COMPARISON OF DIMENSIONAL ACCURACY OF DIGITAL DENTAL MODELS PRODUCED FROM SCANNED IMPRESSIONS AND SCANNED STONE CASTS

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Abstract

Introduction: Digital models of dental arches play a more and more important role in dentistry. A digital dental model can be generated by directly scanning intraoral structures, by scanning a conventional impression of oral structures or by scanning a stone cast poured from the conventional impression. An accurate digital scan model is a fundamental part for the fabrication of dental restorations.

Aims: 1. To compare the dimensional accuracy of digital dental models produced by scanning of impressions versus scanning of stone casts. 2. To compare the dimensional accuracy of digital dental models produced by scanning of impressions made of three different materials (polyvinyl siloxane, polyether or vinyl polyether silicone).

Methods and Materials: This laboratory study included taking addition silicone, polyether and vinyl polyether silicone impressions from an epoxy reference model that was created from an original typodont. Teeth number 28 and 30 on the typodont with a missing tooth number 29 were prepared for a metal-ceramic three-unit fixed dental prosthesis with tooth #29 being a pontic. After tooth preparation, an epoxy resin reference model was fabricated by duplicating the typodont quadrant that included the tooth preparations. From this reference model 12 polyvinyl siloxane impressions, 12 polyether impressions and 12 vinyl polyether silicone impressions were made. All 36 impressions were scanned before pouring them with dental stone. The 36 dental stone casts were, in turn, scanned to produce digital models. A reference digital model was made by scanning the reference model.

Six groups of digital models were produced. Three groups were made by scanning of the impressions obtained with the three different materials, the other three groups involved the scanning of the dental casts that resulted from pouring the impressions made with the three different materials. Groups of digital models were compared using Root Mean Squares (RMS) in terms of their dimensional accuracy, which is defined as the absolute value of deviation in micrometers from the reference model. A two-way analysis of analysis of variance (ANOVA) was applied to calculate if the measurements for the six test groups were statistically significantly different from the original reference model as well as between test groups ($p <.05$). Tukey's HSD was also applied to characterize the differences.

Results: The mean (± SD) RMS was 29.42 ± 5.80 microns for digital models produced from polyether impression scans, 27.58 ± 5.85 microns for digital models from PVS impressions scans, and 24.08 ± 4.89 microns for digital models produced from VPES impressions scans. 26.08 ± 6.58 microns for digital models produced by scanning stone casts poured from PE, 31.67 ± 9.95 microns for digital models produced by scanning stone casts poured from PVS and 22.58 ± 2.84 microns for digital models produced by scanning stone casts poured from VPES.

In the Two-Way ANOVA, the p-value for the material factor was 0.004, reflecting a statistically significant difference between the accuracy of the three impression materials, with VPES showing the highest accuracy (mean RMS = 23.33 ± 3.99 microns) followed by PE (mean RMS = 27.75 ± 6.3 microns) and PVS (mean RMS = 29.63 ± 8.25 microns). For the technique factor, the p-value was 0.870 reflecting no statistically significant difference between the accuracy of the two techniques (impression scan and stone cast scan). The mean RMS values were 27.03 ± 5.82 microns and 26.78 ± 7.85 microns, respectively. In the post-hoc tests for the material factor, a significant difference was found between the accuracy of

VPES and PVS (p-value = 0.004) with VPES having the higher accuracy (lower mean RMS). No significant difference was found between the accuracies of PE and PVS (p-value = 0.576), and between the accuracies of PE and VPES (p-value = 0.054).

Conclusions: Within the limitations of this *in vitro* study, it can be concluded that:

1. There is no statistically significant difference in dimensional accuracy between digital models produced by scanning dental impressions and those produced by scanning stone casts.

2. Digital models produced from the scans of VPES impressions are dimensionally more accurate than those produced from PVS impressions scans. No significant difference in accuracy was observed between PE and PVS impression scans, or between PE and VPES impression scans.

Dedications

To My Parents, My Wife, My Son, My Daughter,

My Brothers and Sisters

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COMPARISON OF DIMENSIONAL ACCURACY OF DIGITAL DENTAL MODELS PRODUCED FROM SCANNED IMPRESSIONS AND SCANNED STONE CASTS

1. Introduction and Literature Review:

1.1. Background:

Three-dimensional [3-D] computer models of dental arches play a more and more important role in dentistry.(1) In Prosthodontics, for instance, they can aid in the design and fabrication of prosthodontic restorations or in the planning of dental implant treatment by allowing to preselect and position virtual implants on the digital 3D models.(2) In Orthodontics, digital dental models can be used as study models and aid, therefore, in space analysis, and they were found to be as reliable as the traditional stone models, and will become the standard for orthodontic clinical use.(3)

A digital scanner can be used to produce restorations directly, i.e., digitally via a CAD/CAM system, or indirectly by using the digital impression for fabricating casts, on which restorations can be made.

In 1987, the Cerec System (Sirona Inc., Bensheim, Germany) was launched as the first CAD/CAM system in dentistry, which allows digital impressions, design and in office milling of dental inlays and onlays. In 1997 the Procera system (Nobel Biocare AB, Gothenburg, Sweden) followed, which is based on a touch-probe extraoral scanning concept to scan dental casts and produce dental restorations. The 3Shape and the Lava scanners were launched in 2005 and 2006, respectively.

They are both specifically dedicated for taking digital impressions and producing virtual or physical working models that can be used by other milling systems or by the laboratory technicians to fabricate dental restorations.

Various methods are available for digitizing the geometry of a body into a digital form. Some of them are mechanical touch-probing concepts, while others are optical scanners. In particular when scanning single teeth, the accuracy of mechanical touch-probing systems was satisfactory. Dental casts have a complex shape with undercuts, and an optical scanner is required to measure from different directions to minimize blind areas that need to be synthesized.(4) An optical scanner operates by using laser, white light, x-ray or blue light. The laser or light is projected onto the object, and the reflected patterns are registered through a digital camera. After the reflections have been tracked in the camera image, 3-D point clouds can be obtained using triangulation technology. In general, the advantage of optical methods is the use of a no-contact system that allows the scanning of soft and brittle materials. However, the optical properties of the object may affect the accuracy of the scan data.(5)

Optical scanners that produce 3-D computer models of dental arches have been proven to provide sufficient system accuracy for clinical application, Therefore, optical scanners are used to import scan data for fabricating dental restorations.(5,7,8)

The quality of dental restorations has improved significantly since the introduction of a standardized production process. CAD/CAM technology has made it possible to utilize interesting new prosthetic materials such as the high performance ceramics.[5,6]

In order to transform the prepared tooth into a virtual model, several different methods are available for dental application.[5] The steps involved in data capture for dental reconstructions can vary depending on the CAD system used. In order to optimize the manufacturing process, the number of steps involved should be brought to minimum without compromising the accuracy of the final product. For instance, direct intra-oral scanning will omit the need for an impression and for fabricating a stone cast, eliminating two of the steps, which can affect the accuracy of the final product.[6-8,9] However, some intra-oral scanners might require the application of titanium oxide on the tissues to be digitized, and this may alter the topography of the surfaces and compromise the exactness of the internal fit.[10-13]

Although the requirements for data capture have not been standardized, the most important criteria are good accuracy and precision of the virtual replica and an efficient reproduction process. The aim for the final product is to reach a precise internal fit that includes the thickness of the cement space.[14]

CAD/CAM technology has made it possible to compensate for the significant shrinkage of high performance ceramics such as alumina and zirconia.[15]

The main reason for undertaking laboratory *in vitro* studies is the need for a standard physical reference called the reference model, and the chance to digitize both the reference and the replicas using a similar digitization method. In 2006, Persson et al. compared the quality of data acquired by different digitization devices, and mapped geometrical differences between the stone replica and the master model. This study created the basis of a technique for evaluating the quality of acquired data and determining the influence of material characteristics. [15]

In a subsequent article, the potential for gaining high quality input data directly from the impression was investigated using a single master die and an experimental impression material that was specifically designed for optical measuring with a laser scanner, they demonstrated that high quality three-dimensional-data could be obtained by directly scanning impressions.[16]

However, in the clinical environment with the presence of neighboring and opposing teeth leads to a variable thickness of the impression material and a higher risk for distortion as the impression is removed from the dental arch. In order to mimic these conditions in a laboratory environment, Persson et al.[16] presented a study using full dental arches of plastic teeth mounted in an articulator. The aim of the study was to apply virtual three-dimensional analysis to compare the exactness of digitized simulated clinical impressions with that of digitized stone replicas of full crown preparations, they found that both impressions and stone replicas could be digitized repeatedly with a high reliability. However, they used two different scanners to scan the impressions and the ceramic replicas. Moreover, they scanned single crown preparations rather than preparations for fixed partial dentures.

Virtual models can be produced by several methods. The most direct method is by using an intraoral laser-scanner. This method makes the impression superfluous, but the clinical chair time may be increased depending on the level of experience of the clinician with intraoral scanning. Digital virtual models can also be produced by a negative surface model technique generated by laser-scanning the inside of an impression. However this method might encounter greater difficulties caused by undercuts and the limited access to the inside details of an impression. The most frequently applied method seems to be to pour a stone cast as a halfway step. The cast is then digitized to produce the virtual model.[(16)]

Delong et al. in 2003 found that computer models from scanned impressions were more accurate than computer models from scanned casts.[(17)] An even more interesting finding of these authors was that common dental methods of duplicating oral tissues could produce computer models with accuracies equivalent to the commonly used methods of recording occlusal contacts, such as shimstock and transillumination. Therefore, it is possible to record occlusal contacts on computer models as in the clinic. [17] Computer models can provide a quantitative permenant record of occlusal contacts that can be viewed at any time. Sequential 3D computer models can detect any change in occlusal measures and contacts and identify occlusal problems such as tooth attrition and loss of vertical height.

3-D modeling of dental arches will have considerable advantages, particularly in circumventing the need for extensive storage facilities by skipping the process of impression pouring with stone, allowing for a faster process in the production of dental restorations, reducing the risk of physical damage and/or the disappearance of the casts stored in the wrong location. In addition, there is the possibility of sharing the models online or via e-mail with colleagues involved in the treatment as well as with the patient.[18]

Alcan et al. (2009) found that virtual measurements performed on digital models displayed less variability than the corresponding measurements performed with the digital caliper on the actual models, and this may have a major impact on the expansion of their orthodontic use.[19]

In 2011, Ender and Mehl concluded from their study that the accuracy of digital impressions is similar to that of conventional impression. However, the authors suggested that the evidence for their findings still would need to be confirmed.[20]

Digital scanning systems have made a dramatic historical transition in dental impression technology from bites to bytes.[21] Zweig (2009) stated that with digital impression techniques, the number of operator and material variables is reduced, and the restorative procedure becomes more predictable and easier to accomplish.[22]

However, the cost of digital impression systems is still a major issue. Christensen suggested that the relative cost of digital versus elastomer impressions will depend on the number of impressions that a dentist takes per month. A digital impression system has to be used for a significant amount of time to compensate for its cost.[23]

1.2. Digital Scanners:

Different types of scanners exist in the field. Some of them are used to scan dental structures intraorally (intraoral scanners), others are only used extraorally to scan models or impressions (extraoral scanners). One has to also differentiate between so-called open systems, who allow sharing of data and workflows for example in that scan data of one manufacturer’s scanner can be used by other systems for the design and manufacturing process of dental restorations. In other instances, scanners are part of a so-called closed system, in which digital processes are only possible within one manufacturer’s circle of workflow components.

Scanners can be further grouped by their scanning mode. Some scanners depend on a mechanical touch probe scanning technique, others are optical scanners that use either laser, white light, blue light or x-rays.

After the scanning process is completed, a 3-dimensional virtual model will be formulated from point clouds on the computer screen.[24-26] In some systems, this virtual model can be translated into a physical replica made of a resinous material, either by a subtractive CAD/CAM milling process or by an additive resin printing process known as stereo-lithography.

1.3. Laser Scanners:

Laser scanners operate through a red laser light beam, which is reflected by the oral structures. The reflected image is captured with a digital camera. An example of a laser scanner is the 3-Shape D-700 impression scanner (D-700, 3Shape A/S, Copenhagen, k Denmark). It uses the confocal technology and is characterized by:

• Two cameras combined with 3-axis scanning, which are needed for effective scanning of impressions,

• Adaptive scanning that ensures complete scans results, and

• Virtual model creation tools which enable high quality virtual and physical models.

With these characteristics, the D700 scanner is optimized for scanning of dental impressions as well as dental stone casts.

To our knowledge, no studies are available in the literature to compare the dimensional accuracy of virtual models produced by digital reproduction of polyvinyl siloxane, polyether and vinyl polyether silicone dental impressions with virtual models produced by digital reproduction of dental stone casts produced from different impression materials.

2. Specific Aims and Hypotheses:

2.1. Aims:

I. To compare the dimensional accuracy of digital 3-D duplicates of a dental arch reference model produced with two different methods:

a. Scanning of dental impressions of the reference model.

b. Scanning of the stone casts made from the above impressions.

II. To compare the dimensional accuracy of digital duplicates of a dental arch reference model produced with three different methods:

a. Digital scanning of polyvinyl siloxane impressions (PVS).

b. Digital scanning of polyether impressions (PE).

c. Digital scanning of vinyl polyether silicone (VPES).

2.2. Hypotheses:

I. Digital duplicates of a dental arch reference model are more accurate when produced by scanning the stone casts produced from impressions of the reference model compared to scanning the impressions directly.

II. Digital duplicates of a dental arch reference model are more accurate when produced from scanned polyvinyl siloxane impressions than digital duplicates from scanned polyether or vinyl polyether silicone impressions.

3. Clinical Implication:

The results will contribute to the scientific evidence about the accuracy of digitally generated dental models when directly scanning dental impressions of different materials, or scanning their stone casts, using an extra-oral laser scanner.

4. Methods and Materials:

This is a laboratory study that included taking silicone rubber impressions from an epoxy reference model. This model was created from an original Typodont (ModuPRO Pros, Acadental Inc, Overland Park, KS).

Teeth number 28 and 30 on the typodont with a missing tooth #29 were prepared for a metal-ceramic three-unit fixed dental prosthesis with tooth #29 being a pontic. After preparation, an epoxy resin reference model was fabricated by duplicating the typodont quadrant that includes the tooth preparations. From this reference model 12 polyvinyl siloxane impressions, 12 polyether impressions and 12 vinyl polyether silicone impressions were made. All impressions were then scanned before pouring them with dental stone. The dental stone casts were, in turn, scanned to produce digital models. A reference digital model was made by scanning the reference model.

This way, six test groups of digital models were produced. Three of them were made by scanning of the impressions obtained with the three different materials while the other three test groups were made by scanning of dental casts resulted from pouring of those impression materials.

Groups of digital models were compared in terms of their dimensional accuracy, which is defined as the absolute value of deviation in micrometers from the reference model. Figures 1 and 2 explain the design of the study, including the different stages of the study, the test groups' subjects, and how they were compared.

4.1. Sample Size Calculation and Sample Selection:

The statistical software nQuery (nQuery Advisor Version 7.0, Saugus, MA) was used to determine sample size. It was found that 10 models were needed per group to detect a difference with a power of 99% for both factors (scan technique and type of impression material). This calculation was based on the following mean accuracies extracted from the literature:

Group 1: Digital models resulted from PVS impressions scan: 13 ± 3 microns.

Group 2: Digital models resulted from PE impressions scan: 18 ± 3 microns.

Group 3: Digital models resulted from VPES impression scan: 24 ± 2 microns.

Group 4: Digital models resulted from scanning of stone casts poured from PVS impressions: 24 ± 2 microns.

Group 5: Digital models resulted from scanning of stone casts poured from PE impressions: 25 ± 6 microns.

Group 6: Digital models resulted from scanning of stone casts poured from VPES impressions: 25 ± 4 microns.

The measurement of interest for each group (outcome) is the dimensional deviation from the reference model (Dimensional Accuracy), and it is measured in micrometers. To increase power, the number of models was increased to 12 per group. The total number of digital models was 72.

Inclusion and Exclusion Criteria:

Only models which are qualified as acceptable were included in the study. Models with a rough surface, air bubbles, surface defects, fracture or any other defects were excluded from the study samples.

4.2. Tooth Preparation:

The preparation was started with tooth number 30 on the typodont, followed by tooth number 28, the two teeth were prepared according to the guidelines described by Rosental et. al.[27] as following:

The round-tipped rotary diamond fine grit (#.014, Premiere corp., Plymouth Meeting, PA**)** was used to create three depth grooves, one in the center of the facial surface, and one each in the approximate locations of the mesiobuccal and distobuccal line angles, then the same depth grooves were established in the lingual surface. These grooves were created in two planes; the cervical portion and the occlusal portion, the occlusal portion of buccal reduction extended half-way down the buccal surface. After that; another three depth grooves were placed on the occlusal surface using the same diamond with a different size (# .016, Premiere corp., Plymouth Meeting, PA). Then, the occlusal reduction was done with the use of a large size Round-tipped rotary diamond (# .016) allowing for a clearance of

1.8-2 mm. Since the tooth is in the mandibular arch, the buccal cusps undergone functional cusp beveling using the same diamond.

After preparing the occlusal surface, the buccal reduction was performed next using a round-ended tapered diamond (# .014) to remove the remaining tooth structure between depth grooves creating a deep chamfer at the cervical margin, which is 0.5 mm coronal to the gingival margin, and extended to the proximal embrasures, water and air spray was used to enhance visibility.

The next step was to prepare the axial proximal and lingual walls respectively, using the same tapered diamond to provide a distinct smooth deep chamfer of about 1.0 mm width, however, this finish line was increased to 1.5 mm.

The proximo-axial and lingo-axial surfaces were reduced with the round-ended tapered rotary diamond (.014) held parallel to the intended path of withdrawal of the restoration. These walls converse slightly from the cervical to the occlusal area, with a total taper of approximately 21 degrees.

The final step was to finish all the prepared surfaces, starting with a fine-grit round tipped rotary diamond (# .014), then the finishing stones (HSS299 - #299 Arkansas Conical) was used, all at a lower speed of the hand piece (Midwest Dentsply, Des Plaines, IL) to remove all surface irregularities and leave a smooth surface.

After finishing the preparation of tooth number 30, the other abutment tooth (number 28) was prepared, following the same steps and guidelines described above. Now the teeth on the typodont were ready for the duplication process, to produce an Epoxy resin reference model (Fig. 3).

4.3. Typodont Duplication:

I. Impression:

Following tooth preparation, the typodont model was duplicated as follows:

After removing the typodont model, a rigid plastic stock perforated right mandibular quadrant tray of a suitable size was selected (#8 UL/LR, Posterior Quadrant Tray, Discus Dental, Los Angeles, CA) so that the minimum thickness of impression material was 2-3 mm. The tray was then brushed with a thin layer of tray adhesive (Dentsply Caulk Tray Adhesive; Midwest Dentsply, Des Plaines, IL) following manufacturer's directions. After mixing the putty impression material (Exaflex Putty, GC America, Alsip, IL) with a base to catalyst ratio of 1:1, it was loaded into the tray as one piece without layering the material. One polyethylene sheet was then used to cover the putty surface before taking the impression to create a uniform space for the light body wash. The tray was seated onto the typodont vertically and the putty left to set undisturbed for 4 minutes from the start of mixing. Polyethylene sheet peeled off.

Light body silicon rubber impression material (Examix NDS light Body, GC America, Alsip, IL) was then dispensed over the putty as well as the teeth in the typodont model using an auto mixing syringe (3M ESPE; Seefeld, Germany), and the typodont model seated into the filled tray. The light body wash was then let to set undisturbed for 5 minutes.[28-31,33] After that the model was removed by pulling it off from the impression tray slowly to break the seal. The impression was thenwashed, air-dried and prepared for pouring with epoxy resin model and die material (Fig.4).

II. Fabrication of Reference Model:

The next step was to fabricate the reference model. For this purpose, the obtained impression of the typodont model was poured with epoxy resin model and die material. Epoxy resin base/activator with a ratio of 10 g of base to 1 g of catalyst was mixed according to manufacturer’s instructions (EP 85-215, Eager Polymers, Chicago, IL). Mixing was performed at room temperature. The material was mixed by hand with a metal stainless steel spatula for 1 minute, after which the tray was loaded manually using the spatula. The working time is about 6 minutes. The filled impression was placed in an electric centrifuge, counterbalanced, and centrifuged for 5 minutes to eliminate bubbles as described by Paquette et al.[34] The poured impression was stored at room temperature (22°C) for 24 hours.

The set epoxy resin model was used as the reference model (standard) for comparing all measurements made on the digital models produced by different techniques (Fig.5).

4.4. Polyvinyl Siloxane Impressions from the Epoxy Reference Model:

Twelve polyvinyl siloxane right mandibular quadrant impressions (Fig. 6) were obtained from the reference model using the two-step putty wash technique in the following manner:

A suitable plastic stock perforated quadrant tray was selected (#8 UL/LR, Posterior Quadrant Tray, Discus Dental, Los Angeles, CA) so that to be rigid and allow at least 2-3 mm thickness of impression material. Then a thin layer of tray adhesive (Dentsply Caulk Tray Adhesive) was brushed onto the tray following the manufacturer's directions.

Air spray was used to remove any remnants or dust from the reference model surface. Then, with the use of the supplied scoops, a putty base and catalyst (Exaflex Putty, GC America, Alsip, IL) was dispensed in the ratio of 1:1 on the mixing pad and kneaded with a clean hands for approximately 45 seconds, until a uniform steak-free color was achieved. An even layer of the mix was applied onto the tray, and a polyethylene sheet was used to cover the putty surface. Then the covered tray was placed onto the epoxy reference model; first vertically seated, then forth-back and side-to-side movements. The loaded tray was then removed from the model after it had reached a rubbery consistency, and left aside for 4 minutes undisturbed until fully set. The polyethylene sheet was removed after the putty fully set, then the putty impression was washed and air-dried. The light body of the silicon impression material (Examix NDS light Body, GC America, Alsip, IL) was dispensed into the putty impression using an auto-mixing device (3M ESPE DENTAL; Seefeld, Germany). The wash material was also applied around the preparation on the model. The tray was then seated on the model within one and half minute of starting dispensing the wash material and held in position without excessive pressure for 5 minutes until firmly set. The impression was then removed by pulling slowly to break the seal and then pulled off along the long axis of the teeth. This was followed by rinsing the impression under cold water and drying it with air.

The above process was repeated 12 times, and all 12 impressions were stored in resealable plastic bags at room temperature (22°C) until the digital scanning was performed.

4.5. Polyether Impressions from the Epoxy Resin Reference Model:

A rigid stock plastic perforated quadrant tray (#8 UL/LR, Posterior Quadrant Tray, Discus Dental, Los Angeles, CA) was painted with a thin layer of tray adhesive (DENTSPLY Caulk PE Tray Adhesive). Polyether impression material (Impregum Penta Soft, 3M ESPE, Minneapolis, MN) was mixed in a monophase technique using the Pentamix mixing unit (3M ESPE, Minneapolis, MN). Impression tray and Penta Elastomer Syringe (3M ESPE, Minneapolis, MN) were loaded with material from the same mix. After applying syringe material to the prepared teeth, the loaded tray was placed onto the reference model. The material was allowed to set for 7 minutes and then removed as described above. Twelve PE right mandibular quadrant impressions (Fig. 7) were taken from the reference model to be scanned later.

4.6. Vinyl Polyether Silicone Impressions from the Epoxy Resin Reference Model:

Vinyl Polyether Silicone (VPES) is a combination of polyether and polyvinyl siloxane materials. This material was used through a double mix dual-phase putty wash technique as follows:

A rigid plastic stock perforated quadrant tray (#8 UL/LR, Posterior Quadrant Tray, Discus Dental, Los Angeles, CA) was painted with a thin layer of tray adhesive (DENTSPLY Caulk Tray Adhesive) which was left to dry.

Air spray was used to remove any remnants or dust from the reference model surface. Then, with the use of the supplied scoops, a putty base and catalyst (EXA'lence Putty, GC America, Alsip, IL) was dispensed in the ratio of 1:1 on the mixing pad and kneaded with a clean hands for approximately 45 seconds, until a uniform steak-free color was achieved. An even layer of the mix was applied onto the tray, and a polyethylene sheet was used to cover the putty surface. Then the covered tray was placed onto the epoxy reference model; first vertically seated, then forth-back and side-to-side movements. The loaded tray was then removed from the model after it had reached a rubbery consistency, and left aside for 4 minutes undisturbed until fully set. The polyethylene sheet was removed after the putty fully set, then the putty impression was washed and air-dried. The light body of the silicon impression material (EXA'lence Light Body Regular Set, GC America, Alsip, IL) was dispensed into the putty impression using an auto-mixing device (3M ESPE DENTAL; Seefeld, Germany). The wash material was also applied around the preparation on the model. The tray was then seated on the model within one and half minute of starting dispensing the wash material and held in position without excessive pressure for 5 minutes until firmly set. The impression was then removed by pulling slowly to break the seal and then pulled off along the long axis of the teeth. This was followed by rinsing the impression under cold water and drying it with air.

Twelve VPES right mandibular quadrant impressions (Fig.8) were taken from the reference model to be scanned later.

4.7. Digital Scanning and Virtual Model Production:

The polyvinyl siloxane impressions, polyether impressions, and vinyl polyether silicone impressions as well as the epoxy reference model were digitally scanned to produce virtual models (Fig. 9). This was carried out with the use of a laser scanner (D-700, 3Shape A/S, Copenhagen, K Denmark). The 12 impressions within each group were digitized in the laser scanner to generate point-clouds. The laser scanner uses an optical scanning system, in which laser planes are projected onto the object. Two high-resolution digital cameras acquire images of the lines created on the object. The software automatically processes the images and calculates, by the triangulation technique, a point-cloud as a three-dimensional model. The accuracy is stated by the manufacturer to be less than 20 μm. Each impression was attached in a tray holder and placed on a rotation plate (360-degree rotation). The plate with the impression attached was moved along a linear axis (translation) and a secondary rotation (tilt) was performed, to ensure maximum exposure of the preparation. Each impression was digitized with an overview digitization. Thereafter, each preparation was marked individually, and a detailed scan was performed.

All the 36 impression were scanned, to produce digital models (STL files) that were divided into groups 1, 2 and 3 based on the type of impression material.

Next, the epoxy resin reference model was scanned to produce a virtual reference model by the same technique used for the impressions.

4.8. Production of Dental Stone Casts:

The three types of dental impressions (PVS, PE and VPES) were poured with dental stone to yield the dental stone replicas, as follows:

One hundred and forty grams of type IV die stone (Resin Rock Ivory, Whip Mix Corp, Louisville, KY) was weighted and 28 ml of water was measured. The die stone was added to the distilled water in a clean rubber mixing bowl. The mix was allowed to soak and then hand spatulated for 10 seconds with a round-ended steel spatula before putting it into a mechanical vacuum spatulator (Bego vacuum mixer, Lincoln, RI) for 25 seconds to obtain a creamy, bubble-free mix.

A clean spatula was used to place the mixed dental stone on the periphery of the impression. The vibration frequency of the mechanical vibrator was set at 6000 Hz before pouring the impression. With the impression held on the model vibrator in a tilted position, the mixed dental stone was carefully dispersed over the periphery of the impression to flow into its deepest portion. Additional increments of the mixed dental stone were added over the periphery of the impression until the impression became covered and the filled impression was placed in a pressure pot (Bego, Licoln, RI) at 4 bars. After the stone reached initial setting (30 minutes from start of mix), a base was added to the stone cast, and the stone was allowed to set for at least 10 hours without disturbance.

All 36 impressions were poured in the same manner and allowed to set to produce a total of 36 dental stone casts. Those casts were scanned with the same dental scanner used earlier (D700, 3Shape A/S, Copenhagen, Denmark) to produce digital models (STL files) that were divided into groups 4, 5 and 6 based on the type of impression material from which the stone cast was produced (Figs. 10 & 11).

This way, 72 digital models were produced, 36 by impression scanning and the other 36 by stone cast scanning (Fig. 12).

4.9. Digital Model Superimposition and Comparative Analysis:

The deviation of digital models produced by scanning impressions and stone casts from the reference model was calculated with a matching software (Convince Premium 2011, 3Shape A/S, Copenhagen, k Denmark), in which the digital models were first aligned to the reference digital model and then overlapped. Deviation of the replica's deviation from the reference was calculated at a number of point clouds, and the replica' root mean square (RMS) of deviation from the reference was set as the accuracy parameter. Mathematically, the RMS is the square root of the mean of the squared deviations; a lower number indicates greater accuracy. (Figs. 13-15).

4.10. Statistical Analysis:

Descriptive statistics of the study groups were calculated, including means and standard deviations. A two-way analysis of analysis of variance (ANOVA) was then applied to assess whether differences in accuracy were statistically significant for each factor (impression material and technique). P-values less than .05 were considered statistically significant. Post-hoc Tukey's Honestly Significant Difference (HSD) tests were also performed to compare each pair of materials following a significant result from the two-way ANOVA.

Accuracy was quantified by the value of the root mean square (RMS) of the replica's deviation from the reference model. The higher the RMS, the lower the accuracy. Mathematically, root Mean Square (RMS) of a set of values is the square root of the mean of the squares of the original values.

5. Results:

For the 72 digital models, the mean (± SD) RMS of deviation from the reference model was 26.78 ± 7.85 microns. For the six groups, the mean (± SD) RMS was 29.42 ± 5.80 microns for digital models produced by PE impressions scan, 27.58 ± 5.85 microns for digital models produced by PVS impressions scan, 24.08 ± 4.89 microns for digital models produced by vinyl polyether silicone VPES impressions scan, 26.08 ± 6.58 microns for digital models produced by scanning stone casts poured from PE, 31.67 ± 9.95 microns for digital models produced by scanning stone casts poured from PVS and 22.58 ± 2.84 microns for digital models produced by scanning stone casts poured from VPES (Fig.16).

In the two-way ANOVA, the p-value for the material factor was 0.004, reflecting a statistically significant difference between the accuracy of the three impression materials, with VPES exhibiting the highest accuracy (mean RMS = 23.33 ± 3.99 microns) followed by PE (mean RMS = 27.75 ± 6.3 microns) then PVS (mean RMS = 29.63 ± 8.25 microns). For the technique factor the p-value was 0.870

reflecting a non-significant difference between the accuracy of the two techniques (impression scan and stone cast scan) with mean RMS values of 27.03 ± 5.82 microns and 26.78 ± 7.85 microns, respectively.

As a result, post-hoc tests were performed for the material factor to determine which differences were statistically significant. A significant difference was found between the accuracy of VPES and PVS (p-value = 0.004) with VPES having greater accuracy (lower mean RMS). No significant difference was found between the accuracies of PE and PVS (p-value = 0.576), or between the accuracies of PE and VPES (p-value = 0.054). (Fig. 17&18)

6. Discussion:

The current body of literature indicates that digital dentistry is promising.[3,5,8,19] Based on data provided by Dalstra M et al. (2009)[44], the models produced by digital scanning are more accurate than their conventional counterparts produced via dental stone. On the other hand, Persson et al. (2006) found that impression scans of a single tooth preparation were as accurate as cast scans of the same preparations.[5] The purpose of our study was to compare impression scans and cast scans of a fixed partial prosthesis (FPP) situation.

The stage at which extraoral digital scanners should be used in the digital fabrication workflow is still contradictory. While DeLong et al. (2003)[17] stated that scanning of a conventional impression leads to a more accurate result, Persson et al. (2006) found no difference between using the scanner to either scan impression or to scan a reference model.[5,15,16] The findings of our study are consistent with those of Persson and coworkers. This would mean that similar to single tooth preparations, the scanning of impressions for a 3-unit fixed dental prosthesis is as accurate as the scanning of the respective cast. Moreover, this study was carried out using three impression materials, polyvinyl siloxane (PVS), poly-ether (PE) and vinyl polyether silicon (VPES), therefore providing evidence on which impression material would give the most accurate digital model upon

scanning. PE and PVS are used widely as final impression materials in FBD constructions.[51] VPES is claimed by the manufacturer to have the advantages of both PVS and PE, namely the dimensional accuracy of PVS and the hydrophilicity of PE, no data are available on those two properties of VPES.

Polyether impressions were taken using the mono-phase technique, while polyvinyl siloxane impressions were taken using the two-step putty wash technique. These two techniques were reported in the literature as being the most accurate impression techniques for these two materials.[30,31,33,46] No studies were found in the literature about the most accurate technique for taking vinyl polyether silicone impressions.

An interesting finding of this study is that the type of impression material to be scanned has a significant effect on the accuracy of digital model produced by that scan, with VPES impression scan models having the highest accuracy. Nevertheless, it should be stressed that with the post hoc tests, the significant difference was found to be only between VPES and PVS, whereas no significant differences were found between PVS and PE and between PE and VPES.

The difference in the accuracy between the digital models produced by scanning the three different impression materials could be inherited from the difference in the materials, or it could otherwise be due to the difference in the ‘scannability’

and optical properties of each impression material and the ability to capture accurate digital models. Comparisons between the accuracies of conventional PVS and PE impressions have been controversial. While PE was reported to be more accurate by Habib et al. (1995)[47], Hossanie at al., (2012)[48] found that PVS was more accurate. However, no difference in accuracy between the two materials was found in experiments by Faria et al. (2008).[49]

The reference model was fabricated of dental epoxy resin because of its reported excellent hardness and strength properties.[34,45]

Root mean square (RMS) of the replicas’ deviation from the digital reference model was used as a parameter to calculate the accuracy, this was to ensure the absolute values of the differences between test models and the reference models were measured as stated by the definition of dimensional accuracy.

A limitation of this study lies in the fact that it is an in vitro study, which means that the conditions were close to ideal in terms of making optimal tooth preparations and accurate impressions. In clinical conditions, the presence of saliva, blood, or ginigival fluid as well as higher temperatures will most likely affect the accuracy negatively.[17]

Future clinical studies are necessary to confirm the results obtained from this laboratory study.

7. Conclusions:

Within the limitations of this *in vitro* study, it can be concluded that:

1. There is no statistically significant difference in dimensional accuracy between digital models produced by scanning dental impressions and those produced by scanning stone casts.

2. Digital models produced from the scans of VPES impressions are dimensionally more accurate than those produced from PVS impressions scans. No significant difference in accuracy was observed between PE and PVS impression scans, or between PE and VPES impression scans.

Figure 1: Study Design; Six Test Groups of Digital Models Were Produced

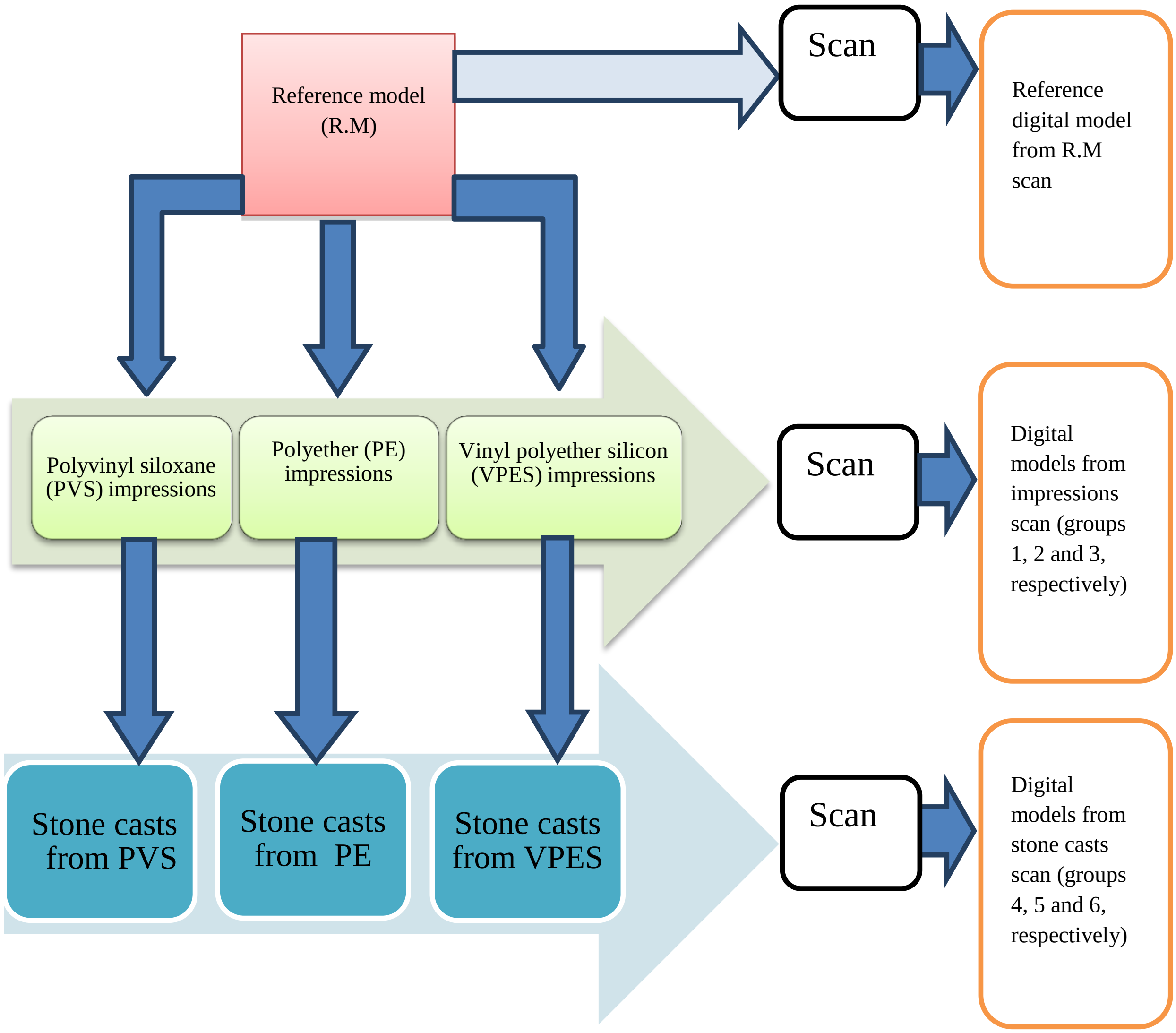


Figure 2: Stages of the Study

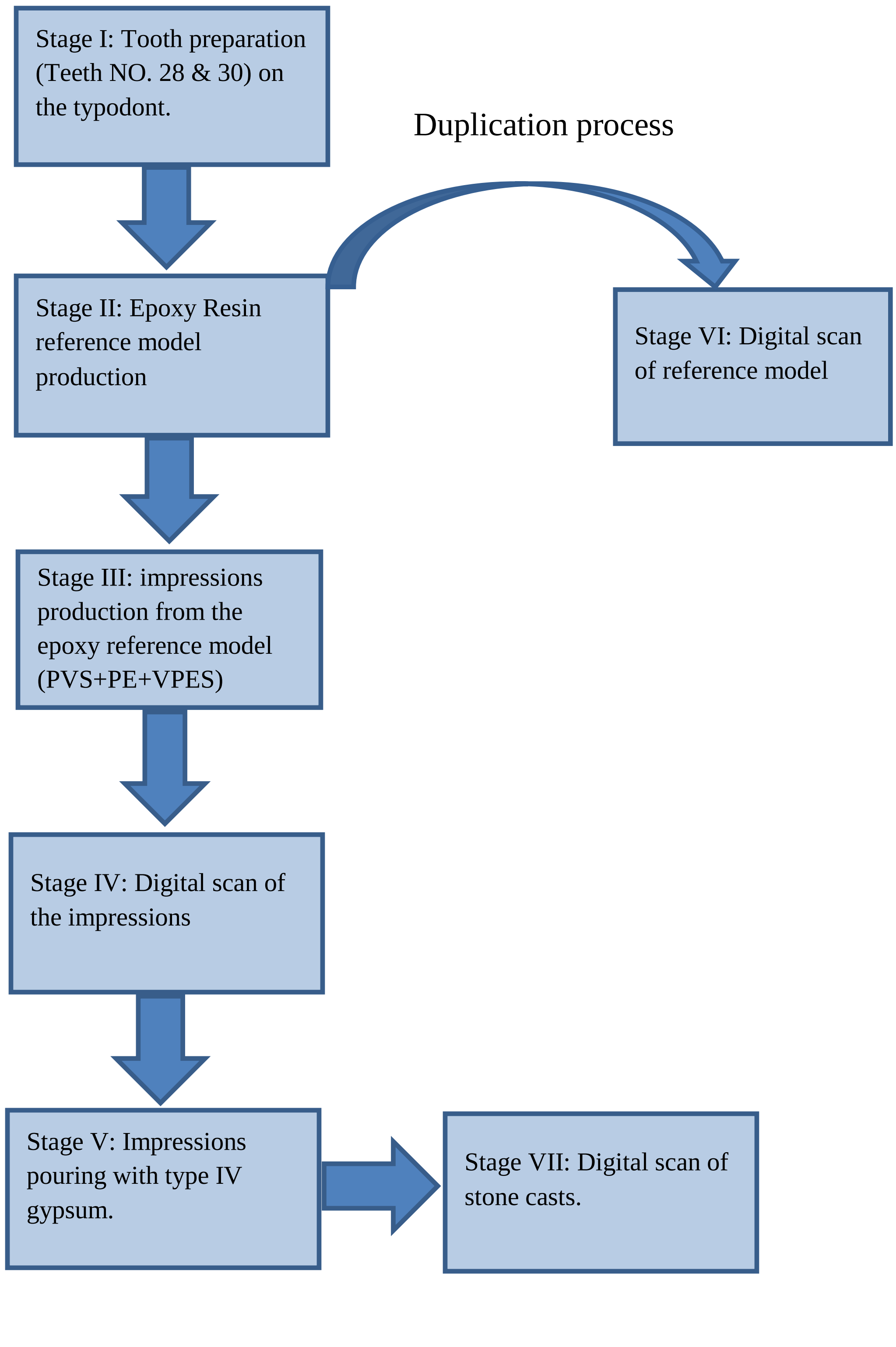


Figure 3: Typodont with Teeth NO. 28 and 30 Prepared for a Three Unit Bridge.

Figure 4: PVS Impression of the Typodont Using Two Step Putty Wash Technique.

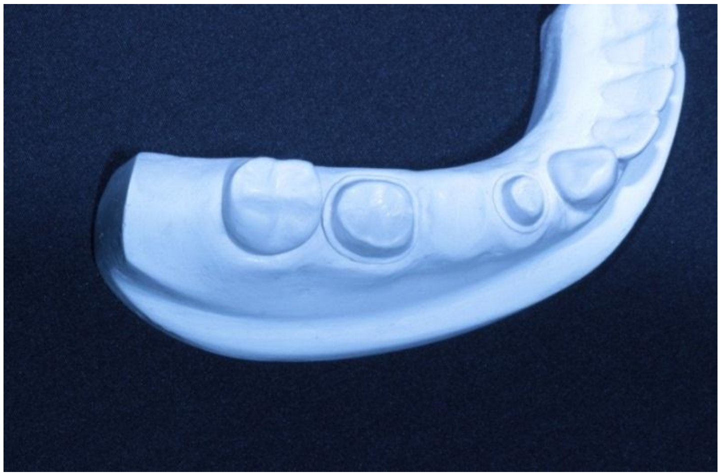


Figure 5: Epoxy Resin Reference Model.

Figure 6: PVS Impression from the Reference Model.

Figure 7: Polyether Impressions from the Reference Model (Mono-Phase Technique).

Figure 8: Vinyl Polyether Silicon Impression from the reference model (Two-Step Putty Wash Technique).

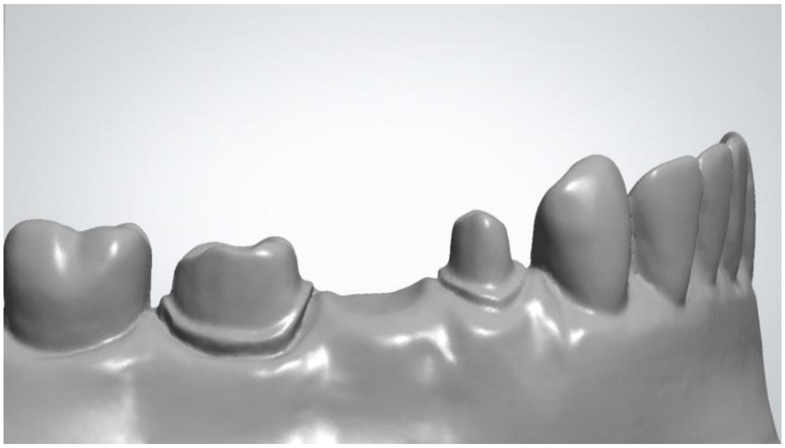


Figure 9: Digital Model Produced by Impression Scan.

Figure 10: Stone Cast Produced by Pouring the Impression with Type IV Gypsum.

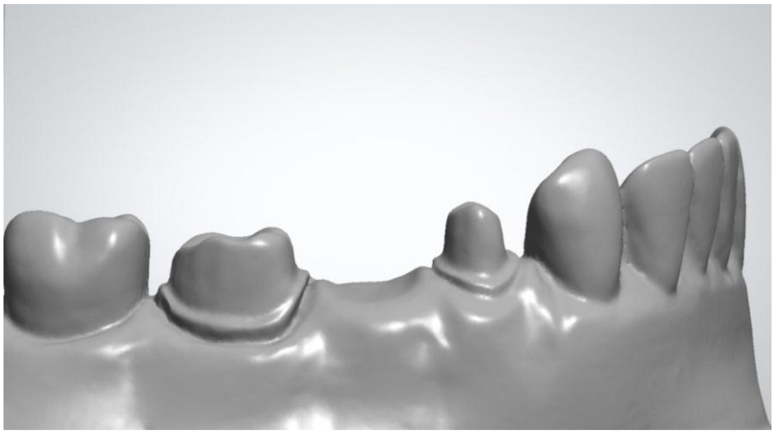


Figure 11: Digital Model Produced by Scanning Stone Casts.

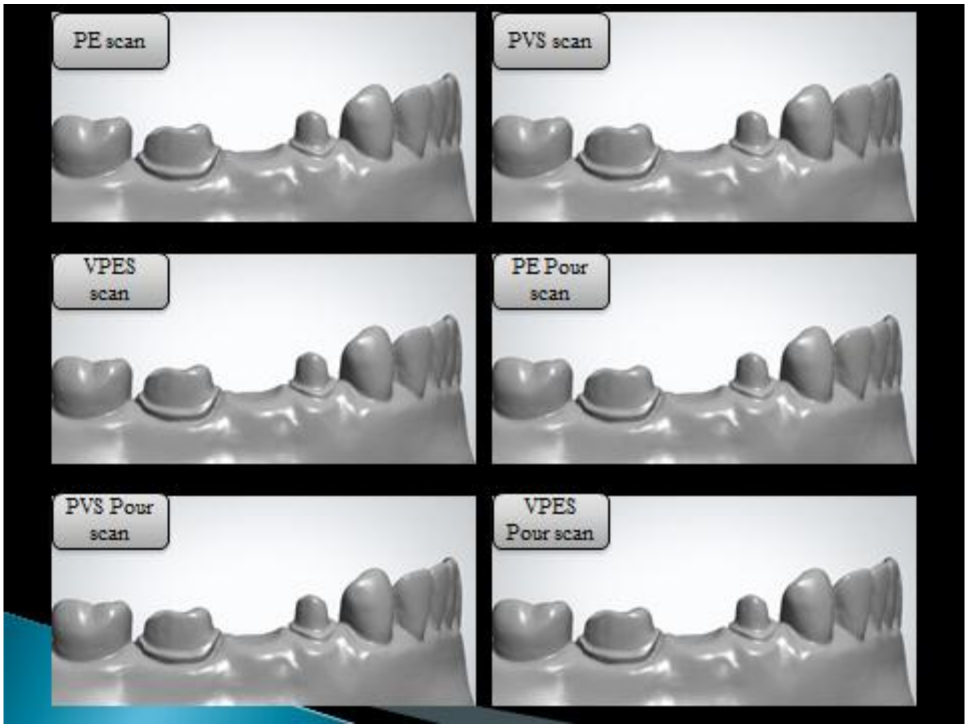


Figure 12: Six Groups of Digital Models Were Produced, three by Scanning Impressions and Three by Scanning Stone Casts.

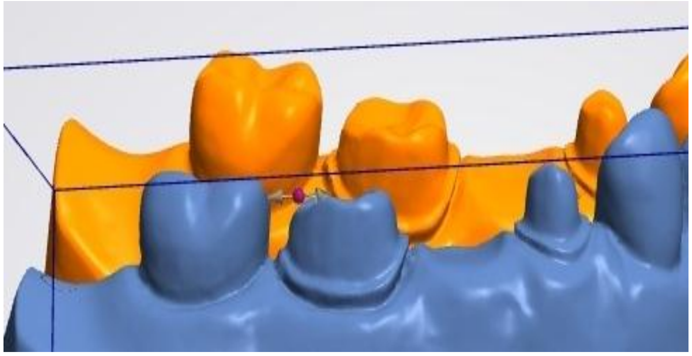


Figure 13: Digital Replicas Aligned to the Reference.

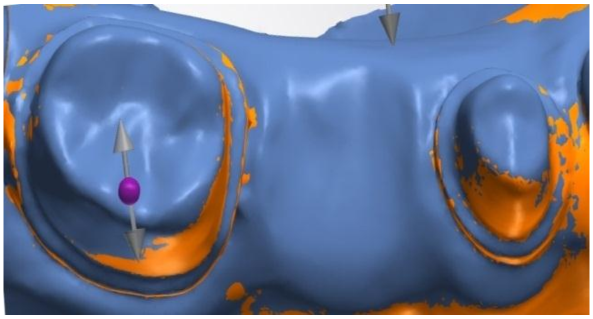


Figure 14: Digital Models Overlapped with the Reference Model.

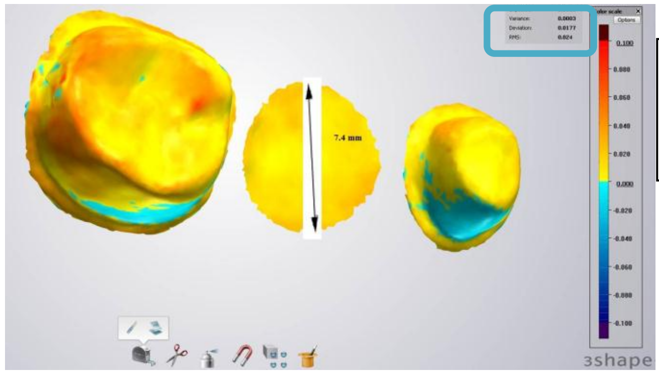
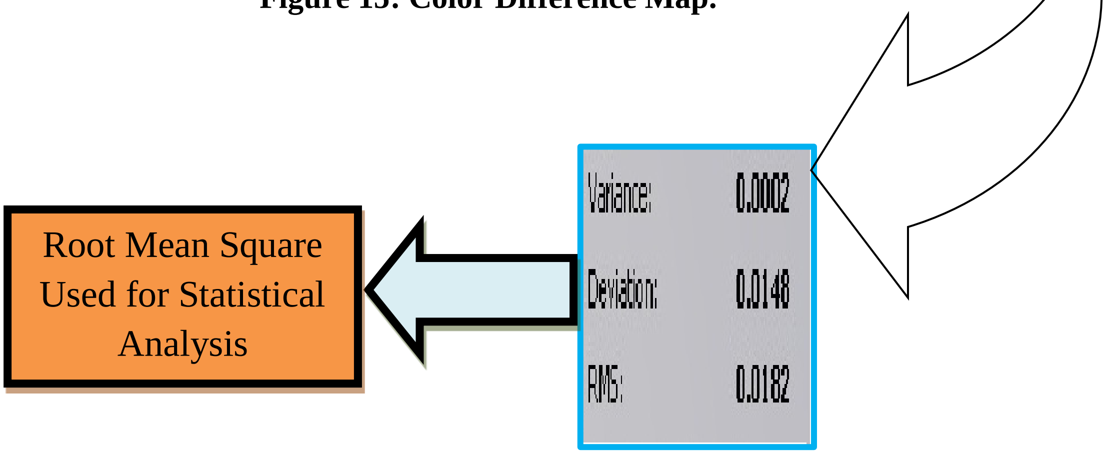


Figure 15: Color Difference Map.



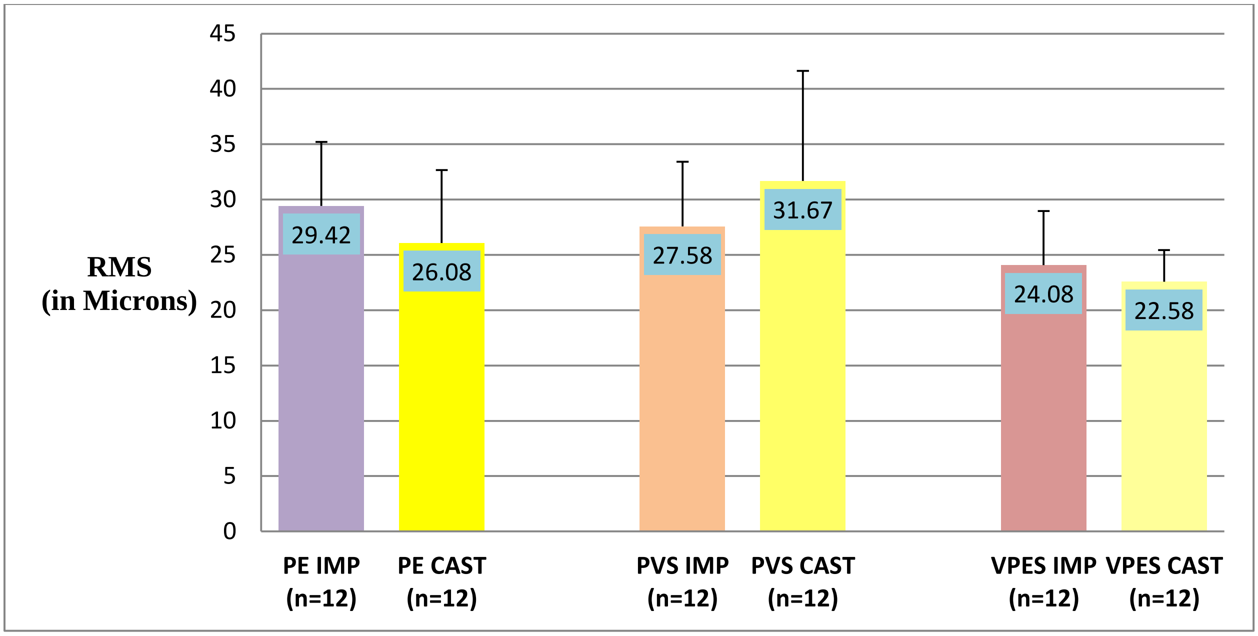


Figure 16: Comparison of Average Deviations from the Reference Model.

RMS: root mean square of the replica's deviation from the reference model.

Digital models produced via PE impressions scan

Digital models produced PVS impressions scan

Digital models produced via VPES impressions scan

Digital models produced via scanning stone casts poured from PE impressions

Digital models produced via scanning stone casts poured from PVS impressions

Digital models produced via scanning stone casts poured from VPES impressions

Mean RMS

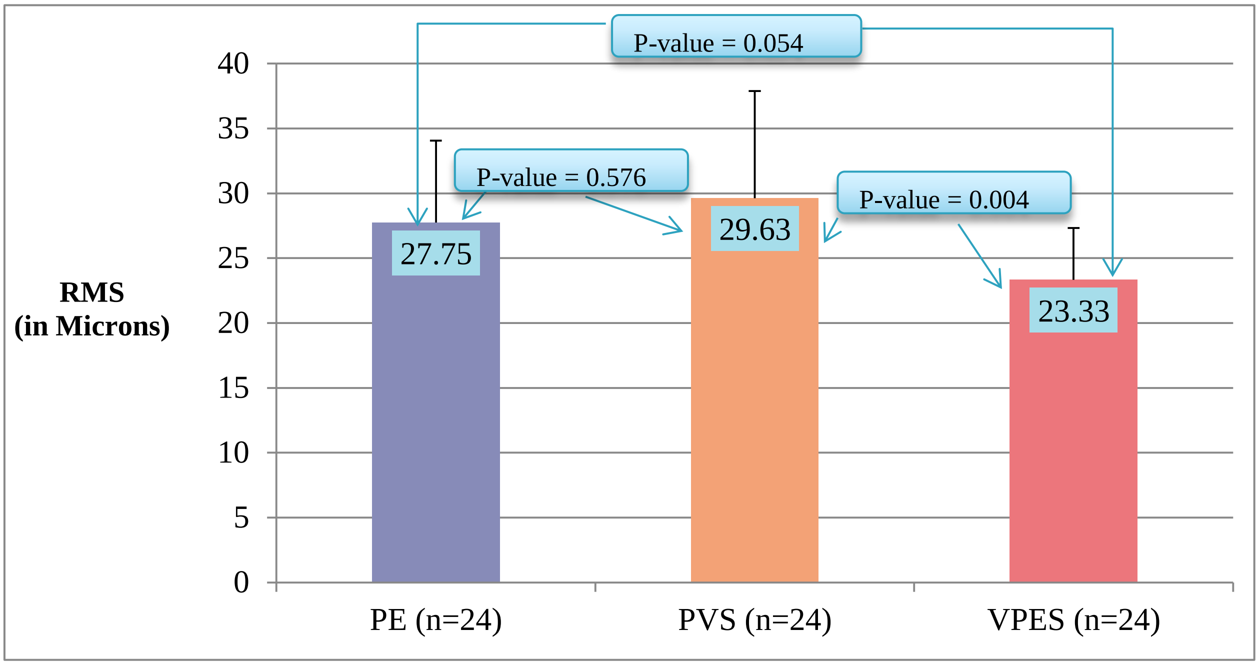


Figure 17: Comparison of Average Deviation by Material.

(a statistically significant difference was found between VPES and PVS, no significant differences were found in other two comparisons)

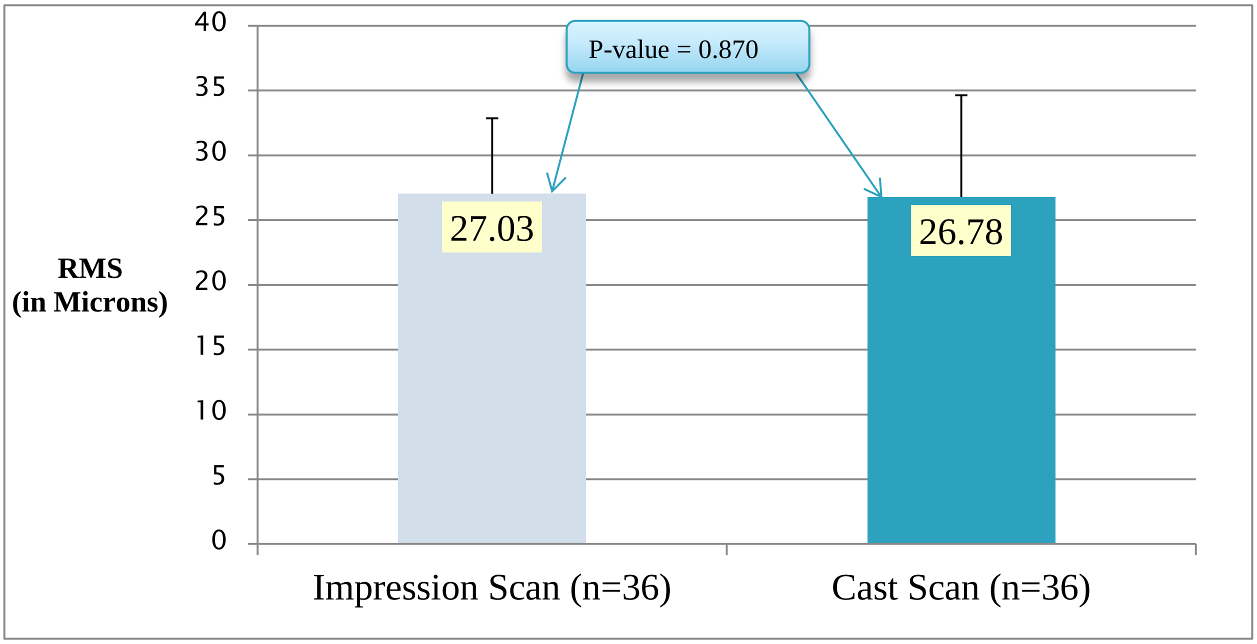


Figure 18: Comparison of Average Deviation by Technique.

(no statistically significant difference was found between impression scan and stone cast scan)

Table 1: Instruments used in the study

Instrument	Specification
Typodont	ModuPRO Pros, Acadental Inc, Overland Park, KS
Round-tipped rotary diamonds	Coarse # 747.6, and Coarse # 782.10, Fine # 782.8, Premiere corp., Plymouth Meeting, PA
Flat-ended tapered diamonds	Coarse (# 723.6), Fine (# 514.4), Premiere corp., Plymouth Meeting, PA
Finishing stones	#299 Arkansas Conical, HU-Friedy, Chicago, Illinois
High speed hand piece	Midwest Dentsply, Des Plaines, IL
low-speed hand piece	Midwest Dentsply, Des Plaines, IL
Plastic stock perforated quadrant trays	#8 UL/LR, Posterior Quadrant Tray, Discus Dental, Los Angeles, CA
Auto mixing devices	3M ESPE, Seefeld, Germany, GC America, USA and Pentamix Mixing Unit
Laser scanner (3Shape D800 scanner)	D-700, 3Shape A/S, Copenhagen, Denmark
Mechanical vacuum spatulator	Vacuum mixer, Bego, RI
Digital caliper	Dentagauge1, Erskine Dental, Marina Del Rey, CA

Table 2: Materials used in the study

Material	Specification
Impression tray adhesive	DENTSPLY Caulk tray adhesive, Midwest DENTSPLY, Des Plaines, IL
Polyvinyl siloxane putty impression material	Exaflex NDS putty, GC America, Alsip, IL
Polyvinyl siloxane light body impression material	Examix NDS light body, GC America, Alsip, IL
Vinyl polyether silicone putty impression material	EXA'lence putty, GC America, IL
Vinyl polyether silicone light body impression material	EXA'lence light body, regular set, GC America, Alsip, IL
Polyether impression material	Impregum Penta Soft medium body, 3M ESPE, St. Paul; MN
Epoxy resin model and die material	EP 85-215, Eager Polymers, Chicago, IL
Surfactant solution	DeLar Debubblizer, DeLar Corporation, lake Oswego, OR
Type IV gypsum (Die stone)	Resin Rock Ivory, Whip Mix Corp, Louisville, KY

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