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School of  
Dental Medicine

Comparison of Marginal and Internal Adaptation of All Ceramic  
Crowns Fabricated Using Three Different Intra-Oral Digital  
Scanners. In Vitro Study.

A Thesis

Presented to the Faculty of Tufts University School of Dental Medicine  
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Master of Science in Dental Research

by

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# **Thesis Committee**

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## **Abstract**

**Purpose:** The purpose of this study was to investigate the marginal and internal adaptation of all ceramic crowns fabricated/milled using impressions from new CareStream 3600 Intra-Oral Scanner and compare it to two other Intra-Oral Scanners IOS (True Definition and Trios).

**Materials and Methods:** A typodont tooth was prepped for an all ceramic zirconia crown. Three different IOS systems (Carestream 3600, True Definition, Trios) were used to scan the preparation and crowns were designed with ExoCad laboratory software. The crowns were milled using a 5-axis Tizian milling unit (n=10). Internal and marginal adaptation were evaluated under stereo microscope and using replica technique.

**Results:** Marginal adaptation ( $\mu\text{m}$ ) statistics were as follows (mean, SD): Carestream (11.5, 3.8), Trios (2.8, 2.2), True Definition (12.5, 3.3). One-way ANOVA revealed significant differences ( $p < 0.001$ ) in mean marginal adaptation among the groups. Tukey's HSD test was significant for Carestream vs. Trios ( $p < 0.001$ ) and Trios vs. True Definition ( $p < 0.001$ ), and non-significant for Carestream vs. True Definition ( $p = 0.762$ ). Occlusal surface adaptation ( $\mu\text{m}$ ) were as follows (mean, SD): Carestream (114.4, 26.4), Trios (63.2, 15.9), True Definition (114.2, 20.5). The Kruskal-Wallis test revealed significant differences ( $p < 0.001$ ) in mean occlusal adaptation among the groups. Post-hoc comparisons using the Mann-Whitney U test and Bonferroni correction were significant for Carestream vs. Trios ( $p = 0.001$ ) and Trios vs. True Definition ( $p < 0.001$ ) and non-

significant for Carestream vs. True Definition ( $p=0.820$ ). Axial surface adaptation ( $\mu\text{m}$ ) statistics were as follows (mean, SD): Carestream (41.3, 7.9), Trios (55.8, 5.8), True Definition (30.8, 4.7). One-way ANOVA ( $p<0.001$ ) and post-hoc comparisons using Tukey's HSD test were significant for Carestream vs. Trios ( $p<0.001$ ), Trios vs. True Definition ( $p<0.001$ ), and Carestream vs. True Definition ( $p=0.002$ ).

**Conclusions:** Trios had significantly better marginal and occlusal adaptation than Carestream and True Definition IOS. True Definition had significantly better axial adaptation than Trios and Carestream IOS.

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## **Introduction:**

Fabricating dental prostheses requires skills and demanding steps. These steps can be challenging to the patients and the dental providers. Technology in dentistry has developed quite a bit in the past few decades to minimize and control these necessary steps while not compromising on accuracy. Over four decades ago, the dental field had employed the use of computers to aid in the fabrication of dental prostheses. Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) were introduced and used in the fabrication of dental prostheses.<sup>1</sup> The development of CAD/CAM systems has helped dental providers to fabricate accurate dental prostheses in simpler ways.<sup>2</sup> Achieving accurate outcomes requires precise steps and the use of proper materials. Dentists are required to capture three-dimensional images of tooth preparations via intraoral impressions and communicate with laboratories to fabricate the final prosthesis. The conventional process requires the use of dental materials with certain limitations. These materials include dental impressions that are susceptible to shrinkage due to the chemical reaction of the materials while setting.<sup>3</sup> It also includes dental stone which on the other hand is prone to expansion while setting.<sup>4</sup> In addition to the limitations of the materials, the actual casts are transferred physically to a laboratory to fabricate the dental prostheses. The use of the conventional approach has been proven to be costly and susceptible to inaccuracy.<sup>5,6</sup>

Recently, dental laboratories have applied the use of CAD/CAM systems to help minimize their costs by reducing the time required for the technician to fabricate dental prostheses and as a result maximize their profits.<sup>7</sup> Dental practices also have implemented the use of dental technology in recent years to increase patient comfort and lower the cost

of materials.<sup>8</sup> Dental practices have increased the use of digital impressions due to their ease of use and faster communication with dental laboratories. The use of digital impressions through intraoral scanners has led to a reduction in the use of dental materials, minimized distortion of dental materials, reduced chair time required for impression making, and increased patient comfort during impression making.<sup>9</sup>

The use of digital impressions in dental practices and laboratories has encouraged the development and advancement in the use of digital technology and intraoral scanners.<sup>10</sup> In recent years, many companies have developed different scanning systems and intraoral scanners (IOS). Since the introduction of IOS in the market, a lot of studies have been done to test the accuracy of these new scanners. Most of the studies have compared the accuracy of IOS to the conventional system of impression making and fabrication of final prostheses. Ng et al compared the accuracy of final restorations obtained from one intraoral scanner (True Definition) to conventional methods. They concluded that the digital IOS system resulted in better accuracy than conventional methods.<sup>11</sup> Pedroche et al also showed that using IOS (Trios) directly from the patient resulted in more accurate outcomes of restorations when compared to scanning models and impressions.<sup>12</sup> SeelBach et al showed in their study that all ceramic crowns fabricated through the use of IOS yielded similar accuracy to the conventional methods.<sup>13</sup> In a systematic review, Tsirogiannis et al showed that outcomes of single unit restorations fabricated through the use of IOS were comparable and not significantly different from the ones fabricated through the use of conventional methods.<sup>14</sup>

Digital impressions and the use of IOS have improved the accuracy of dental prostheses by eliminating the potential source of errors that can occur with the use of

conventional methods.<sup>15</sup> The accuracy of digital impressions, however, can vary between different IOS systems. Recent studies have compared different IOS systems and evaluated the accuracy of dental prostheses fabricated directly from the use of different scanners. The direct comparison between IOS can help guide clinicians in selecting the appropriate IOS for their practice.

### **Digital Impressions:**

The IOS system was developed for dental practices to overcome some of the inaccuracies and difficulties associated with conventional impression techniques.<sup>16</sup> With the help of CAD/CAM systems, dental prostheses have been produced through a digital process.<sup>7</sup> This process has helped improve the quality of dental restorations through the use of a more efficient digital workflow.<sup>17</sup> A digital impression is constructed by calculating points of interest on an external surface of an object through the use of a point clouding concept. A light source which is required of all IOS is projected on an object and recorded as an image or video and then compiled by a computer software to create points of interest on three coordinates (x, y, and z).<sup>5,18</sup> The points of interest on the three coordinates create a digital mesh that is then converted by a software to produce a 3-D image of the scanned object.<sup>19</sup>

### **Intraoral Scanners:**

Many different types of intraoral scanners have been introduced to the market. These include 3M True Definition Scanner, 3Shape Trios 3D, Carestream CS 3600, CEREC Omnicam, Condor, Dental Wings, iTero Element 2, Itero Element Flex, Planmeca

Emerald, and Viz Intraoral Scanner. These scanners are used to acquire the data needed to mill the restoration. These data acquisition units work in different ways; however, the main goal is to provide an accurate scan of the preparation. Some of these units require the use of a powder which consists of titanium dioxide. This powder is used to increase the accuracy of the scan by producing uniform light dispersion.<sup>10</sup>

These scanners transfer data either through closed or open systems. Closed systems are restricted to the data limited to the system itself. Most of the IOS systems are open systems where the data is stored in surface tessellation/triangulation language (STL) format which most dental laboratories can open and manipulate as needed.

The three scanners selected for this study were CS 3600 (Carestream, Rochester, NY, USA), Trios (3-Shape, Copenhagen, Denmark), and True Definition (3M Espe, S. Paul, MN, USA).

The Carestream Dental Company first introduced CS 3500 IOS to the market in 2014. The version of the scanner then was improved to CS3600, which was introduced in 2016. CS3600 differs from CS3500 by the ability of continuous scanning in comparison to still image capturing used in CS3500. The scanner does not require intraoral use of powder. CS3600 IOS uses the technology of structured LED light and parallel confocal through the use of active speed 3D video.<sup>15,20,21</sup> The IOS is available in a USB version and can be used by connecting to laptops directly. CS3600 is an open system scanner that allows communication with the Exocad software. (Figure 1)



*Figure 1. Carestream Intraoral Scanner*

Trios-3 is an improved IOS from previous Trios versions (Trios standard 2011 and Trios Colour 2013). Trios-3 was introduced to the market in 2015. The IOS does not require powder and is capable of producing colored images. It uses the technology of LED pattern projection and confocal microscopy through the use of 3D video. The confocal technology uses a process of optical sectioning by applying a spatial filter to block out and eliminate out-of-focus light during image formation. The acquisition of in-focus images at specific depths produces increased resolution of optical images. By capturing multiple 2D images at different depths, optical sectioning enables the construction of a 3D object.<sup>22, 23</sup> The scanner comes in a wireless scanning unit with a touch screen monitor and an intraoral scanning wand.<sup>15, 20, 21</sup> (Figure 2)



*Figure 2.* Trios Intraoral Scanner

The True Definition scanner uses blue LED light and an active wavefront sampling (AWS) technology through 3D video method. Unlike other systems, AWS system captures depth of information through the use of only one optical path. The system requires an off-axis aperture module and a camera. The module moves on a circular path around the optical axis to produce the rotation of target points on a circle of a plane's image.<sup>22</sup> The reflected image during scanning with this system is projected onto a sensor after passing through a lens system. The image is produced in focus when the distance of an object is at the focal length of the lens. However, when the image is out of focus, the distance between blurred

object and the lens is calculated through a mathematical formula.<sup>24</sup> The scanner requires the use of a powder (titanium dioxide) to be sprayed on the final tooth preparation in order to help with the location of reference points during scanning. The powder is used to optimize the digital impression by reducing reflectivity of reflective surfaces such as polished surfaces, enamel, and mucosal tissue.<sup>25, 26</sup> The scanner includes a wireless scanning unit with a touch screen monitor and an intraoral scanning wand.<sup>11, 19-21</sup> (Figure 3)



*Figure 3.* True Definition Intraoral Scanner

### **Marginal and Internal Adaptation of Dental Restorations:**

Adaptation accuracy is a very important feature of IOS. Many studies have shown that IOS systems are more accurate than conventional methods.<sup>9</sup> Accuracy has been determined by measuring many different parameters including axial adaptation, occlusal adaptation, and marginal adaptation.

The clinical success of prosthetic restorations involves an adequate fit. The internal fit is defined as the fit of the inner surface of a restoration to the occlusal and axial surface of the preparation and the marginal fit is defined as the fit of the restoration at the margin.<sup>27</sup> Accurate impressions provide better marginal and internal adaptation through closer adaptation of the prepared surfaces with the dental prostheses.<sup>28, 29</sup> These parameters have been shown to increase the success and longevity of restorations.<sup>30-32</sup> It has been found with general consensus in the literature that restorations with a marginal gap of less than 120 micrometers are acceptable and more likely to be successful.<sup>33-39</sup> Restorations with a marginal gap of more than 120 micrometers would result in a thicker cement film. This compromises the longevity of the restorations due to possible cement dissolution and more exposure to chemical and mechanical forces.<sup>17, 34</sup> Wider marginal gap could also cause accumulation of plaque which might lead to secondary caries and more biological complications.<sup>40-42</sup> Although it has been reported that there was no direct correlation between marginal opening alone and microleakage, White et al described marginal fit as the most important criterion for the success of dental restorations.<sup>30</sup>

The fit of the crown also allows for a certain amount of cement thickness. According to American Dental Association, it was indicated in Specification No. 8 that the space for cement film thickness should be less than 40 micrometers. Minimizing the cement film thickness by improving adaptation would help increase the strength of the restoration.<sup>43</sup> Restorations with excessive cement film thickness and wider internal surface gap might compromise the strength of restorations. Tuntiprawon and Wilson evaluated the effect of increased cement thickness on the strength of all ceramic crowns. They showed that as the cement thickness increased there was a decrease in strength of the restoration,

attributing to porcelain deformation and as a result an increase in restorations' failure.<sup>43</sup> Increased cement thickness can lead to decreasing resistance and retention forms and increase of tensile stresses on the cement layer and restorations.<sup>44, 45</sup>

### **Methods for Evaluating Marginal and Internal Adaptation:**

Methods for measuring marginal and internal adaptation include direct view, cross sectional technique, impression technique, micro CT, and profilometry.<sup>46</sup> The direct view technique involves measuring the gap between the dye and the margin externally. Internal adaptation cannot be evaluated with this method. This cannot be done intraorally because it involves the use of a microscope to evaluate the gap. The advantages are that it is cost effective, faster to perform, and less chance of error with using duplicates or additional steps prior to evaluation of the fit.<sup>46</sup>

Impression technique also described as a cement replica technique measures the internal and marginal adaptation by making a silicone replica of the cement. A light body silicone material is used to seat the restoration; once set, the restoration is gently lifted. The heavy body silicone material is injected inside the cement replica to stabilize the cement replica and allow for sectioning once set.<sup>47, 48</sup> Sectioning is done at varying planes and then the thickness of the cement replica is measured and evaluated under the microscope. Some advantages of this technique are that it can be used in vivo and in vitro, and the specimen can be spared. This technique allows for measurements in multiple reference points.<sup>49</sup> It is a relatively inexpensive, reliable, and easy method to use.<sup>50, 51</sup> Some disadvantages include that the cement replica can tear upon crown removal, and sectioning of incorrect planes that can lead to incorrect measurements.<sup>46, 49, 52</sup>

The cross-sectional technique involves the cementation of the restoration and then sectioning of the specimen in horizontal or vertical planes. This technique allows for the direct evaluation of the cement, restoration and dye or tooth interface. This technique however can only be used for in vitro methods. Also, the selective sectioning may not be an accurate presentation of the cement interface throughout the entire specimen.<sup>46, 52</sup>

Micro computed tomography is a non-destructive method of evaluating the adaptation of restorations. It involves 2D and 3D evaluation of internal and marginal adaptation. The disadvantages are that it takes a long time to evaluate multiple specimens and it is expensive.<sup>53-55</sup>

Profilometry is a technique that uses a profilometer that measures the surface profile. This technique is non-destructive and can be used for evaluating marginal adaptation through measuring the surface roughness. However, this technique can lead to false interpretations in cases of vertical overextension.<sup>56</sup>

### **Methods of Milling Zirconia Restorations:**

Unlike other types of all ceramic restorations, dental technicians cannot fabricate zirconia restorations using traditional methods such as powder/liquid or lost-wax techniques. Zirconia restorations require the use of digital processing to design and mill from prefabricated blocks. Zirconia crowns can be milled by two different processing methods: hard machining or soft machining.<sup>19</sup> Hard machining refers to milling dental restorations from zirconia blocks that are in a densely sintered stage. This method mills restorations to the actual final size and some studies demonstrated minor superiority of fit.<sup>57-59</sup> However, milling in a densely sintered stage comes with some difficulties and

challenges. It requires longer milling times and greater wear to the milling instruments.<sup>19,</sup>  
<sup>57, 58</sup> Milling thin sections of restorations can also be challenging using this technique.

Soft machining on the other hand allows technicians to mill restorations out of zirconia blocks in a more soft and porous pre-sintered stage. This method has the advantages of milling restorations easily and in a short period of time. It has also shown less wear to milling instruments and less chance of chipping on the milled restorations.<sup>60</sup> However, soft machining requires a sintering process that causes 20-30% of sintering shrinkage. This percentage of shrinkage has to be counted and compensated for during the milling stage. Precise calculation of the post milling and sintering shrinkage stage can be challenging to the software during the design stage.<sup>59, 61, 62</sup> Kunii et al studied these challenges of the dental software and concluded in their study that CAD software demonstrated efficiency and precision in compensating for sintering shrinkage.<sup>57</sup> Studies in the literature have suggested that the advantages of simplicity and cost effectiveness of the soft machining method should be considered and weighed against the minor superiority of hard machining method.<sup>17, 57-59</sup>

### **Aim of the Study:**

The aim of the study was to investigate the marginal and internal adaptation of all ceramic crowns milled using digital impressions from new Carestream 3600 Intra-Oral Scanner and compare it to two other intraoral scanners (True Definition and Trios).

**Hypothesis:**

It was hypothesized that all ceramic crowns fabricated using impressions from True Definition IOS would provide better marginal and internal adaptations compared to crowns fabricated using impressions from Trios and CS3600 IOS.

**Materials and Methods:****Power calculation and sample size calculation:**

A sample size calculation was performed with the software package nQuery Advisor Version 7.0. Based on the results of Ali et al<sup>18</sup>, it was assumed that the mean values for overall marginal adaptation would be 69.1 $\mu$ m for True Definition, 69.6 $\mu$ m for Trios, and 95.1 $\mu$ m for Carestream, and that the within-group standard deviation would be 9.0 $\mu$ m. Under these assumptions, a sample size of n=10 per group was adequate to achieve a power greater than 99% alongside a Type I error rate of 5%.

**Master Model Fabrication:**

A mandibular right first molar was prepped in a typodont (Frasaco, Greenville, N.C., USA) (Figure 4). The preparation followed the guidelines of Goodacre for all ceramic crowns with dimensions of: 1.0mm reduction of the axial walls, 1.0mm marginal reduction with chamfer finish line, 2.0mm reduction of the functional buccal cusps, and 1.5 mm reduction of the non-functional lingual cusps.<sup>63</sup> A dental high-speed handpiece (Midwest, Dentsply, Des Plaines, IL) was used to prep the tooth under water and air spray. The tooth

was prepped using tapered round-end coarse-diamond rotary cutting instruments and smoothed with fine-diamond rotary cutting instruments (Brasseler, Savannah, GA).



*Figure 4.* Preparation of tooth #30 on the master model.

### **Digital Impression Making:**

The typodont and prepped tooth were cleaned, dried, and scanned by all three scanners. Three different intraoral scanners were used. These were the CS 3600 (Carestream, Rochester, NY, USA), Trios (3-Shape, Copenhagen, Denmark), and True Definition (3M Espe, S. Paul, MN, USA). Figure 5 shows a flowchart of the study design.

The same operator used each scanner to scan the typodont and prepped tooth. Each scanner was used on different days to avoid operator fatigue and inconsistency. Ten scans were taken from each scanner in a day (three days total). Carestream and Trios scanners were first used since they did not require the use of surface powder (titanium dioxide powder). All thirty digital impressions (ten scans from each scanner) were made following the guidelines and instructions of each scanner's manufacturer. Each scan included maxillary and mandibular right sides of the typodont in addition to occlusal registration.

The digital scans and .STL files were exported and sent directly to the dental laboratory software (ExoCad; exocad GmbH, Fraunhofer IGD, Fraunhoferstrasse 5, Darmstadt, Germany). Carestream and Trios allowed for exporting .STL files on USB flash drive which was used to transfer files to ExoCad software. The digital scans made from the True Definition scanner were sent to 3M ESPE dental production center for data processing before obtaining .STL files through email.

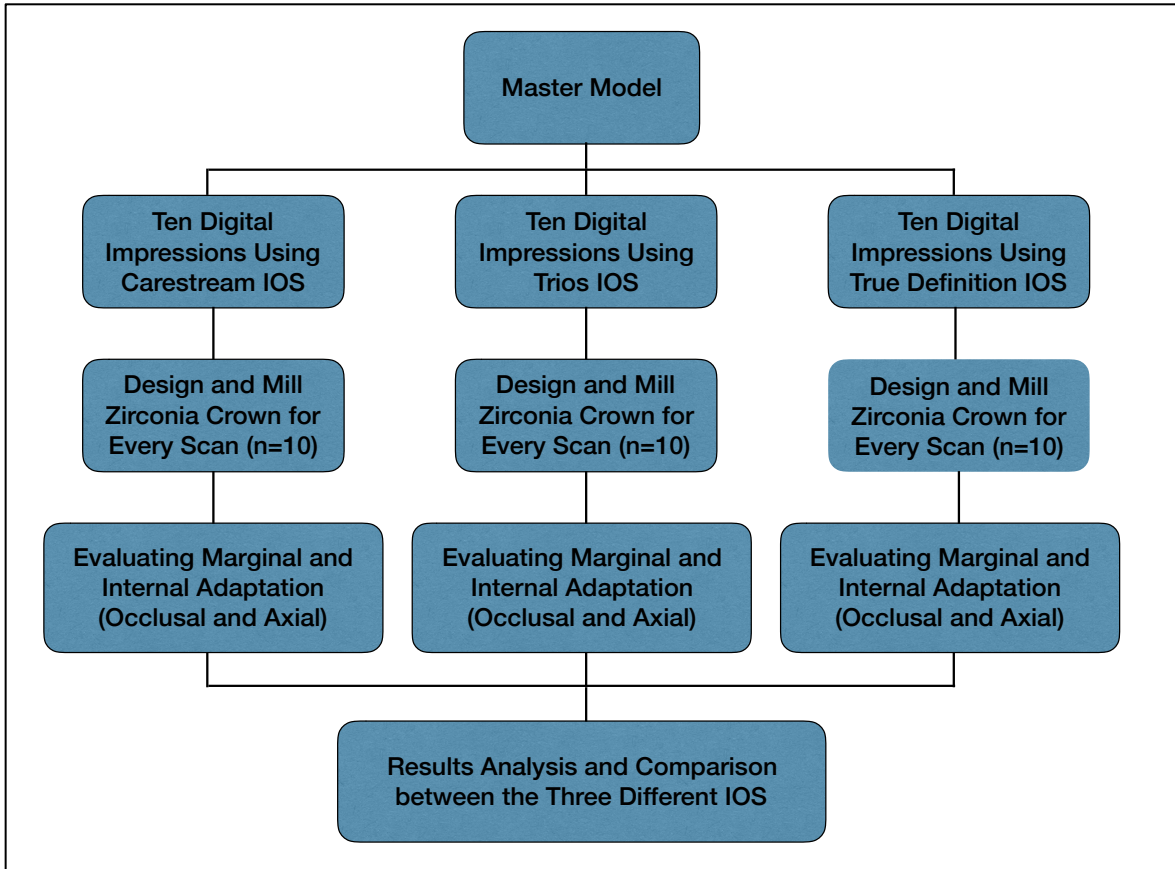


Figure 5. Flowchart of Study Design

**Group 1: Intervention group:**

CS3600 (Carestream, Rochester, NY, USA):

The typodont was scanned ten times and the .STL files were sent to the laboratory software ExoCad using a USB flash drive.

**Group 2: Comparison group:**

Trios (3-Shape, Copenhagen, Denmark):

The typodont was scanned ten times and the .STL files were sent to the laboratory software ExoCad using a USB flash drive.

### **Group 3: Comparison group:**

#### True Definition (3M ESPE, S. Paul, MN, USA):

The typodont was scanned ten times and the .STL files were sent electronically to the 3M dental production center. The production center then sent the .STL files through email. These files were then downloaded to the laboratory software ExoCad.

### **Designing and Milling of All Ceramic Zirconia Crowns:**

All scans were sent directly to the ExoCad software which designed a digital wax up for full contoured all ceramic zirconia crowns. The crowns were designed with a cement space of 35 micrometers ( $\mu\text{m}$ ) starting 1 mm above the margins. Thirty zirconia crowns were then transferred to a 5-axis milling unit Tizian (Schütz Dental, Rosbach, Germany) (Figure 6). The restorations were digitally oriented and milled out of monolithic pre-sintered blocks of yttria-stabilized zirconia (Katana Zirconia HT 10, Kuraray, Noritake, Japan). The milled zirconia crowns in the pre-sintered stage were cleaned from any debris and inspected under stereo microscope for any possible damages. The crowns were then placed into a sintering furnace (MIHM-VOGT, Dental-Gerätebau, Karlsruhe, Germany) at 1500°C according to the manufacturer's instructions (Figure 7). Each crown was inspected visually under stereo microscope and the fit was evaluated by the same operator.

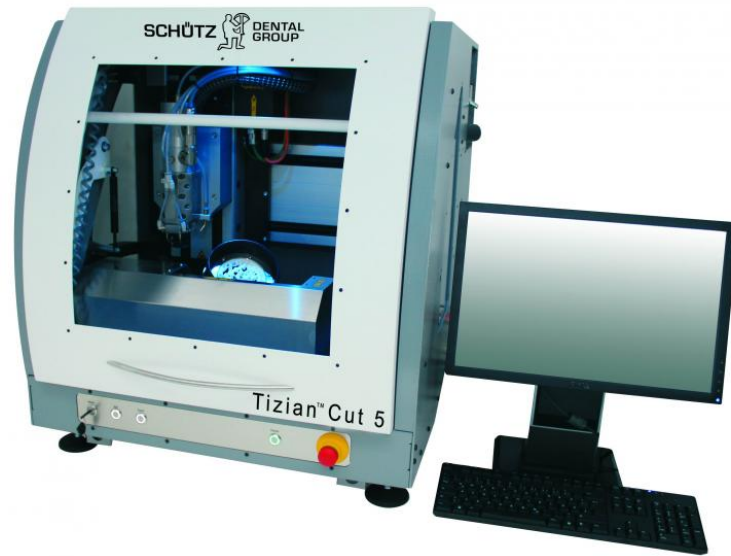


Figure 6. 5-axis milling unit Tizian Cut 5 (Schütz Dental, Rosbach, Germany).

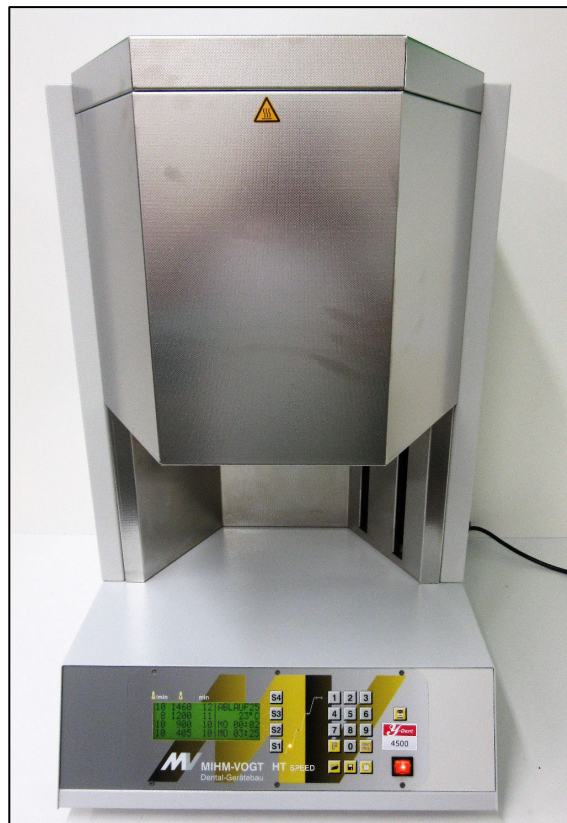


Figure 7. Sintering furnace (MIHM-VOGT, Dental-Gerätebau, Karlsruhe, Germany)

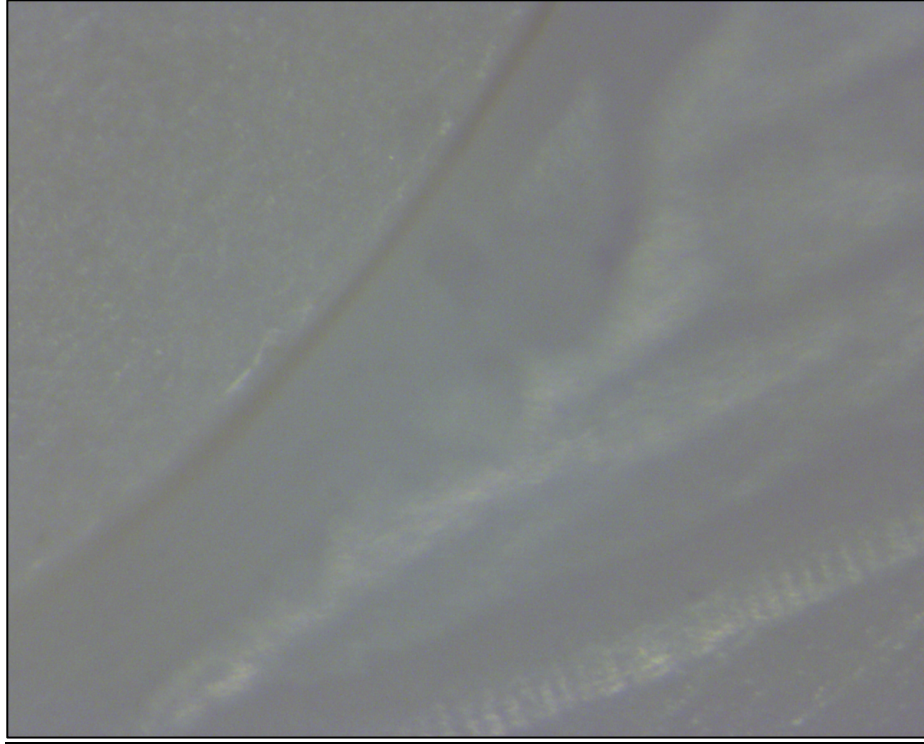
## Measurement and Testing:

### Marginal Adaptation:

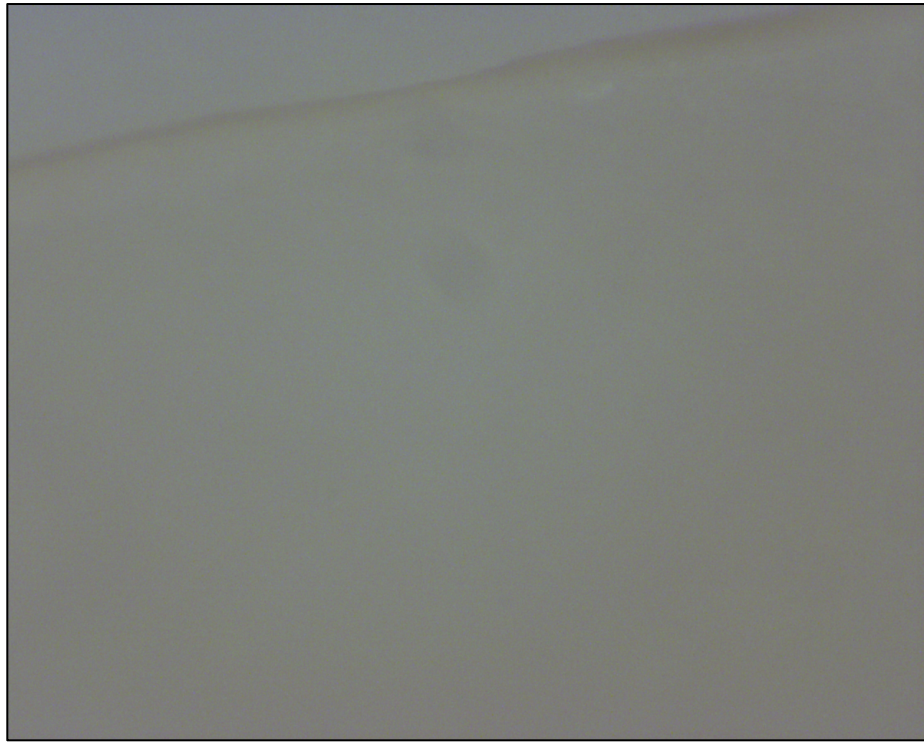
Each crown fabricated was placed on the prepped tooth and the marginal adaptation was measured under direct visualization from four different points (mesial, distal, buccal, and lingual). As described and defined by Holmes et al, the marginal fit is determined by the vertical aspect of the marginal gap.<sup>64</sup> There was no cement medium used to seat the crowns on the prepped tooth. The measurements were visualized under a x92 magnification of stereo microscope with super depth of focus. (Olympus SZX16, SDF 0.8X; Japan) (Figure 8) The marginal gaps were calculated and measured using computer Buehler Omnimet 9.5 software (Figures 9 to 12). The average of the measurements was used to compare the crowns between the three different groups.



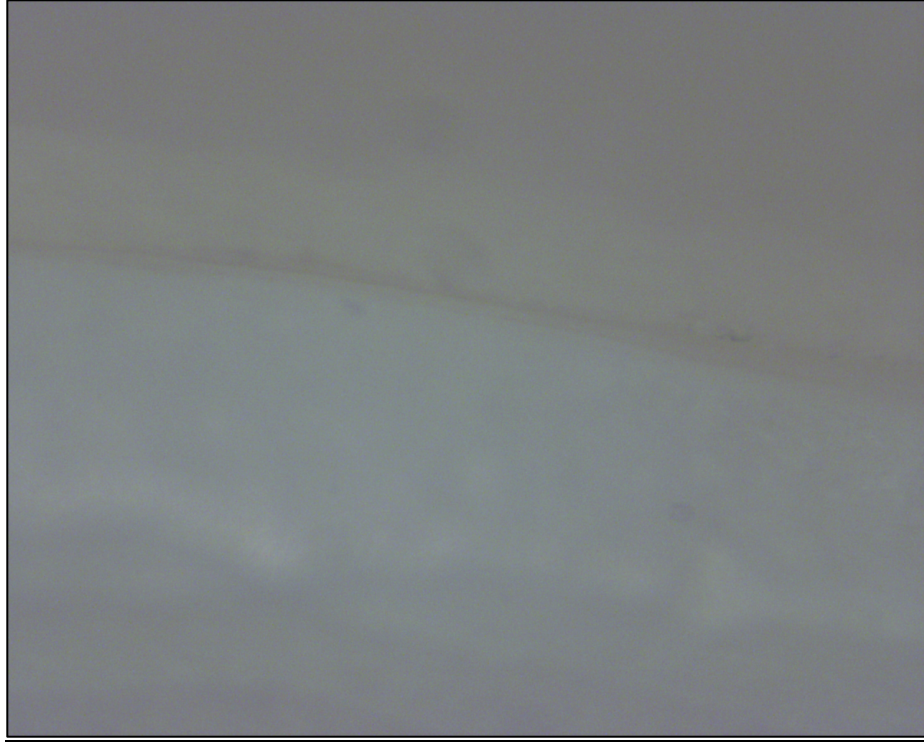
*Figure 8.* Stereo microscope with super depth of focus (Olympus SZX16, SDF; Japan).



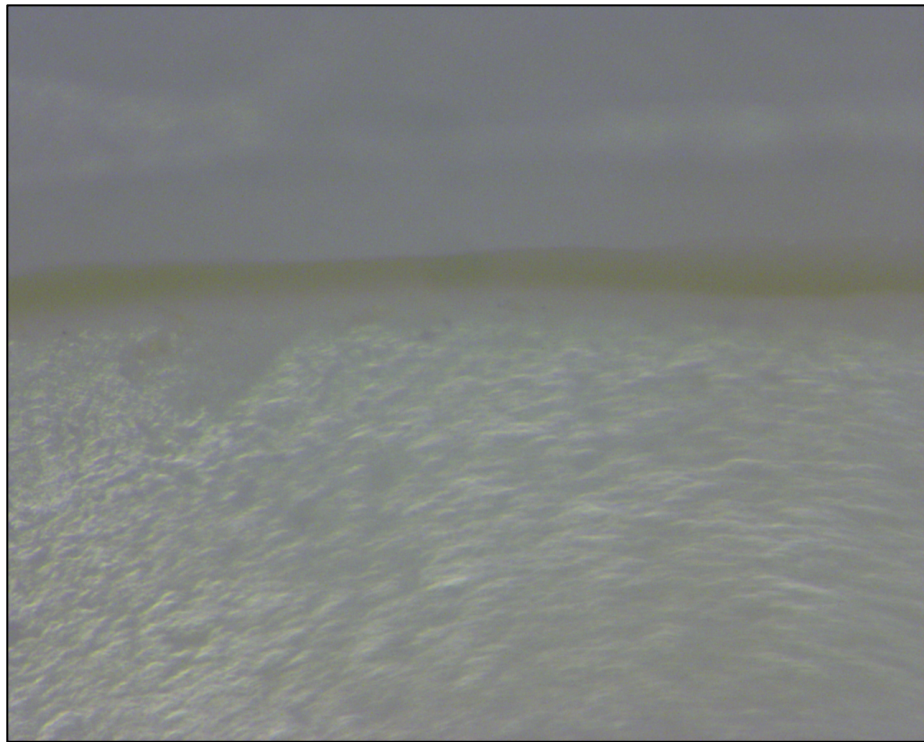
*Figure 9.* View under stereo microscope of space at the mid-point of mesial margin.



*Figure 10.* View under stereo microscope of space at the mid-point of buccal margin.



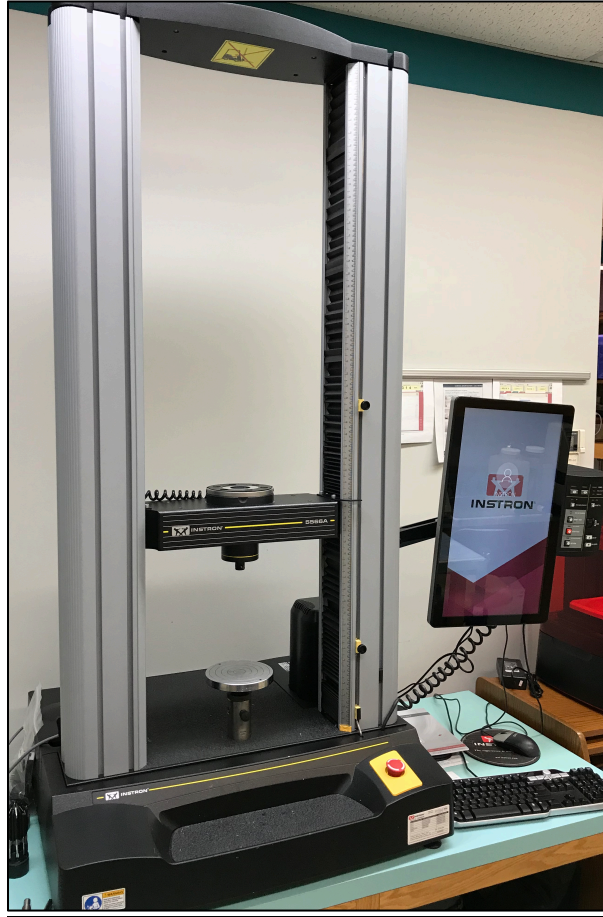
*Figure 11.* View under stereo microscope of space at the mid-point of lingual margin.



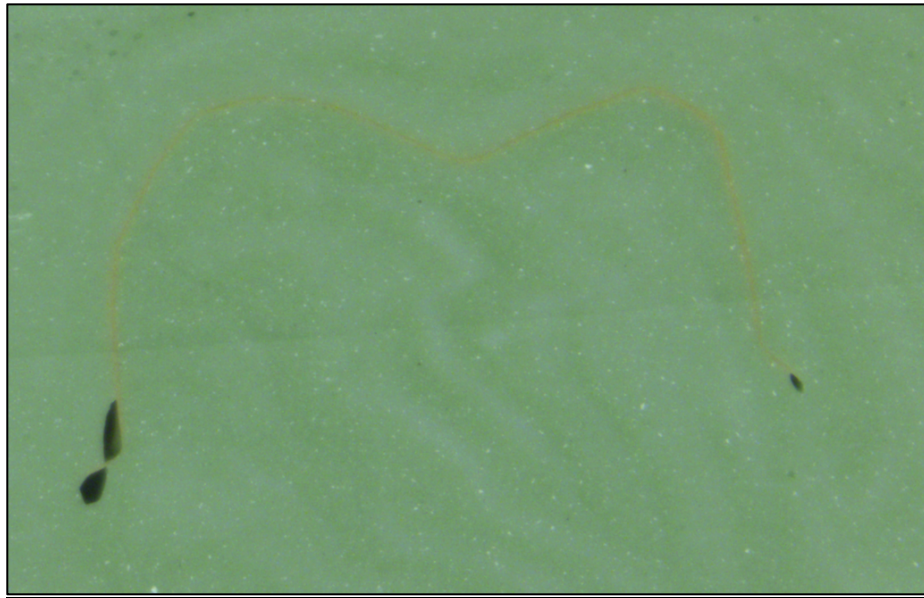
*Figure 12.* View under stereo microscope of space at the mid-point of distal margin.

**Internal Adaptation:**

Each crown from each group was seated on the prepped tooth using light body PVS (polyvinyl siloxane materials) as the cement silicone replica.<sup>65-68</sup> An Instron machine (Illinois Tool Works, Illinois, USA) was used to seat the crowns under 50 N/cm. Figure 13 shows an illustration of the Instron machine which is a device used to test for mechanical properties of materials. The Instron machine was used to apply a constant pressure during seating and setting of the PVS impression materials. A pressure of 50 N/cm was used as an equivalent to 5 Kg of weight. The crowns were lifted, and the external surface of the cement replica and the prepped tooth were embedded in a heavy body PVS impression material (Reposil, Dentsply, York, PA). The prepped tooth then was lifted, and internal surfaces of the cement replica were filled with heavy body PVS creating a prepped replica. The encompassed cement replicas were sectioned into four pieces. The sectioning was carried out using a sharp scalpel blade in buccal-lingual and mesial-distal directions. The thickness of the sectioned cement replica was measured and examined under stereo microscope (Figures 14 to 16). The average of the measurements was calculated and compared between the groups. The internal adaptation was divided into occlusal and axial adaptations. The occlusal adaptation included five different points of measurements (buccal cusp, lingual cusp, central fossa, mesial marginal ridge, and distal marginal ridge). The axial adaptation included four different points of measurements (mesial axial wall, distal axial wall, buccal axial wall, and lingual axial wall).



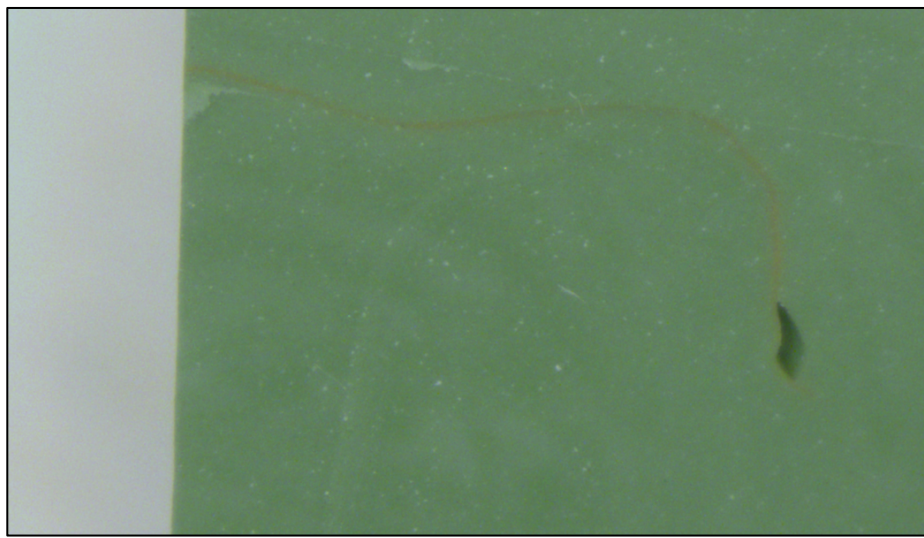
*Figure 13. Instron Machine (Illinois Tool Works, Illinois, USA).*



*Figure 14. View under stereo microscope showing internal adaptation surfaces of sectioned cement replica (buccal to lingual section).*



*Figure 15.* View under stereo microscope showing internal adaptation surfaces of sectioned cement replica (mesial section).



*Figure 16.* View under stereo microscope showing internal adaptation surfaces of sectioned cement replica (distal section).

### **Statistical Analysis:**

The data were collected, and the measurements were converted from millimeter (mm) to micrometer ( $\mu\text{m}$ ). The measurements were entered into SPSS software Version 25.0. Descriptive statistics (means, medians, standard deviations, and interquartile ranges) were calculated for each group. The assumption of normality was assessed using quantile-quantile plots and the Kolmogorov-Smirnov test. The assumption of homogeneity of variances was assessed using Levene's test. For the data that exhibited normality and homogeneity of variances, one-way ANOVA was used to compare the groups, and Tukey's HSD was used for post-hoc comparison between the groups. On the other hand, non-parametric tests were used for data that did not exhibit normality. In particular, for such data, the Kruskal-Wallis test was used to compare the groups, and the Mann-Whitney U test with Bonferroni correction was used for post-hoc comparison. Additionally, an analysis was undertaken in which all samples from the three different intraoral scanners were pooled together and the Pearson correlation between the different types of adaptation (marginal, occlusal, and axial) was computed.

## **Results**

### **Marginal Adaptation:**

Means, standard deviations, medians, and interquartile ranges for each intraoral scanner are shown in Table 1. The assumption of normality was found to be tenable using quantile-quantile plots and the Kolmogorov-Smirnov test ( $p > 0.05$  for each group). Levene's test did not find a significant violation of the assumption of homogeneity of

variances ( $p > 0.05$ ). Based on these results, one-way ANOVA was used to compare the means of the three different groups. The one-way ANOVA test resulted in significant differences between the groups ( $p < 0.001$ ). Tukey's HSD showed that the Trios group exhibited statistically significant differences compared to Carestream ( $p < 0.001$ ) and True Definition ( $p < 0.001$ ). Specifically, the Trios group (mean=2.8, SD=2.2) showed smaller marginal adaptation when compared to Carestream (mean=11.5, SD=3.8) and True Definition (mean=12.5, SD=3.3). However, the post-hoc test failed to show a statistically significant difference between Carestream and True Definition ( $p = 0.762$ ). Figure 17 displays box plots of marginal adaptation by group.

*Table 1. Results for Marginal Adaptation by Group*

<u>Intraoral Scanner</u>	<u>Mean</u>	<u>SD</u>	<u>Median</u>	<u>IQR</u>	<u>p*</u>
<u>Carestream</u>	11.5	3.8	11.3	6.3	<0.001
<u>Trios</u>	2.8	2.2	2.5	5.0	
<u>True Definition</u>	12.5	3.3	12.5	5.6	

Measurements are in Micrometer ( $\mu\text{m}$ )

\*p-value shown is for the one-way ANOVA test. Results of post-hoc comparison using the Tukey HSD test were as follows:

- Carestream vs. Trios:  $p < 0.001$  (significant)
- Carestream vs. True Definition:  $p = 0.762$  (not significant)
- Trios vs. True Definition:  $p < 0.001$  (significant)

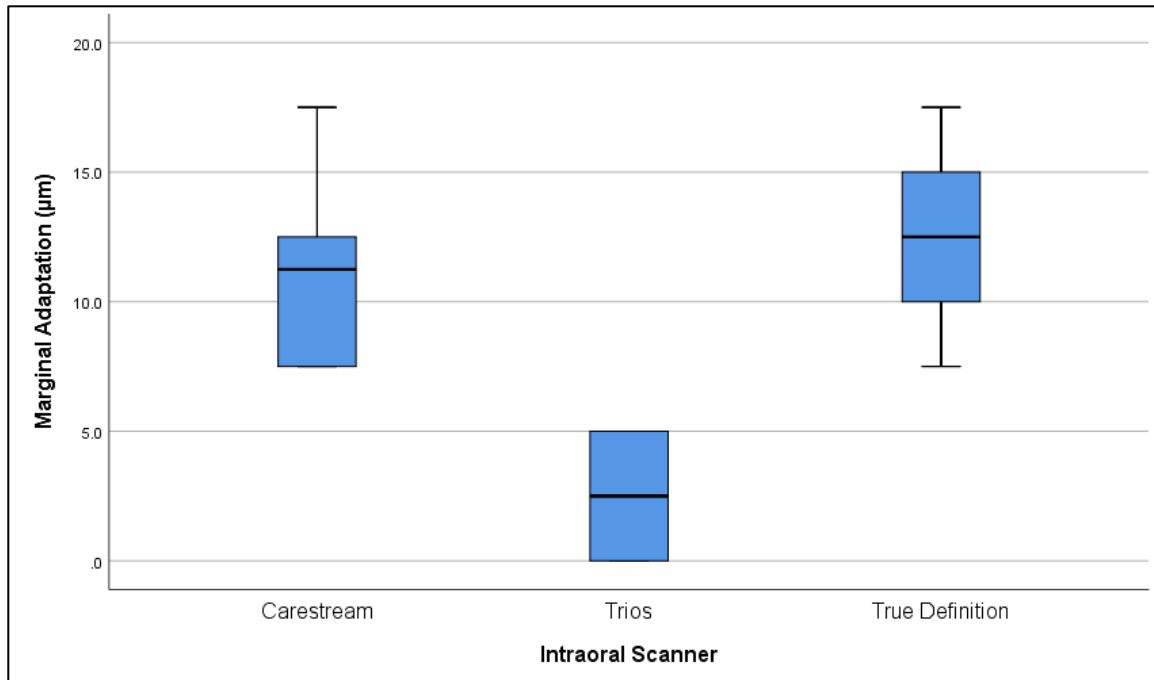


Figure 17. Side-by-Side Box Plots of Marginal Adaptation

### Results for Occlusal Surface Adaptation:

Means, standard deviations, medians, and interquartile ranges for each intraoral scanner are shown in Table 2. The assumption of normality was assessed and rejected ( $p < 0.05$ ) for two groups (Carestream and Trios) using the Kolmogorov-Smirnov test as well as quantile-quantile plots. Based on these results, the Kruskal-Wallis test was used to compare the three intraoral scanners. The Kruskal-Wallis test resulted in significant differences between the groups ( $p < 0.001$ ). Results of the post-hoc Mann-Whitney U tests with Bonferroni correction showed that Trios exhibited statistically significant differences when compared to Carestream ( $p = 0.001$ ) and True Definition ( $p < 0.001$ ). The Trios group (median=59.0 & IQR=14.0) showed smaller occlusal surface adaptation when compared to Carestream (median=102.0 & IQR=29.5) and True Definition (median=113.0 &

IQR=42.0). However, post-hoc testing failed to show statistical significance between Carestream and True Definition (p=0.820). Figure 18 displays box plots of marginal adaptation by group.

Table 2. Results for Occlusal Surface Adaptation by Group

<u>Intraoral Scanner</u>	<u>Mean</u>	<u>SD</u>	<u>Median</u>	<u>IQR</u>	<u>p*</u>
<u>Carestream</u>	114.4	26.4	102.0	29.5	<0.001
<u>Trios</u>	63.2	15.9	59.0	14.0	
<u>True Definition</u>	114.2	20.4	113.0	42.0	

Measurements are in Micrometer ( $\mu\text{m}$ )

\*p-value shown is for the Kruskal-Wallis test. Results of post-hoc comparison using the Mann-Whitney U test and Bonferroni correction were as follows:

- Carestream vs. Trios: p=0.001 (significant)
- Carestream vs. True Definition: p=0.820 (not significant)
- Trios vs. True Definition: p<0.001 (significant)

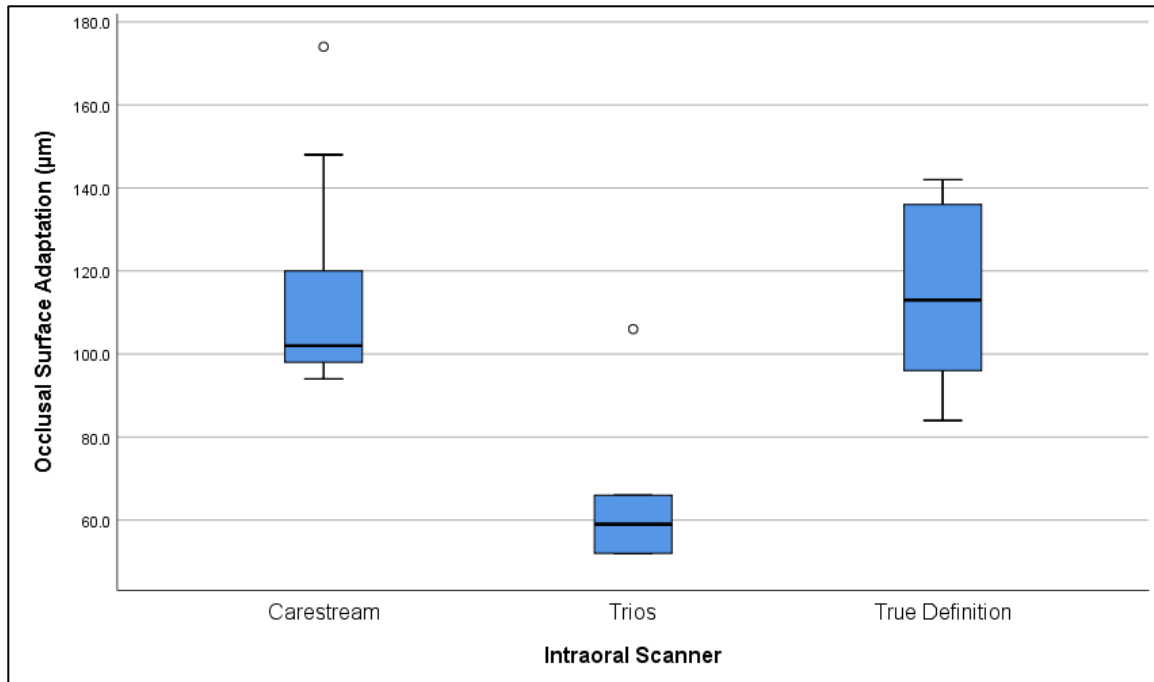


Figure 18. Side-by-Side Box Plots of Occlusal Surface Adaptation

### Results for Axial Surface Adaptation:

Means, standard deviations, medians, and interquartile ranges for each intraoral scanner are shown in Table 3. The assumption of normality was found to be tenable using quantile-quantile plots and the Kolmogorov-Smirnov test ( $p > 0.05$ ). Levene's test did not find a significant violation of the assumption of homogeneity of variances ( $p > 0.05$ ). Based on these results, one-way ANOVA was used to compare the means of the three different groups. The one-way ANOVA test resulted in significant differences between the groups ( $p < 0.001$ ). Tukey's HSD showed that the Trios group exhibited statistically significant differences compared to Carestream ( $p < 0.001$ ) and True Definition ( $p < 0.001$ ). Specifically, the Trios group (mean=55.8, SD=5.8) showed larger axial surface space when

compared to Carestream (mean=41.3 & SD=7.9) and True Definition (mean=30.8 & SD=4.7). Tukey’s HSD test also revealed a statistically significant difference in mean axial adaptation between Carestream and True Definition (p=0.002). Figure 19 displays box plots of marginal adaptation by group.

Table 3. Results for Axial Surface Adaptation by Group

<u>Intraoral Scanner</u>	<u>Mean</u>	<u>SD</u>	<u>Median</u>	<u>IQR</u>	<u>p*</u>
<u>Carestream</u>	41.3	7.9	43.8	13.8	<0.001
<u>Trios</u>	55.8	5.8	55.0	9.4	
<u>True Definition</u>	30.8	4.7	31.3	6.3	

Measurements are in Micrometer (µm)

\*p-value shown is for the one-way ANOVA test. Results of post-hoc comparison using the Tukey HSD test were as follows:

- Carestream vs. Trios: p<0.001 (significant)
- Carestream vs. True Definition: p=0.002 (significant)
- Trios vs. True Definition: p<0.001 (significant)

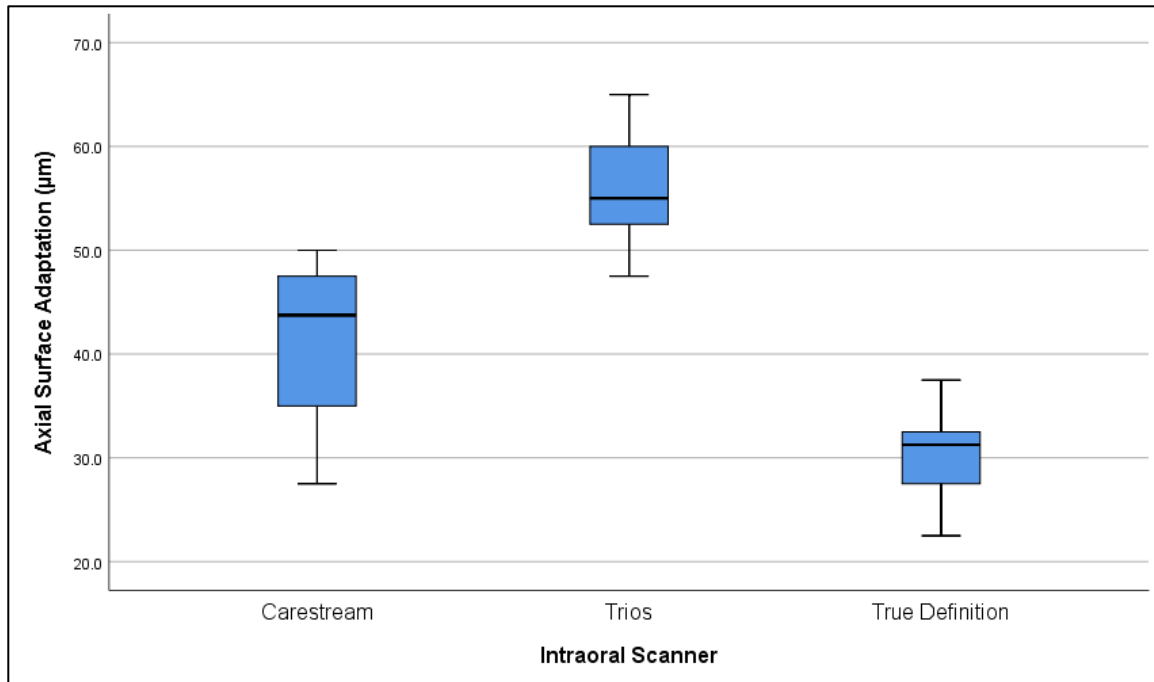


Figure 19. Box plot of Axial Surface Adaptation

***Test for Correlation:***

The data were tested for possible correlation between the three dependent variables (marginal, occlusal, and axial adaptation). All of the data were pooled and assessed for normality using quantile-quantile plots and the Kolmogorov-Smirnov test. The tests did not indicate non-normality of the data ( $p > 0.05$ ). The Pearson correlation was used, and the corresponding hypothesis test showed statistically significant correlation between the different variables (Table 4 and Figures 20 to 22). There was significant positive correlation between occlusal surface adaptation and marginal adaptation ( $r = 0.717$ ,  $p < 0.001$ ). There was significant negative correlation between occlusal surface adaptation

and axial surface adaptation ( $r=-0.548$ ,  $p=0.002$ ). There was also significant negative correlation between axial surface adaptation and marginal adaptation ( $r=-0.634$ ,  $p<0.001$ ).

*Table 4.* Results of Correlation between Marginal, Occlusal Surface, and Axial Surface Adaptation

<u>Variables</u>		<u>Marginal</u> <u>Adaptation</u>	<u>Occlusal</u> <u>Surface</u> <u>Adaptation</u>	<u>Axial</u> <u>Surface</u> <u>Adaptation</u>
<u>Marginal</u> <u>Adaptation</u>	Pearson correlation		0.717	-0.634
	p		<0.001	<0.001
<u>Occlusal Surface</u> <u>Adaptation</u>	Pearson correlation	0.717		-0.548
	p	<0.001		0.002
<u>Axial Surface</u> <u>Adaptation</u>	Pearson correlation	-0.634	-0.548	
	p	<0.001	0.002	

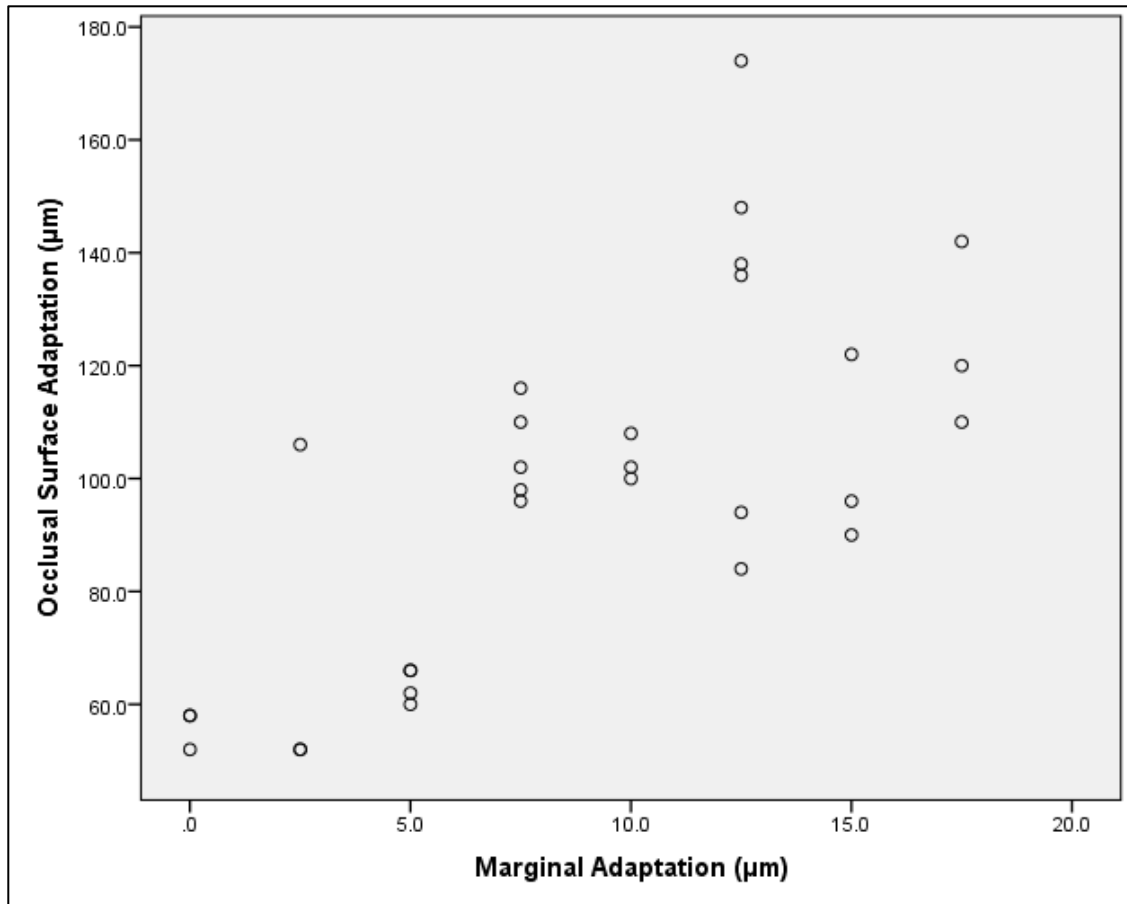


Figure 20. Scatterplot of Marginal and Occlusal Surface Adaptation

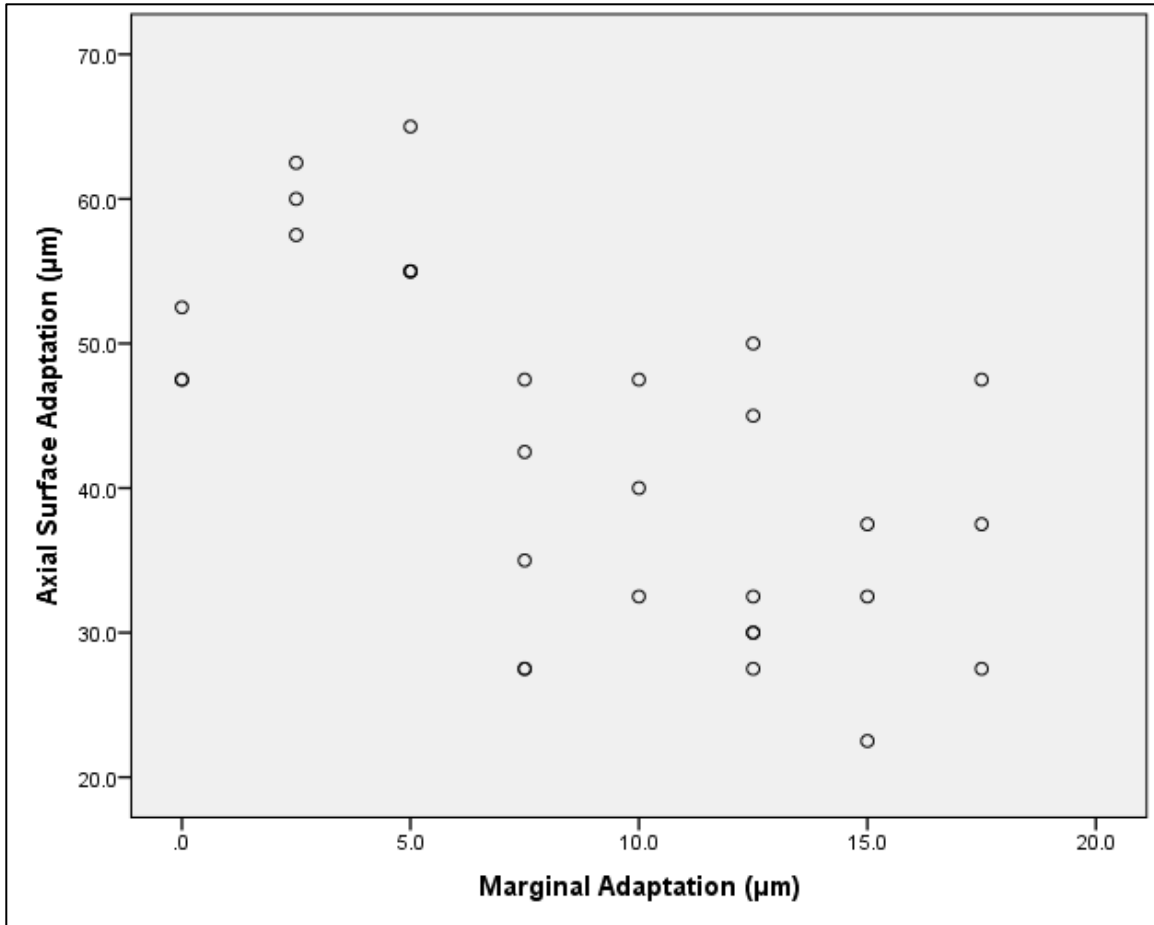


Figure 21. Scatterplot of Marginal and Axial Surface Adaptation

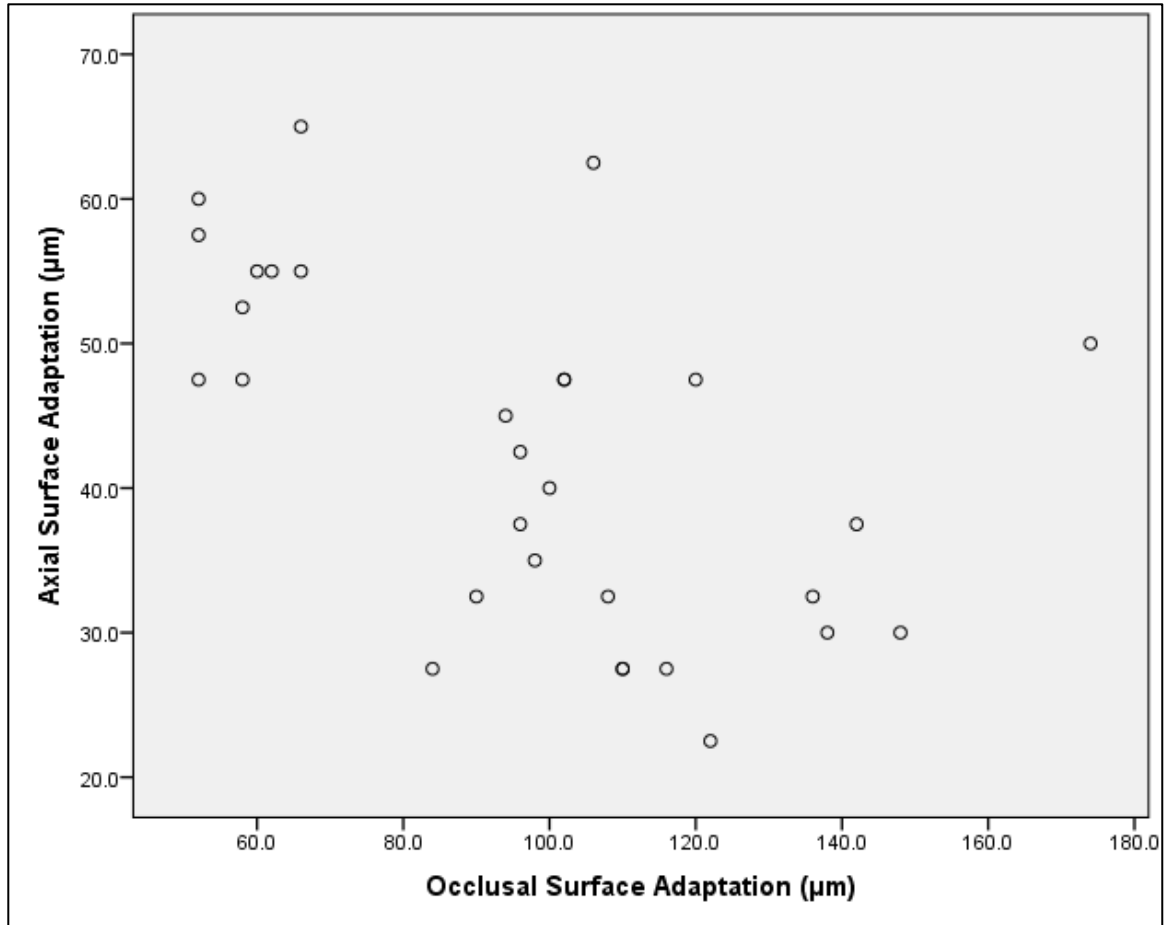


Figure 22. Scatterplot of Occlusal and Axial Surface Adaptation

### Discussion:

This study was designed to test the marginal and internal adaptation (axial and occlusal) of three different intraoral scanner systems. Marginal and internal adaptations are considered one of the most critical factors in the success of ceramic crowns.<sup>49</sup> The study showed that there is a statistically significant difference among these systems in the

parameters tested. However, the Carestream and True Definition groups did not exhibit statistically significant differences in mean marginal and occlusal adaptations. The all ceramic crowns fabricated using impressions from True Definition IOS did not provide better marginal and internal adaptations compared to crowns fabricated using impressions from Trios and Carestream 3600 IOS. It only provided a better axial adaptation than Trios and Carestream 3600.

Carestream 3600 was introduced to the market in 2016. Nedelcu et al investigated the scanner in a descriptive comparison study. They showed that Carestream 3600 had better finish line accuracy over other scanners when evaluating the impression only.<sup>21</sup> The study did not evaluate the fabricated prostheses from the scanner. In this study, we tried to minimize any source of error by directly communicating the scanner to the CAD/CAM system and the fabrication of the dental prostheses. In an effort to minimize possible cumulative errors, we also measured the results directly from the master model without having to use replicas of the master model. We investigated the accuracy of fabricated all ceramic crowns through the marginal and internal adaptations

Marginal adaptation was investigated and examined using direct visualization under stereo microscope. Tight marginal adaptation is essential in the success of dental restorations. Large marginal gap can lead to biological and mechanical complications.<sup>69, 70</sup> The Carestream 3600 (mean=11.5  $\mu\text{m}$ ) exhibited slightly better marginal adaptation than True Definition (mean=12.5  $\mu\text{m}$ ); however, this difference was not statistically significant ( $p=0.762$ ). It did not perform as well as Trios, which showed better marginal adaptation (mean=2.8  $\mu\text{m}$ ) in comparison to Carestream 3600 ( $p<0.001$ ) and True Definition ( $p<0.001$ ). Although the study showed significant differences in marginal adaptation

between the three intraoral scanners, all three systems exhibited excellent clinical marginal adaptation. The intraoral scanners exhibited much lower values in comparison to the acceptable clinical marginal gap of 120  $\mu\text{m}$  reported in the literature.<sup>33-39</sup>

The majority of studies of single ceramic crown restorations obtained from intraoral scanners were in vivo studies.<sup>6</sup> Syrek et al demonstrated in their study that marginal gap of a single crown obtained from a digital impression had a mean of 49  $\mu\text{m}$ .<sup>68</sup> Also Seelbach et al investigated the marginal gap of single ceramic restorations made from three different intraoral scanners. In their study, Seelbach et al showed a mean marginal gap of 41 to 48  $\mu\text{m}$ .<sup>13</sup> On the other hand, the majority of in vitro studies examined marginal gap on multiple restorations. In the study performed by Su et al of a 3-unit bridge, a mean marginal gap of 63  $\mu\text{m}$  was found for intraoral digital impressions.<sup>6</sup> In another in vitro study, Ali et al examined the marginal gap of a 3-unit bridge of five intraoral scanners. Ali et al study's found a mean marginal gap of 69.6 to 105.6  $\mu\text{m}$  depending on the intraoral scanner.<sup>18</sup> Although our study tended to find better marginal adaptation, the results confirmed the accuracy of impressions made from intraoral scanners. The tighter results obtained from our study might be due to the direct transfer of files from the intraoral scanners to the milling unit. In addition, examining the marginal gap of restorations directly on the master model could eliminate possible sources of errors from steps of fabricating a replica of the master model. Also, other studies used different intraoral scanners.

The internal adaptation was divided into two measurements; occlusal and axial surfaces. Both sections were tested using a non-destructive cement impression replica technique which has shown reliability and ease of use in the literature.<sup>50, 51</sup> The cement impression replica was sectioned and examined under stereo microscope. The size of the

cement replica reflected the size of the cement space. A greater thickness indicates a larger internal gap. Studies have shown that a larger internal gap can lead to higher flexural stress on the cement and restorations; this can lead to a higher chance of the restorations' failure.<sup>71, 72</sup>

With regard to axial adaptation, Carestream (mean=41.3  $\mu\text{m}$ ) had a tighter adaptation than Trios (mean=55.8  $\mu\text{m}$ ,  $p<0.001$ ) but did not perform as well as True Definition (mean=30.8  $\mu\text{m}$ ,  $p=0.002$ ). Carestream (mean=114.4  $\mu\text{m}$ ) had the least accuracy in terms of occlusal adaptation; however, it was not significantly different from the accuracy of True Definition (mean=114.2  $\mu\text{m}$ ). Trios (mean=63.2  $\mu\text{m}$ ) had a significantly tighter occlusal surface adaptation than the other scanners. Although there was a significant difference between the groups, all three intraoral scanners exhibited acceptable internal surface adaptation of less than 122  $\mu\text{m}$  as mentioned in the literature.<sup>43</sup> The higher mean values of occlusal surface adaptation for Carestream and True Definition might be due to tight adaptation on the axial wall. The software was programmed to allow for 35  $\mu\text{m}$  of cement space when fabricating the final restorations. However, True Definition resulted in a smaller mean of 30.8  $\mu\text{m}$  for axial surface adaptation. This finding is in agreement with the suggestion to account for thicker cement spacer of 30 to 60  $\mu\text{m}$  when digitally designing final restorations.<sup>49</sup> This is also reflected in the results of the correlation shown in this study. Restorations with smaller axial adaptation exhibited larger marginal and occlusal adaptation.

This study was performed in vitro and may not directly correlate with the same results if performed in vivo. Factors such as soft tissue, saliva, and bleeding are not evaluated with in vitro studies. Future studies should be done intraorally to determine its

clinical accuracy. There were only three scanners tested out of all the scanners that are available in the market. Future studies should also include other intraoral scanners available to have a better comparison of what is available to the practitioner.

Within the limitations of this study, it can be concluded that intraoral scanners can be used to provide accurate dental prosthesis; however, not all perform the same in terms of accuracy. Some scanners may perform better than others in regard to their occlusal, axial and marginal adaptations. One scanner may perform better in occlusal adaptation but not necessarily axial adaptation; therefore, its internal adaptation may not be considered better without looking at both parameters. This should be considered when selecting an intraoral scanner for prosthetic restorations.

## **Conclusion:**

- Intraoral scanners provide accuracy in both marginal and internal adaptation.
- Trios scanners provide more accurate marginal and occlusal adaptation when compared to CareStream3600 and True Definition.
- True Definition provided a more accurate axial adaptation compared to CareStream3600, which provided a more accurate axial adaptation compared to Trios.
- Intraoral scanners should be evaluated for all parameters of adaptation to determine the most accurate intraoral scanner system.

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