Computer-aided design/computer-aided manufacturing (CAD/CAM) systems have been developed to simplify the processing of dental prostheses while producing accurately fitted restorations.1 Previously, low-resolution scanning and inadequate computing power resulted in the poor marginal and internal fit of CAD/CAM prostheses.2 However, recent advances in technology, engineering, and materials have led to CAD/CAM systems that use highly accurate scanners and more sophisticated software to digitize the complex shapes required in dentistry.1,3-5

The importance and the effect of the internal fit, specifically with regard to crown seating and marginal adaptation, have been reported. Eames et al6 discovered that a 25-μm thickness of a die spacer not only improved the casting seating but also increased retention by 25%. Grajower and Lewinstein7 noted that the thickness of the spacer should allow for the cement film thickness, roughness of the tooth and casting surfaces, dimensional inaccuracies of the die, and distortions of the wax pattern. Wilson8 showed a significant correlation between increased spacing and

**ABSTRACT**

**Statement of problem.** No studies have evaluated the internal adaptation of pressed and milled ceramic crowns made from digital impressions.

**Purpose.** The purpose of this in vitro study was to evaluate the internal fit of pressed and milled ceramic crowns made from digital and conventional impressions.

**Material and methods.** Thirty polyvinyl siloxane (PVS) impressions and 30 Lava COS impressions made of a prepared dentoform tooth (master die) were fabricated. Thirty crowns were pressed in lithium disilicate (IPS e.max Press), and 30 crowns were milled from lithium disilicate blocks (IPS e.max CAD) (15/Impression technique) with the E4D scanner and milling engine. The master die and the intaglio of the crowns were digitized with a 3-dimensional laser coordinate measurement machine. The digital master die and intaglio of each crown were merged. The distance between the die and the intaglio surface of the crown was measured at 3 standardized points. One-way ANOVA was used for statistical analysis (α=.05).

**Results.** One-way ANOVA revealed that the internal gap obtained from the Lava/press group (0.211 mm ±SD 0.041) was significantly greater than that obtained from the other groups (P<.001), while no significant differences were found among PVS/press (0.111 mm ±SD 0.047), PVS/CAD/CAM (0.116 mm ±SD 0.02), and Lava/CAD/CAM (0.145 mm ±SD 0.024).

**Conclusions.** The combination of the digital impression and pressed crown produced the least accurate internal fit. (J Prosthet Dent 2015;113:304-309)
Clinical Implications
Different combinations of impression procedures, die materials, and crown fabrication techniques affect the size and uniformity of the internal adaptation. Large and inhomogeneous internal gaps may adversely affect the marginal fit and strength of the cemented crown.

decreased seating time and seating discrepancy and that a spacing of less than 40 μm prevented the crown from seating, which resulted in increased marginal discrepancy. Olivera and Saito9 evaluated the effect of die spacer on the fit and retention of complete cast crowns by using 3 different cements. The results showed that better marginal fit was obtained when the die spacer covered all but the area 0.5 mm short of the preparation margin.

Another important aspect of the internal fit of crowns is its effect on the fracture resistance of ceramic restorations. Tuntiprawon and Wilson10 evaluated the effect of increasing cement thickness (with platinum foil and die spacer) on the fracture strength of ceramic crowns. Each crown was cemented onto a metal die with zinc phosphate cement and loaded until fracture. They found that strength decreased with the increase of cement thickness and that the decrease in strength could be attributed to the greater deformation of the porcelain into the cement and to the decreased thickness of the crown itself.

More recently, Liu et al,11 by creating numerical simulations, which indicated that although an optimal cement thickness of approximately 90 μm can reduce the stress level in ceramic crowns, the thickness itself is of secondary importance to stresses in the core or veneer compared to the influence of loading conditions or the elastic modulus of the cement.

In this study, 2 CAD/CAM systems were used: the Lava Chairside Oral Scanner (COS) (3M ESPE) (testing the impression technique) and the E4D Dentist System (E4D Technologies; Planmeca) scanner and milling engine (testing the crown fabrication method).12 These systems use different principles and technologies. The COS system uses active wave-front sampling, and the E4D system uses optical coherence tomography and confocal microscopy to acquire accurate impressions.

CAD/CAM systems are most commonly used in conjunction with ceramic materials such as lithium disilicate (IPS e.max; Ivoclar Vivadent). Lithium disilicate is a ceramic restorative material that combines high flexural strength with excellent esthetics.13,14 Restorations can be fabricated from lithium disilicate with either a CAD/CAM technique or the lost wax technique.15 No studies have evaluated the influence of both the impression technique and the prosthesis fabrication technique on the internal fit of the definitive ceramic restoration. Therefore, the aim of this study was to evaluate in vitro the internal fit of ceramic crowns made from 2 different impression techniques (digital and conventional) and 2 different fabrication methods (CAD/CAM and lost wax).

MATERIAL AND METHODS
The materials and methods follow those in a previous publication,15 and are summarized here. A single operator (E.A.) prepared a mandibular right first molar (Dentaform Corp) for a ceramic crown by following standardized tooth preparation procedures (Fig. 1). A pilot study was conducted to test the proposed protocol, conduct a power analysis to determine the sample size, and validate the new digital measurement technique.

Light-body and heavy-body polyvinyl siloxane (PVS) (Extruze; Kerr Dental) were used in a quadrant custom tray (SternTek; Sterngold Restorative Systems) to make 30 master impressions of the prepared tooth. Type IV stone (Resinrock; Whip Mix Corp) was used to pour the definitive casts, and all dies were trimmed under a light microscope (Fig. 2).

Thirty scans of the same prepared tooth were made with the Lava COS. A thin dusting of titanium dioxide powder (3M ESPE) was applied to the Dentoform before scanning. The scanning data were sent to the manufacturing center (InTech Industries Inc), and 30 stereolithographic (SLA) models with removable dies (SLA resin casts; 3M ESPE) were produced (Fig. 3).

Thirty IPS e.max Press (IPS e.max Press LT A1) complete-coverage crowns were made with the lost wax technique, 15 on stone dies produced by conventional impression and 15 on resin dies produced by digital impressions. A rubber-based removable die spacer (Rem-e-die; Ivoclar Vivadent) extending 1 mm occlusal to the crown margin ramp. The crown thickness was

An E4D HD scanner was used to scan the remaining 15 stone casts and 15 resin models. The crowns were invested and pressed following the manufacturer’s directions. Any positive nodules found on the intaglio of the pressed crowns from the investing procedure were carefully removed with a diamond rotary instrument under a microscope (×10). No further adjustments were made to the intaglio surface.

An E4D HD scanner was used to scan the remaining 15 stone casts and 15 resin models. The crowns were designed with the E4D Design Center (Dentalogic 4.5.0.34). In order to compare them with the pressed crowns, the CAD crowns were designed with the following specifications: “0.04” spacer thickness and “1.00” crown margin ramp. The crown thickness was
greater than 1 mm, and the margins were enhanced by using the default settings “0.150” and “2.000” under Margin Boost Settings to avoid chipping during milling. The E4D milling engine was used to mill the ceramic crowns from IPS e.max CAD blocks (IPS e.max CAD LT Block I12 A1; Ivoclar Vivadent). Horizontal margin overhangs were adjusted with a polishing disk (Brasseler) under the microscope. No adjustments were made to the intaglio surface. The crowns were crystallized in a ceramic furnace (Ney Centurion Qex; Dentsply Ceramco).

Four study groups (n=15 per group) were tested: conventional impression-IPS e.max Press (PVS/press), conventional impression-IPS e.max CAD (PVS/CAD/ CAM), digital impression-IPS e.max Press (Lava/press), and digital impression-IPS e.max CAD (Lava/CAD/ CAM) (Fig. 6).

A triple scan protocol as previously described by Holst and colleagues was used as the measurement method. The surveyor ZS-Series scanner that is a 3-dimensional laser coordinate measurement machine with a scan accuracy of ±0.009 mm (Laser Design Inc; GKS) was used to digitize the master die and the intaglio of each crown. Scanning was facilitated with a light coat of spray (Spotcheck; Magnaflux). Scans were made of the prepared Dentoform tooth (master die) secured on a standardized metal base with PVS material, the intaglio of each ceramic crown, and each crown on the Dentoform tooth in a clinically appropriate position.

Separate data sets in stereolithography (STL) format were generated from point clouds with software (Qualify 2012; Geomagic) for each specimen. The master die STL file and the crown/master die STL file were first registered by manual alignment, followed by best-fit registration. The same procedure was followed to register the crown STL file and crown/master die STL file. The crown/master die STL data set was deleted, and the aligned crown to master die STL data set was used for fit assessment.

Two sections, facial-lingual and mesial-distal, were made through the grooves on the standardized metal base of the tooth. The distance between the die and the intaglio surface of the crown was measured at 6 standardized points, 3 from each section (2 on the axial walls and 1 on the occlusal surface) (Figs. 7, 8). All the measurements obtained from each of the 6 points were...
averaged to evaluate the internal fit as a single variable to facilitate statistical analysis.

One-way ANOVA with the post hoc Tukey honestly significant difference test was used to determine whether significant differences existed in mean internal gap values among the 4 experimental groups (α=.05) with software (SAS v9.3; SAS Institute Inc).

RESULTS
The results of the study are summarized in Table 1 and illustrated in Figure 9. A significant effect was found for the crown fabrication techniques on the internal fit (P<.001). The internal gap obtained from the Lava/press group was significantly greater than for the other 3 groups, whereas no significant differences were found between Lava/CAD and PVS/CAD, or between PVS/press and PVS/CAD.

DISCUSSION
The internal fit of ceramic crowns fabricated from conventional and digital impressions was assessed. No previous studies have assessed the internal adaptation of ceramic crowns made from the combination of those techniques. The measurement technique that was selected with the digital sections enables the visualization of the adaptation of the crown on the die surfaces, not only on the measurement points but also throughout the entire section. The use of such sophisticated software allowed 3-dimensional measurements; however, 2-dimensional sections were used to facilitate the visualization of the internal gap in each part of the tooth and also to compare the results with previous studies. However, direct comparisons with previous studies reporting 2-dimensional measurements made from physical sections should be made with caution because of the differences of physical and digital models.

The results of the study showed that with any combination of analyses, when the pressed crowns were fabricated on the SLA dies, they had a larger internal gap than the other groups. Because the technique/software can see the overall fit of the crown, 2 of the crowns were found to have larger and nonuniform internal gaps. Thinking that maybe the difference was due to those 2 outliers, the data of those 2 were removed, and the
statistical analysis was repeated. However, the new analysis showed the same statistical significance as the first, indicating that the Lava/press group had a larger internal gap compared to the remaining 3 groups.

One possible reason for this difference may have been that as a result of the fabrication procedure, the irregularities on the SLA model surfaces would not allow a uniform internal adaptation of the crowns. The 2 SLA dies that produced the pressed crowns with the largest internal gap were subsequently examined under a microscope (×10), and no substantial differences were detected compared to the remainder of the SLA dies. That this was not noticed in the Lava/CAD crowns might suggest that surface irregularities were not the primary reason for the larger internal gap; this cannot be concluded, however, because of the difference in crown fabrication technique between the 2 groups. For the CAD/CAM crowns, the SLA models were scanned, which could alter the model surface, either because of the resolution of the scanner or because software processing that would eliminate any defects interfering with the CAD/CAM procedure.

Another possible reason for the larger internal gap of the Lava/press group was the type of die spacer used. The die spacer used for this study was rubber based, as recommended by the manufacturer (Ivoclar Vivadent). Although this type of material was used successfully with the stone dies, it might not be compatible with the SLA resin models because of the poor wettability of the dies. This would result in the material not adapting evenly on all surfaces of the die and could cause a nonuniform or irregular appearance of the intaglio of the crowns, as seen in Lava/press group, and could be a limitation of this study. This assumption is further supported by the fact that no statistical difference could be found in the marginal fit of this group compared to the PVS/CAD/CAM and Lava/CAD/CAM groups because the area where the marginal gap measurements were made was not covered by die spacer.¹³

For the internal fit, the results also revealed that within the CAD/CAM crown fabrication method groups (PVS/CAD/CAM and Lava/CAD/CAM), the mean internal gap for the PVS impression group (PVS/CAD/CAM) was significantly smaller than that for the digital impression (Lava/CAD/CAM) group (0.116 mm versus 0.145 mm). In other words, the combination of digital impression and CAD/CAM crowns produced a larger internal gap compared to the conventional impression and CAD/CAM crown. The E4D HD scanner has established protocols for 3 different types of scanning: intraoral scanning or direct digitalization, scanning of the impression or indirect digitalization, and scanning of the cast/model or indirect digitalization. This scanner, therefore, should be able to capture data from surfaces with different properties, including translucency, reflection, and smoothness. For this project, indirect digitalization was used by scanning the stone and SLA models. The gypsum and the resin dies have very different surfaces, with stone being more opaque and smooth and resin being more reflective and less smooth because of the lines produced when printed. The scanner may not have captured the data from the SLA model with as high a degree of accuracy. Most of the scanners available today, in order to accurately capture the surface, need it to be coated with an opaque spray or dye. The E4D HD manufacturer claims to achieve that accuracy without the use of a spray but has not been tested with SLA models before.

Other limitations of this study may include the software used to obtain the measurements, the spray used for digitizing the specimens, and the lack of actual crown cementation. As described previously, with regard to the reported decrease in strength when the cement thickness was increased, the longevity and survival of the ceramic crowns that were pressed using resin dies may be compromised; however, this was not tested in this study.

**CONCLUSIONS**

Within the limitations of the in vitro study, it was concluded that the combination of the digital impression and pressed crown produced the largest internal gaps. There was no statistical difference among the conventional impression/CAD crown, conventional impression/press crown, and digital impression/CAD crown with regard to internal fit. Although not evaluated in this study, excessive internal gaps may adversely affect the fracture strength and clinical longevity of ceramic crowns. Future in vivo studies should evaluate the clinical performance of crowns made from digital impressions compared to conventional impressions.

**REFERENCES**


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