**	0.998	0.188**	0.998	0.188**	0.998	0.005*	1.000	0.006*	1.000	0.002	1.000
37 to 47	0.188**	0.998	0.186**	0.998	0.205**	0.998	0.005	1.000	0.005	1.000	0.040	1.000
Subtotal average	0.147	0.982	0.147	0.982	0.163	0.982	0.006	1.000	0.007	1.000	0.014	1.000
Vertical distance measurements in teeth from most cervical points to (buccal) cusp tips												
13	0.116	0.985	0.122	0.984	0.116	0.985	0.027	0.999	0.027	0.999	0.023	0.999
15	0.158	0.975	0.161	0.974	0.161	0.974	0.008	1.000	0.009	1.000	0.006	1.000
23	0.043	0.997	0.044	0.997	0.045	0.997	0.008	1.000	0.009	1.000	0.004	1.000
25	0.169	0.959	0.173	0.958	0.170	0.959	0.008*	1.000	0.008*	1.000	0.006	1.000
33	0.051**	0.998	0.055**	0.998	0.056**	0.997	0.008*	1.000	0.008*	1.000	0.003	1.000
35	0.036**	0.999	0.033**	0.999	0.034**	0.999	0.006	1.000	0.008	1.000	0.004	1.000
43	0.076**	0.996	0.074**	0.996	0.072**	0.996	0.007	1.000	0.007	1.000	0.007	1.000
45	0.034**	0.998	0.078*	0.992	0.079*	0.992	0.031	0.998	0.035	0.997	0.009	1.000
Subtotal average	0.085	0.988	0.093	0.987	0.092	0.987	0.013	1.000	0.014	1.000	0.008	1.000
Total average	0.138	0.985	0.141	0.985	0.146	0.985	0.009	1.000	0.009	1.000	0.008	1.000

Abbreviations: OC, original stone casts; PU, polyurethane casts prepared by iTero™ system; rmse, root mean square of errors; RP, casts prepared by rapid prototyping; VC, virtual casts in form of STL file.
** Denotes statistically significant difference (p<0.05); ** Denotes statistically significant difference (p<0.01).*

the measurements of the iTero casts showed statistically significant differences in comparison to the other three types of casts. The RP casts showed statistically significant differences in comparison to the virtual and original casts in several measurements only at the 0.05 significance level. In comparison to the virtual and original casts, there were no statistically significant differences.

With the measurements from the original casts as references, the differences and percentage differences of measurements from the other three casts are summarized in Table 2. The iTero casts exhibited greater absolute differences from the original casts than did the other two casts. The average difference from the original casts to the iTero casts ranged from 0.033 to 0.250 mm, and the average percent difference ranged from 0.240% to 1.344%, whereas the differences between the other two casts ranged from 0.002 to 0.016 mm, and percent difference ranged from 0.003% to 0.179%.

DISCUSSION

The importance of reproducibility of impression material and working casts has not been diminished even though the recent introduction of digital dentistry has started a new era of powder-free dental clinics by changing the method of impression. In contrast to other systems, the iTero system can be used only as a digital impression tool for the fabrication of working casts for conventional laboratory work. This use meets the need of conventional fabrication when the milled prosthesis is not prop-

Table 2: *Average Absolute Difference (Standard Deviations) from Original Casts (as References)*

	VC		PU		RP	
	Absolute Difference, mm	**% Absolute Difference**	**Absolute Difference, mm**	**% Absolute Difference**	**Absolute Difference, mm**	**% Absolute Difference**
Horizontal distance measurements between maxillary teeth						
11 to 21	0.003 (0.005)	0.021 (0.019)	0.171 (0.061)	0.994 (0.404)	0.009 (0.007)	0.053 (0.024)
12 to 22	0.005 (0.006)	0.017 (0.011)	0.224 (0.110)	0.756 (0.333)	0.005 (0.003)	0.017 (0.012)
13 to 23	0.004 (0.002)	0.010 (0.006)	0.205 (0.069)	0.576 (0.279)	0.004 (0.003)	0.011 (0.007)
14 to 24	0.004 (0.003)	0.008 (0.007)	0.189 (0.082)	0.422 (0.180)	0.008 (0.006)	0.018 (0.024)
15 to 25	0.003 (0.004)	0.006 (0.005)	0.122 (0.076)	0.240 (0.084)	0.006 (0.005)	0.011 (0.007)
16 to 26	0.004 (0.003)	0.007 (0.003)	0.227 (0.067)	0.407 (0.139)	0.007 (0.004)	0.012 (0.008)
17 to 27	0.003 (0.004)	0.005 (0.003)	0.248 (0.098)	0.395 (0.121)	0.006 (0.004)	0.010 (0.006)
Subtotal average	0.004 (0.004)	0.011 (0.008)	0.198 (0.081)	0.541 (0.221)	0.006 (0.004)	0.019 (0.012)
Horizontal distance measurements between mandibular teeth						
31 to 41	0.002 (0.002)	0.014 (0.008)	0.139 (0.025)	1.274 (0.427)	0.008 (0.005)	0.074 (0.034)
32 to 42	0.007 (0.004)	0.031 (0.026)	0.197 (0.047)	0.886 (0.234)	0.008 (0.004)	0.035 (0.024)
33 to 43	0.007 (0.005)	0.024 (0.018)	0.149 (0.051)	0.549 (0.197)	0.008 (0.008)	0.031 (0.018)
34 to 44	0.004 (0.003)	0.012 (0.005)	0.157 (0.066)	0.451 (0.170)	0.003 (0.005)	0.009 (0.008)
35 to 45	0.003 (0.003)	0.008 (0.004)	0.168 (0.034)	0.420 (0.074)	0.007 (0.004)	0.017 (0.011)
36 to 46	0.002 (0.002)	0.003 (0.003)	0.250 (0.076)	0.525 (0.121)	0.005 (0.004)	0.010 (0.007)
37 to 47	0.007 (0.006)	0.012 (0.009)	0.231 (0.084)	0.422 (0.127)	0.005 (0.005)	0.009 (0.006)
Subtotal average	0.005 (0.003)	0.015 (0.010)	0.184 (0.055)	0.647 (0.194)	0.006 (0.005)	0.024 (0.015)
Vertical distance measurements in teeth from most cervical points to (buccal) cusp tips						
13	0.002 (0.004)	0.021 (0.025)	0.050 (0.022)	0.395 (0.188)	0.016 (0.012)	0.172 (0.115)
15	0.006 (0.003)	0.061 (0.031)	0.130 (0.016)	1.344 (0.276)	0.009 (0.007)	0.089 (0.073)
23	0.004 (0.003)	0.044 (0.027)	0.060 (0.022)	0.677 (0.304)	0.009 (0.009)	0.093 (0.090)
25	0.008 (0.004)	0.079 (0.022)	0.033 (0.005)	0.342 (0.056)	0.008 (0.006)	0.083 (0.069)
33	0.002 (0.004)	0.023 (0.029)	0.071 (0.046)	0.726 (0.295)	0.009 (0.007)	0.090 (0.070)
35	0.004 (0.002)	0.047 (0.031)	0.042 (0.020)	0.580 (0.236)	0.008 (0.004)	0.113 (0.117)
43	0.007 (0.004)	0.072 (0.039)	0.082 (0.050)	0.834 (0.335)	0.008 (0.006)	0.084 (0.064)
45	0.010 (0.007)	0.131 (0.076)	0.082 (0.065)	1.100 (0.608)	0.014 (0.012)	0.179 (0.158)
Subtotal average	0.005 (0.004)	0.060 (0.035)	0.069 (0.031)	0.688 (0.287)	0.010 (0.007)	0.113 (0.095)
Total average	0.005 (0.004)	0.030 (0.019)	0.147 (0.055)	0.628 (0.235)	0.008 (0.006)	0.055 (0.042)

Abbreviations: PU, polyurethane casts prepared by iTero™ system; RP, casts prepared by rapid prototyping; VC, virtual casts in form of STL file.

erly created or preferred. In addition, the working cast provided by the system can be used during the adaptation of the prosthesis.

In this respect, the accuracy of working casts of the system has to be evaluated. In the present study, the comparison between original and virtual casts demonstrated the performance of the intraoral scanner, while the comparison between virtual and milled casts and between virtual and prototyped casts exhibited the reproducibility of the polyurethane milling system and RP machine.

According to the results of the present study, the iTero scanner system provided reproducible virtual casts. The errors and differences between the original casts were small, a result that coincides with those of previous studies.[10-13] In contrast, the reproducibility of polyurethane casts fabricated by the iTero milling system was not as good as that associated with virtual casts. This was verified by the fact that the casts fabricated by RP machines exhibited smaller differences and much greater ICCs than did polyurethane casts.

Like the conventional stone cast, two steps are required for cast fabrication: impressions and construction. Based on the results, the inaccuracy of casts from the iTero system seems to come from the cast construction phase. While there are specifications for impression materials and gypsum products for cast fabrications, there are no such specifications for digital impressions. Even though a direct comparison is impossible, the accuracy shown by the casts from the iTero system was not ideal when compared with results described in previous literature about conventional systems. For example, when comparing our results with data from irreversible hydrocolloid impression material, which is the most widely used material in dental clinics for antagonist impressions, the system showed no superiority. This inaccuracy not only caused misfits of the prosthesis but it also increased the required amount of chairside adjustment.

In contrast, the performance of the iTero intraoral scanner system seemed to be excellent within the limits of this study. The lack of a requirement for a dedicated spray coating should be stressed as a great advantage of the system. The use of opaque powder spray provides uniform light dispersion and enhances the accuracy. However, the coating seemed to affect the measurement and led to the increase of dimensions according to the times of coating in our unpublished pilot study using other 3D scanners, such as the CEREC Bluecam intraoral scanner (Sirona, Bensheim, Germany) and the extraoral scanner (optoTOP-HE, Breckmann GMBH, Meersburg, Germany). This result partly coincides with that of a previous study,[14] but there is also a report[15] that compared the impressions of powdered teeth vs nonpowdered stone casts and found that the marginal gap of onlay restorations was not different when the optical impression was taken intraorally vs extraorally without powdering. In clinics, spraying and removing excess powder with air causes the additional steps and associated time, and in some cases it is hard to apply as a result of a lack of ideal isolation or depth of the preparation. In addition, careless spraying can cause irritation to sensitive patients.[15]

Several issues related to this study should be pointed out. First, the virtual model fabricated by scan using the intraoral scanner was not in an intraoral environment. In addition, the scanned objects were not real teeth and gums but rather the stone cast. The intraoral environment contains saliva and humidity, and there are various kinds of hindrances associated with it, including less stable positioning of the scanner during the impression-taking process. In addition, human enamel has a different reflective and dispersive property compared to dental cast stone. Therefore, there is a possibility of compromising the accuracy of impression taking when using the intraoral scanner in a clinical situation. The accuracy of intraoral scanning should be tested intraorally in further studies. Second, the measurements were performed on the unprepared casts; the results can be interpreted to represent the accuracy of antagonizing casts. In order to suggest more specific clinical implications, study using casts with prepared dies of varying spans would be recommended.

From a practical point of view, impression-taking time should be considered. In the present study, a substantial amount of time was needed for the full arch digital impression taking using the system compared with the time needed for conventional impression taking. This additional time might be due to the limitations of the operating system or computer hardware and could be alleviated by rapid technological advances in the near future. However, this disadvantage can cancel the overall merit of this system for long-span prostheses, at least for the time being.

RP is a CAD/CAM technology that was originally developed to fabricate prototypes for industrial purposes. This method automatically constructs physical models from computerized 3D data. RP has recently been successfully applied in various medical fields, such as in the fabrication of implant surgical guides[16,17] and maxillofacial prosthetics[18,19] and in frameworks for removable partial dentures.[20] Recently, the use of RP in the frameworks of fixed restorations was studied,[21] and the results of this study seemed to be promising, even though further improvements are needed.

CONCLUSIONS

The reproducibility of four types of casts was evaluated in this study. Virtual casts made by the iTero intraoral scanner showed excellent reproducibility in general. However, when comparing original stone casts, virtual casts, RP casts, and casts fabricated by the iTero milling machine, the casts from the iTero milling machine exhibited greater dimensional differences and lower reproducibility than did the other types of casts. The reproducibility must be improved, and the system should be used with caution for working cast fabrication. The RP casts showed some promise. The results of the present *in vitro* study did not come from clinical situations; therefore, there should be *in vivo* studies verifying the intraoral performance of the scanner system with prepared teeth.

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Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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