An In-Vitro Comparison of the Marginal Adaptation Accuracy of CAD/CAM Restorations Using Different Impression Systems

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ABSTRACT

Objective: The objective of this *in-vitro* study was to compare the marginal adaptation of 3-unit zirconia fixed dental prosthesis (FDPs) obtained from Intraoral digital scanners (Lava True Definition, and Cadent iTero), scanning of a conventional silicone impression, and the resulting master cast with an extraoral scanner.

Materials and Methods: One reference model was fabricated from intact, non-carious, unrestored human mandibular left first premolar and first molar teeth (teeth #19 and #21), prepared for a three-unit all ceramic FDP. Impressions of the reference model were obtained using four impression systems (n=10), group 1 (PVS impression scan), group 2 (Stone cast scan), group 3 (Cadent iTero), and groups 4 (Lava True Definition). After that the three-unit zirconia FDPs were milled. Marginal adaptation of the zirconia FDPs was evaluated using Optical Comparator at four points on each abutment. The Mean (SD) was reported for each group. One-way ANOVA was used to assess the statistical significance of the results, with post-hoc tests conducted via Tukey’s HSD. P-values less than 0.05 was considered statistically significant. All analyses were done using SPSS 22.0.
Results: The mean (SD) marginal gaps for the recorded data from highest to lowest were silicone impression scan 81.4 \( \mu \text{m} \) (6.8), Cadent iTero scan 62.4 \( \mu \text{m} \) (5.0), master cast scan 50.2 \( \mu \text{m} \) (6.1), and Lava True definition scan 26.6 \( \mu \text{m} \) (4.7). One way ANOVA revealed significant differences (P<0.001) in mean marginal gap among the groups. The Tukey’s HSD tests demonstrated that the differences between all groups (silicone impression scan, master cast scan, Lava True definition scan, iTero Cadent scan) were statistically significant (all P<0.001). On the basis of the criterion of 120 \( \mu \text{m} \) as the limit of clinical acceptance, all marginal discrepancy values of all groups were clinically acceptable.

Conclusions: Within the confines of the study, it can be concluded that the marginal gap of all impression techniques was within the acceptable clinical limit (120 \( \mu \text{m} \)).

Group 4 showed the lowest average gap among all groups followed by group 2, 3, and 1; these differences were statistically significant.
DEDICATION

To my Parents, and my husband.

Thank you for your prayers, love, inspiration, and constant support
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I am so grateful to Allah (God), “Who taught man by the pen. Taught man what he knew not.” (Qur’an), the Almighty God, for all the bounties he grants me throughout my life.

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An *In-Vitro* Comparison of the Marginal Adaptation Accuracy of CAD/CAM Restorations Using Different Impression Systems


**Introduction**

The fit of a dental restoration depends on quality throughout the entire manufacturing process. The final result is affected by several factors, such as tooth preparation design, final impression technique, master cast production, fabrication of the restoration, chair side adjustment of the restoration, and the material and method used for cementation.\(^1\)\(^-\)\(^4\)

The impression technique, in addition to the properties of the impression material that is used, may affect the fitting precision of fixed restorations. The fabrication of a master cast compensates for volumetric changes of the impression material to a certain extent; however, the fabrication of a stone master cast is a time-consuming and error-prone method that requires the presence of, or collaboration with, a dental laboratory.\(^5\),\(^6\)

A new approach currently used in dentistry employs digital impression technology. The impression is taken digitally using intraoral scanners, in which the master cast of the digital impression is manufactured by computer-controlled systems. This approach claims to eliminate the dimensional changes of the impression materials, the expansion of the dental stone and the human errors associated with master cast fabrication.\(^7\)
There are many digital impression systems presently available in dentistry; in this study, we will include two of the most commonly used. Each one of these systems has its specific technique for impression making. One of these, the Lava True Definition system (Lava, 3M ESPE, St Paul, MN), which was launched in the fall 2012, uses video motion with surface powdering. Powder application is not required for the iTero (CADENT, San Jose, CA) digital impression system, which was introduced for dental application in 2007. This system uses a snapshot intraoral camera, which is able to capture surface details using parallel confocal imaging.

The major goal in making an accurate final impression is to obtain a final restoration with a clinically acceptable marginal adaptation. The increase in the marginal gap between the crown and the prepared tooth promotes a washout of the luting material, micro-leakage and plaque retention. This can result in secondary caries, pulp inflammation, and periodontal tissue diseases, which could lead to a failure of the restorations. Reich et al. proposed that the marginal gaps of the zirconia frameworks used for all ceramic three-unit fixed partial dentures (FPDs) lies between 64-83µm.

Some investigators have examined and measured the accuracy of different digital impression systems; these studies have provided varying and controversial
results. Kim et al. concluded that the conventional impression was significantly more accurate than the iTero digital impression. Loos et al. found that applying titanium oxide powder prior to surface scanning alters the geometry of the surface, and may compromise the exactness of the internal fit. On the other hand, Ender et al. stated that direct intra-oral scanning circumvents the need to take an impression and pour up a stone cast, eliminating two of the steps that can influence the accuracy and precision of the final result. Similarly, Syrek et al. found that the Lava C.O.S. crowns from intra-oral scans revealed significantly better marginal fits compared to the conventional impression technique. Also, Luthardt et al. showed that indirect data acquisition using impression taking will improve internal fit, compared with the direct procedure.

There has been a controversy in the literature about the accuracy of these systems due to the limitations related to each system in data gathering. Hence, the purpose of this in-vitro study was to measure the marginal adaptation of zirconia three-unit fixed dental prosthesis (FDPs) fabricated using different impression systems.

**Literature Review**

There are many clinical steps that will influence the accuracy of final restorations. Each step can create a variable that can increase the chances of the inaccuracy of
the end result. The procedures and materials involved in the conventional method and the digital methods of impression making can also be factors in the accuracy of the final restoration.

**Conventional Impression**

*Tray Selection*

One of the important factors in determining the degree of accuracy achieved in forming a master cast is the dimensional stability of the impression tray. The materials of impression tray fabrication have to be rigid, dimensionally stable, and should not exhibit permanent deformation during making the impression and removing it from the oral cavity.

Stock trays are ready made, so there is no time or effort consumed in their fabrication. In addition, they are inexpensive, which is why they are useful in everyday impression making. On the other hand, there are several studies demonstrating that stock plastic trays produce casts with greater dimensional change compared to custom trays. Plastic stock trays are non-rigid and flexible. Their flexibility causes dimensional changes that occur during the polymerization of the impression materials.\textsuperscript{17-20} Carrotte et al.\textsuperscript{21} suggest that stock metal trays provide greater accuracy than flexible plastic ones.
Custom trays are considered to be more accurate than stock trays. Burton et al.\textsuperscript{22} concluded that the accuracy of an impression is, to a considerable extent, dependent on the tray material used.

Autopolymerizing acrylic resin has been one of the materials of choice for the fabrication of custom trays. Its main disadvantages are the exposure of the oral tissues to the monomer, and the distortion from polymerization shrinkage,\textsuperscript{23} which is why it is recommended to have some interval between the fabrication of an acrylic resin custom tray and the impression making procedure.\textsuperscript{24} Pagniano et al.\textsuperscript{25} stated that autopolymerizing acrylic resin trays should not be used for at least nine hours after fabrication. Distortion of the tray, which could produce an inaccurate impression, is possible if the impression is made immediately after the acrylic resin custom tray is fabricated; a study by Mowery et al.\textsuperscript{26} showed that autopolymerizing acrylic resins continue to shrink for up to 180 days, resulting in a significant dimensional change.

Thermoplastic materials have also been used for custom tray fabrication, due to the ease of construction and the fact that they contain no monomer; however, they can easily distort during the impression making procedure.\textsuperscript{20,23}

Light-polymerized resins have gained popularity because they are easy to handle and can be used immediately after fabrication.\textsuperscript{23} Advantages such as accuracy of
fit, superior strength, complete polymerization without residual compounds, ease of fabrication and manipulation, patient acceptance, and low bacterial adherence make this material an important addition to the choices available to dentists.\(^{27-30}\)

The main disadvantage of light-polymerized resin is its insufficient flexural strength and tendency to fracture.\(^{31}\)

**Impression Materials**

Impression materials are used to register or reproduce the form and relation of teeth and the surrounding oral tissue. Several factors should be considered when choosing an impression material. Some of them are: accuracy, dimensional stability, effect of bulk of the material on accuracy, time of pour and a repeat of pour, viscosity, and tear strength.\(^{32,33}\)

Impression materials have been developed over time. Non-elastic materials such as zinc oxide eugenol paste, wax, modeling compound, and impression plaster were the first impression materials to be used. These materials were difficult to manipulate in the patient’s mouth and had a prolonged setting time, and a lack of elastic property that made them hard to be removed without distortion or breakage.\(^{34}\) However, a significant change has been made with the development of the elastic impression materials, which are subdivided into hydrocolloids (alginate, agar) and elastomerics (polyethers, polysulphides, and silicones).\(^{34}\)
According to the American Dental Association (ADA) specification number 19, both polyether and polivylosiloxane (PVS) materials are considered the most commonly used materials for fixed and removable prosthodontic procedures due to their high tear strength, high accuracy and detail reproduction of up to 20 µm, and good performance upon retrieval from undercuts.\textsuperscript{35}

Thongthammachat et al.\textsuperscript{23} evaluated the dimensional accuracy of dental casts fabricated from different types of trays and impression materials, which were poured at different and multiple times. They reported that a polyether impression should be poured only once within one day after impression making due to the material distortion that occurs over time. Therefore, it was also recommended not to store polyether impression in contact with moisture.

In the present study, polivylosiloxane impression materials were used to obtain conventional impressions and casts due to their excellent detail reproduction and dimensional accuracy under dry conditions.

*Stone Cast*

According to the Glossary of Prosthodontic Terms, a dental cast is a positive, life-size reproduction of part or parts of the oral cavity. The ADA Specification number 25 classifies gypsum products into five categories, two of which were examined in this study. Type IV (high strength, low expansion) and Type V (high
strength, high expansion) dental stones are commonly the materials of choice in fixed prosthodontics because of their detail reproduction, surface hardness, abrasion resistance and high strength. The concern with any type of stone used in dentistry is its dimensional stability. Heshmati et al. measured the linear setting expansion of six ADA type IV and V dental stones, compared their expansion at two hours relative to ADA Specification 25, and characterized expansion changes up to 120 hours. The results of this study showed that among the die materials tested, no single material was superior to the others in all respects. Ragain et al. concluded that adequate detail reproduction of prepared teeth can be achieved with any combination of impression materials to die stones. Type four resin-reinforced die stones are less scratch resistant on the surface than type four stones. The authors stated that no combination of die and impression materials was superior to another for all the surface properties studied when polyvinylsiloxane or polyether impression materials were used. Type IV dental stone was used in this study because of the need for high strength and low expansion to achieve dimensionally stable casts.

**Digital Impressions**

*Concept of Digital Impressions*
Digital impression systems work through the concept of point clouding the external surface into a large number of points that have $X$, $Y$, and $Z$ coordinates. The point cloud files that are created by the intra-oral scanners are converted into triangle mesh models, and the image of the scanning is presented in a three-dimensional way on the computer screen. The process of converting the point cloud file into the 3D format is done by using Delaunay triangulation approaches$^{38}$ (Figure 1).

**Lava True Definition Scanner**

The Lava True Definition (3M ESPE, St. Paul, MN) system consists of a mobile cart and a touch screen display monitor. Its scanning wand has a 13.2 mm wide tip and weighs 14 ounces. The camera at the tip of the wand contains 192 LEDs and a 22 lens system.$^8$ The method used by this scanner involves Active Wavefont Sampling (A.W.S.) for capturing 3D impressions, which requires only one optical path to capture the depth of the digital impression. The LAVA True Definition scanner captures approximately twenty 3D data sets per second, or close to 2400 data sets per arch in video mode. The finished preparations are lightly dusted with titanium dioxide powder to locate the reference points, which is not needed for the other systems.$^{39,40}$
**Cadent iTero Scanner**

The Cadent iTero (Cadent, Carlstadt, NJ) digital impression system was introduced in early 2007. The iTero system uses parallel confocal imaging to quickly capture the digital impression. Parallel confocal imaging uses laser and optical scanning to digitally capture the surfaces and contours of the tooth and gum structure. The Cadent iTero scanner captures 100,000 points of red laser light and has focus images of more than 300 focal depths of the tooth structure, which are spaced approximately 50 µm apart.\(^7\) This technology allows scans to be taken without coating the teeth with powder. The absence of powder means that the scanner can be rested directly on the teeth during scanning. The system provides voice and visual commands to guide the clinician through each scan; a typical series ranges from 15 to 30. The monitor combines these scans to provide a 3D color model of both arches.\(^41\) After the scan is approved, the file then will be transmitted to the dental laboratory.

**3Shape Lab Scanner**

The 3Shape lab scanner D700 (3Shape A/S, Holmens Kanal 7, Copenhagen K, Denmark) has the ability to scan both impression and gypsum models. This scanner consists of two red laser cameras with 3-axis motion system tilts, rotates
and translates the object, facilitating scanning from any viewpoint. Many tabletop scanners have been designed to capture 3D images of either impressions or physical models to create 3D models. These scanners have an auto-rotating unit to minimize the blind area.  

Sousa et al. suggested that linear measurements of arch width and length on digital models with the 3Shape scanner are highly accurate and reproducible. The accuracy of the shell/shell deviations of 3D images of the R700 3Shape scanner was compared with the gold standard images from the SLP250 Laser Probe scanner. The results indicated that the R700 3Shape scanner has sufficient accuracy and can be used by clinicians with confidence.

**Zirconia**

Zirconia is a crystalline dioxide of zirconium. Its mechanical properties are very similar to those of metals and its color is similar to the tooth color. Zirconia crystals can be organized in three different patterns: monoclinic (M), cubic (C), and tetragonal (T). By mixing ZrO₂ with other metallic oxides, such as MgO, CaO, or Y₂O₃, greater molecular stability can be obtained. Yttrium-stabilized zirconia is presently the most studied combination. ZrO₂ stabilized with Y₂O₃ has better
mechanical properties than other combinations; although its sintering is much more difficult, this is the principal kind of zirconia considered for current medical use. The 3 mol% yttria-stabilized zirconia (3Y-TZP) exhibits a very important feature related to the polymorphic transformation for monoclinic phase when a mechanical stress is applied. This phenomenon, known as transformation toughening, can prevent crack growth, which results in a material with high toughness and mechanical strength. At a crack tip, the matrix constraint on the tetragonal particles of 3Y-TZP is reduced by tensile stresses so that a transformation to the monoclinic structure takes place. This transformation produces a local 4-5% increase in volume, which results in compressive stresses within the matrix, thereby increasing the energy necessary for further crack growth. On the other hand, this transformation also alters the phase integrity of the material and increases aging susceptibility. Aging (the low temperature degradation) of zirconia is a well-documented phenomenon exacerbated noticeably by the presence of water.

3Y-TZP is available in dentistry for the fabrication of custom abutments and fixed partial dentures. Zirconia FPDs cannot be manufactured by dental technicians using the traditional methods of powder/liquid techniques. FPDs have to be milled from prefabricated blocks using a digital process called Computer Aided
Manufacturing (CAM).\textsuperscript{51} The restorations are processed either by soft machining of pre-sintered blocks followed by sintering at high temperature, or by hard machining of fully sintered blocks.\textsuperscript{52}

**Soft Machining**

This technique allows the frameworks to be ground out of zirconia in the pre-sintered, soft stage. This sintering procedure is accompanied by high sintering shrinkage of zirconia of about 22\%. In order to compensate for the shrinkage, the size of the milled pre-sintered frameworks has to be larger by this difference.\textsuperscript{55-56}

The soft machining technique prevents stress-induced transformation from tetragonal to monoclinic and leads to a final surface that is virtually free of a monoclinic phase unless grinding adjustments are needed or sandblasting is performed. Most manufacturers of 3Y-TZP blanks for dental applications do not recommend grinding or sandblasting, as these cause both the t $\rightarrow$ m transformation and the formation of surface flaws that could be detrimental to long-term performance, despite the apparent increase in strength due to the transformation-induced compressive stresses.\textsuperscript{57}

**Hard Machining of (Y-TZP)**

3Y-TZP blocks are prepared by pre-sintering at temperatures below 1500°C to reach a density of at least 95\% of the theoretical density. The blocks are then
processed by hot isostatic pressing at temperatures between 1400°C and 1500°C under high pressure in an inert gas atmosphere. The latter treatment leads to a very high density in excess of 99% of the theoretical density.\(^{58}\) Processing zirconia in its densely sintered stage makes the grinding procedures difficult; it is time consuming and leads to the high wear of milling instruments. Also, the restorations produced by hard machining of fully sintered 3Y-TZP blocks have been shown to contain a significant amount of monoclinic zirconia. This is usually associated with surface microcracking, higher susceptibility to low temperature degradation and lower reliability.\(^{59}\)

In this study, Zenostar Zr Translucent (Wieland Dental + Technik, Schwenninger Straße 13, Pforzheim, Germany), which is a partly sintered yttrium-stabilized zirconium oxide block (Y-TZP), was used.

**Marginal Adaptation**

All ceramic restoration long-term clinical success can be influenced by marginal discrepancies.\(^{60}\) Holmoe et al.\(^{61}\) stated that the term “marginal gap” can be summarized to be the discrepancy, or the “gap” between a restoration and the prepared tooth margin.

There is no general agreement as to what constitutes a biologically acceptable marginal fit. However, the American Dental Association specification 22 states
that the luting cement film thickness for a crown restoration should be no more than 25 μm using a type I luting agent or 40 μm with a type II luting agent. Furthermore, Oilo et al.\textsuperscript{62} proposed that the marginal fit of restorations in the range of 25 to 40 μm is the clinical goal.

There is substantial evidence from previous literature that various prostheses produce better marginal adaptation than others.\textsuperscript{61} May et al.\textsuperscript{63} measured the precision of fit of the crown fabricated with CAD/CAM technology for the premolar and molar teeth fit to a die and found that the mean gap dimensions for marginal openings, internal adaptation, and precision of fit for the crown groups were below 70 μm. Mehl et al.\textsuperscript{64} reported that the accuracy of digital scanners can be up to 132 ± 3.6 micrometers.

In terms of accuracy, the following factors were identified to have an influence on the fit of zirconia FPD: difference in fabrication systems, differences in span length, effect of veneering, effect of framework configuration, and effect of zirconia aging.\textsuperscript{65}

\textit{Zirconia state at milling}

Bindl and Mormann found that milling post-sintered zirconia provided a tendency for less marginal discrepancy than milling at the pre-sintered stage; however, the difference was not statistically significant.\textsuperscript{65} In contrast, Att et al.\textsuperscript{66} showed that
milling at the pre-sintered stage provided a superior outcome compared with post-sintered milling. Furthermore, milling zirconia at the post-sintered stage has been reported to be difficult, especially milling of the thin sections. Therefore, the cost effectiveness and simplicity of zirconia milling at the pre-sintered stage should be weighed against the benefit that can be gained from the reported minor superiority of the fit of milling of post-sintered zirconia.

**CAD/CAM versus CAM**

Bindl and Mormann reported that CAD/CAM provides a significantly better marginal fit than CAM systems. Beuer et al. also concluded that CAD/CAM provides a more accurate marginal fit than CAM. The CAM system has been shown to provide a marginal discrepancy of 2-3 times higher than that of CAD/CAM, which may be a concern when clinical variables are considered. This concern is supported by a clinical trial on zirconia FPD by Sailer et al. who reported a 21.7% incidence of recurrent caries in 5 years.

**Metal casting versus CAD/CAM**

Gonzalo et al. found that Procera frameworks had a significantly better margin fit than a metal framework, while Lava did not significantly differ from the metal framework. In the same study, they attributed their results to utilizing CAD/CAM
and omitting the several steps involved in the conventional casting procedure. In relation to the internal gap, the axial gap of zirconia frameworks was significantly larger than the axial gap for the metal frameworks. Wettstein et al.\textsuperscript{71} found that CAM zirconia frameworks exhibited a larger internal gap than gold alloy frameworks.

\textit{Effect of span length}

Because of the superior mechanical properties of zirconia, there is relative confidence in the fabrication of longer span FPDs. Tinschert et al.\textsuperscript{67} found after comparing 3-, 4- and 5-unit frameworks of post-sintered zirconia that the mean marginal discrepancy did not differ significantly. However, there was a tendency for higher values of marginal discrepancy with longer spans. With pre-sintered milling, Reich et al.\textsuperscript{72} found that there was a significant difference in marginal fit between 3- and 4-unit zirconia frameworks. However, the values obtained were still within the clinically acceptable range.

\textbf{Objective}

The objective of this \textit{in-vitro} study was to compare the marginal adaptation of 3-unit zirconia fixed dental prosthesis (FDPs) obtained from intraoral digital
scanners (Lava True Definition, and Cadent iTero), scanning of a conventional silicone impression, and the resulting master cast with an extraoral scanner.

**Clinical Significance**

The result of this study will help the clinician in the decision-making on the selection of an impression system that leads to restorations with better marginal adaptation.

**Hypotheses**

- Restorations obtained from intraoral digital scanners provide better marginal adaptation compared to restorations obtained from scanning the impression and the master cast.
- The iTero scanner will provide a better marginal adaptation compared to the Lava scanner.

**Materials and Methods**

**Sample Size Calculation**

A power calculation was conducted using nQuery Advisor (Version 7.0). Assuming means of 31µm for the iTero scanner, 48µm for the Lava scanner, and 64µm for the impression scan,* a common within-group standard deviation of
17.57, * and equal means for the two conventional groups, a sample size of n = 10 per group was adequate to obtain a Type I error rate of 5% and a power of 98%.

* Results from pilot study.

**Reference Model Fabrication**

Intact, noncarious, unrestored human mandibular right first premolar and first molar teeth (teeth #19 and #21) were collected in a labeled jar containing a liquid Sterall 0.5% sodium hypochlorite (Colgate Oral Pharmaceuticals, New York, NY) from the oral surgery department at Tufts University School of Dental Medicine. The selected teeth were cleaned of surface debris and stains with an ultrasonic scaler (Cavitron GEN-119, SpSTM, Dentsply, York, PA). The selected teeth were mounted in an autopolymerizing epoxy resin (American Dental Supply, Inc., Allentown, PA). Before mounting, a retentive groove was made on the root surface of the extracted teeth to secure them in the epoxy resin. Thereafter, a typodont mandibular second premolar tooth (#20) was glued to the distal surface of tooth #19 and to the mesial surface of tooth #21. Then, the block of the three teeth was mounted in the autopolymerizing epoxy resin (American Dental Supply, Inc., Allentown, PA). Subsequently, the abutment teeth were mounted 1mm shorter than the cementoenamel junction. After setting of the epoxy material, the typodont tooth #20 was removed and the abutments were prepared for
three units all ceramic bridge, following the guidelines proposed by Goodacre et al.\textsuperscript{73}

**Tooth Preparation**

The mounted teeth were prepared as follows: 1.5 mm axial reduction, 2 mm occlusal reduction, and a 360\(^\circ\) chamfer finish line. Tooth preparations were carried out under water spray using a high-speed handpiece (Midwest, Dentsply Plaines, IL) and a coarse diamond-tapered rotary cutting instrument (450K Max: Brasseler, Savannah, GA) for the initial gross reduction, followed by a fine bur (KD7W6 Brasseler, Savannah, GA) to smooth the surface of the preparation. The diamond rotary cutting instrument selected for the preparation is recommended in the literature to create a chamfer finish line,\textsuperscript{73} and to provide an optimal preparation for interpretation by the die scanning devices used in the fabrication of the zirconia frameworks (Figure 2).

**Final Impressions**

*Group 1: Polyvinylsiloxane (PVS) Impression*

Ten PVS impressions of the prepared teeth were made using prefabricated plastic impression trays and one-step dual polyvinylsiloxane impression material (PVS; Densply, York, PA) per the manufacturer’s recommendations. Part of the material
was meticulously syringed into the prepared teeth on the reference model, and the remaining impression material was syringed into the impression tray. Each tray was seated on the reference model with gentle finger pressure. All impressions were evaluated by the same operator. The ten impressions were scanned using a 3Shape lab scanner D700 (3Shape A/S, Holmens Kanal 7, Copenhagen K, Denmark) to obtain the information scanned in an STL format.

*Group 2: Master Cast*

After scanning of the impressions was completed, the ten PVS impressions were poured with type IV dental stone (ResinRock, Whip Mix, Louisville, KY) after being mixed using a vacuum mixer (Twister Pro, Renfert, St. Charles, IL) at the water/powder ratio recommended by the manufacturer. The stone cast was allowed to set removed from the impression after 24 hours, and evaluated for air bubbles. The ten master casts were then scanned with the 3Shape lab scanner D700 (3Shape A/S, Holmens Kanal 7, Copenhagen K, Denmark). The impression and its corresponding master cast were given the same number (Figure 3).

Before digital impressions were taken all the used systems were calibrated according to the manufacturer recommendation, and updated to the latest software versions.
Group 3: Digital impression system using snapshot intraoral camera (Cadent iTero)

Ten digital impressions were made with the iTero intraoral scanner. The reference model was stabilized in a fixed position on a table, and all the impressions were made in the same way. The camera captured the data by applying parallel confocal imaging using red laser light and optical scanning to capture the tooth surfaces beginning with the occlusal surface, followed by the buccal and the lingual surfaces on each abutment tooth; thereafter, the scanner software stitched and matched the images together. The ten digital impressions were sent to a production center (Align Technologies Inc., San Jose, CA) to obtain the STL files (Figure 4).

Group 4: Digital impression system using video motion with surface powdering (Lava True Definition)

Ten digital impressions were made using a Lava True Definition intraoral scanner. Before the scanning began, the prepared teeth were sprayed with titanium oxide powder provided with the scanner. To obtain the best focus, the camera must be held at a certain distance from the scanned tooth surface. The images were taken in video mode, which allows some freedom while scanning the prepared teeth surfaces. After all ten impressions were made, the scanning information was sent to the production center at 3M ESPE Dental (Lava, 3M ESPE, St Paul, MN) to
obtain the STL files. All scans were performed by one operator. See Figure 5 for a flow chart of the study design.

**Designing and Fabrication of Zirconia FPDs**

Upon receipt of the digital files in STL format for the impressions made by the lab and the intraoral digital scanners, the files were transferred into the Exocad® Dental CAD software (exocad GmbH, Fraunhofer IGD, Fraunhoferstrasse 5, Darmstadt, Germany) to design fully contoured zirconia FPDs with a 35 µm cement space starting 1mm above the margin. The design of all 3-unit zirconia FDPs was standardized using the same wax up scan. Each FDP was marked with a number. Then the designed FDPs were transferred to the milling machine, Tizian Cut 5 (Schütz Dental, Rosbach, Germany), which is a 5-axis cutting system. Zenostar Zr Translucent (Wieland Dental and Technik, Schwenninger StraBe 13, Pforzheim, Germany) blanks were used in this study (Figures 6, 7a, 7b, and 7c).

**Measuring the Zirconia Marginal Fit**

The forty 3-unit zirconia FDPs (4 groups, 10 per group) were evaluated and examined on the reference model for fully seating before measuring; none was rejected. The reference model was placed on the surveyor’s table and transferred to the Optical Comparator’s movable table (Figure 8).
Marginal adaptation was assessed with the Optical Comparator (Horizontal Optical Comparator System, Deltronic, Santa Ana, CA). This device is composed of a screen with horizontal and vertical reference lines and it has a movable table to allow positioning on the screen of the object to be studied. The light source projects a magnified image of the object onto the screen in the form of a shadow, so that the sharp edges of the projected silhouetted form of the abutments become the reference points of measurements that were used to obtain the results from each sample. The device has a measurement precision of 1 µm. The measurement was taken by positioning the surveyor’s table so that the light source was perpendicular to the area designated for measurement.

The marginal gap of each 3-unit zirconia FDP was measured three times on four points (mesial, distal, buccal, and lingual) in order to reduce the amount of error. The points were marked on the reference model in order to measure the same point on all specimens. An average reading was obtained for each point. All tests were performed by one operator (Figure 8).

Because the objective of the study was to measure and compare the average marginal gap of the FDPs, the four different measurements taken at the four
different points (mesial, distal, buccal, and lingual) were averaged prior to proceeding with the analysis.

**Statistical Analysis**

Descriptive statistics (means, standard deviations, minima, and maxima) were reported for each group. One-way ANOVA was used to assess the statistical significance of the results, with post-hoc tests conducted via Tukey’s HSD. P-values less than 0.05 were considered statistically significant. All analyses were done using SPSS 22.0. Normality was assessed using quantile-quantile plots. The assumption of equal variances was assessed using Levene’s test.

**Results**

The mean (SD) marginal gaps for the recorded data from highest to lowest were group 1: 81.4 μm (6.8), group 3: 62.4 μm (5.0), group 2: 50.2 μm (6.1), and group 4: 26.6 μm (4.7) (Table 2). Side-by-side boxplots are displayed in Figure 9. The p-value of Levene’s test was 0.865; hence, there was no evidence of the assumption of equal variance being violated. The quantile-quantile plots indicated no evidence of non-normality. One way ANOVA revealed significant differences (P<0.001) in mean marginal gap among the groups. The Tukey’s HSD tests demonstrated that the differences between all groups were statistically significant (all P<0.001).
Group 4 showed the lowest average gap among all groups, followed by group 2, group 3, and group 1. All differences were statistically significant.

On the basis of the criterion of 120 µm as the limit of clinical acceptance, the marginal discrepancy values of all groups were clinically acceptable. That is, no marginal discrepancy value exceeded 120 µm for any group.

**Discussion**

The marginal gap has the most clinical impact after crown fabrication. The increase in the gap between the crown and the prepared tooth promotes plaque retention, secondary caries, pulp inflammation, and periodontal tissue diseases, which could lead to a failure of the restorations. In this study, the accuracy of fit of the 3-unit zirconia fixed dental prosthesis (FDPs) was assessed based on the marginal gap.

The analysis of the results of this study showed that the mean marginal gap of the 3-unit zirconia FDPs obtained from the four groups (group 1, 2, 3, and 4) fell within the clinically acceptable limit of marginal opening, which is less than 120 µm according to what most authors would agree upon.

In this study the average marginal gap of 3-unit zirconia FDPs fabricated using the Lava True Definition scanner (group 2b) was 26.6 µm, which was significantly the
lowest among all groups. This could be due to the application of the opaque powder (titanium dioxide), which provides a uniform light dispersion that enhances the accuracy of the scan. This finding is in accordance with Syrek et al.\textsuperscript{15} who stated that the Lava C.O.S. crowns from intraoral scans revealed significantly better marginal fits (49 µm) compared to the conventional impression technique (71µm), which is similar to what was found in this study. In addition, Kim et al.\textsuperscript{12} concluded that the conventional impression was significantly more accurate than the iTero digital impression by comparing the digitalized images of the working dies. Reich et al.\textsuperscript{11} showed that the marginal fit of zirconia frameworks used for all ceramic 3-unit FDPs exhibited discrepancies in a range between 64 and 83 µm, which corresponds closely to the values reported in the present study. Gonzalo et al.\textsuperscript{70} also stated that the marginal discrepancies for zirconia 3-unit FDPs were significantly smaller than those for the metal ceramic (PFM) group. The reproducibility of the CAD/ CAM systems would seem to have contributed to these results, because the metal ceramic technique involved the use of die spacers to allow space for the cement, whereas in the CAD/ CAM technique, the space for the cement is adjusted during the manufacturing process.

On the other hand, there are few other studies that are in disagreement with the present study. Loos et al.\textsuperscript{13} stated that applying titanium oxide powder prior to
surface scanning alters the geometry of the surface and may compromise the exactness of the internal fit. Banday and Nathanson\textsuperscript{41} compared the accuracy of the marginal gaps of cast gold metal copings fabricated using conventional casts and iTero milled casts, and they found no statistically significant difference between the two systems. In their study the restorations were fabricated on the casts, whereas in this study, the restorations were fabricated using CAD/CAM technology. Completely sintered blocks have been used previously for the fabrication of zirconia prosthesis using CAD/CAM systems, which resulted in better fit but increase in cost and time. However, in this study green blanks were used, which offered the advantages of an easy machining process without water-cooling or lubrication.\textsuperscript{11} Nevertheless, chipping of thin margins can be the drawback of this process. It has been observed in previous studies that cementation can influence the measurement of the marginal gap, and many investigators reported that cementation can increase the marginal discrepancies of fixed restorations.\textsuperscript{74,75,81,82} In the current study the marginal gaps of the 3-unit zirconia FDPs were measured without cementing.

Based on the results obtained, intraoral digital scanners seem to be a legitimate alternative to the elastomeric impression materials. With the advancement of
technology, it can be expected that intraoral scanners will replace conventional impression techniques not too far.

However, the limitations of *in-vitro* studies, which may not completely simulate *in-vivo* performance, should be appreciated. Although the reference model was made of natural teeth, its condition differed from natural teeth in an oral environment since soft tissue, saliva, sulcular fluid, and patient movement that may affect the digital scanning process were not present. Many clinical factors besides impression techniques influence the quality of the final restorations. Different zirconium oxide compositions and luting cements can also affect the accuracy of the marginal fit. In addition, the clinical acceptance of crown prosthesis requires more than simply an acceptable marginal gap; further studies and clinical trials are recommended to fully investigate the accuracy of digital scanners available in dentistry.

**Conclusions**

Within the confines of the study, the following can be concluded:

- The marginal gap of all impression systems was within the acceptable clinical limit (120 µm).
- Group 4 had the smallest average gap among all groups, followed by group 2, group 3, and group 1.
• There was a statistically significant difference in the marginal gap between the four impression systems tested in this study.
References


13) Loos R, Quaas S, Luthardt RG. Accuracy of conventional impression taking compared to intraoral digitising—A randomized controlled trial. Joint Meeting of the Continental European (CED) and Scandinavian (NOF) Divisions of the IADR. 2005


Appendices

Appendix A: Tables

Table 1: Materials used in this study

<table>
<thead>
<tr>
<th>Product</th>
<th>Commercial name/ Content</th>
<th>Company</th>
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<tbody>
<tr>
<td>Epoxy Resin</td>
<td>Type 8000 100 Gram Tan</td>
<td>American Dental Supply, Allentown, PA</td>
</tr>
<tr>
<td>PVS impression material</td>
<td>Reprosil PVS Material</td>
<td>Dentsply, York, PA</td>
</tr>
<tr>
<td>Type IV dental stone</td>
<td>Plaster of Paris, Crystalline Silica, Titanium dioxide</td>
<td>ResinRock, Whip Mix, Louisville, KY</td>
</tr>
<tr>
<td>Partly sintered zirconia</td>
<td>Zirconium oxide, ytrrium oxide, hafnium moxide, aluminium oxide</td>
<td>Wieland Dental + Technik, Schwenninger StraBe 13, Pforzheim, Germany</td>
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Table 2: Marginal Gap statistics (µm) by group

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1; Impression Scan</td>
<td>10</td>
<td>81.4</td>
<td>6.8</td>
<td>73.6</td>
<td>93.5</td>
<td></td>
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<tr>
<td>Group 2; Master Cast Scan</td>
<td>10</td>
<td>50.2</td>
<td>6.1</td>
<td>38.6</td>
<td>59.3</td>
<td>&lt; 0.001</td>
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<td>Group 3; iTero Cadent</td>
<td>10</td>
<td>62.4</td>
<td>5.0</td>
<td>55.3</td>
<td>69.3</td>
<td></td>
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<tr>
<td>Group 4; LavaTrue Definition</td>
<td>10</td>
<td>26.6</td>
<td>4.7</td>
<td>20.9</td>
<td>34.2</td>
<td></td>
</tr>
</tbody>
</table>

*P-value of the one way ANOVA. The P-value of all Tukey’s HSD tests were also < 0.001
Appendix B: Figures

Point Cloud                    Surface Triangulation       3D Shape of the scanning

Figure 1: Delaunay triangulation approaches.\textsuperscript{38}
Figure 2: Reference model fabrication

2a. Natural teeth #19 and #21, typodont tooth #20,  2b. Teeth mounted in Epoxy Resin,
2c. Preparation for 3-unit FDP

Figure 3: Scanning the silicone impression and the master cast with 3Shape lab scanner

3a. PVS impression,  3b. Type IV stone cast,  3c. 3Shape D700 scanner
Figure 4: Intraoral digital scanners

4a. Cadent iTero, 4b. Lava True Definition
Reference model

Group 1; 10 (Silicone) Impressions
- Scanning using 3shape lab Scanner
  - 10 Zirconia FDPs

Group 2; 10 Master Cast type IV dental stone
- Scanning using 3Shape lab scanner
  - 10 Zirconia FDPs

Group 3; 10 impressions Cadent iTero scanner
- 10 Zirconia FDPs

Group 4; 10 impressions Lava True Definition scanner
- 10 Zirconia FDPs

Figure 5: Flow chart of the study design

Figure 6: Designing of 3-unit zirconia FDPs using Exocad software
Figure 7: Fabrication of Zirconia FPDs

7a. Tizian cut 5 milling machine Zirconia, 7b. FDPs milled using Zenostar blanks,
7c. 3-unit zirconia FDPs obtained from the four tested groups
Figure 8: Measuring of the zirconia FDPs using the Optical Comparator
Figure 9: Side-by-side box plots of the marginal gap of each group