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# Three Dimensional Analysis of Intraoral Scanners Accuracy: An In-Vitro Study

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# Three Dimensional Analysis of Intraoral Scanners Accuracy: An In-Vitro Study

by

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A Thesis submitted in partial satisfaction of
the requirements for the degree
Masters of Science in Prosthodontics

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June 2019

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABBREVIATIONS

| | |
|---|---|
| 3D | Three-dimensional |
| TOC | Total occlusal convergence |
| PEMA | Poly(ethyl methacrylate) |
| STL | Stereolithography |
| CAD/CAM | Computer-aided design and computer-assisted manufacture |
| TRU | True Definition® (3M™ ESPE, St. Paul, MN, USA). |
| TRI | Trios 3® (3-Shape, Copenhagen, Denmark) |
| μm | Micrometer |
| mm | Millimeter |
| ANOVA | Analysis of variance |
| PC | Partial coverage |
| CC | Complete coverage |
| IOS | Intraoral scanner |
| AAD | Average absolute discrepancy |
| MAD | Maximum absolute discrepancy |

ABSTRACT OF THE MASTER THESIS

Three Dimensional Analysis of Intraoral Scanners Accuracy:
An In-Vitro Study

by

Rami Ammoun

Master of Science, Advanced Education Program in Prosthodontics
Loma Linda University, May 2019
Mathew T. Kattadiyil, Chairperson

**Purpose:** To evaluate and compare the accuracy of two intraoral scanners (IOS) for partial and complete coverage tooth preparations in the presence and absence of adjacent teeth using three-dimensional (3D) comparisons.

**Materials and Methods:** Eight different complete coverage (CC) and partial coverage (PC) tooth preparations were scanned by two IOS, the Trios (TRI) IOS from 3Shape and the True Definition (TRU) IOS from 3M. All teeth preparations were scanned with the IOS in the presence and absence of adjacent teeth. Four groups were established for each scanner; Group 1: PC preparations with adjacent teeth. Group 2: CC preparations with adjacent teeth. Group 3: PC preparations without adjacent teeth. Group 4: CC preparations without adjacent teeth. 3D analysis was performed on scanned preparations using 3D compare software to examine average absolute discrepancy (AAD) and maximum absolute discrepancy (MAD). A Two-way ANOVA was performed followed by a post-hoc Tukey's test HSD to evaluate the effect of adjacent teeth, preparation design, and the type of intraoral scanner used

**Results:** For TRI IOS, the AAD for Groups 1, 2, 3, and 4 were 20.0±1.8 μm, 19.6±2.4 μm, 15.5±2.7 μm, and 12.9±1.4 μm respectively, whereas the MAD for groups 1, 2, 3, and 4 were 109.7±13.5 µm, 93.2±8.9 µm, 85.6±16.1 µm, and 66.0±11.2 µm respectively. For TRU IOS, the AAD for Groups 1, 2, 3, and 4 were 22.1±3.7 µm, 17.9±2.0 µm, 20.1±5.9 µm, and 14.9±1.8 µm respectively, whereas the MAD for groups 1, 2, 3, and 4 were 130.6±38.5 µm, 92.7±13.5 µm, 89.1±20.4 µm, and 68.0±11.8 µm respectively. Two-way ANOVA showed statistically significant differences between the AAD and MAD of both TRI and TRU IOS ($P < .001$), as well as the presence or absence of adjacent teeth ($P < .001$) and preparation design ($P < .001$).

**Conclusions:** Within the limitations of this study, PC preparation scans exhibited lower accuracy than CC scans. In addition, the presence of adjacent teeth decreased the accuracy of both IOS. Comparable accuracy for CC preparation scans were found for both IOS, with the TRI IOS having better accuracy for PC preparation scans.

# CHAPTER ONE

## INTRODUCTION AND A REVIEW OF THE LITERATURE

Computer-aided design & computer-aided manufacturing (CAD/CAM) technology was first used to produce dental restorations by Anderson in the early 1980s.(1) This technology has revolutionized the way dentistry is practiced and has become integrated into patient care.(2,3) The CAD/CAM digital workflow consists of 3 main steps: surface scan, restoration design, and manufacture (milling/fabrication).(2) The first use of intraoral scanning has been attributed to Mörmann in 1980.(4) The surface scan is completed by directly scanning the patient's mouth using an intraoral scanner.(5) Recent advancements have produced intraoral scanners (IOS) that provide patient comfort, operator friendliness,(2,3) an accuracy with a 3-unit span, reduced operation time (compared to conventional impression technique), and the capability of producing well-fitting restorations.(6) Intraoral scanning, or digital impression making is however not free from limitations. They are associated with a high initial investment cost, a limited ability in accurate recording of complete maxillary and mandibular arches and complete arches of implants, and a limited ability to accurately record preparation finish lines in the presence of saliva, blood, or soft tissues.(7)

Recently, it has been demonstrated that the digital workflow is sufficiently accurate for the fabrication of up to a 4-unit fixed partial denture which indicates there is a capability of using quadrant impressions.(8-10) The data acquired from scanning oral surfaces is used to obtain a digital model of the scanned objects. An error in the data acquisition can create inaccuracies that may accumulate through the rest of the workflow, ultimately leading to an ill-fitting restoration.(7)

A recent literature review and meta-analysis compared the accuracy of digital impressions versus conventional impressions.(11) They concluded that the digital impression technique provided better marginal and internal fit of fixed restorations than conventional techniques. The amount of marginal fit discrepancy has not been consistent throughout the literature. According to De Villaumbrosia et al,(2) any discrepancy greater than 120 micrometers is large enough for bacteria to grow, leading to biological and mechanical problems. Another paper by Vandeweghe reported that the acceptable clinical marginal gap is between 50 and 75 micrometers.(12) They added that a gap larger than 150 micrometers seems to promote cement dissolution, microleakage, and plaque retention. It should be noted that these discrepancies are set for the restoration fabrication level, which is the last step in the CAD/CAM process. For data acquisition, the marginal discrepancy should be less than the fabrication level. Errors occur on the level of acquisition (scanning) of the scan data and from fabrication of the restoration. For the purposes of this study, 100 micrometers of discrepancy was considered the threshold, above which higher values would indicate unacceptable clinical values.

Some of the errors that may cause inaccuracies with the data acquisition are: camera tilt angle exceeding the axial wall angle of the tooth (total occlusal convergence);(13) the nature of light emitted by the scanner (white or blue light); the span of the scanned areas; poor technique;(3) and flaws in the stitching algorithm of the scanning software. Previous studies have examined the accuracy and precision of intraoral scanning.(3–5,7)(Figure 1). Precision describes how close repeated measurements are to each other(14). Therefore, a scanner with higher precision correlates to a more repeatable and consistent scan. Trueness or accuracy describes how far the measurement deviates from the actual dimensions of the measured object.(15) A scanner with high trueness indicates that the scanner delivers a result that is close or equal to the actual dimensions of the object being scanned. Figure 1 illustrates the difference between precision and trueness.

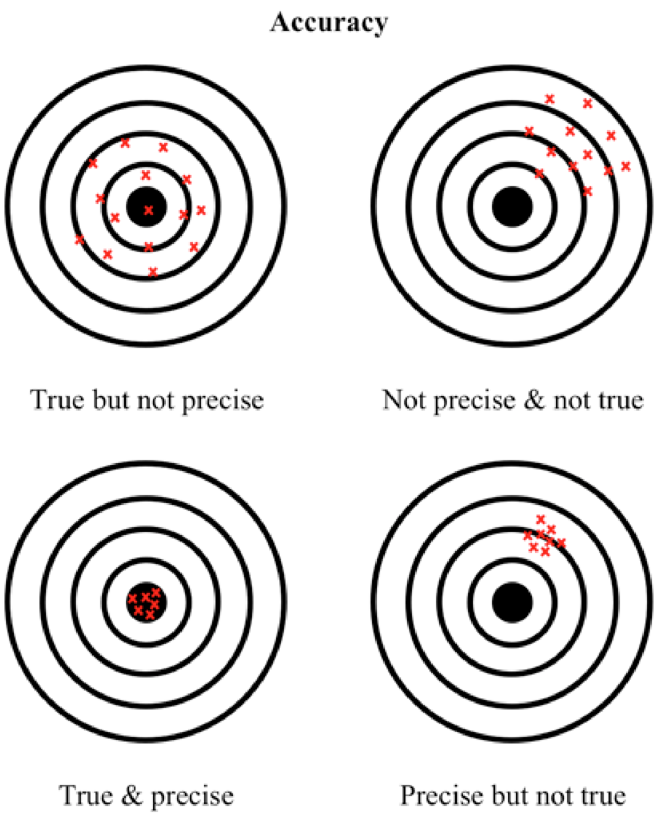


***Figure 1.*** Illustration showing the differences between trueness and precision.

Ender et al.(10) compared the accuracy of digital and conventional methods of obtaining complete-arch dental impressions. They concluded that the conventional technique using polyvinyl siloxane (PVS) impression materials were more accurate than digital techniques. In their study, they authors didn’t study tooth preparation designs for single teeth. The addition of prepared single teeth as a variable may add more geometry to the scanned surfaces and hence may lead to decreased accuracy. A similar finding was demonstrated in an *in vivo* study by Atieh et al.(8) where conventional impression techniques demonstrated higher accuracy than intraoral scanners. Multiple studies have demonstrated that conventional impressions are still superior to 3D scanning.(3,8,17,18)

Nedelcu et al.(16) evaluated the scanning accuracy and precision of 4 intraoral scanners and assessed the influence of different scanning materials and coating thickness. They found that the scanners that used a surface coating had better results in comparison to scanners that did not require a surface coating. They also reported that excessive coating did not seem to have a significant adverse effect on accuracy.  In this study, the scanned objects were non anatomic and adjacent teeth were not evaluated.

Lee et al.(19) compared the accuracy of a desktop scanner with that of intraoral scanners by using different image impression techniques on a maxillary first molar master model made out of poly(methyl methacrylate). The Blue cam (Cerec) showed better trueness than the Omnicam and lab scanner. However, the model did not have adjacent teeth and was a complete crown preparation.

Vögltin et al.(9) compared the accuracy of master models with two IOS (Lava and iTero) and a silicone (A- silicone) impression. The authors reported the most accurate method was with the silicone impression material. Out of the two scanners that were evaluated, the iTero scanner demonstrated the best accuracy. They concluded that the accuracy of the master models obtained on the basis of the digital scans were accurate enough to fabricate fixed partial dentures with up to four units. However, preparation designs were cylindrical-like and thus this study had a limitation of not replicating true anatomic geometry of teeth preparations.

Matta et al.(20) evaluated three different methods with which to build an accurate virtual model of a 3-dimensional implant in the oral cavity. They found that impression scanning had the highest accuracy for implant impressions. However, the models contained only implant scan bodies.

Bohner et al.(21) evaluated and compared the trueness of intraoral (Trios, Cerec Blue Cam) and extraoral (D250 and Cerec InEosX5) lab scanners in scanning-prepared teeth. They found a higher frequency of discrepancies in the cervical region and on the occlusal surface. They concluded that intraoral and extraoral scanners showed similar trueness in scanning prepared teeth. They also included a single tooth preparation with a single adjacent tooth. The authors postulated the shape of the prepared tooth might affect scanning accuracy, however, it was not within the scope of their study and they suggested further studies to evaluate this variable..

Villaumbrosia et al.(2) evaluated and compared the accuracy and resolution of 6 CAD/CAM extraoral scanners by comparing features and scan technology. The model they scanned was a single die with sharp line angles. The die was non-anatomical with no adjacent teeth. They stated that overall the scanners performed better than the manufacturer's claimed accuracy. The authors reported that the results they obtained were due to the design of the tooth preparation. This result occurred because the master die was designed with sharp edges and undercut areas as well as smooth surfaces to assess the scanners' performance under extreme conditions. This study raised the question of whether the scanners would perform better if they were scanning an "ideal" shape, that is, one with only straight surfaces and rounded edges.

Jeon et al.(5) evaluated the repeatability of conventional impressions of abutment teeth digitized with white- and blue-light scanners and compared the findings for different types of abutment teeth. They scanned separate abutment teeth of an incisor, canine, premolar, and molar complete crown preparations. In their study, they included abutment teeth to describe the nature of the scanning error patterns. They concluded that the blue light scanner exhibited better results than the white light scanner. However, regarding different abutment teeth, the results were not correlated. For the blue light scanner, the canine had the highest mean discrepancy. They mentioned, "this was attributed to the morphological characteristics of the canine tooth, which has a narrow and deep shape that appears to shadow the rest." For the white light scanner, the molar had the highest mean discrepancy. This study didn't have adjacent teeth since they scanned single abutment impressions. They also had complete coverage crowns only.

Mejīa et al.(7) evaluated the influence of abutment tooth geometry [total occlusal convergence (TOC) angles] on the accuracy of conventional and digital methods of obtaining dental impressions. They concluded that conventional dental impressions alone or those further digitized with an extraoral digital scanner cannot reliably reproduce abutment tooth preparations when the TOC angle is close to zero degrees. In contrast, digital impressions made with intraoral scanning can accurately record abutment tooth preparations independently of their geometry. However, in their study, the abutments were non-anatomic and had no adjacent teeth. Thus, for the intraoral scanner, the scanner was able to move in all the angulations possible to register the details of the abutments, which is something impossible to be replicated in a patient's mouth.

Renne et al.(3) evaluated and compared the accuracy of 6 intraoral scanners and 1 laboratory scanner in both sextant and complete-arch scenarios. They concluded that sextant scanning, using the Planscan, was found to be the most precise and true scanner. For complete-arch scanning, the 3Shape Trios was found to have the best balance of speed and accuracy. In their study, the scanned model was a complete arch maxillary Kilgore typodont. No teeth preparations were included in the study.

This literature review has included a relatively large number of studies demonstrating the accuracy of intraoral scanners. However, these studies have limitations in their designs and cannot truly reflect clinical scenarios. Therefore, there is a need to evaluate the accuracy of scanners in regards to different preparation designs and the presence or absence of adjacent teeth. To the best of the authors knowledge, those parameters had not yet been evaluated.

## Aim

The purpose of this study was to evaluate the accuracy of two different intraoral scanners, the 3Shape Trios, and the 3M™ True Definition for partial and complete coverage single restorations with and without the presence of adjacent teeth. The first null hypothesis was that partial and complete coverage restorations with and without adjacent teeth will have no effect on scanning accuracy between the two scanners. The second null hypothesis was that there will be no statistical significant differences in scanning accuracy between 1) the two scanners, 2) the partial and complete coverage restorations, and 3) with and without adjacent teeth.

# CHAPTER TWO

# MATERIALS AND METHODS

## Study Design and Control Groups

This in-vitro study was conducted at the Advanced Education Program in Prosthodontics, Loma Linda University School of Dentistry, California. A pilot study was performed to validate the methodology that is presented, and to confirm the sample size needed for each group. The study design is summarized in Figure 1. The scanners included in this study were the Trios (TRI) and the True Definition (TRU) IOS. The TRI works according to the principle of confocal microscopy. The scanner includes color in its data acquisition, does not need powder for scanning, and requires field calibration on a weekly basis. The TRU IOS uses active wave-front sampling in data acquisition and does require powder spray in order to scan adequately. The obtained scan has no color and this scanner does not require calibration according to the manufacturer (Table 1).(22)

**Table 1.** The scanners used with their corresponding software versions.

| Scanner Type | Technology of data acquisition | Powder | Color capture | Software version | STL file acquisition |
|---|---|---|---|---|---|
| Trios | Confocal microscopy | No | Yes | 1.4.6.3 | Open system. STLs can be directly obtained from the 3Shape software |
| True Definition | Active wave-front sampling | Yes | No | 4.5.1 | STL files can be obtained via 3M Connection Center. |

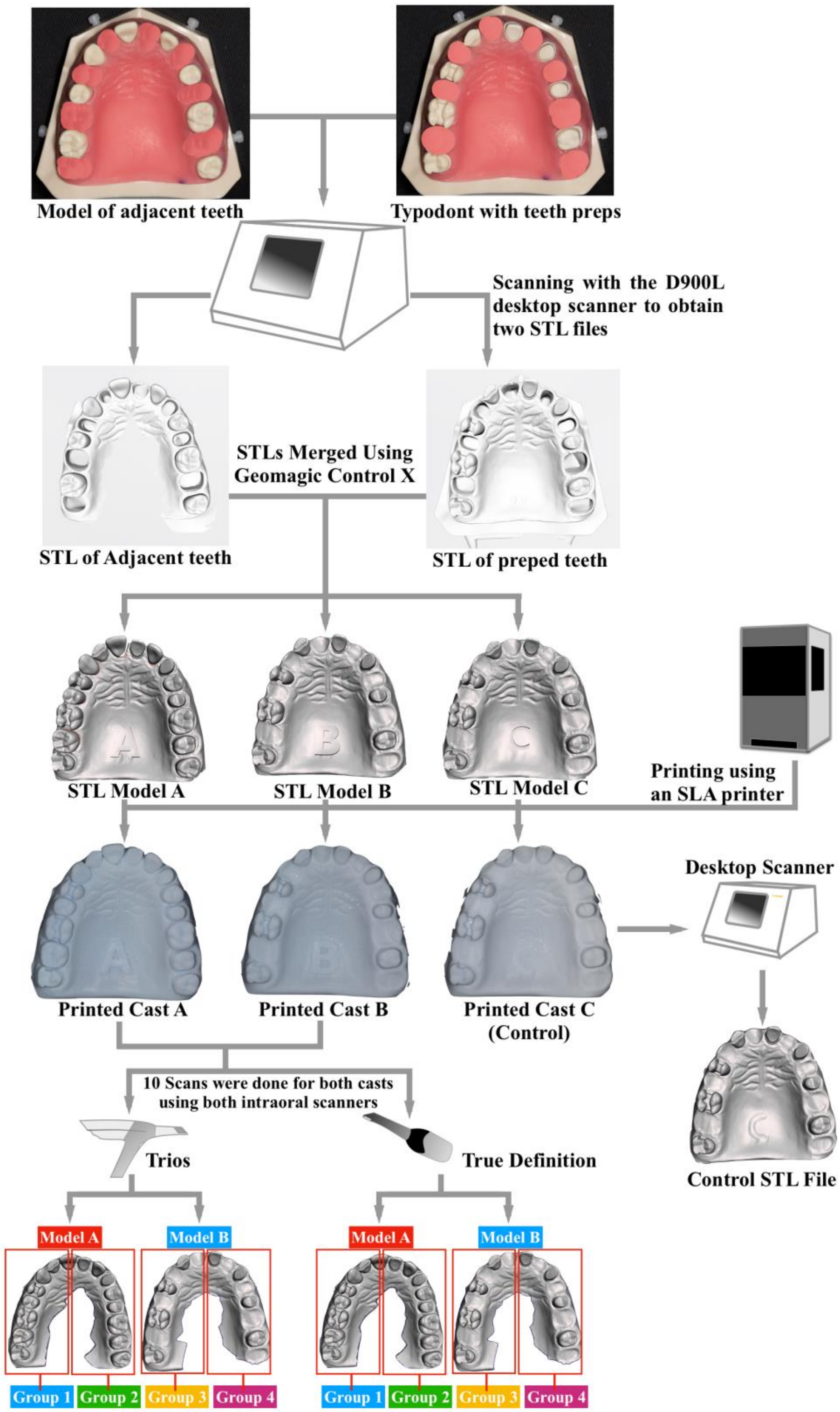


***Figure 2.*** Flowchart demonstrating the study design.

### *Preparing the Control (Master) Cast*

A maxillary typodont (Columbia Dentoform®, NY, USA) was used for fabrication of the master cast. The cast included 8 teeth preparations (Figure 3). Four preparation designs were for partial coverage restorations and four preparation designs were for complete coverage all-ceramic crown restorations. The preparations were formed using appropriate diamond instruments (Kit Ref. LD0366B, Kommet, USA). Preparation designs were made according to guidelines described by Goodacre et al.(23)

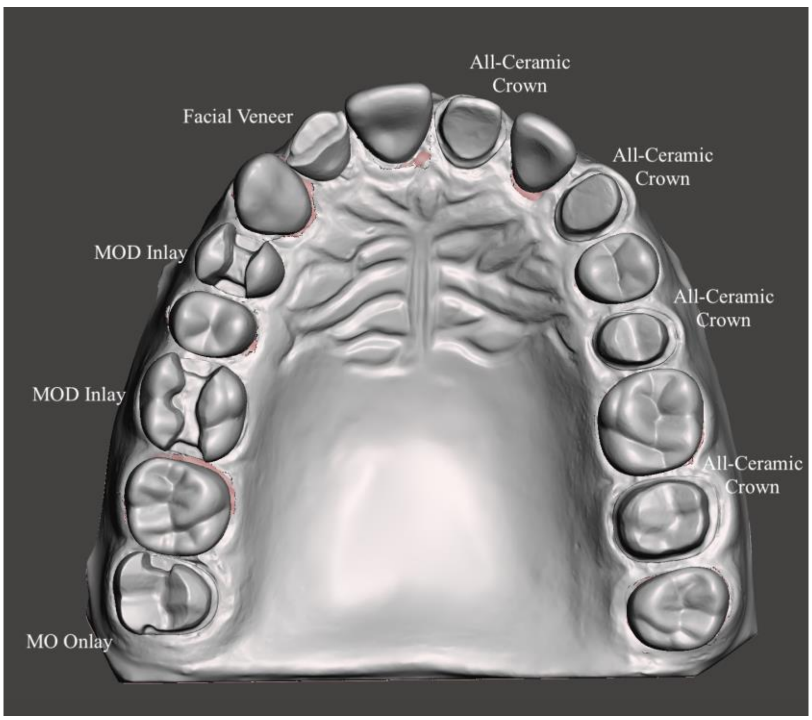


***Figure 3.*** Diagram of the teeth preparation designs.

The preparation designs were as follows:

1. Tooth #1: MOL ceramic onlay restoration. Design: Deep chamfer finish line to be located at the cervical area of the lingual cervical area. Shoulder finish line in the mesial box. 1.0 to 1.5 mm occlusal reduction with a 1.5 mm reduction of the lingual

cusps. Total occlusal convergence (TOC) of axial walls will be 10 to 14 degrees to allow for adequate divergence of the preparation and avoid undercuts.

2. Tooth #3: MOD ceramic inlay restoration. Design: 1.5 to 2 mm occlusal depth. Buccal lingual width will be 1/3$^{rd}$ the tooth width. At least 0.5 mm of clearance between the axial walls of the preparation and the adjacent tooth. Proximal boxes will be deep to allow 1 mm between the external edge of the box and the adjacent tooth. Box width will be 1.5 mm wide. TOC will be approximately 10 degrees.
3. Tooth #5: MOD ceramic inlay restoration. Design: Similar to tooth #3.
4. Tooth #7: Partial coverage ceramic veneer restoration. Design: 0.5 mm depth on the cervical finish line, progresses to reach 1 mm on the incisal one third. 1.5 to 2mm of incisal reduction with a type C veneer preparation.
5. Teeth #'s 9, 11, 13, and 15: Complete coverage all-ceramic tooth preparation. Design: A rounded shoulder of 1.2 mm depth at the labial surface. A deep chamfer finish line at the cervical area of the lingual, mesial, and distal surfaces. Facial and lingual axial surfaces will be reduced by 1.0 to 1.5 mm and incisal edge or occlusal surface by 1.5 to 2.0 mm. Facial, lingual, mesial, and distal surfaces will be prepared at 10 to 20 degrees of angulation with the axial wall. The point and line angles were rounded.

### *Digital Modeling of the Control (Master) Model*

The typodont was scanned using a desktop lab scanner (D900L, 3Shape, Copenhagen, Denmark). Two scans were obtained. The first scan included the typodont with the prepared teeth (#'s 1, 3, 5, 7, 9, 11, 13, and 15) only. This was used to generate the STL file of the prepared teeth (Labeled:  STL File B). The prepared teeth were then removed and the adjacent teeth (#'s 2, 4, 6, 8, 10, 12, and 14) were placed back into the typodont. A second scan was performed for the typodont with adjacent teeth. This scan was digitally merged with the first scan using Geomagic Control X 2018 (3D Systems, MA, USA). This produced an STL model with all teeth in the typodont (Labeled: STL File A).

### *Printing the Control and Study (Master) Models*

STL file A was used to fabricate a 3D printed cast (Model A – with adjacent teeth). STL file B was used to fabricate a 3D printed cast (Model B – without adjacent teeth). Another print of STL file B was made and was scanned using the D900L desktop scanner to fabricate the control model that contained the control preparations (Labeled: Model C). The working casts were scanned by an industrial scanner from In-Tech Industries (MN, USA) and printed by the iPro™ SLA® systems technology (SLA = Stereolithography). Model C was then scanned again using the desktop lab scanner (D900L, 3Shape, Copenhagen, Denmark) to generate the STL file (Labeled: REF STL). REF STL served as the reference to which all scans were compared. The reason this method was used is due to the difficulty of the desktop scanner to capture the interproximal landmarks of the typodont. This technique yielded the best results when acquiring the landmarks and producing highly detailed 3D models (Figure 4).

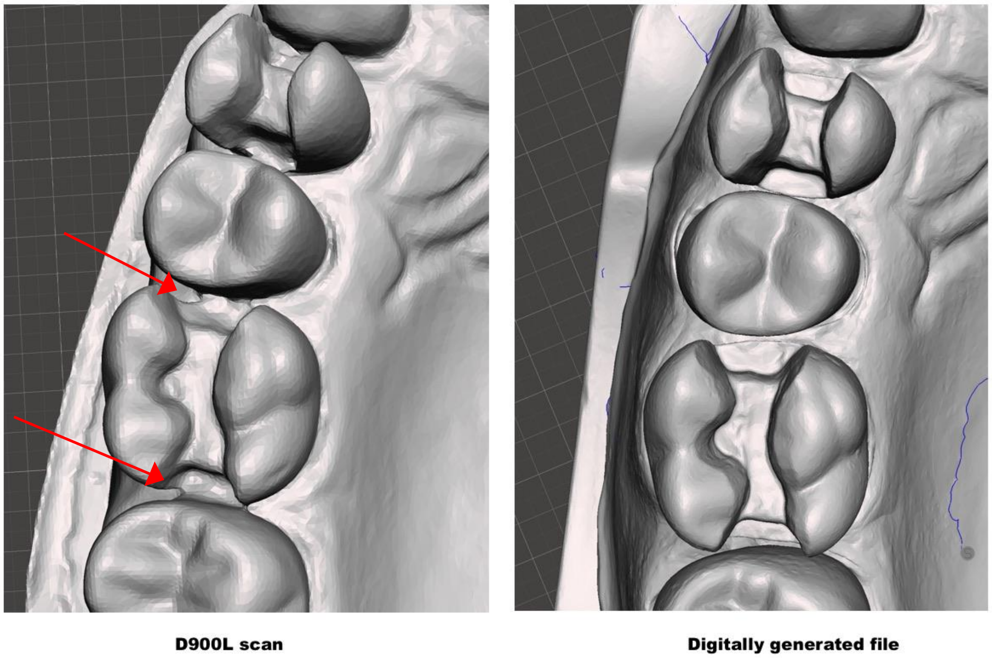


***Figure 4.*** Images showing the inaccuracy at the interproximal areas from the reading of the desktop scanner due to adjacent teeth.

### *Scanning the Study Preparations*

Model A and Model B were scanned with the TRU and TRI IOS following the manufacturers' instructions. For TRU scans, light coat of Titanium Oxide powder was used. Ten scans were completed with each IOS. The IOS STL files were named and saved accordingly for each scan. To reduce the error from the intraoral scanners stitching of the scanned dental arches,(15) each preparation from the intraoral scanners STLs were cut out from the full arch STL model using Geomagic Control X 2018 (3D Systems, MA, USA). For each scanner, 4 groups were established based on the preparation design, and presence or absence of adjacent teeth (Figure 5). The group distributions were as following:

- Group 1: Partial coverage preparations with adjacent teeth
- Group 2: Complete coverage preparations with adjacent teeth

- Group 3: Partial coverage preparations without adjacent teeth
- Group 4: Complete coverage preparations without adjacent teeth

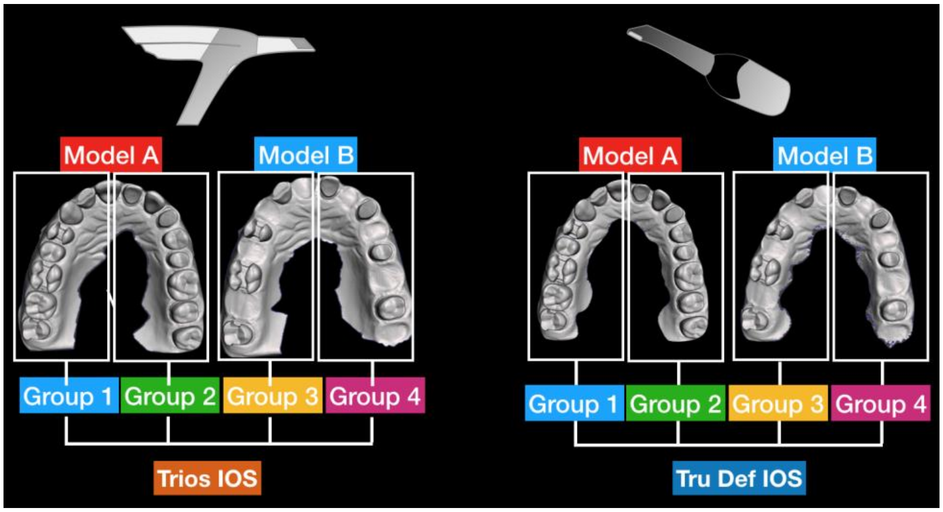


***Figure 5.*** Groups distribution based on adjacent teeth and preparation design for each scanner**.**

### ***3D Analysis***

Each preparation was superimposed to its reference STL preparation using the best fit algorithm. The average fit was calculated for each preparation using Geomagic Control X and the overall 3D deviations were evaluated using the same software via iterating through each vertex on the preparation and by calculating the Euclidean distance between that vertex and the surface of the reference preparation. This method is called full sampling. This process provides the maximum-, the minimum-, the average deviations (µm), and the standard deviations of each preparation in relation to the reference. The absolute discrepancy was obtained from the average negative discrepancy by multiplying it by (-1) then added to the average positive discrepancy which was then divided by the sum of 2. This was also performed in Vandeweghe et al's study because negative and positive values would compensate for each other, which would falsely improve the outcome, therefore absolute values were used.(11) The equation is presented below:

Absolute discrepancy = (Positive Discrepancy + (-1 X Negative Discrepancy))/2

## Statistical Analysis

A two-way ANOVA was conducted that examined the effect of presence of adjacent teeth, preparation design, and type of scanner on the accuracy of scanning through average absolute discrepancy (AAD) and maximum absolute discrepancy (MAD). Post hoc comparisons of AAD and MAD were conducted with Tukey HSD pairwise tests. All hypothesis tests were two-sided and tested at an alpha level of 0.05 using Statistical Package for Social Science (SPSS) version 24 (SPSS®, IL). Trueness or accuracy was presented as means of groups, and precision was presented as standard deviations.

## CHAPTER THREE

## RESULTS

The descriptive statistics for AAD and MAD are shown in Table 2 and Table 3. For TRI IOS, the AAD for Groups 1, 2, 3, and 4 were 20.0±1.8 µm, 19.6±2.4 µm, 15.5±2.7 µm, and 12.9±1.4 µm respectively, whereas the MAD for groups 1, 2, 3, and 4 were 109.7±13.5 µm, 93.2±8.9 µm, 85.6±16.1 µm, and 66.0±11.2 µm respectively. For TRU IOS, the AAD for Groups 1, 2, 3, and 4 were 22.1±3.7 µm, 17.9±2.0 µm, 20.1±5.9 µm, and 14.9±1.8 µm respectively, whereas the MAD for groups 1, 2, 3, and 4 were 130.6±38.5 µm, 92.7±13.5 µm, 89.1±20.4 µm, and 68.0±11.8 µm respectively. Box plots for AAD (Figure 6) and MAD (Figure 7) show the range of one half of the data stratified by the interquartile range (IQR: Difference between lower and upper quartiles or 25th and 75th percentiles, respectively). The bars at the end of the extended lines show the maximum and minimum value that is less than, greater than, or equal to the mark that is 1.5 IQRs above or below the upper or lower quartile, respectively. The means are also shown as a line within the boxplots. The presence of adjacent teeth ($P$<.001), preparation design ($P$<.001), and type of scanner ($P$<.001) revealed statistically significant effects on the accuracy of the scanners (Tables 4 and 5). Figure 8 and Figure 9 demonstrate the marginal discrepancies among different groups in terms of AAD and MAD. Group 4 has the least marginal discrepancies, while Group 1 has the largest marginal discrepancies. Group 2 and 3 are in the middle ranges in terms of marginal discrepancies for both AAD and MAD; however, the marginal discrepancies in these two groups vary with the type of scanner. Post hoc Tukey pairwise comparisons between all groups for both scanners are demonstrated in the $P$-values in Table 6 for AAD and Table 7 for MAD. The pairwise comparisons are graphically represented for all groups to compare the performance of both scanners in Figure 8 for the AAD and Figure 9 for MAD. The TRI IOS performed better than the TRU in all groups except for group 2 for the AAD and MAD.

**Table 2.** Descriptive statistical analysis of AAD for groups in µm.

| Scanner Type | Group 1 | Group 2 | Group 3 | Group 4 | Total |
|---|---|---|---|---|---|
| **TRI** | | | | | |
| Mean (µm) (Trueness) | 20.1 | 19.6 | 15.5 | 12.9 | 17.1 |
| S.D. (Precision) | 1.8 | 2.4 | 2.7 | 1.4 | 3.6 |
| **TRU** | | | | | |
| Mean (µm) (Trueness) | 22.1 | 17.9 | 20 | 14.9 | 18.7 |
| S.D. (µm) (Precision) | 3.6 | 2 | 5.9 | 1.7 | 4.5 |

**Table 3.** Descriptive statistical analysis of AAD for groups in µm.

| Scanner Type | Group 1 | Group 2 | Group 3 | Group 4 | Total |
|---|---|---|---|---|---|
| **TRI** | | | | | |
| Mean (µm) (Trueness) | 109.7 | 93.2 | 85.6 | 66.1 | 88.68 |
| S.D. (µm) (Precision) | 13.5 | 28.9 | 16.1 | 20.1 | 20.1 |
| **TRU** | | | | | |
| Mean (µm) (Trueness) | 151.47 | 92.21 | 92.6 | 71.4 | 101.9 |
| S.D. (µm) (Precision) | 38.4 | 17 | 23.6 | 11.9 | 38.7 |

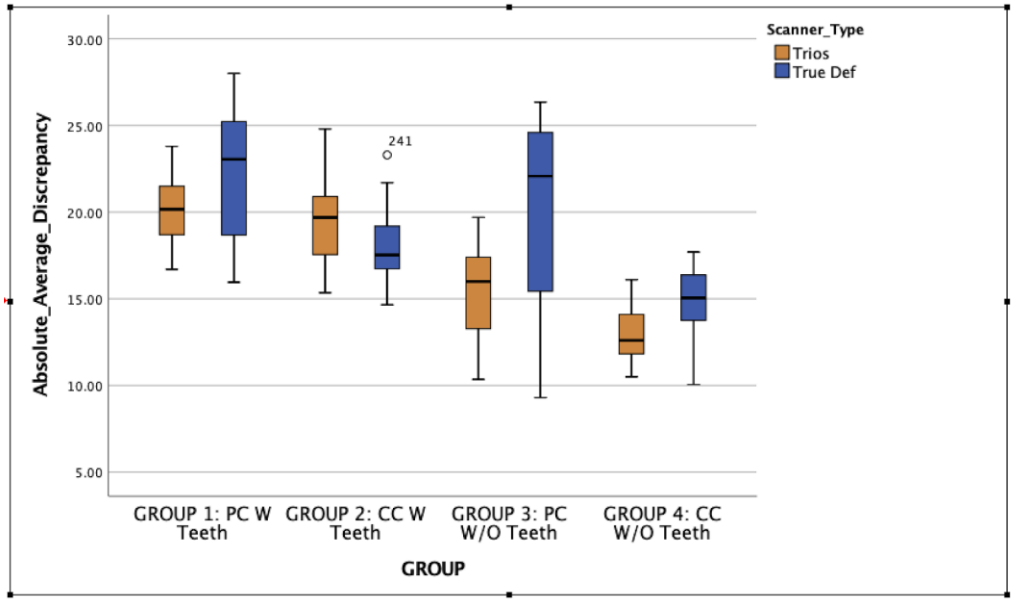


***Figure 6.*** Boxplots showing the comparisons between groups for each scanner for AAD.

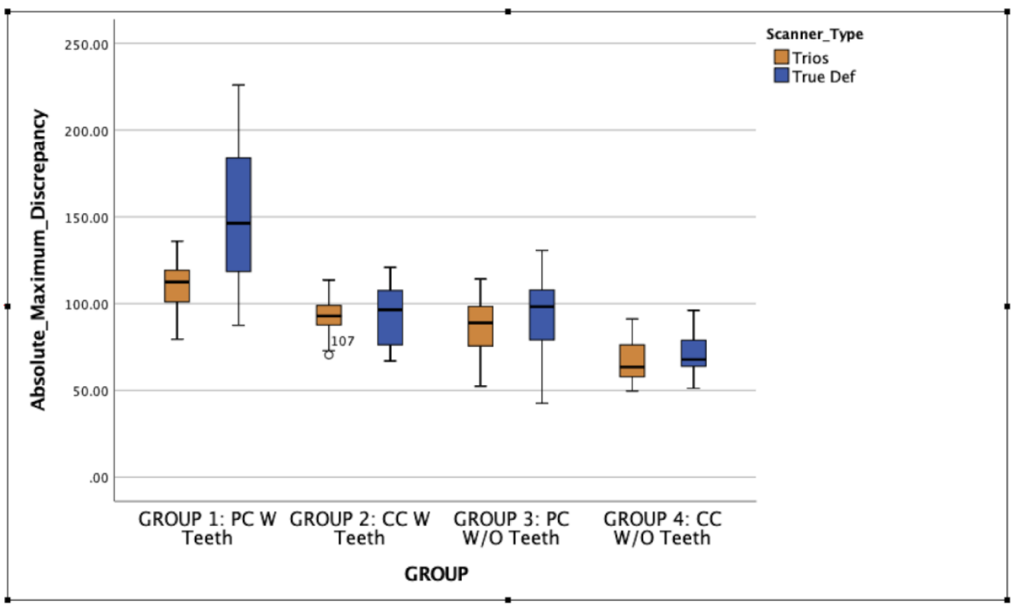


***Figure 7.*** Boxplots showing the comparisons between groups for each scanner for MAD.

**Table 4.** Two-way ANOVA for AAD.

| Source | Mean Square | F | Sig |
|---|---|---|---|
| Intercept | 102615.347 | 10814.15 | .000 |
| Adjacent Teeth | 1315.23 | 138.607 | .000 |
| Preparation Design | 764.62 | 80.58 | .000 |
| Scanner type | 231.966 | 24.44 | .000 |
| Error | 9.489 | | |

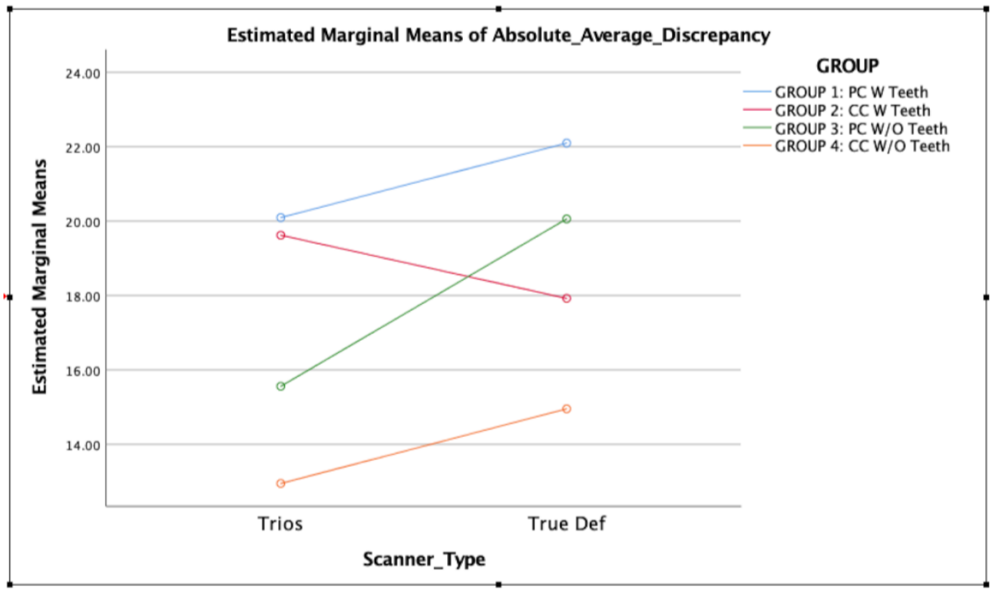


***Figure 8.*** Profile plot showing the difference between TRI and TRU for each group for the AAD category.

**Table 5.** Two-way ANOVA for MAD.

| Source | Mean Square | F | Sig |
|---|---|---|---|
| Intercept | 2907059.84 | 7458.119 | .000 |
| Adjacent Teeth | 85767.342 | 220.03 | .000 |
| Preparation Design | 67821.93 | 173.99 | .000 |
| Scanner type | 14039.038 | 36.01 | .000 |
| Error | 389.78 | | |

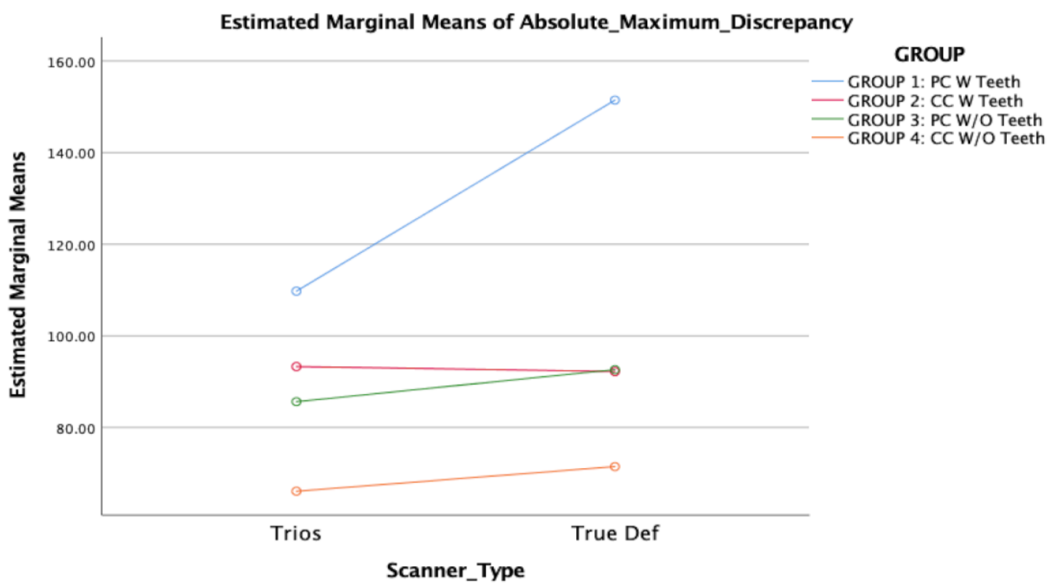


***Figure 9.*** Profile plot showing the difference between TRI and TRU for each group for the MAD category.

**Table 6.** P-value of pairwise comparisons between all groups for the AAD.

| Group | TRI Group 1 | TRI Group 2 | TRI Group 3 | TRI Group 4 | TRU Group 1 | TRU Group 2 | TRU Group 3 | TRU Group 4 |
|---|---|---|---|---|---|---|---|---|
| TRI Group 1 | X | .005 | .000 | .000 | .000 | .002 | .003 | .000 |
| TRI Group 2 | .005 | X | .666 | .000 | .000 | 1.00 | 1.00 | .000 |
| TRI Group 3 | .000 | .666 | X | .000 | .000 | .813 | .762 | .031 |
| TRI Group 4 | .000 | .000 | .000 | X | .000 | .000 | .000 | .927 |
| TRU Group 1 | .000 | .000 | .000 | .000 | X | .000 | .000 | .000 |
| TRU Group 2 | .002 | 1.00 | .813 | .000 | .000 | X | 1.00 | .000 |
| TRU Group 3 | .003 | 1.00 | .762 | .000 | .000 | 1.00 | X | .000 |
| TRU Group 4 | .000 | .000 | .031 | .927 | .000 | .000 | .000 | X |

**Table 7.** P-value of pairwise comparisons between all groups for the MAD.

| Group | TRI Group 1 | TRI Group 2 | TRI Group 3 | TRI Group 4 | TRU Group 1 | TRU Group 2 | TRU Group 3 | TRU Group 4 |
|---|---|---|---|---|---|---|---|---|
| TRI Group 1 | X | .997 | .000 | .000 | . 074 | . 037 | 1.00 | .000 |
| TRI Group 2 | . 997 | X | . 000 | .000 | .009 | 0.215 | .998 | .000 |
| TRI Group 3 | .000 | .000 | X | .004 | .000 | .015 | .000 | .988 |
| TRI Group 4 | .000 | .000 | .004 | X | .000 | .000 | .000 | .074 |
| TRU Group 1 | .074 | .009 | .000 | .000 | X | .000 | .064 | .000 |
| TRU Group 2 | .037 | 0.215 | .015 | .000 | .000 | X | .440 | .000 |
| TRU Group 3 | 1.00 | .998 | .000 | .000 | .064 | .440 | X | .000 |
| TRU Group 4 | .000 | .000 | .988 | .074 | .000 | .000 | .000 | X |

# CHAPTER FOUR

# DISCUSSION

The primary goal of this study was to examine if there was any effect from preparation design and the presence of adjacent teeth on the accuracy of two IOS commonly used in dental practices. The results reject the null hypotheses and statistically demonstrate that there are interactions between the type of intraoral scanners, presence of adjacent teeth, and preparation design. In terms of IOS, the Trios overall seems to perform better than the True Definition. The range of accuracy (AAD) in this study is comparable to previous studies.(24)(25,26) The difference in the accuracy of these two scanners are known in the literature. However, this study is one of the first to determine the influence of adjacent teeth and preparation design on the accuracy of intraoral scans. Most previous studies focused on abutment preparations with a complete coverage restoration design or unprepared teeth.(25–27)(28)

The partial coverage tooth preparation with adjacent teeth has long been widely advocated together with intraoral scanning and in-office milling of restorations.(29)(30) However, the complete coverage design with good access to the interproximal area (especially when there was no adjacent teeth present) was found to provide the best scan data and as a result, logically the better fitting restoration. Scanning direction and scanning access to the finish line and interproximal contact area are reflective of the scan accuracy. These results are similar to the orthodontic scanning literature. It is also interesting to note that severe dental irregularity or crowding can result in inaccurate intraoral scanning.(30,31)

Another interesting observation was that the most inaccuracies occurred in the interproximal region for both types of tooth preparations: complete coverage and partial coverage restorations, which indicates that scan angulations can lead to inaccuracies in scanning (Figure 10). Practically, clinicians may consider adjusting the interproximal area of adjacent teeth, or increase the total occlusal convergence on tooth preparation walls that are next to adjacent teeth to allow better scan angulations and access. It should be noted that for both scanners, Group 1 showed MAD that exceeded 100 micrometers discrepancy, which was not clinically acceptable. It was beyond the scope of this study to evaluate the extent of the discrepancy and its clinical significance due to the presence of many variables that were already evaluated. Thus, further investigations are needed to determine the significance of the MAD in those areas. Based on the results obtained from this study, better accuracy and precision was found with less complex preparation designs (e.g. full coverage) and ease of access with the intraoral scanning camera.

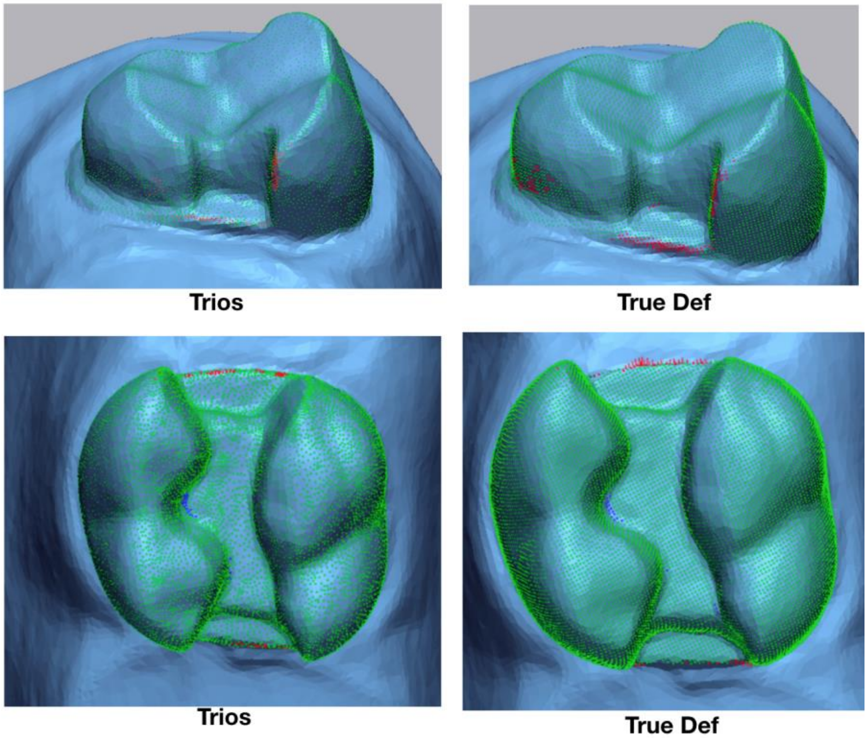


***Figure 10.*** Screenshots of the interproximal discrepancies from the 3D map analysis from Geomagic Control X on scanned preparations.

An additional interesting observation was that despite the overall better performance for the TRI IOS compared to the TRU IOS, the TRU IOS had better performance for the AAD for the CC groups. This finding might be attributed to the enhanced readability due to the powder used by the TRU IOS for preparations that have a more simple geometry. This finding agrees with a study done by Nedelcu and Persson(16) where they concluded that powder IOS are more accurate than non-powder scanners. However, the decline in performance of the TRU IOS was steep compared to the TRI IOS as the geometry became more complex, that is for the PC groups with adjacent teeth. This opposes the finding by Mejīa et al(7) where they stated that the geometry (taper) did not affect the scanning accuracy.

There are some limitations to this study. First, this is an *in vitro* exploratory study with limited sample size. While the study design allows direct comparison between two scanners, two types of abutment preparation designs, and the presence/absence of adjacent teeth, the study was not performed intraorally. The oral cavity may present challenges like limiting the scanning access along with the presence of oral fluids and therefore, this is likely to produce a greater inaccuracy. Second, the preparation designs and adjacent teeth were standardized. There will be degrees of variations in real life patients. More importantly, modifications of adjacent teeth and different abutment preparation design can have an influence in the scanning accuracy. Finally, there were only two types of IOS used in this study. Numerous IOS are available in the market. More advanced ones are currently being developed. The results here may not represent the wide variety of IOS or the new generations of IOS. Future studies involving human subjects with other modifications of the study designs with different IOS would be the next direction.

# CHAPTER FIVE

## CONCLUSIONS

Within the limitations of this study, partial coverage preparation scans showed significantly less accuracy than complete coverage preparation scans. In addition, the presence of adjacent teeth can decrease the accuracy of intraoral scanning of abutment preparations. Furthermore, the Trios scanner performed better than the True Definition scanner for scanning partial coverage scans, but the performance was comparable for complete coverage scanning. Clinicians should consider with caution using intraoral scanners for scanning partial coverage preparations in the presence of adjacent teeth since this yielded the highest inaccuracy among all groups.

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