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Interproximal Distance Analysis of Stereolithographic Casts Made by CAD-CAM Technology: An in Vitro Study

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Interproximal distance analysis of stereolithographic casts made by CAD-CAM technology: An in vitro study

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Abstract

Statement of problem

The accuracy of interproximal distances of the definitive casts made by computer-aided design and computer-aided manufacturing (CAD-CAM) technology is not yet known.

Purpose
The purpose of this in vitro study was to compare the interproximal distances of stereolithographic casts made by CAD-CAM technology with those of stone casts made by the conventional method.

Material and methods
Dentoform teeth were prepared for a single ceramic crown on the maxillary left central incisor, a 3-unit fixed dental prosthesis (FDP) on the second premolar for a metal-ceramic crown, and a maxillary right first molar for a metal crown. Twenty digital intraoral impressions were made on the dentoform with an intraoral digital impression scanner. The digital impression files were used to fabricate 20 sets of stereolithographic casts, 10 definitive casts for the single ceramic crown, and 10 definitive casts for the FDP. Furthermore, 20 stone casts were made by the conventional method using polyvinyl siloxane impression material with a custom tray. Each definitive cast for stereolithographic cast and stone cast consisted of removable die-sectioned casts (DC) and nonsectioned solid casts (SC). Measurements of interproximal distance of each cast were made using CAD software to provide mean ±standard deviation (SD) values. Data were first analyzed by repeated measures analysis of variance (ANOVA), using different methods of cast fabrication (stone and stereolithography) as one within subject factor and different cast types (DC and SC) as another within subject factor. Post hoc analyses were performed to investigate the differences between stone and stereolithographic casts depending upon the results from the repeated measures ANOVA (α=.05).

Results
Analysis of interproximal distances showed the mean ±SD value of the single ceramic crown group was 31.2 ±24.5 µm for stone casts and 261.0 ±116.1 µm for stereolithographic casts, whereas the mean ±SD value for the FDP group was 46.0 ±35.0 µm for stone casts and 292.8 ±216.6 µm for stereolithographic casts. For both the single ceramic crown and the FDP groups, there were significant differences in interproximal distances between stereolithographic casts and stone casts ($P<.001$). In addition, the comparisons of DC with SC of stone and stereolithographic casts for the single ceramic crown and FDP groups demonstrated there was statistically significant differences among interproximal distances between DC stereolithographic casts and SC stereolithographic casts only for the FDP group ($P<.001$).

Conclusions
For both the single ceramic crown and the FDP groups, the stereolithographic cast group showed significantly larger interproximal distances than the stone cast group. In terms of the comparison between DC and SC, DC stereolithographic casts for the FDP group only showed significantly larger interproximal values than those of the SC stereolithographic casts for the FDP group.

Clinical Implications
Because the interproximal distances of stereolithographic casts made by CAD-CAM technology were significantly larger than the ones of stone casts made by the conventional method, more chairside clinical adjustment time is anticipated.

Accurate reproduction of interproximal (IP) contacts is integral to the fabrication of fixed dental prostheses (FDP).1, 2 The importance of IP contacts on masticatory function and stability is well known.[1] Excessively large proximal contact areas make plaque control more difficult and can be a contributing factor to periodontal disease.[1] Large IP contacts can also result in inadequate seating of the definitive dental prosthesis.[1] Conversely, very small IP contact areas may be unstable and cause drifting, whereas noncontacting teeth causes food impaction, provoking pain and discomfort.[1] Interproximal contacts are also important in maintaining proper distribution of forces during mastication, which is a mechanism for protecting the teeth and periodontium.[1] Therefore, it is clear that IP contacts play an important role in the success of a dental prosthesis.[2]

The first clinical step for precementation adjustment is the adjustment of IP contacts.[3] To obtain accurate IP contacts of FDP, a laboratory adjustment is performed to definitive stone casts prior to the clinical adjustment appointment. Procedures including impression making,[4, 5] stone pouring,[5] and die sectioning can be described as an accumulation of errors which may cause inaccuracies of IP contacts in the definitive dental prosthesis.[6, 7, 8, 9, 10, 11, 12, 13] These errors are due to 4 factors: accuracy of the impression materials; various cast/die systems;[6, 7, 8] dimensional accuracy and stability of definitive cast materials; and precise repositioning of the removable die.[9, 10] Type IV and V dental stone are most often used for removable stone die systems.[14, 15, 16] Type IV dental stone has a setting expansion of 0.1% or less, whereas Type V dental stone expands as much as 0.3% in accordance with American National Standards Institute/American Dental Association specification 25.[9, 17]

According to Millstein,[10] the evolution of digital technologies has the potential to address the problem of compounding errors during definitive impression making for the fabrication of FDP.[10] There are currently 2 types of digital workflows in dentistry.[18, 19, 20, 21, 22, 23] The first type is a completely digital workflow where digitized replicas of the prepared teeth are captured and transmitted electronically to a laboratory.[18] The laboratory designs a definitive restoration virtually, in which the end product is fabricated using computer-aided manufacture (CAM).[18] The second workflow involves steps for the definitive restoration to be fabricated by using a combination of digital and conventional methods.[18] The difference here is that a physical definitive cast is fabricated from the intraoral scan, and then the restoration is designed and fabricated by conventional methods.[18] The intraoral scanners that use physical casts include iTero (Align Technologies) and Lava chairside oral scanner (Chairside Oral Scanner; 3M ESPE).[18, 19] In these systems, definitive casts are fabricated by milling with polyethylene (iTero) or by stereolithography (SLA) and rapid prototyping with a polymer resin (Lava COS).[18, 19]

Stereolithography is an additive fabrication process, building casts layer-by-layer.[24] Syrek et al[25] determined that the marginal fit of crowns fabricated with the Lava COS system were clinically acceptable and possibly had a better fit than crowns fabricated using the conventional technique with polyvinyl siloxane (PVS) impressions. When comparing casts produced by the method using digital intraoral impressions and SLA with conventional PVS impression/stone casts, Cho et al[26] reported no statistical differences in internal fit and finish line areas. In terms of accuracy and reproducibility, however, the conventional stone cast was significantly more accurate than the SLA cast.[26] In other studies, Patzelt et al[18, 19] reported that SLA-based casts (CEREC Acquisition Center with Bluecam and Lava COS) was more accurate than milled casts (iTero).

Most studies of digital technologies in dentistry have focused on the fit of the prostheses made from the 2 different methods,[25] the overall area of the casts,[27, 28, 29, 30, 31, 32] or the use of digital technology in oral and maxillofacial surgery.[20, 33, 34] However, the accuracy of the IP distance of the casts made by computer-aided design (CAD)-CAM technology is not yet known. Therefore, the purpose of this study was to compare the IP distances of SLA casts fabricated by CAD-CAM technology with those of stone casts made by conventional methods. A comparison between removable die-sectioned definitive casts (DC) and nonsectioned definitive solid casts (SC) of both SLA and stone casts was also performed. The null hypotheses were that there are no differences in IP distances between the SLA casts and stone casts and that there are no differences in IP distances between the DC and SC in both the SLA casts or the stone casts.

Material and Methods

A single ceramic crown (SCC) on the maxillary left central incisor, an FDP on the maxillary right second premolar for a metal-ceramic crown, and the maxillary right first molar for a metal crown were prepared on a dentoform[35] (M-PVR-1560; Columbia Dentoform Teaching Solutions) (Fig. 1).

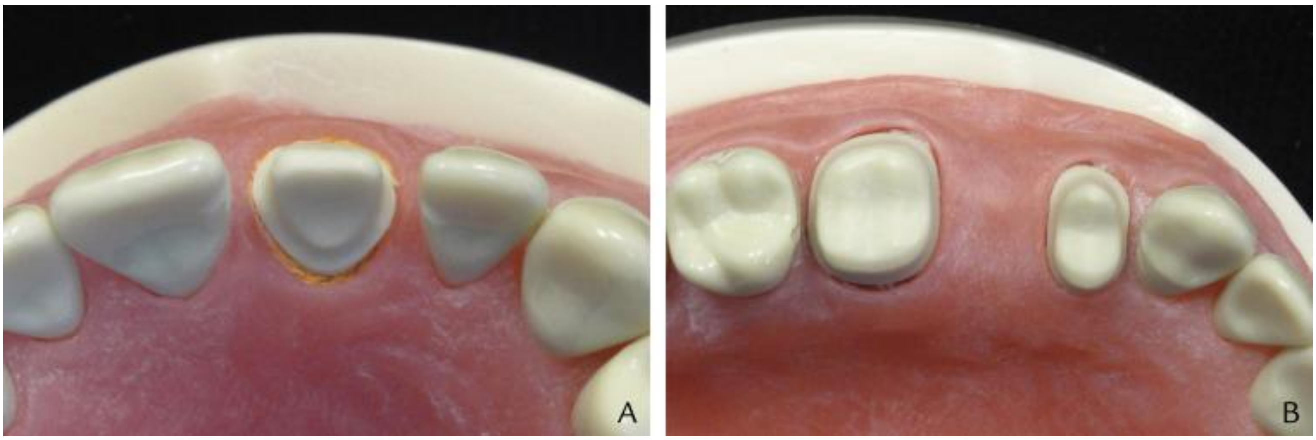

Figure 1. A, Prepared maxillary left central incisor and small notches on interproximal surfaces of adjacent teeth. B, Prepared maxillary right first molar, second premolar, and small notches on interproximal surfaces of adjacent teeth.

Twenty digital intraoral impressions were made on the dentoform, using an intraoral digital impression scanner (Lava COS; 3M ESPE) by one of the present authors (M.H.). Digital impression data were transferred to the laboratory to fabricate 20 definitive SLA cast sets, which consisted of 10 SLA casts for the SCC and 10 SLA casts for the FDP. Each SLA cast consisted of removable DC and SC (Fig. 2).

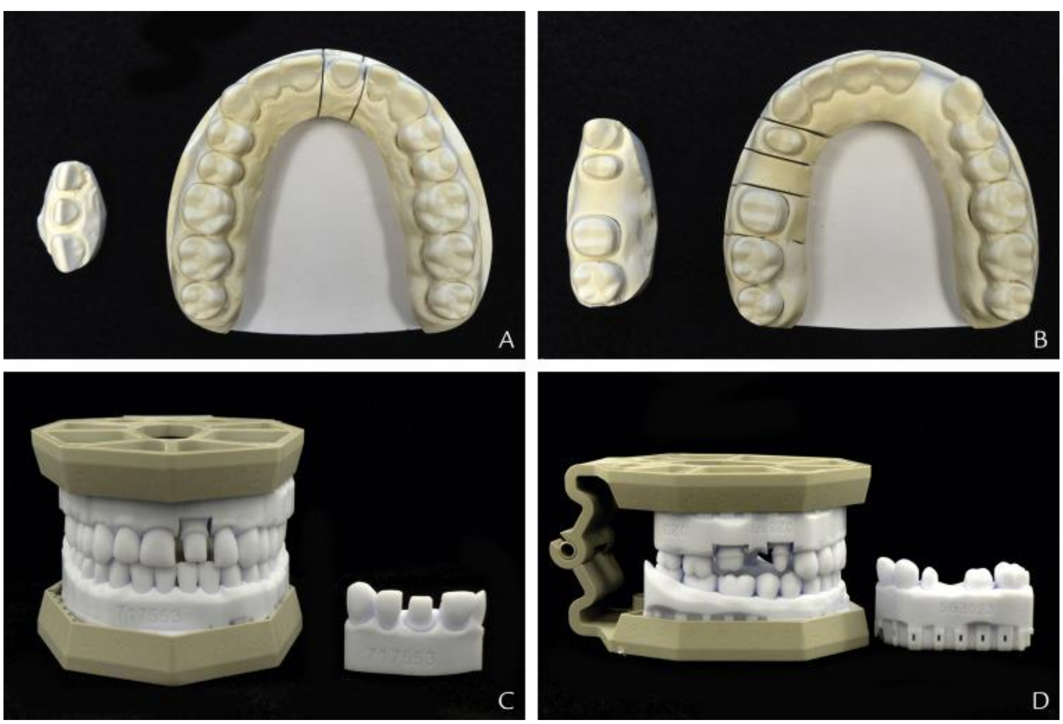

Figure 2. A, Stone definitive removable die-sectioned cast and solid cast for single ceramic crown. B, Stone definitive removable die-sectioned cast and solid cast for fixed dental prosthesis. C, SLA definitive removable die-sectioned cast and solid cast for single ceramic crown. D, SLA definitive removable die-sectioned cast and solid cast for fixed dental prosthesis. SLA, stereolithography.

For the definitive stone cast fabrication, custom trays were fabricated at least 24 hours before definitive impressions to ensure a customized tray with minimal distortion.[10, 36, 37, 38, 39] A thermoplastic sheet (Sta-Guard 0.16-inch; Buffalo Dental Mfg Co Inc) was used over the dentoform on a vacuum thermoforming machine (Ministar; Great Lakes Orthodontics) to create an even and consistent 2- to 3-mm space.[10, 36, 37, 39, 40, 41] A light polymerizing tray material (Triad; Dentsply Sirona) was used to fabricate the custom trays with a handle (12×12×5 mm) and wings (20×4×3 mm) and 8 relief holes (5 on the buccal surface and 3 on the lingual). The extensions of the tray ended at the land area of the dentoform to ensure a consistent and reproducible seating of the tray during definitive impression making. The internal surface of the customized tray was uniformly painted with PVS tray adhesive (vinyl polysiloxane tray adhesive; Parkell Products Inc) and allowed to dry for at least 5 minutes.[17, 41]

Twenty definitive impressions were made with extra-light body PVS material (Aquasil Ultra Smart Wetting Impression Material; Dentsply Sirona) injected uniformly around the prepared teeth, and heavy body PVS material (Aquasil Ultra Smart Wetting Impression Material; Dentsply Sirona). The impressions remained on the dentoform for 10 minutes, twice the manufacturer's recommended time, to compensate for polymerization at room temperature rather than intraorally,[42, 43, 44] in accordance with the American Dental Association specification 19.[45, 46] The impressions were removed from the dentoform and inspected for inaccuracies. The 20 PVS impressions were stored at room temperature for 24 hours. This delay stimulated the time required to send impressions for pouring by commercial laboratories. Prior to stone pouring, the impressions were sprayed with surfactant (Delar surfactant; DeLar Corp).[47, 48] They were poured with Type IV stone (ResinRock; Whip Mix Corp) according to the manufacturer's recommendations to create a total of 20 definitive removable DCs as 10 sets for the SCC and 10 sets for the FDP.[17] Twenty-four hours later, the impressions were separated from the casts.

A second pour with the same stone (ResinRock; Whip Mix Corp) was made for the fabrication of a nonsectioned SC, immediately after the first pour was separated. The SCs were separated from the impressions 24 hours after pouring. All stone casts were trimmed immediately after separation. The DC casts were fabricated using a total of 11 pinholes for the FDP cast and a total of 7 pinholes for the SC casts, using a Pindex machine (Pindex system; Coltène). After completely drying for 24 hours, the pins (Mainstay dowel pin; Whip Mix Corp) were cemented into the pinholes of the cast base with cyanoacrylate adhesive (Loctite Super Glue; Henkel Corp). Antirotational grooves were placed on the buccal and lingual aspects of each pin location. Gypsum separating agent (Super Sep; Kerr Corp) was applied to the base of the cast.[17] The Pindex red sleeves were placed over the pins, followed by the black stoppers. For the base fabrication, Type III stone (Flow stone; Whip Mix Corp) was poured into a rubber mold (Flexible mold; Coltène). The stone base was allowed to set for 45 minutes. The base was separated from the rubber mold, and excess stone was trimmed (3/4 horsepower Wet model trimmer; Whip Mix Corp). The dies were cut with a saw (Laboratory Saw Kit; Dentsply Sirona). Each definitive stone cast consisted of removable DCs and nonsectioned SCs (Fig. 2).

The dentoform, 40 stone casts, and 40 SLA casts were digitized using a laboratory scanner (D8100; 3 Shape) in order to produce the standard tessellation language format files. For the SCC group, there were 10 stone DCs, 10 stone SCs, 10 SLA DCs, and 10 SLA SCs; for the FDP group, there were also 10 stone DCs, 10 stone SCs, 10 SLA DCs, and 10 SLA SCs. Measurements of the IP distances of each cast were made using CAD software (Rhino 5; McNeel North America) to provide mean ±standard deviation (SD) values. Data were first analyzed by repeated measures analysis of variance (ANOVA) using different methods of cast fabrication (stone and SLA casts) as 1 within-subject factor and different cast types (DC and SC) as another within-subject factor. Furthermore, post hoc paired Student *t* test analyses were performed to investigate the differences between stone and SLA casts depending upon the results from the repeated measures ANOVA (α=.05).

Results

Table 1 summarizes the mean ±SD of the IP distances for the SCC and FDP groups and shows the absolute differences between IP distances. In the SCC group, the mean ±SD value was 31.2 ±24.5 µm for the stone casts and 261.0 ±116.1 µm for SLA casts, whereas in the FDP group, the mean ±SD value was 46.0 ±35.0 µm for stone casts and 292.8 ±216.6 µm for SLA casts. From paired Student *t* tests for both the SCC and the FDP groups, there were significant differences between IP distances between SLA casts and stone casts (*P*<.001).

Table 1. Absolute difference of interproximal distance (µm) for SCC and FDP groups

Cast	**Group**	
	SCC	**FDP**
Stone	31.5 ±24.5[a]	46.0 ±35.0[b]
SLA	261.0 ±116.1[a]	292.8 ±216.6[b]

FDP, fixed dental prosthesis; SCC, single ceramic crown; SLA, stereolithography. Values presented as mean ±SD. Same superscript letters in column indicate statistical difference (*P*<.05).

Table 2 shows the repeated measure analysis of 3-way ANOVA to evaluate the effect of cast fabrication method (stone versus SLA), cast type (DC versus SC), and their interaction for SCC and FDP groups. For the interaction effect, there was a statistically significant difference for the FDP group (*P*<.001). Therefore, Table 3 demonstrates the comparison of absolute differences between DC stone and SC stone, as well as between DC SLA and SC SLA for SCC and FDP groups by post hoc paired *t* test; there were statistically significant differences in IP distances between DC SLA and SC SLA for the FDP group (*P*<.001); the mean ±SD value was 458.5 ±173.6 µm for the DC SLA and 127.1 ±88.8 µm for the SC SLA (Fig. 3).

Table 2. Effects of cast fabrication methods, cast type, and interaction for SCC and FDP groups (α=.05)

Interaction	***P***	
	SCC	**FDP**
Stone×SLA	<.001	<.001
DC×SC	.028	.001
Stone×SLA×DC×SC	.152	<.001

DC, die-sectioned cast; FDP, fixed dental prosthesis; SC, nonsectioned solid cast; SCC, single ceramic crown; SLA, stereolithography. Repeated measure analysis of 3-way ANOVA evaluating effects of cast fabrication method (stone and SLA cast), cast type (DC and SC) and their interaction for SCC and FDP groups (α=.05)

Table 3. Absolute difference values between DC stone and SC stone, DC SLA cast and SC SLA for SCC and FDP groups by post hoc paired Student *t*-test (α=.05)

Group	*P*	
	SCC	FDP
DC stone-SC stone	.138	.051
DC SLA-SC SLA	.066	<.001

DC, die-sectioned cast; FDP, fixed dental prosthesis; SC, nonsectioned solid cast; SCC, single ceramic crown; SLA, stereolithography.

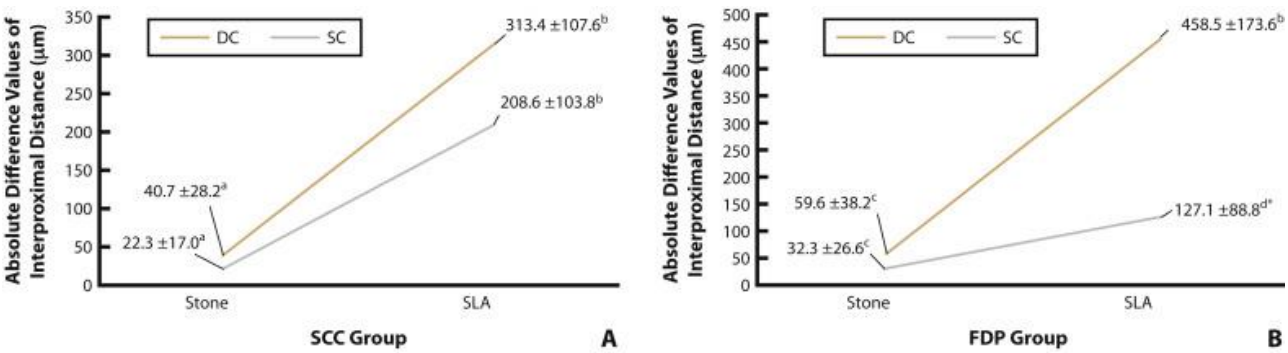

Figure 3. Mean ±standard deviation values (µm) of absolute difference of interproximal distance for die-sectioned casts (DC) and solid casts (SC) for A, SCC group; B, FDP group. Note: Same letters indicates no statistically significant difference. *Statistically significant differences between same letter.

Discussion

The present study quantitatively evaluated the accuracy of the IP distance of SLA casts made by digital intraoral impressions in comparison with that of stone casts made using conventional PVS impression material. The null hypotheses were rejected because statistically significant differences were found between the SLA casts and stone casts. In order to understand these results, the 4 variables that can influence the quality of the definitive casts should be examined further. As presented earlier, these four variables included (1) accuracy of the impression procedure, (2) various cast/die systems,[6, 7, 8] (3) dimensional accuracy and stability of definitive cast materials, and (4) precise repositioning of the removable die.[9, 10]

Polyvinyl siloxane impression materials demonstrate dimensional stability when adequate techniques, such as customized tray fabrication, 2- to 3-mm thickness of PVS materials, use of tray adhesive, no moisture contamination, and appropriate seating pressure are used.[4, 5] The accuracy of the digital impression has been evaluated in previous studies.[18, 19, 27, 28, 29] Patzelt et al[19] and Ender and Mehl[27, 28] investigated the reliability and accuracy of the intraoral scanners, such as CEREC, Lava COS, iTero (Align Technologies), and Zfx Intra Scan (Zimmer Dental). These studies found that, although the conventional systems (PVS and stone) demonstrated greater accuracy than digital impression systems, the dimensions of the die obtained from both systems were within the clinically acceptable range. Furthermore, Cho et al[26] showed that the digital intraoral impressions produced overall less accuracy than the conventional method, with the mean discrepancy of 27 ±7 µm for digital intraoral impression group and 11 ±3 µm for the conventional method group. In the present study, the IP distancesof the SLA cast group were significantly larger than those of the stone cast group. The results of these aforementioned studies, which demonstrated that digital impressions show less accuracy than digital impressions, can help explain the result of the present study.

In addition to the Pindex system, other cast and die systems have been used for fabricating definitive casts: the Accu-Trac precision die system (Carson Dental, Freud Dental), the brass dowel pin system (JM Ney Corp), the plastic base DVA (Dental Ventures of America), and the Di-Lok (Patterson Dental).[11, 12, 17] Serrano et al[17] reported that the Pindex system showed the least horizontal movement; and the brass dowel system produced the least occlusogingival reseating discrepancy when used for implant dentistry. Wee et al[11] supported the use of double-pour (Pindex) or plastic base (DVA) die systems for a multi-implant-retained prosthesis. The Pindex system is one of the most accurate cast and die system, which was also shown in the present study.[12] For the CAD-CAM casts, there are various types of cast/die system. The SLA cast system (Lava COS; 3M ESPE), made by rapid prototyping techniques, is similar to Di-Lok system, whereas the iTero cast system (Align Technologies) produces a Geller-type polyethylene cast made by milling technology, which preserves the gingival portion with removable dies.[18] Studies have reported that SLA casts made by rapid prototyping techniques showed improved precision compared with milling technology.[30, 31, 32]

The 2 dental stones most commonly used as die materials include Type IV dental stone (high-strength, low-expansion) and Type V dental stone (high-strength, high-expansion).[6] Linear expansion of the conventional Type IV and Type V dental stone has an expected expansion within the range of 0.06% to 0.5%. One study found Type IV resin-impregnated dies to be more dimensionally accurate than conventional Type V stone,[14] whereas another study found no significant differences between conventional gypsum and Type VI resin-impregnated stone.[15] Kenyon et al[16] examined the linear (either horizontal or vertical) dimensional accuracy of 7 die materials, regular Type IV, regular Type V, resin-impregnated Type VI, epoxy resin, polyurethane resin, copper-plated, and bisacryl composite resin. The results showed that Type IV resin-impregnated dental stone and copper-plated dies were more dimensionally accurate than the other die materials tested. Furthermore, the results demonstrated that the impression material restricted the horizontal expansion, but not the vertical dimension.[16] In other words, the expansion in the mesiodistal dimension was restricted but not in the occlusogingival dimension. Teraoka et al[13] demonstrated similar findings, as there were significant differences in the dimensional change in the vertical direction and horizontal directions of stone casts in open tray. This was an important distinction in light of the result of the present study. The mesiodistal (interproximal) dimension of stone casts showed minimal increase compared with that of the dentoform (control): 31.5 µm for the SCC group and 46.0 µm for the FDP group (Table 1). However, Keating et al[20] found that the SLA casts produced significant differences in the incisogingival dimension in comparison with stone casts. Additionally, other studies demonstrated that complete-arch scanning was less accurate than small area scanning.[22, 23] Another aspect of the dimensional accuracy of casts fabricated with CAD-CAM is the direction of dimensional change. Patzelt et al[18] demonstrated the dimension of SLA casts was changed by centripetal shrinkage with horizontal contraction at the posterior area. This finding emphasized the potential risk of distortion in CAD-CAM-generated casts, which can affect the interproximal distances of the definitive casts.

In the stone and SLA casts, the dies were sectioned and subsequently independently removable within the arch. As this movement is introduced into definitive casts, inaccuracies can occur. Serrano et al[17] stated that the stone expansion could create stress at the stone-plastic interface of the Pindex system, resulting in inaccuracy after the cast is sectioned. In terms of comparison between DC and SC, the present study showed there was a statistically significant difference only in the SLA FDP groups, which means SC should be used for FDPs fabricated on the SLA casts. However, there were no significant differences between DC and SC for other groups. Ahmad et al[12] reported that the Pindex system has shown the greatest amount of repositioning accuracy because the removable dies of the Pindex are locked securely by metal with a sleeve.

There are several limitations to this research with respect to methods, materials, and technology used. There are various methods to make definitive casts. The present study used only the Pindex system for definitive cast fabrication. Dimensional changes of dental impression materials by thermal changes should be considered because the PVS impression materials were polymerized at room temperature in the present study.[44] In addition, other dental stone types (Type V) can be used for further study. Moreover, due to limited technology and product for the present study, the results may not be applicable to other CAD-CAM technology and systems. Thus, further studies will be needed to investigate the accuracy for other comparative technologies and methods.

Conclusions

Within the limitations of this in vitro study, the following conclusions were drawn:

1. For both the SCC and FDP groups, stone cast groups demonstrated significantly more accurate values of IP distances than SLA cast group.

2. In terms of the comparison between DC and SC, SC SLA for FDP group only showed significantly more accurate values for IP distances than DC SLA for FDP group.

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