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Comparative In Vitro Study on the Accuracy of Digital versus
Conventional Full Arch Implant Impressions

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ABSTRACT

Aim & Hypothesis: An accurate implant impression is integral for generating an accurate master cast, which is necessary for the fabrication of an accurately-fitting prosthesis. The aim of this study was to compare two different intra-oral scanners (CEREC Omnicam and 3M True Definition) with each other and with conventional implant impressions in terms of accuracy for a completely edentulous mandibular cast. The hypothesis was that the splinted open tray impressions would be more accurate than digital impressions in cases of complete edentulism.

Materials & Methods: A PMMA model representing an edentulous mandible was fabricated using five internal connection implant analogs (Straumann Bone Level RC, Basel, Switzerland). The 3 median implants were parallel to each other, the far left implant had 10 degrees distal angulation and the far right had 15 degrees distal angulation. An impression was taken using polyether to produce a stone master cast to serve as control. Digital impressions (n=10) were taken with two intraoral optical scanners (CEREC Omnicam and 3M True Definition) after connecting polymer scan bodies to the master cast. A splinted open-tray technique was used for the conventional polyether impressions of the master cast (n=10). Master cast and conventional impression casts were digitized with an extra-oral high resolution scanner (Activity 880 scanner; Smart Optics, Bochum, Germany) to obtain digital files. Standard tessellation language (STL) datasets from the three groups of digital and conventional impressions were superimposed with the STL dataset from the master cast to assess the 3-D deviations. Deviations were recorded as root mean square error. To compare the master cast with conventional and digital impressions at the implant-level, Welch's F test was used together with Games-Howell post-hoc test.

Results: Group I (conventional impression technique - splinted open tray impression) had a mean value of 167.93 μm (SD 50.37); Group II (OmniCam Digital Impression technique) had a mean value of 46.41 μm (SD 7.34); Group III (True Definition Digital Impression Technique) had a mean value of 19.32 μm (SD 2.77). The Kolmogorov-Smirnov test showed no evidence of non-normality. Levene's test showed lack of homogeneity of variances; hence, Welch's F test was used together with the Games-Howell test for post-hoc comparisons. Welch's F test showed a significant difference between the groups ($p < 0.001$). The Games - Howell Test showed statistically significant differences between all three groups ($p < 0.001$).

Conclusion: Within the limitations of this in vitro study, full arch digital implant impressions using True Definition scanner and Omnicam were significantly more accurate than the conventional impressions with the splinted open-tray technique. Additionally, the digital impressions with the True Definition scanner had significantly less 3-D deviations when compared with the Omnicam.

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Comparative In Vitro Study on the Accuracy of Digital versus
Conventional Full Arch Implant Impressions

Introduction

The number of completely edentulous patients seeking fixed prosthodontic rehabilitation with implants is progressively rising. The introduction of guided surgery and computer-assisted designing/computer-assisted machining (CAD/CAM) technology in implant prosthodontics has improved the workflow by making many of the treatment steps easier [1,2].

It is generally accepted that optimal fit of an implant fixed complete dental prosthesis (IFCDP) is beneficial for its long-term success. Thus, construction of an accurately fitting restoration is of significant importance [3]. Although achieving absolute passive fit of the IFCDP framework is stated to be nearly impossible and it is yet to be established what degree of prosthesis misfit will lead to biologic or technical complications, clinicians are obligated to aim for the best possible clinical fit of the implant framework [3,4].

The accuracy of the implant master cast affects the passive fit of the IFCDP; and the accuracy of the impression technique primarily affects the accuracy of the implant master cast [3,4]. An accurate implant impression is an integral pre-requisite for obtaining an accurate master cast and an accurate master cast is the key for fabricating an accurately fitting prosthesis [4,5].

There are various implant impression techniques that have been utilized to fabricate a definitive cast that will result in the production of an accurately fitting IFCDP [4]. A recent systematic review on the accuracy of implant impression techniques reported that splinting of the impression copings prior to impression-making produces a more accurate definitive cast than

non-splinting for both partially and completely edentulous patients [5]. Moreover, it has been stated that there is no difference in accuracy between open-tray and closed-tray impressions for partially edentulous patients; however, open-tray impressions were found to be more accurate than closed-tray impressions for patients with complete edentulism [5]. As of then, no data were available for the accuracy of digital implant impressions.

Only a few case reports looked into the use of full-arch digital implant impressions. Digital impression procedures have been recently introduced in fixed and implant prosthodontics, as by their nature, these procedures may eliminate the error-prone conventional impressions and stone models [5]. Digital impressions using an intra-oral optical scanner (IOS) eliminate the errors associated with tray selection, dispensing and polymerization of impression materials, disinfection and sending the impression to the laboratory, while maintaining patient comfort. The digital impressions are sent and stored electronically, improving efficiency [5].

Currently, the most popular video-acquisition IOS systems are the TRIOS (3shape), the Omnicam (CEREC by Sirona) and the True Definition scanner (3M ESPE). In regards to completely edentulous patients, only one study exists [6] on the accuracy of digital implant impressions using TRIOS. There are no data on the accuracy of digital implant impressions made with the Omnicam and True Definition scanners.

Therefore, a study analyzing the accuracy of digital impressions using IOS such as the CEREC Omnicam and the 3M True Definition scanner and comparing it to conventional impressions for a completely edentulous scenario would contribute to the validation of this technology.

Literature Review

1. Passive Fit

Passive fit is claimed to be one of the most important requirement for maintaining the bone-implant interface. In the absence of an external load, the framework of an implant superstructure should induce absolutely no strain on the supporting implant components and the surrounding bone [7].

In 1983, Brånemark was the first to define passive fit and he reported that it should exist at the 10 μm level to promote bone maturation and remodeling in response to occlusal forces [8]. Jemt suggested that at up to 150 μm , an acceptable level of framework misfit occurred, which is clinically equivalent to up to half-a-turn necessary to completely tighten the gold occlusal screw after the initial seating resistance [9]. In 1996, Jemt and Book stated that a range from 91 to 111 μm for one-piece abutment-level IFCDPs is adequate [10]. Although the precedent numbers have been reported and iterated in the literature, they were of empirical origin [11].

In 2012, Papaspyridakos et al. reported that for one-piece implant-level IFCDPs the maximum discrepancy resulting in acceptable clinical fit ranged from 59 to 72 μm [12]. However, there is no consensus regarding what is an acceptable three-dimensional misfit. According to the current

scientific data, it has been deduced that absolute passive fit cannot be achieved despite the competence of present-day dental technology used for framework fabrication [7].

2. Evaluating Implant Framework Fit

Despite the fact that absolute passive fit may not be achievable, a certain degree of misfit could be accepted if this misfit has no deleterious effect on the implant/ prosthesis complex [13]. There are various techniques that have been suggested for clinical assessment of framework fit. Every procedure has pros and cons; therefore, clinicians should aspire to use a combination of several methods rather than adopt a single technique [13]. According to Kan et al, the accuracy and validity of clinical evaluation of a framework fit can be influenced by several factors, such as implant number and location, rigidity of the framework, ability of the screw to close the gap at the implant-framework interface, location of the interface which depends on depth of the implant, operator's eyesight, lighting and magnification and level of operator experience [11].

An immediate method for primary macroscopic evaluation of implant framework fit was suggested by Henry by seating the prosthesis and applying finger pressure alternatively on one terminal abutment, then the other. This alternate pressure helps disclose any fulcrums that may be apparent [11,13,14]. This method can be further enhanced by observing salivary movement at the framework-abutment junction [15].

However, this method is highly subjective and it can be difficult to interpret for short-span multi-

ple implant prostheses or where sub gingival margins are present [11]. Other methods include visual inspection and tactile sensation via a dental explorer. This technique is markedly dependent on margin location, manual dexterity, clinician's vision and experience and the size of explorer tip. Visual and tactile inspection as a sole method does not suffice in the determination of framework misfit, especially in the presence of subgingival margins [11, 13].

Periapical radiographs play an important role in assessing fit in cases where subgingival framework margins exist. The x-ray tube should be as perpendicular as possible to the long axis of the implant-abutment junction. An angle of 5 degrees between the tube and the long axis of the implant does not significantly affect the identification of openings of 50 microns or less, and should not be exceeded. An inclination of more than 15 degrees may distort the readings and delay the detection of marginal gaps [16].

Jemt and Book suggested the single screw test (Sheffield Test) as a useful method to evaluate framework fit [9]. Tan further described this test as the tightening of one screw at one terminal abutment and observing any misfit or discrepancy at the other abutments [17]. The vertical gap on the unscrewed abutments can be assessed with the aid of visual inspection and tactile sensation when the margins are supragingival or with periapical radiographs when the margins are subgingival.

In 1991, Jemt introduced the screw-resistance test on the basis that 150 μm is an acceptable level of misfit, and it corresponds to half the distance between the threads of a gold prosthetic screw.

The protocol involves tightening of the screws one at a time, starting with the implant closest to the midline until initial resistance was achieved and diagnosing a misfit if more than half a turn is required to torque the gold screw from 10 to 15 Ncm [9].

Disclosing materials can also be used in conjunction with the screw resistance test for evaluation of framework fit. Materials such as Fit Checker, pressure-indicating paste or powdered spray can be used at the interface between the framework and the implant to indicate misfit. Disclosing materials can be used for sub gingival or supra gingival application. Certain materials of known thickness such as shim stock (8-12 μm) and unwaxed dental floss (12 μm) can also be used for verification of fit [18]. These techniques are not practical and are not routinely used. Other techniques such as three-dimensional photogrammetric systems can measure misfits up to the nearest 10 μm ; however, it is very clinically impractical due to technique sensitivity and expensive cost [19].

3. Factors Affecting Framework Fit

The cause of implant-supported framework misfit is multifactorial and can be categorized into clinical and laboratory factors [20 - 22]. Clinical factors entail implant angulation, impression techniques and materials, verification jigs and clinician's experience. Laboratory factors include master cast fabrication techniques and materials, framework design and material and technician's experience [19, 23].

The degree of misfit was also found to be greater after increasing prosthesis span, as seen in one-piece castings. The fabrication of such long span splinted castings is technique sensitive, and a certain degree of distortion (approximately 100 μm [24]) is unavoidable. It was also found that the fit of the framework becomes more critical as the number of implants increases, and the prosthesis span decreases [25].

4. Complications with Implant Framework Misfit

Ill-fitting implant frameworks may result in mechanical complications of the prostheses, implants or biologic complications of the surrounding tissues. Mechanical complications were described by several authors and may involve loosening of the prosthetic and abutment screws, bending or fracture of different components [26, 27].

It has been stated that mechanical failures can be the cause of numerous factors and that occlusal forces may be contributory to failure of mechanical components. In 1996, Rangert et al. conducted a retrospective study comprising thirty-nine patients with implant fractures who were analyzed as to probable causes. The results showed that 92% of the fractured implants were associated with peri-implant alveolar bone loss. It can be concluded that an increase in occlusal overload may have contributed to an increase in bone loss, resulting in decreased bone support for the implant and an increased susceptibility to fracture. Another assumption is that the increased overload may have caused a fatigue failure within the implant resulting in fracture by crack propagation, which in turn can cause bone resorption above the mobile or broken portion of the implant. Narrow diameter implants are more susceptible to fracture as a

result of flexural overload at a much higher rate than implants of regular or wide diameter [28].

Biologic complications may include adverse tissue reactions, pain, tenderness and marginal bone loss [11]. However, according to a clinical and radiographic study by Jemt et al [10], two groups of patients with implant-supported fixed complete dental prostheses were evaluated for one year prospectively and five years retrospectively for an association between framework misfit and marginal bone loss and the findings showed no correlation. Although none of the prostheses demonstrated a passive fit, there was no evidence of bone loss beyond the clinically acceptable range (0.2 - 0.5 mm), even after five years. It was concluded from this study that a range of prosthesis misfit exists that is well-tolerated by osseointegrated implants and allows for long-term stability [29].

It was then stated that because bone biologic reaction due to chronic loading remains unclear, as well as whether bone resorption will occur and by how much, clinicians should aim to attain a precise, passive fit of implant frameworks to minimize supplemental stresses at the implant-bone interface [30]. Another biological complication resulting from misfit is increased plaque accumulation which may affect soft and/or hard tissues surrounding the implant [31].

5. Accuracy of Impression Materials and Techniques

An accurate impression is a crucial prerequisite for obtaining a passive fit between the implant and the superstructure [32]. An in vivo study by Jemt et al. used strain gauges to evaluate abutment strain in both removable and fixed maxillary prostheses and it was found that absolute pas-

sive fit is impossible to achieve [33]. However, it is a widely established concept that prosthesis misfit should be minimized and that an accurate implant level impression is the first step in minimizing misfit [27]. The main objective of an implant level impression is to accurately transfer information regarding the three-dimensional position and orientation of the implant from the mouth to a stone cast on which the implant prosthesis is fabricated. An accurate implant impression is essential in order to produce an accurate master cast, which is the basis for the generating an accurately-fitting prosthesis.

There are many factors that will influence the accuracy of an implant level impression. These factors can result from the steps performed by the dentist or the dental technician during the fabrication of the master cast. These factors can also be related to the materials used for the impression-making process, as the procedure relies primarily on the dimensional stability of the impression material. The factors that will influence the accuracy of implant impressions can be categorized as follows:

5.1- Technique Used:

5.1.1 Stock Vs Custom Trays

5.1.2 Open Tray Vs Closed Tray

5.1.3 Splinting Vs Non-Splinting

5.2- Impression Material

5.3- Implant Number and Angulation

5.4- Other Factors

5.1. Impression Techniques

5.1.1 Stock Trays Versus Custom Trays

The main goal in the construction of an impression tray is to provide a rigid or semi-rigid tray which provides enough retention of the impression material. It was stated that custom trays contribute to a superior impression and a more accurate master cast than stock trays. This was further explained by the fact that custom trays maintain a consistent thickness of the impression material and thus have more control of the resulting volumetric changes [34].

In the study by Eames et al [34], nine elastomeric impression materials were tested using custom trays with 2, 4 and 6 mm spacer thickness. It was found that the 2mm spacer produces the most accurate impression. In another study by Burns et al, it was stated that custom tray rigidity offers another advantage over stock trays by keeping impression material distortion to a minimum [29]. Custom trays should be fabricated from materials that are rigid, dimensionally stable and that resist deformation during impression making or upon removal from the mouth. Auto-polymerizing acrylic resin has been recommended for use in custom tray fabrication due to its rigidity; however, polymerization shrinkage has led to significant changes in tray dimensions [35]. In order to overcome this, a number of authors have advocated fabrication of the custom tray at least 24 hours in advance to allow the auto-polymerizing resin to become relatively dimensionally stable [36, 37, 38].

Other materials that have been recommended for custom tray fabrication are light-polymerized resins, which have been proven to overcome the disadvantage of polymerization shrinkage.

Moreover, these materials have improved dimensional stability and reduced moisture sensitivity and can be fabricated immediately before impression-making [39]. Stock trays can be used as an alternative to custom trays, but the likelihood of producing an inaccurate impression continues to be a drawback. This is due to the fact that they are more flexible and do not maintain a constant thickness of the impression material [40].

5.1.2 Open Tray Versus Closed Tray

There are two main techniques described in the literature regarding implant impressions. The first is the closed tray technique in which tapered impression copings are screwed onto the implants. Upon removal of the impression from the oral cavity, the impression copings remain screwed onto the implants. The impression copings are then removed from the patient's mouth and manually transferred to the impression. Certain implant manufacturers such as Straumann have developed a plastic impression coping that snaps onto the implant. This technique also uses a closed tray but instead of the copings being manually transferred, they are picked up by the impression [41].

The second is the open tray impression technique in which impression copings are screwed onto the implants, retained within the impression and picked upon its removal from the patient's mouth. A window is always required in the impression tray to allow access to the impression coping screws and facilitate impression removal after setting of the material [41].

Daoudi et al conducted an in vitro study to test the accuracy of repositioning the copings after closed tray implant impressions by three different groups: senior dentists, postgraduate dental students and dental technicians. The results demonstrated larger deviations in analogue position

with repositioning the copings in the closed tray impression technique than with the pickup (open-tray) technique. The rotational errors were large enough to be of clinical concern. When the impression is needed for multiple implants, the error is multiplied; therefore, an open tray technique should be used [42].

A recent systematic review by Papaspyridakos et al [5] reported that for full arch implant cases, the open tray impression technique is more accurate than the closed tray technique. For partial edentulism, in vitro studies have shown that the open tray technique is more accurate; however, the only available clinical study reported no difference.

5.1.3 Splinting versus Non-splinting

The objective behind splinting is to connect the implant impression copings together using a rigid material to prevent their displacement during and after impression-taking of multiple implants. Various splinting materials have been described in the literature and used clinically to connect the impression copings such as dental floss and polymethyl methacrylate (PMMA), metal bars or light cured resins. Prefabricated PMMA bars have also been used and connected to the copings intra-orally to minimize polymerization shrinkage. To reduce dimensional changes of the splinting material, it was recommended to connect the copings followed by sectioning the splinting resin and connecting it again [5, 43]

In the systematic review by Papaspyridakos et al [5], it was stated that all the included clinical studies and most in vitro studies supported the use of the splinted over the non-splinted tech-

nique, owing to a more accurate impression in completely edentulous patients. The aforementioned systematic review also reported that splinting of the impression copings led to improved accuracy with partially edentulous implant impressions.

5.2. Impression Material

The impression material of choice should exhibit certain properties such as biocompatibility, dimensional stability, high tear resistance, ease of use, acceptable taste, compatibility with die materials and accurately recording fine details [44]. Several impression materials have been recommended for the use with implant impressions such as polyether, polyvinyl siloxanes (PVS) and polysulfide. This is due to their high tear strength, accuracy of recording fine details and dimensional stability.

Concerning implant impressions, torque resistance and strength are the most important properties when selecting an impression material, especially when the open tray technique is used. According to a study by Wee et al, master casts fabricated using polyether were more accurate than those fabricated from other impression materials. The study also showed that polyether exhibited the highest torque values [45]. Assuncao et al reported that polyether and high viscosity polyvinyl siloxanes are the most accurate impression materials [46].

Thongthammachat et al concluded that silicone impression materials exhibit better dimensional stability than polyether and that the latter should be poured only once within the same day after impression making. This is due to the fact that polyether absorbs water from the gypsum and ex-

pands with each successive pour [47]. A systematic review by Papaspyridakos et al reported that there no difference in accuracy between polyether and PVS [5].

However, if the implants are placed deep subgingivally, more accuracy was achieved by using putty and light body combination PVS rather than medium body polyether impression material [48].

5.3. Implant Number and Angulation

Accuracy of implant impressions may also be affected by implant number and angulation. For partially edentulous patients, a systematic review by Papaspyridakos et al[5] concluded that in cases with three implants, 15 degree angulation did not affect the accuracy of the impression.

However, for 30 and 40 degrees angulations, the splinted technique showed better results. In cases where four implants are used, 5 degree angulations did not affect accuracy, but the splinted technique showed more accuracy with angulations of 20 degrees and more. For completely edentulous patients, the aforementioned systematic review recommended the use of the open tray splinted impression technique, with no difference in accuracy between PVS and polyether.

Another study, an in vitro evaluation of a metal block with four implants placed at four different angulations in relation to the horizontal axis of the block (90, 80, 75 and 65 degrees), found that with less angulation of the implant, a more accurate impression was produced. Different impression techniques were used and the worst combination was implant angulated at 65 degrees with the closed tray impression technique [49].

In patients where multiple implants are placed at multiple angulations, the likelihood of distorting the impression material upon removal increases. More studies are required to determine a relationship between the effect of implant angulation and number.

5.4. Other Factors

There are other factors affecting the accuracy of implant impressions such as implant depth and machining tolerance of different implant components. A study was conducted by Lee et al assessing the effects of implant depth on impression accuracy. The study used two different impression materials (heavy-body PVS and medium-body polyether) and a master cast with five implants placed at different depths. The results showed that implant depth had no effect on impression accuracy [50].

Ma et al defined “machining tolerance” as the inherent disparity in position between two metal components when they are held together by their respective fastening screws and reported that the measured discrepancies ranged from 22 μm to 100 μm for the first generation Branemark system implants. It was also reported by Eames et al that machining tolerance between implant components and the implant was lower in vivo than in vitro, meaning that a passive fit achieved by the lab technician on the master cast will not necessarily be achieved in the patient’s mouth [51].

6. CAD/CAM

The introduction of CAD/CAM technology in the dental field began in the early 1980's when Dr. Mörmann and Dr. Brandestini created the first CAD/CAM inlay through their introduction of the CEREC system (Sirona, Bensheim, Germany). At the time, the CEREC system was the first CAD/CAM system in dentistry which allowed digital impressions, design and in office milling of dental inlays and onlays [52]. In the years to follow, continuous developments and evolution in technology led to the use of CAD/CAM in a much wider spectrum of clinical and laboratory procedures.

CAD/CAM systems consist of three main components: the digital scanning component, design component (CAD software) and the manufacturing component (CAM software). The digital scanning component is responsible for data acquisition by compiling three dimensional data of abutment teeth, edentulous spans or implant components using different technologies [53].

There are different types of scanners available - intraoral scanners which allow clinicians to acquire data directly from the patient's mouth without the need to make a conventional impression and extra-oral (lab) scanners used to scan models or impressions. Scanners can be further categorized by scanning mode into contact digitization technique, laser scanning, or the recently introduced optical cameras. After the scanning process is completed, a 3-D virtual model will be formulated on the screen which can then be converted into a physical resin model either by milling or printing [54 - 56].

Intra-oral scanners reduce the number of steps required in manufacture of the prostheses such as the need for an impression and fabrication of the stone cast which reduces the errors associated with these two steps such as expansion, shrinkage, and distortion of impression materials and/or the gypsum master model. According to the CAD/CAM system used, IOS may require the application of titanium oxide powder on the object to be digitized which may alter the topography of the scanned surfaces. CEREC Bluecam and 3M True Definition are two intra-oral scanners that require powdering; however, CEREC Omnicam, TRIOS by 3shape do not require powdering prior to scanning [57,58].

In 2014, Ender and Mehl conducted an in vitro study using a dentate reference model scanned using CEREC Bluecam, CEREC Omnicam, iTero and Lava and compared those full arch scans with conventional impressions made with different materials. The results showed that digital intra-oral impressions do not show superior accuracy to accurate conventional impression techniques but provide excellent clinical results within their application (single-unit restorations up to 4-unit FPD's). Also, digital scanning provides higher reliability due to the elimination of steps in the workflow [59].

Another study by Patzelt in 2014 was conducted to test the accuracy of full arch dentate digital impressions with four different intra-oral scanners (CEREC Bluecam, LAVA, iTero and Zfx Intrascan). Results of this study showed that except for one intraoral scanner system (CEREC AC Bluecam), all tested scanners showed comparable levels of trueness and precision values in full-

arch scans of prepared teeth [53].

In regards to completely edentulous patients, only one study exists by Papaspyridakos et al [6] which compares the accuracy of digital implant impressions using TRIOS with conventional impression techniques. The conclusion of the aforementioned study was that digital implant impressions with TRIOS are as accurate as conventional open tray splinted implant-level impressions and both are more accurate than the open tray non-splinted impression technique. There are no current studies on the accuracy of full arch digital implant impressions made with the Omnicam and True Definition scanners.

Aim and Hypothesis:

The aim of this study was:

To compare two different intra-oral scanners (CEREC Omnicam and 3M True Definition) with each other and with conventional implant impressions in terms of accuracy for a completely edentulous mandibular cast.

Hypothesis:

The hypothesis was that the splinted open tray impressions are more accurate than digital impressions in cases with complete edentulism.

Materials and Methods:

A mandibular acrylic model containing 5 inter-foraminal internal connection implant analogs (Bone Level implant analogs RC, Straumann) was fabricated to mimic a routinely-occurring clinical situation (Figure1). Since the clear acrylic model cannot be scanned and digitized, a stone master cast was fabricated from the acrylic model (to function as a control) by taking a splinted open-tray impression using polyether (Impregum; 3M ESPE, St. Paul, Minn) and connecting implant analogs to the impression copings. The impression was then poured with low expansion (0.09%) type IV die stone (Resin Rock; Whipmix Corp, Louisville, KY). Once the stone cast was completed, it served as the master cast (control) for all three groups (Figure 2).

A custom tray was then constructed using light-curing acrylic resin (Triad TruTray; Dentsply) after four fiducial marks were made on the master cast to standardize custom tray positioning during open-tray impression taking. Two layers of baseplate wax (NeoWax, Dentsply, York, PA, USA) were used to create the desired 2 mm space for the custom tray. The tray material is dimensionally stable after it is light-cured, and it has relatively high stiffness as reported by Martinez et al [43]. The tray included five holes to accommodate the impression coping guide pins (Figure 3).

Implant impression procedures

The three impression groups consisted of the following:

Group I - Splinted open-tray implant-level impression (n=10):

Implant-level impression copings were secured to the implant analogs in the stone cast. The impression copings were splinted using urethane dimethacrylate-based visible light-cured resin (Triad gel; Dentsply Inc, York, PA) (Figure 4). In order to regulate the dimensions of the splinting material, prefabricated resin bars were made by filling drinking straws with Triad. The straws were then light-cured and stored for 24 hours. The resin bars were then sectioned and connected to the impression copings by adding a small quantity of Triad (Papaspriidakos, Lal et al. 2011; Papaspriidakos, Benic et al. 2012). Impressions were then taken using Polyether (Impregum; 3M ESPE, St. Paul, Minn).

A matrix was then fabricated using addition reaction silicone to aid in the pouring of all the impressions (Figure 5). This matrix was used allow a standardized shape of the poured stone casts and to control the amount of dental stone used for pouring. This process was carried out 10 times to produce 10 stone models.

Group II - Digital impressions using CEREC Omnicam (n=10)

Polymer implant impression scan bodies (RC; Straumann, Basel, Switzerland) were connected to the implants on the control master cast and hand-tightened (Figure 6). Ten digital impressions were taken with a white light intra-oral scanner (CEREC Omnicam; Sirona, Germany) at the implant level. Scanning using CEREC Omnicam required no powdering. After obtaining ten digital

impressions, the scanned data were exported as Standard Tessellation Language (STL) files and saved.

Group III - Digital impression with 3M True Definition (n=10)

Using the same polymer scan bodies, ten repeated digital impressions were taken with a blue light intra-oral scanner that uses active wavefront sampling technology (True Definition: 3M ESPE, Germany). The master (control) model and scan bodies were sprayed with powder prior to scanning (according to manufacturer's instructions). After the acquisition of ten repeated digital impressions, the digital scans were exported as STL files and saved.

Stone cast digitization procedures

All stone models were stored at room temperature for 1 week prior to scanning and recording any measurements. Group I stone models were digitized for comparison with a high-resolution extraoral scanner (Activity 880 scanner; Smart Optics, Bochum, Germany). The Activity 880 scanner features a 3-D transformation tool that aids in scanning and capturing the implants' 3-D position. This scanner uses a white light camera, which can capture multiple pictures and transform it to a three-dimensional image.

The same plastic scan bodies (Scan bodies RC; Straumann, Basel, Switzerland) that were used for digital scanning with the Omnicam and True Definition scanners were connected to the analogs on the first stone model from Group I and the model was digitally scanned. The scan bodies were then removed and placed on the second cast and the same scanning process was performed for all 10 casts. For every scan, the scan bodies were moved from their position in cast 1

to their matching position in all 10 casts in order to eliminate any error associated with the scan bodies. The STL digital files were saved. Each scanner (Omnicaam IOS, True Definition IOS and Activity 880) was calibrated as per manufacturer's instructions prior to scanning.

STL Superimposition Procedures:

Inspection software (Geomagic control 2015 (3D systems)) was then used to superimpose the STL datasets of each cast of each test group to an STL dataset of the control (master cast). The primary method to calculate the difference was the root mean square (RMS) error, which was obtained by Geomagic control (Figures 7, 8 and 9).

Power Calculation:

A power calculation was conducted using the statistical software package R (Version 3.1.2). Based on the results of a previous study [6], and assuming equal accuracy between the digital groups, a sample size of $n = 10$ per group was sufficient to produce a Type I error rate of .05 and power more than 80%.

Statistical Analysis:

Descriptive statistics (means and standard deviations) were calculated for each group (Conventional, Omnicam, and True Definition). Differences in accuracy between the three groups were analyzed via Welch's F test (with the Games-Howell test for post-hoc comparisons). P-values less than 0.05 were considered statistically significant. SPSS Version 21 was used in the analysis.

Results:

The RMS values for the overall 3-D distortion of all 10 scans of each group were tabulated (Table 1). The mean and SD of the results were calculated and are presented in Table 2 as follows:

Group I (conventional impression technique - splinted open tray impression) had a mean value of 167.93 μm (SD 50.37), a minimum of 110.06 μm , and a maximum of 283.69 μm . Group II (OmniCam Digital Impression technique) had a mean value of 46.41 μm (SD 7.34), a minimum of 33.24 μm , and a maximum of 61.86 μm . Group III (True Definition Digital Impression Technique) had a mean value of 19.32 μm (SD 2.77), a minimum of 15.33 μm , and a maximum of 24.20 μm .

The Kolmogorov-Smirnov test showed no evidence of non-normality. Levene's test showed lack of homogeneity of variances; hence, Welch's F test was used together with the Games-Howell test for post-hoc comparisons. Welch's F test showed a significant difference between the groups ($p < 0.001$). The Games - Howell Test showed statistically significant differences in 3D deviations between all three groups ($p < 0.001$).

Figure 10 shows a bar graph with the mean RMS errors of Groups I, II and III and a statistically significant difference between the three groups. A box plot summarizes the results for each group (Figure 11).

Discussion:

A large number of patients with complete edentulism request rehabilitation with full arch implant prostheses. In order to ensure long term success and minimize biologic and mechanical complications, it is imperative that an accurately fitting prosthesis is fabricated. The key to an accurately fitting prosthesis is an accurate master cast which is a result of an accurate implant impression. Achieving complete passive fit with implant-supported fixed complete dental prostheses (IFCDP) is impossible to achieve due to the inherent tolerance in the different prosthetic components. According to the literature, clinically acceptable discrepancy should range from 59 to 72 μm [12], from 91 to 111 μm [10] or less than 150 μm [9].

The available implant impression techniques have been subjected to scrutiny. Comparisons in the literature reported that the use of the splinted open tray implant impression technique is superior to other conventional techniques. A systematic review by Papaspyridakos et al [5] concluded that splinted open tray impression technique is more accurate than non-splinted open tray. In this study, splinted open tray impression technique has been used for Group I impressions.

An experimental study by Sabouhi et al. digitally compared the accuracy of three implant impression techniques in partially and completely edentulous mandibles with two implant analogs placed in bilateral canine sites. The impression techniques performed for each condition were splinted open-tray, unsplinted open-tray and closed tray. The six groups of casts were digitized

and superimposed with the digital file of the master cast. The results of Sabouhi's study showed that the in partially and completely edentulous conditions, cast accuracy was not affected by the impression technique performed [60]. The mean discrepancy of the edentulous open-tray splinted technique in Sabouhi et al's study was 25 μm , which is a much smaller discrepancy than the mean of Group I in this study (167.93 μm). This could be attributed to the fact that in this study, the edentulous model contained five implant analogs which increases the likelihood of error.

The accuracy of a conventionally produced master cast is dependent on a number factors such as tray selection, impression material and impression technique and type of stone used to pour the impression. Each step in the process of producing the definitive cast is accompanied by a degree of error. To overcome some of the errors that are attributed to conventional impression techniques, intra-oral digital scanning was introduced in fixed and implant prosthodontics.

A number of studies was conducted to test the accuracy of different intra-oral scanners in dentate patients. Results by Ender and Patzelt [59, 53] showed that intra-oral scanners provide excellent results when used within their application and that the digital scans showed a superior level of trueness and precision. According to the aforementioned studies, trueness was defined as the closeness of the absolute values of the 3D deviations of each test dataset in comparison to the control dataset.

In terms of full arch implant impressions, two studies by Gimenez et al in 2014 and 2015 [61 and 62] studied a completely edentulous maxillary model with 6 implants (2 of which were at a

30 degrees angle) was digitally scanned using i-Tero scanner and LAVA COS respectively and the accuracy of the digital impressions was assessed based on clinician experience, implant angulation and depth. The results of that study showed that the operator affected the accuracy of the measurements; however, operator performance did not necessarily depend on experience. Moreover, implant angulation and implant depth did not have a significant impact on the 3-D deviations.

Regarding comparisons between conventional and digital impressions for implant-supported prostheses, there is a limited amount of evidence-based data. A study by Lee and Galluci evaluated the efficiency outcomes of digital versus closed tray impressions for a single implant restoration. They concluded that digital impression techniques were less time consuming, more efficient and easier than conventional impression techniques [63].

In another in vitro study by Lee, Betensky et al. [64] the accuracy of stone casts produced from conventional implant impressions was compared to milled models created from digital impressions using intra-oral scanners for a single implant. They stated that the digital impressions were similar in accuracy to the conventional ones. The conclusion of their study was that milled models from digital impressions are comparable in accuracy to stone models from conventional impression.

A study by Lin et al [65] compared the accuracy of definitive casts fabricated with digital and conventional techniques in a partially edentulous mandible with 2 implant analogs placed at dif-

ferent degrees of divergence. The results of this study showed that the degree of divergence did not affect the accuracy of the conventionally generated stone casts but it had a significant impact on the accuracy of milled casts generated digitally. At less angulation (0 and 15 degrees), the digital technique resulted in significantly less accurate casts; however, at 30 and 45 degrees divergence, the digitally-produced casts showed insignificant to no difference with conventionally-produced casts. These results stress the importance of a verification jig even with a digital workflow, which may be unnecessary with future improvement and development of intraoral scanners and CAD/CAM systems.

A recent in vivo study by Gherlone et al [66] assessed the accuracy of definitive prostheses for “all -on-four” implant rehabilitations using Lava COS and followed-up for up to 12 months. The results showed accuracy at the bar-implant interface and no statistically significant bone loss between upright and tilted implants. The conclusion of this in vivo study was that intra-oral scanning improves efficiency and provides benefit to the dentist, technician and to the patient.

Regarding patients with complete edentulism needing full arch implant rehabilitations, only one study [6] recorded the accuracy of full-arch digital implant impressions using the TRIOS Intra-oral Scanner compared to conventional impression techniques. The conclusion of that study was that digital implant impressions with TRIOS are as accurate as conventional open tray splinted implant-level impressions and both are more accurate than the open tray non-splinted impression technique.

There are no data on the accuracy of digital implant impressions made with the Omnicam and True Definition scanners. Therefore, this study was conducted using the CEREC Omnicam and the 3M True Definition intra-oral scanners in comparison to conventional impressions for a completely edentulous mandible in order to contribute to clinically verify this cutting-edge technology.

In the present study an edentulous mandibular model with five internal connection implant analogs (Straumann Bone Level) was used as a control (master cast). Ten conventional splinted open-tray impressions were taken, poured and the casts digitized with an extra-oral scanner. Ten digital scans were taken of the master cast with each intra-oral scanner (Omnicam and TrueDefinition) and the STL data sets were extracted. The master cast was also digitized and the digital files of all three groups were superimposed with the STL file of the master cast and assessed for overall 3D deviations.

The superimposition of the STL datasets was done by the best fit algorithm which was described by Guth et al [67] as one of the most common methods to test accuracy, especially in cases where the model tested lacks reference shapes. Using best fit matching produces positive and negative deviations between reference and test objects which could lead to results canceling each other out and not representing the real divergence. This inaccuracy was avoided by using the Root Mean Square error to measure 3-D deviations. Other superimposition techniques used in the literature are using one parallel implant as a reference [6], "least squares method" [3] and "zero method" [61]. The accuracy outcomes may be dependent on the type of extra-oral scanner

used in the digitization of the conventionally produced models. In this study, Activity 800 lab scanner was used which was calibrated to a known inaccuracy of 10 μm .

The findings of the present study showed that intra-oral digital scanning with Omnicam and True Definition were more accurate than conventional splinted open-tray impressions. Moreover, scans using True definition were significantly more accurate than those with Omnicam. These findings invalidate the hypothesis.

These findings were different from the ones by Papaspyridakos et al [6] where the results showed that full arch digital implant impressions were as accurate as conventional splinted open-tray impression techniques. This could be due to the use of a different method of superimposition of test groups and control, or as an effect of different accuracies in the intra-oral scanners.

Limitations:

There were some limitations to this study. The first one lies in the fact that it was an in vitro study, which means that the conditions were close to ideal in terms of making an optimal impression. In clinical conditions, the presence of saliva, blood, or gingival fluid may affect the accuracy.

Another limitation is that True Definition requires powdering prior to scanning while Omnicam does not require powder. Powdering of the master cast for True Definition was applied according to manufacturer's instructions and was replenished only in areas that seemed deficient with consecutive scanning. There was no way to standardize the powdering procedure for each scan. The

use of powder intra-orally may lead to different results. However, in a study by Ender and Mehl comparing three different intraoral scanners stated that the powder-free scanning system provides the same level of accuracy compared to scanning systems with surface pretreatment [68].

Moreover, digitization of the conventional models with an extra-oral scanner leads to an added inaccuracy; however, in this study the lab scanner was calibrated and the inaccuracy was known to be 10 μm . This is within the range of accuracy of reference scanners used in other studies (5 - 30 μm). Other studies use coordinate measuring machines (CMM) with a trueness of 1 μm ; however, these do not accurately measure certain surfaces such as deep fissure lines due to the size and shape of the tip of the stylus [69].

Workflow and implications:

Digital workflow in implant dentistry comprises a series of steps:

- 1) A radiographic evaluation using a CBCT Scan
- 2) 3-D virtual surgical planning with or without the utilization of a surgical stent for guided surgery
- 3) Surgical implant placement
- 4) Digital impression following implant osseointegration, and
- 5) Manufacturing of the implant prosthesis using CAD/CAM technology [70].

After the scanning process is completed, a 3-D virtual model will be formulated on the screen which serves as the data for the CAD (design) process followed by CAM (manufacture) process

in a virtual procedure without a working cast. The virtual model can also be converted into a physical resin model either by milling or printing.

Clinical implications of this study show that digital impressions using intra-oral scanners have the potential to serve as an alternative to conventional impression procedures for implant-supported prostheses. This could enhance efficiency, and facilitate workflow. This could also decrease discomfort for the patient such as gagging, pain and partially inconvenient taste associated with conventional impressions.

Future clinical studies are necessary to confirm the results obtained from this in vitro study by comparing digital and conventional impression techniques in a clinical setting. Additionally, the virtual models can be milled/printed and compared with the stone models using a framework to help in the assessment of the clinical significance of the results.

Conclusion:

Under the limitations of the present in vitro study, the following conclusion may be drawn:

Full arch digital implant impressions using True Definition and Omnicam intra-oral scanners were significantly more accurate than the conventional impressions with the splinted open-tray technique. Additionally, the digital impressions with the True Definition scanner had significantly less 3-D deviations when compared with the Omnicam.

REFERENCES

1. Papaspyridakos, P, Chen, CJ, Chuang, SK, Weber, HP. Implant loading protocols for edentulous patients with fixed prostheses: a systematic review and meta-analysis. *Int J Oral Maxillofac Implants* 2014; 29: 256-270
2. Kapos, T, Evans, C. CAD/CAM technology for implant abutments, crowns, and superstructures. *Int J Oral Maxillofac Implants* 2014; 29:117-36
3. Jemt, T and Hjalmarsson, L. In vitro measurements of precision of fit of implant-supported frameworks. A comparison between “virtual” and “physical” assessments of fit using two different techniques of measurements. *Clin Implant Dent Relat Res* 2012;14:75-82
4. Papaspyridakos, P. and Lal, K. Computer-assisted design/computer assisted manufacturing zirconia implant fixed complete prostheses: clinical results and technical complications up to 4 years of function. *Clin Oral Implants Res* 2013; 24: 659-665
5. Papaspyridakos, P, Chen, CJ, Gallucci, GO, Doukoudakis, A, Weber, HP, Chronopoulos, V. Accuracy of implant impressions for partially and completely edentulous patients: a systematic review. *Int J Oral Maxillofac Implants* 2014; 29:836-845
6. Papaspyridakos, P, Gallucci, GO, Chen, CJ, Hanssen, S, Naert, I, Vandenberghe, B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. *Clin Oral Implants Res* 2016; 27:465-72
7. Sahin, S, Cehreli, MC. The significance of passive framework fit in implant prosthodontics: current status. *Implant Dent* 2001;10:85–92
8. Branemark, PI. Osseointegration and its experimental background. *J Prosthet Dent* 1983; 50:399-410
9. Jemt, T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implant in the edentulous jaw: a study of treatment from the time of prostheses placement to the first annual check up. *Int J Oral Maxillofac Implants* 1991; 6:270-6
10. Jemt, T, Book, K. Prosthesis misfit and marginal bone loss in edentulous implant patients. *Int J Oral Maxillofac Implants* 1996;11:620-5

11. Kan, JY, Rungcharassaeng, K, Bohsali, K, Goodacre, CJ, Lang, BR. Clinical methods for evaluating implant framework fit. *J Prosthet Dent* 1999; 81:7-13
12. Papaspyridakos, P, Benic, GI, Hogsett, VL, White, GS, Lal, K, Gallucci, GO. Accuracy of implant casts generated with splinted and non-splinted impression techniques for edentulous patients: an optical scanning study. *Clin Oral Implants Res* 2012; 23:676-81
13. Abduo, J, Bennani, V, Waddell, N, Lyons, K, Swain, M. Assessing the fit of implant fixed prostheses: a critical review. *Int J Oral Maxillofac Implants* 2010; 25:506-15
14. Henry, PJ. An alternate method for the production of accurate casts and occlusal records in the osseointegrated implant rehabilitation. *J Prosthet Dent* 1987; 694-7
15. Adell, R, Eriksson, B, Lekholm, U, Brånemark, P, Jemt, T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. *Int J Oral Maxillofac Implants* 1990; 5:347–359
16. Ormaechea, MB, Millstein, P, Hirayama, H. Tube angulation effect on radiographic analysis of the implant-abutment interface. *IJOMI* 1999; 14: 77-85
17. Tan, KB, Rubenstein, JE, Nicholls, JI, Yuodelis, RA. Three-dimensional analysis of the casting accuracy of one piece, osseointegrated implant retained prostheses. *Int J Prosthodont* 1993;6:346-63
18. Goll, GE. Production of accurately fitting full-arch implant frameworks: part I—clinical procedures. *J Prosthet Dent* 1991;66:377-84
19. Jemt, T, Lie, A. Accuracy of implants supported prostheses in the edentulous jaw: analysis of precision of fit between gold alloy framework and master cast by means of 3-D photogrammetric technique. *Clin Oral Implants Res* 1995;6: 172-80.
20. Gelbard, S, Aoskar, Y, Zalkind, M, Stern, N. Effect of impression materials and techniques on the marginal fit of metal castings. *J Prosthet Dent* 1994;71:1-6.
21. Willis, LM, Nicholls, JI. Distortion in dental soldering as affected by gap distance. *J Prosthet Dent* 1980;43:272-8.
22. Ziebert GJ, Hurtado A, Glapa C, Schiffleger BE. Accuracy of one piece castings, preceramic and post ceramic soldering. *J Prosthet Dent* 1986;55: 312-7

23. Carr, AB, Brunski, JB. Preload and load sharing of strain gauged CP-Ti implant components. *J Dent Res* 1992;71:528
24. Haselhuhn, K., Marotti, J. Assessment of the stress transmitted to dental implants connected to screw-retained bars using different casting techniques. *J Oral Implantol* 2014;40:641-8
25. Abduo, J, Bennani, V, Waddell, N, Lyons, K, Swain, M. Assessing the fit of implant fixed prostheses: a critical review. *Int J Oral Maxillofac Implants* 2010; 25: 506-15.
26. Burguete, RL, Johns, RB, King, T, Patterson, EA. Tightening characteristics for screwed joints in osseointegrated dental implants. *J Prosthet Dent* 1994; 71:592-599
27. Phillips, KM, Nicholls, JI, Ma, T, Rubenstein, J. The accuracy of three implant impression techniques: a three-dimensional analysis. *Int J Oral Maxillofac Implants* 1994; 9:533–540
28. Rangert, B, Krogh, PH, Langer, B, Van Roekel, N. Bending overload and implant fracture: a retrospective clinical analysis. *Int J Oral Maxillofac Implants* 1996;10:326-34
29. Burns, J, Palmer, R, Howe, L, Wilson, R Accuracy of open tray implant impressions: An in vitro comparison of stock versus custom trays. *J Prosthet Dent* 2003; 89:250-255
30. Eisenmann, E, Mokabberi, A, Walter, M et al. Improving the fit of implant-supported superstructures using the spark erosion technique. *Int J Oral Maxillofac Implants* 2004;19:810-818
31. Ericsson, I, Persson, LG, Berglundh, T, Marinello, CP, Lindhe, J, Klinge, B. Different types of inflammatory reactions in peri-implant soft tissues, *J Clin Periodontol* 1995; 22: 255-261
32. Nakhaei M, Madani AS, Moraditalab A, Haghi HR. Three-dimensional accuracy of different impression techniques for dental implants. *Dent Res J* 2015;12: 431-7
33. Jemt, T, Carlsson, L, Boss, A, Jorneus, L. In vivo load measurements on osseointegrated implants supporting fixed or removable prosthesis: A comparative pilot study. *Int J Oral Maxillofac Implants* 1991;4:413-437
34. Eames, WB, Sieweke, JC, Wallace, SW, Rogers, LB. Elastomeric impression materials: effect of bulk on accuracy. *J Prosthet Dent* 1979;41:304-7
35. Mowery WE, Burns CL, Dickson G, Sweeney WT. Dimensional stability of denture base resins. *J Am Dent Assoc* 1958;57:345-53

36. Anusavice, K.J. Nonaqueous elastomeric impression materials, in Anusavice K. J. (ed): Phillip's science of dental materials (Ed 10). Philadelphia, PA, Saunders. In: ; 1996: 139-176
37. Eames W. B., SJ. Seven acrylic resins for custom tray and five putty-wash systems compared. Oper Dent 1980;5:162-167
38. Goldfogel, M, Harvey, WL, Winter, D. Dimensional change of acrylic resin tray materials. J Prosthet Dent 1985;54:284-6
39. Martinez, LJ, von Fraunhofer, JA. The effects of custom tray material on the accuracy of master casts. J Prosthodont 1998;7:106-10
40. Assuncao, WG, Filho, HG, and Zaniquelli, O. Evaluation of transfer impressions for osseointegrated implants at various angulations. Implant Dent 2004; 13: 358-66.
41. Cehreli, MC, Akca, K. Impression techniques and misfit-induced strains on implant-supported superstructures: An in vitro study. Int J Periodontics Restorative Dent 2006; 26:379-85
42. Daoudi MF, Setchell DJ, Searson LJ. A laboratory investigation of the accuracy of the repositioning impression coping technique at the implant level for single-tooth implants. Eur J Prosthodont Restor Dent 2003;11:23-8
43. Mojon, P, Oberholzer, JP, Meyer, JM, Belser, UC. Polymerization shrinkage of index and pattern acrylic resins. J Prosthet Dent 1990; 64: 684-688.
44. Powers, JM, and Sakaguchi, RL. Craig's Restorative Dental Materials. 2006: Mosby.
45. Wee, AG. Comparison of impression materials for direct multi-implant impressions. J Prosthet Dent 2000; 83:323-31.
46. Assuncao, WG, Filho, HG, and Zaniquelli O. Evaluation of transfer impressions for osseointegrated implants at various angulations. Implant Dent 2004; 13:358-66.
47. Thongthammachat, S, Moore, BK, Barco, MT, Hovijitra, S, Brown, DT, Andres CJ. Dimensional accuracy of dental casts: influence of tray material, impression material, and time. J Prosthodont 2002;11:98-108
48. Lee, H, Ercoli, C, Funkenbusch, PD, Feng, C. Effect of subgingival depth of implant placement on the dimensional accuracy of the implant impression: an in vitro study. J Prosthet Dent 2007;99:107-13

49. Assuncao, WG, Filho, HG, Zaniquelli O. Evaluation of transfer impressions for osseointegrated implants at various angulations. *Implant Dent* 2004;13:358-66
50. Lee H., Ercoli C. Effect of subgingival depth of implant placement on the dimensional accuracy of the implant impression: an in vitro study. *J Prosthet Dent* 2008;99:107-13
51. Ma, T, Nicholls, JI., Rubenstein, JE. Tolerance measurements of various implant components. *Int J Oral Maxillofac Implants* 1997;12:371-5
52. Brandestini M., Mörmann W. Computer-machined ceramic inlays. In vitro marginal adaptation. *J Dent Res* 1985; 64:208
53. Patzelt SB, Bishti S, Stampf S, Att W. Accuracy of full-arch scans using intraoral scanners. *Clin Oral Invest* 2014;18:1687-94
54. Brosky, M, Major, R, DeLong, R, Hodges, JS. Evaluation of dental arch reproduction using three-dimensional optical digitization. *J Prosthet Dent* 2003;90:434-40.
55. Olthoff, L, Van Der Zel, J, De Ruiter, WJ, Vlaar, ST, Bosman, F. Computer modeling of occlusal surfaces of posterior teeth with the CICERO CAD/CAM system. *J Prosthet Dent* 2000; 84:154-62
56. Lo Presti J, David S. New concepts in restorative dentistry: the CEREC CAD/CAM system. *N Y State Dent J* 1994;60:39-42.
57. Kurbad A. The optical conditioning of CEREC preparations with scan spray. *Int J Comput Dent* 2000;3:269-79
58. Luthardt, R, Loos, R, Quaas, S. Accuracy of intraoral data acquisition in comparison to the conventional impression. *Int J Comput Dent* 2005;8:283-94.
59. Ender, A, Mehl, A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. *Quintessence Int* 2015;46:9-17
60. Sabouhi, M, Bajoghli, F, Abolhasani, M. Evaluation of the three-dimensional accuracy of implant impression techniques in two simulated clinical conditions by optical scanning. *Int J Oral Maxillofac Implants* 2015;30:26-34
61. Gimenez, B, Ozcan, M, Martinez-Rus, F, Pradies G. Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience, implant angulation, and depth. *Int J Oral Maxillofac Implants* 2014; 29:853-62

62. Gimenez, B, Ozcan, M, Martinez-Rus, F, Pradies G. Accuracy of a digital impression system based on active wavefront sampling technology for implants considering operator experience, implant angulation, and depth. *Clin Implant Dent Relat Res* 2015;17 Suppl:54-64
63. Lee, SJ., Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. *Clin Oral Implants Res* 2013;24:111-5
64. Lee, SJ, Betensky, RA, Gianneschi, GE, Gallucci, GO. Accuracy of digital versus conventional implant impressions. *Clin Oral Implants Res* 2015;26:715-9
65. Lin WS, Harris, BT, Elathamna, EN, Abdel-Azim, T, Morton, D., Effect of implant divergence on the accuracy of definitive casts created from traditional and digital implant-level impressions: an in vitro comparative study. *Int J Oral Maxillofac Implants* 2015;30:102-109
66. Gherlone, E, Capparé, P, Vinci, R, Ferrini, F, Gastaldi, G, Crespi, R. Conventional versus digital impressions for "All-on-Four" restorations. *Int J Oral Maxillofac Implants* 2016;31:324-30
67. Güth, JF, Keul, C, Stimmelmayer, M, Beuer, F, Edelhoff, D. Accuracy of digital models obtained by direct and indirect data capturing. *Clinical Oral Investigations* 2013;17: 1201–1208
68. Ender, A, Mehl, A. Influence of scanning strategies on the accuracy of digital intraoral scanning systems. *Int J Comput Dent* 2013;16:11-21.
69. Ender, A., Mehl, A. Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision. *J Prosthet Dent* 2013;109:121–128
70. Joda, T. & Bragger, U. Complete digital workflow for the production of implant-supported single-unit monolithic crowns. *Clinical Oral Implants Research* 2014; 25: 1304–1306.

Appendix A: Figures



Figure 1: PMMA Model



Figure 2: Stone Master Model With 4 Notches



Figure 3: Custom Tray

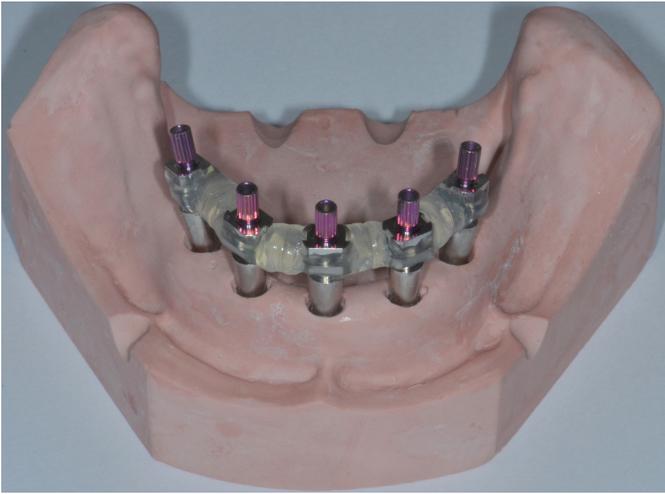


Figure 4: Master Model With Splinted Open Tray Copings

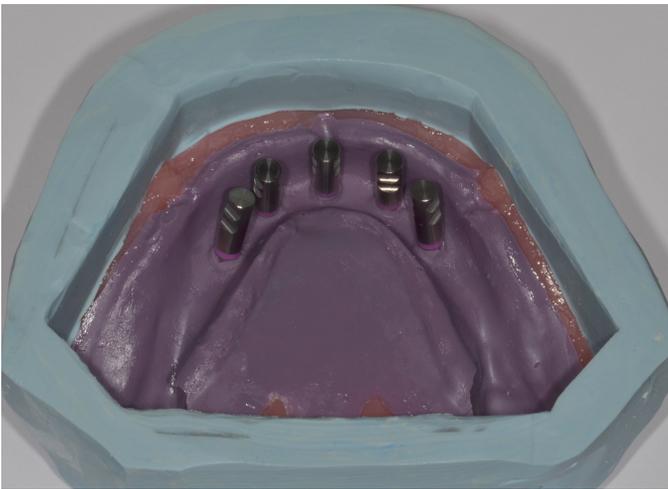


Figure 5: Box For Pouring Conventional Impressions



Figure 6: Master Model With Scan Bodies

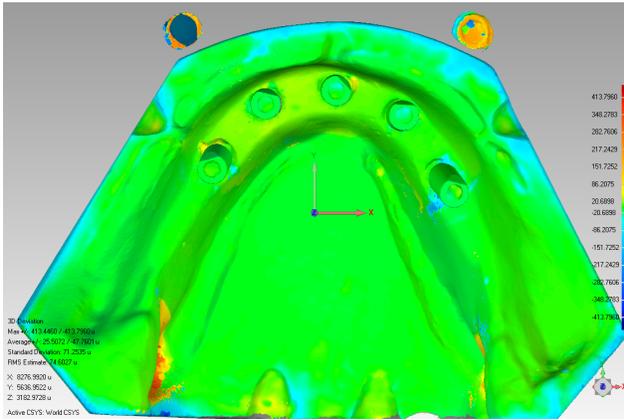


Figure 7: Superimposition of Conventional with Master

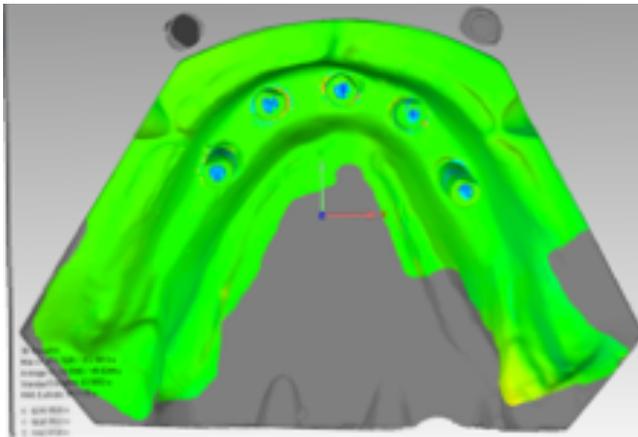


Figure 8: Superimposition of Omnicam with Master

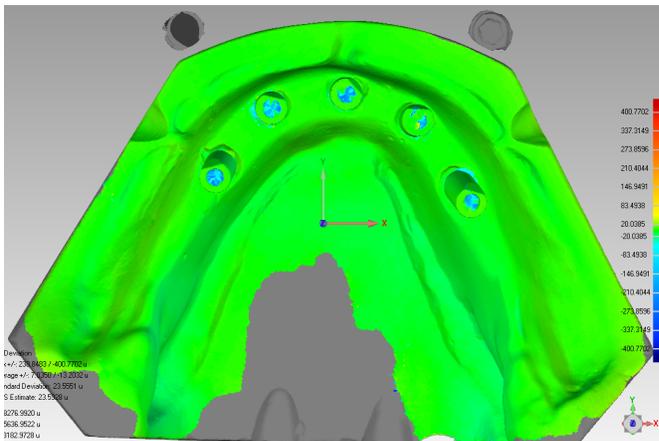


Figure 9: Superimposition of True Definition with Master

Figure 10 - Bar Graph showing mean of Groups I, II, III

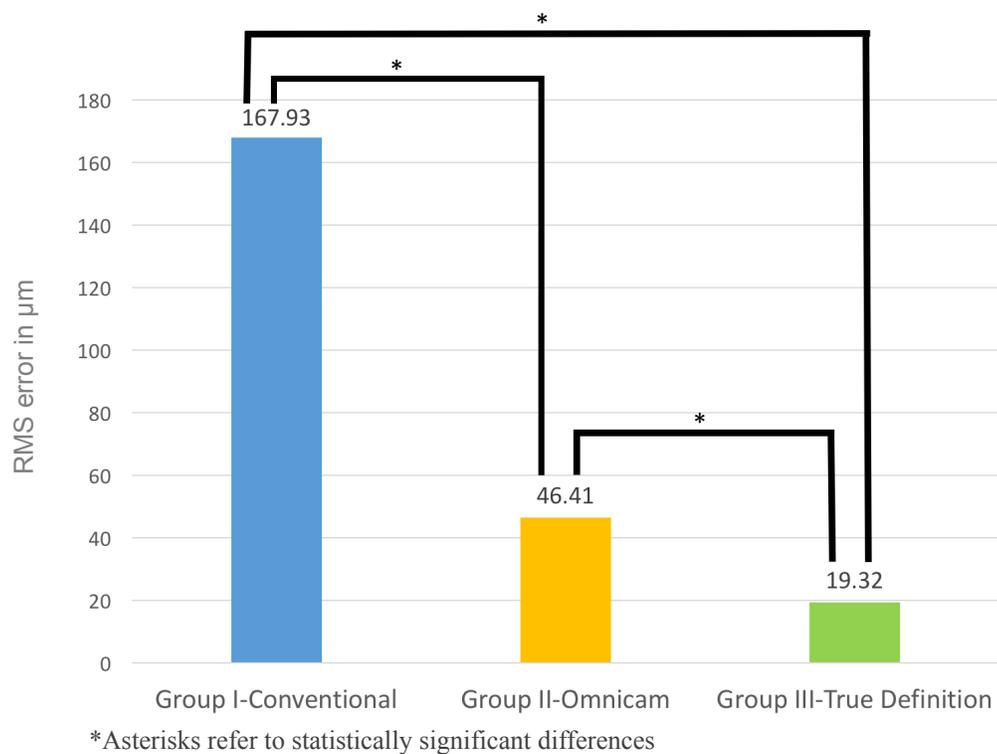
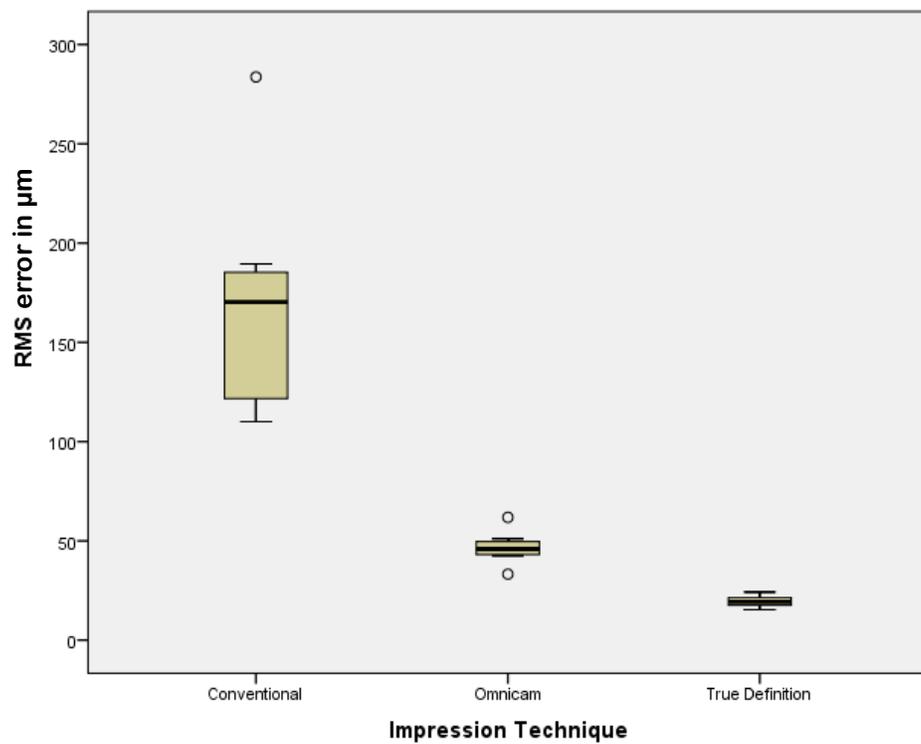


Figure 11 - Side by side box plots comparing RMS error results of Group I, II and III



Appendix B: Tables

	Conventional	Omnacam	True Definition
scan 1	110.06	49.62	19.96
scan 2	115.76	44.63	17.55
scan 3	121.72	43.13	15.83
scan 4	185.29	47.11	15.33
scan 5	178.18	42.57	18.19
scan 6	189.52	51.06	20.23
scan 7	283.69	47.64	24.20
scan 8	153.57	61.86	21.35
scan 9	162.50	43.19	21.95
scan 10	179.03	33.24	18.56

	Conventional	Omnacam	True Definition
Mean	167.93	46.41	19.32
Median	170.34	45.87	19.26
Standard Deviation	50.37	7.34	2.77
Minimum	110.06	33.24	15.33
Maximum	283.69	61.86	24.20

* Welch's F test was statistically significant (P<0.001). All Games-Howell Tests were statistically significant (P<0.001).