Tufts UNIVERSITY | School of Dental Medicine

# Accuracy of fit of digitally fabricated prototypes with different printers: A Comparative Study

A Thesis
Presented to the Faculty of Tufts University School of Dental Medicine
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Dental Research

by
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July 2023

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# ABSTRACT

**Aim:**

To test whether or not digitally fabricated (from two different 3D printers) prosthesis prototypes exhibit acceptable accuracy of fit on the master cast and compared the 3D printers in terms of accuracy of fit.

**Hypotheses:**

The digitally fabricated prosthesis prototypes (from two different 3D printers) generated from a complete digital workflow via the double digital scanning technique will exhibit acceptable accuracy of fit on the master cast.

The Form 3b and Carbon M2 3D printers will be equally accurate in comparison to each other.

**Materials & Methods:**

A maxillary stone cast with 6 abutment-level implant analogs (SRA, Straumann) with adequate antero-posterior (AP) spread simulated a common clinical condition. This stone cast served as the master (reference) cast for taking digital impressions. A screw-retained prototypes prosthesis fabricated on the reference master cast following the Pro-Arch concept. The double digital scanning (DDS) technique was used to generate two STL files, then merged with aid of CAD software into one master STL file. The master STL file was used to print digitally fabricated prototype from 2 different printers (Form 3b+ and Carbon M2).

**Accuracy was evaluated in two methods:**

**Radiographic assessment**

Radiographs taken for each prototype to assess the accuracy of fit on each screw-retained abutment. Prior to taking each radiograph, the prototype torqued to 15 Ncm to simulate the clinical scenario.

**Laboratory Analysis; Accuracy of Fit Assessment**

The accuracy of fit of the digitally generated prototype prostheses on the reference cast was tested. Two blinded clinicians tested the accuracy of fit of the prosthesis on all prototypes using the screw-resistance test.

**Results:**

Out of the 62 digitally fabricated prototypes, 51 (82.26%) presented with accurate fit. The accuracy of fit ranged from 80.65% (25/31) for carbon m2 printer to 83.87% (26/31) for the form 3b lab printer.

**Conclusion:**

Digitally fabricated prosthesis prototypes can be generated with acomplete digital workflow leading to clinically acceptable fit, while reducing the number of appointments and treatment time.

# ACKNOWLEDGMENTS

I am greatly thankful for the help and guidance of my principal investigator, Dr. Papaspyridakos, and my committee members: Dr. El Rafie, dr. Finkelman, Mr. Kudara and Dr. Shruti without whom this master project would not be possible.

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## INTRODUCTION:

As the number of completely edentulous patients increases, the number of patients seeking implant prosthodontic treatment increases. An accurately fitting prosthesis is critical for long-term success with implant-supported fixed complete dental prostheses (IFCDPs). [1]

The application of the guided surgery and computer assisted designing / computer- assisted machining (CAD/CAM) technology in prosthodontics has improved in simplifying several treatment procedures. [1, 2] Additionally, digital impressions with an intra-oral optical scanner (IOS) are gaining popularity in Implant Dentistry.

Starting from Preston and Duret who developed the first CAD/CAM system in the 1970's using optical impressions, fabricating dental prosthesis and then in the 1980's Mörmann and Brandestini developed the CEREC system making it the first commercially available CAD/CAM system, digital technology in dentistry is advancing at a fast rate.[3]

There are many advantages to digital dentistry including the ability to fabricate dental restorations in a single appointment, standardization of fabrication process and reducing cost.[4] In a complete digital workflow utilizing Cone-beam computed tomography (CBCT), intraoral scanners (IOS), and CAD/CAM technology have facilitated the fabrication of surgical guide and have improved the process of immediate implant provisionalization. [5]

For the fabrication of definitive prostheses, full-arch digital implant scans with intraoral scanners (IOS) are becoming more and more common.[6] In a recent systematic evaluation, the accuracy of full-arch digital implant scans was examined. It was shown that for patients with complete natural dentition, scan accuracy was comparable to that of the gold standard open-tray splinted impression approach.[7]

**The implant prosthesis's fit**

It is widely acknowledged that a passive fit is the best fit for an implant fixed complete dental prosthesis (IFCDP), and is essential for its long-term success and making an accurate fit restoration is crucial.[8] While gaining a completely passive fit of prosthetic framework was described as nearly impossible, a misfit dental prosthesis could lead to biological and technical complication like screw fracture, chipping of restoration, bone resorption and implant prosthesis failure.[9]

Many physicians concluded that acceptable fit can be measured by the amount of stress and strain on dental restorations, implant structure, surrounding bone and completely seated prosthesis.[10] While others states that a misfit can be quantify and measure to provide an acceptable range in which misfit prosthesis can be tolerated, authors concluded that 10 µm to 200 µm is tolerable as misfit.[11]

Methods being applied through the years to evaluate fit of implant prosthesis for example, single screw test, screw resistance test, visual evaluation, and radiographs.[10]

The single-screw test (Sheffield test) involves placing and tightening the screw on one side of the distal end while checking for deviation/elevation of the opposite pole. The elevation on the opposite side will measure the vertical discrepancy only, the horizontal discrepancy wouldn't be measure by this method. The single screw test is no longer clinically relevant, especially with internal connection implant systems. In contrast, the screw resistance test evaluates vertical and horizontal discrepancy. The screws are inserted and tightened successively until the initial resistance is reached. If these screws required more than quarter turn of the screwdriver to achieve optimal fit, the framework is considered unacceptable.[12]

Visual evaluation can be done but would only be useful for supragingival implant prosthetic connections. It should be noted that there can be a wide variation in visual judgment within the wide range considered acceptable (30-100 µm).[13]

Radiographs, especially if the interface of the implants is situated in a subgingival position, can also be useful for an assessment of fit. Also, radiographs will help to detect possible gaps if the film is positioned perpendicular to the implant prosthesis junction

All these methods are available to a clinician, with the objective of detecting any discrepancies and achieving the most accurate fit possible. Researchers have identified several factors affecting the accuracy of the implant prosthesis. These factors can be classified into 3 main categories: Implant impression, master cast fabrication, and framework superstructure fabrication related factors. [14-16]

### 1) Implant impression factor

The impression of the implant is one of the key factors that require high registration to produce a well-fitting prosthesis.[17] The final implant impression is a critical clinical step to accurately capture the 3D internal relationships between implants, teeth and adjacent structures.[18] Accuracy according to the International Organization for Standardization (ISO), involves 'trueness' and 'precision'. 'Trueness' refers to the degree of agreement between the arithmetic mean of a large number of test results and the true or accepted value, while 'precision' refers to the degree of agreement between the test results.[19]

An accurate final impression is expected to form a flawless master cast, resulting in a precise passive fit of the prosthetic restoration.[20] Many factors affect the three-dimensional accuracy of an implant impression: impression material properties, impression technique, implant angle, impression strength, and connection type.[21] Also, the choice of impression material depends on several factors, including the presence of undercut, the angle of the implant, the type of reconstruction and the experience of the user.[18]

Polyether and polyvinylsiloxane (PVS) are the most commonly used materials in implant impressions, and the properties of both materials allow accurate registration of the 3D position of the implant.[22] Polyether has high yield strength and modulus and is typically the material for completely edentulous arch cases due to its stiffness and prevention of displacement of impression components. On the other hand, in partially edentulous cases with non-parallel implants, the use of PVS material can be a better choice. Due to the low modulus of elasticity of this material, less force is needed to remove the impression from undercuts.[18]

Several studies have also evaluated the effect of the impression tray technique, and most have concluded that the direct open tray technique always produces more accurate cast than the indirect closed tray technique.[23] Closed-tray technique on the other hand, only one study reported that is more accurate than the open-tray technique.[24]

To guarantee the precision of the impression, investigator favors splinting of the impression copings.[25] According to Papaspyridakos systematic review, which draws on the latest scientific evidence, splinted implant impression exhibits greater accuracy than unsplinted impression, irrespective of the tray technique and impression material used, for both partially and completely edentulous cases.[26] Different techniques have been studied and different materials have been used for impression copings. Auto-polymerizing acrylic resin is one of the most popular materials for splinting impression copings despite the poor dimensional stability of acrylic resin.[27]

In contrast, light cured resin material demonstrated superior dimensional stability compared to self-cured resin material, making it an optimal material for splinting applications.[28] It is recommended, however, that resin bars be fabricated prior to the appointment to overcome the remaining polymerization stress and affixed to impression copings using a minimum amount of material.[29]

In addition to the material used, another reason for the inaccuracy due to the impression copings being splinted is that the internal stress that occurs after the impression is made may cause a displacement of the transferred implant. To avoid stress from the shrinkage that comes with polymerization, researchers suggest taking a few different steps: pre-fabricate the acrylic resin bars at least 17 minutes before the appointment; minimize the amount of acrylic resin used by making it in molds and use thin disks to section the bars, so as to reduce the amount of material needed to reconnect them. This will help avoid mistakes from dimensional changes during the polymerization process.[30]

The last thing that can affect the master cast accuracy is implant angulation. Some researchers found that the accuracy of the final impression is affected by implant parallelism. They found that angulation higher than 15-20 degrees can lower the accuracy of the transferred implant location in the master cast.[31]

To sum up, the systematic review concluded that, regardless of the impression material used and the tray technique chosen, for both partially and completely edentulous implant cases, the splinted implant impression was found to be the most accurate. However, there are adverse effects of conventional impressions, which include patient gagging, irritating taste, and the risk of patient aspiration.[26]

**2) Master cast fabrication factor**

The misfit of the framework can be attributed to any inaccuracies in the master cast's fabrication.[32] A verification jig is a method used to verify the master cast's accuracy. It's made on-master cast, transferred intraorally, sectioned, and re-connected, then re-transferred back to master cast for testing. If there is an inaccuracy in the master cast, it is corrected in one of the following ways: 1. A pickup impression is used to create a new master cast, The jig can alternatively be taken out of the mouth and affixed to the implant replicas; this assembly can then be used to create the implanted position cast using the type IV stone.[32]

The verification jig has been extensively reviewed in the scientific literature, with the overwhelming consensus being in favor of its use. A retrospective study looked at the impact of using a jig to check the fit of implant prostheses that weren't segmented. The study found that using the jig led to 100% passive fitting in the study's sample.[32] A further study, conducted by Papaspyridakos et al., examined the impact of implant angulation on the master cast and the use of various materials for the fabrication of the implant verification jig. The results of this study indicated that the various materials employed for splinting produced similar results.[25] As far as angulation is concerned, they came to the same conclusion as the previous study (Sorrentino et al).

Basically, the angle between implants shouldn't be more than 20 degrees, because anything more than that would cause a large 3D discrepancy that would be difficult to fix.

Other research has focused on the development of more precise implant master casts using photogrammetry.[33] In a pilot trial, photogrammetry was used to capture the location of the implant and to mill the titanium substructure. The researchers found that photogrammetry may be useful for clinicians to achieve a more precise framework fit.[33] In addition, other authors employed photogrammetry to precisely record the implant position at the moment of implant placement and subsequently utilized this data for the development of the provisional restoration.[34]

**3) Framework superstructure fabrication related factors**

The laboratory process of prosthesis fabrication can lead to an ill-fitting implant framework. Traditionally, lost-wax fabrication was used to construct prostheses' frames. This casting process of noble metals and base metals involves several steps. These steps can introduce imperfections that can lead to casting distortion and, eventually, misfit, which can necessitate sectioning or soldering to reach passive fit.[35] Studies have demonstrated that the misfit of the framework is associated with a variety of technical and mechanical issues, including screw loosening; screw fracture; abutment; and implant fracture.[35] CAD/CAM technology, however, allows for the creation of a framework superstructure that is less distorted and fit to the master cast.[36]

**Digital impression**

The relationship between dentist and technician has been significantly altered by the introduction of digital implant dentistry. Digital impressions have played a significant role in this transformation. This is accomplished by using IOSs (Intraoral Scanners) to capture digital impressions as an alternative to the traditional impression method for partially and fully edentulous patients. The benefits of IOSs include eliminating tray selection, dispensing, and setting impression materials, disinfection, and the need to ship impressions to the laboratory.[7] Therefore, IOSs may eliminate errors associated with traditional impressions. In essence, IOSs capture images as digital picture or video in the format of standard tessellation language (STL) files. This type of file can be used to produce a virtual cast for complete digital workflow. Additionally, the STL file can be further used to fabricate casts and/or dental restorations through subtractive and additive methods (milling and 3D printing). The STL files are also sent and stored electronically, which improves efficiency. [29, 37-39] This technology provides a straightforward, comfortable, and efficient treatment workflow for both the dentist and the patient. However, errors can still be encountered with digital workflow. During the scanning process and in CAD software, inaccuracies may occur. The accuracy of the digital workflow can also be affected by the subtractive or additive method of cast or prosthetic generating. Therefore, it is important to analyze each stage of the process. In an in vitro study, conventional impressions were compared to digital implant impressions for a single implant prosthesis (single implant prosthesis). The results showed a significant vertical difference in implant position between the two groups. However, as far as cast fabrication methods are concerned, the results showed similar accuracy for stone cast which are produced using conventional impression technique and milled casts which are produced using intra-oral scanners for most anatomical areas except for grooves and fissures.[40] Vertical displacement was found in two directions: apical direction in conventional group and coronal direction in digital group, resulting in restoration with potential hyper-and infra-occlusion. However, the results showed that the precision of milled casts produced using digital workflow is comparable to that of stone casts in clinical practice.[40]

In several clinical trials, a comparison was made between digital and conventional single implant crowns to determine fit and time-effectiveness. The results of the study indicated that although crowns could be completed with either approach within two clinical visits, digital workflow was more effective in terms of total treatment time and generated implant crowns with a predictable clinical fit and minimal or no occlusion adjustments.[41, 42] They also looked at patient preferences and workflow satisfaction and found that patients prefer intraoral scans over traditional impressions for reasons they believe to be comfort.[43]

Authors assessed the 3D precision of definitive casts produced using conventional and digital impression. In their study, two parallel implants were positioned on the right-side of the master model, and two additional implants were placed at 20° angles of convergence, 10°, and 30° from the vertical plane, respectively. The accuracy of the final cast was evaluated digitally with the help of 3Shape's quality control software convince, using the average of vector magnitude errors (VME) provided by the manufacturer. All definitive casts were also evaluated using a clinical-relevant verification jig that was fabricated on top of the master cast. The study found that the impact of both impression techniques on the accuracy of the final casts was minimal for the conventional group. However, there was no significant difference in the side where implants were not parallel. The authors concluded that the milling from a digital impression resulted in a less precise cast compared to the traditional approach and the angle of implants did not affect the overall precision of the final casts.[44]

Only a few studies have been conducted on the accuracy of digital implant expressions using TRIOS, OMNICAM, and True Definition scanners in patients with completely edentulous conditions. In an in vitro study, author compared the accuracy of digital impression techniques and conventional impression techniques using different variables in completely edentulous patients.[45] The master cast was an edentulous mandible with 5 implants. The variables to be tested are the effect of the splinting impressions copings, the level of the implant impression and the level of 3d accuracy of the digital impression. 5 groups were created and tested including: the splinted Implant Level; the non-Splinted Implant level; the splinted abutment Level; the non-splinted abutment level; the digital impression taken by TRIOS. The authors concluded that the digital impression is as accurate as the conventional implant impression and that splinted impressions are more accurate than non-splinted ones at implant level. On the other hand, splinting impression copings at the abutment level did not show any difference in accuracy.[45]

A systematic review was conducted to evaluate the data on the precision of IOSs for taking digital implant impressions and to identify the primary factors affecting the precision.[46] The review included sixteen studies, however only one was an in vivo study. Most of the studies showed an accumulation of mistakes in the digital workflow. The authors stressed that clinicians should be aware of the factors that influence the accuracy and the type of IOS selected for the intra-oral scan should be known. Factors discussed in the review include scan bodies; reference points; scanning technique and protocol; the IOSs hardware; and clinical aspects. In this systematic review, the single in vivo study showed that the absence of reference points /areas in the edentulous arch impairs the scanning process and compromises accuracy resulting in clinically unacceptable errors. The study further defined various intraoral and patient-related factors that can also impact the scan quality. These factors include saliva, scanning tip fogging, tongue, and mucosa as well as operator experience and patient related factors. In vitro studies showed different results. Unacceptable vertical discrepancies were observed in the milled cast from digital impressions. The accumulation of errors in the digital workflow resulted in the milling procedure being the primary source of inaccuracy rather than the digital impression. Research on the accuracy of new generation IOSs (True Definition, Trios) shows similar accuracy to conventional impressions for partially and fully Edentulous implants.

A systematic review compared the internal and marginal fit of digitally fabricated fixed restorations with restoration produced using conventional impression techniques.[47] They determined the impact of various variables on the fit accuracy. While their results were primarily based on in vitro studies, they found that the digital impression technique provided a better fit of permanent dental restorations compared to conventional techniques. IOS can therefore serve as an alternative to conventional methods.

**3D printing**

Digital technology in dentistry continues to improve over the years and opens new applications. CAD/CAM technology includes three main components. First, it begins by obtaining data with an IOS or by scanning the patient's physical cast with an extraoral scanner. Second, the data obtained is imported into CAD software to design the desired object. Finally, the data exported from the CAD software in the format of a STL file is transferred to the CAM part of the digital workflow to fabricate the object through subtractive or additive manufacturing.[48] Until recently, subtractive manufacturing has always been linked to the CAM element of the digital workflow. In subtractive manufacturing, the object is formed by milling it from a pre-fabricated block of the desired material.[49] The drawbacks of the subtractive technique include: lack of ability to generate fine details, as it is highly dependent on the milling burs' smallest radius and  significant waste of material associated with the milling which can reach up to 90%, and lack of the ability to produce a large number of objects per milling.[4]

3D printing, also known as additive manufacturing or rapid prototyping, is the process of building an object three-dimensionally one layer at a time.[50] The idea of 3D printing is not new; it dates back to the 1980s when Charles Hull successfully printed a 3D object for the first time. In simple terms, in 3D printing, the printer' software cuts the STL file of an object into several 2D layers in the X and Y planes. Then, the printer starts building layers on top of each layer gradually until the object is fully formed.[51] After printing, post-processing is necessary to complete the job. This process minimizes material waste and creates objects with high dimensional accuracy.[51]

The intrinsic properties of 3D printing technology make it very suitable for dentistry, where it has many applications. With 3D printing, dentists can easily print casts, surgical guides, and/or restorations.[52] 3D printers use different printing technologies, such as stereolithography (SLA), digital light processing (DLP), and photopolymer jetting (PPJ), which are the most commonly used technologies for dental applications.[49] Most SLA and DLP printers use the same printing process, but differ in the way they deliver curing light to the resin.

SLA Stereolithography is the most widely used and oldest method of Stereolithography.[53] In Stereolithography (SLA), an object is formed by using a laser beam of Ultraviolet (UV) light and susceptible liquid monomer. The light-curable material creates a thin polymer layer. In addition, a new layer is immersed in the liquid monomer, and a new layer is polymerized by the laser beam. The cycles repeat until a single layer is formed. The process creates a solid 3D object. One of the benefits of this process is that it prevents the polymerization of the cured resin by oxygen which can be avoided by submerging the cured resin in the liquid. Another advantage is that each new layer bonded to the previous layer via the reservoir liquid of the building platform, resulting in smooth surface layers and strong models.[54]

SLA printing technique, however, has a low printing rate because the curing time is dependent on the movement of the laser beam, and SLA also has a lower resolution compared to other methods. However, the accuracy of this technique is high enough to print objects with complex structure and appropriate dimensions.[53]

Digital light processing (DLP) is an alternative method used in 3D printers. Rather than printing individual layers, DLP utilizes digital micro mirror devices, which contain a micro system with a mirror arrangement. This enables the production of a conventional light source for the polymerization of sensitive liquid resins. The high resolution of DLP printing allows for printing a minimum size of 50 µm, with an associated LED lamp projecting the light source as individual pixels on the surface. The primary benefit of DLP technique is that each layer is cured by a single laser exposure, as opposed to scanning each area multiple times with the laser. This allows you to print relatively quickly to run the printer with high accuracy. [49, 51, 53]

Photopolymer jetting, also known as material jetting (MJP), is a type of 3D printing that uses a printing head with multiple nozzles to build up layers incrementally. The printer jets light-sensitive polymer onto a building platform that rises gradually and cures layer by layer using UV light.[51]

Until now, there have been very few studies in dental literature that evaluate the accuracy of 3D printing, especially in implant dentistry. However, there have been many recent studies that have evaluated the accuracy of this approach since the expiration of several additive process patents for 3D printing.[49]

Fused deposition modeling (FDM) is another 3D printing technology, though perhaps less well-known. FDM is a type of extrusion 3D printer because it's based on the extrusion of thermoplastic materials. The materials are pulled through a nozzle, where they are heated, melted, and then deposited one layer at a time on a build platform, with the nozzle moving horizontally and the platform moving vertically after depositing each new layer. The accuracy and speed of FDM is low compared to other 3D printing methods, and the final model quality depends on material nozzle thickness.[51]

Continuous liquid interface production (CLIP) is relatively new printing technology. CLIP is an advanced DLP technique. The principle of CLIP is that the photosensitive resin material is projected in a continuous rapid series of UV light images. The resin hardens by being exposed to UV light. The rest of the liquid – the unpolymerized resin – maintains a constant liquid zone because of oxygen inhibition, which guarantees a continuous rapid curing process. The main benefit of CLIP is its rapid printing capability. The 3D objects are able to grow continuously without interruption by controlling the oxygen flux.[55]

Until recently, there has been a limited amount of research in dental literature that has assessed the precision of each printing method in 3D printing, particularly in the field of implant dentistry. A systematic review of 28 studies on dental model accuracy was conducted to evaluate the accuracy of 3D printed dental models using different technologies. The study authors found that there are several factors that significantly influence the accuracy of the model, such as layer thickness, basic design, post processing, and storage mode. The authors concluded that, regardless of the printing technology used, all printers validated the use of 3D printers for printing dental models (SLA, DLP). However, some printers had lower error rates and were recommended for cases requiring higher accuracy.[54]

Although printed implant casts have not been extensively studied, one in vitro study looked at the accuracy of implant analogue position accuracy in casts printed with different 3D print technologies. The study included 2 MJP, 1 SLA and 1 DLP printer, and measured the position of implants in X, Y, and Z axes using CMM (Coordinate measurement machine). The results showed comparable DLP and MJP printer accuracy to conventional methods for fabricating casts.[56]

In comparison to traditional stone cast fabrication, the accuracy of printable implant casts from a IOS impression has been extensively studied.[57] The author compared edentulous arch printable casts from digital implant intraoral scans with stone cast from conventional impressions. They placed four abutment level implant analogs on mandibular stone casts, which served as the master cast, and scanned these digital casts to generate 25 printable implant casts. After digitally comparing the data by superimposing STL files, the authors found that implant 3D deviations from printed casts differ statistically significantly from master cast but are within acceptable limits for clinical use.[57]

**Fabrication of prosthesis**

A fixed implant supported prosthesis is intended to improve aesthetics and improve patient satisfaction with the dental implant procedure. With CAD/CAM, you can easily design and fabricate high-quality, long-lasting implant prostheses. The accuracy of fit has been demonstrated in several laboratory experiments. This is linked to the design of the implants. It has been demonstrated that implant CAD / CAM abutment and frameworks fit more accurately than traditional cast components.[58]

A comprehensive analysis of 54 studies that examined the fit of implant supported fixed frameworks that were fabricated using various prosthesis materials and methods was conducted.[10] The results of the study indicated that CAD / CAM fabricated implant frameworks, which are affixed to prefabricated cylinders, have the potential to overcome considerable inaccuracies that were generated by the fabrication process. Additionally, implant frameworks with CAD / CAM production tend to provide a reliable outcome. Additionally, this technique provides implant frameworks with a high-quality fit.[10]

As for the choice of implant prosthesis material, a study compared the mid-term and long-term survival of restorative materials in an FPD group (single crowns vs fixed partial dentures) (veneered titanium vs metal ceramic vs metal resin vs veneer zirconia). The author concluded that the choice of prosthetic material does not affect the survival of implants restored.[59] Tooth colored abutments are expected to provide better cosmetic results than metal abutments. This is one of the primary goals of implant dentistry (especially in the aesthetic zone).

A systematic review of zirconia includes 20 studies that were divided into subgroupings based on precision fit, mechanical and physical properties of the zirconia, abutment strength, and bio-compatibility characteristics.[60] The results of these studies suggest that zirconium abutments offer a satisfactory interface with implant prostheses, excellent biocompatibility, and a positive aesthetic outcome.

The technical complications and clinical outcomes with (CAD / CAM) implants supported by zirconia fixed complete prostheses are presented in Papaspyridakos et al. The study included sixteen edentulous arches of fourteen patients. The authors suggest that CAD/ CAM zirconia IFCDPs may be a suitable prosthetic option for both the implant and the prosthesis, with 100% survival up to a 4-year follow-up after prosthesis insertion. [9]

A narrative review by Michelinakis et al., of 72 peer-reviewed studies, evaluated the existing evidence for direct digital workflow in partially and completely arch edentulous patients treated with implant-assisted prostheses.[61] They also compared IOS accuracy with traditional implant impression procedures and provided clinical data on the success rate and survival of implant restorations using zirconia or lithium disilicate. The authors identified several variables that affect IOS accuracy for fixed implant supported restorations, including scanner type, design properties of the scan bodies, and clinical variables such as operator experience and implant stimulation. However, the majority of the new generation scanners provide discrepancy values below 150 μm which is currently acceptable in clinical practice. Furthermore, the review cited numerous studies on implant restorations produced using the direct digital workflows and their survival.

In recent clinical studies, full digital workflows have been described to produce a prototype prosthesis before the final full-arch fixation implant rehabilitation. Double digital scanning is used for a full digital workflow to produce prosthesis prototypes.[62] In vitro study assessing the complete digital workflow for complete-arch prosthesis prototype fabrication for all-on-four implants case scenario. The author concluded, that digitally fabricated prototypes produce accurate fit and 3D printer influence the accuracy of prothesis fit.[63]

To the authors knowledge, there are no studies assessing the complete digital workflow for complete-arch (All-on-6) prosthesis prototype fabrication. The purpose of this in vitro study was to assess, if completely digitally fabricated printed prototypes present with accurate fit for all-on-six maxillary immediate loading treatment. The primary outcome measure was the assessment of accuracy of fit of the digitally fabricated prosthesis prototypes. The secondary outcome was to compare the effect of two different three-dimensional (3D) printers on the accuracy of fit of the prosthesis prototype.

**Aim & Hypothesis**

**Aims**:

To test whether or not digitally fabricated (from two different 3D printers) prosthesis prototypes exhibit acceptable accuracy of fit on the master cast, and to compare the 3D printers in terms of accuracy of fit.

**Hypothesis:**

The digitally fabricated prosthesis prototypes (from two different printers) generated from a complete digital workflow via the double digital scanning technique will exhibit acceptable accuracy of fit on the master cast. The Form 3b+ and Carbon M2 printers will be equally accurate in comparison to each other.

***Materials and Methods:***

A maxillary stone cast with 6 abutment-level implant analogs (SRA, Straumann) with adequate antero-posterior (AP) spread simulated a common clinical condition (Figure 1). This stone cast served as the master (reference) cast for taking digital impressions. A screw-retained prototype prosthesis was fabricated on the reference master cast following the Pro-Arch concepts. The double digital scanning (DDS) technique was used to generate two STL files, then merged with aid of CAD software into one master STL file. The master STL file was used to print digitally fabricated prototype from 2 different printers (Form 3b+ and Carbon M2). A flowchart of the study is illustrated in (Figure 2).

**Implant Impression Procedures**

Digital impressions with Optical Confocal Microscopy Technology

Twenty repeated digital impressions (n=20) were scanned with a white light IOS (TRIOS) at abutment level for calibration purposes (figure 3). Plastic multi-unit implant impression scan bodies (Mono scan bodies, Straumann) were connected to the implants on the control master cast and hand tightened (Figure 4). After the calibration phase, 1 master digital scan exported as Standard Tessellation Language (STL) files and saved.

**Groups (3D printed protypes)**

The master STL file were generated from the digital TRIOS scan used to fabricate 2 groups of 3D printed prototypes each (n=31). The groups labeled 1a and 2b. two different 3D printers will be used to print the prototypes: Form 3b [Form 3b+, Form labs, MA, USA] and Carbon M2 [M2 Carbon 3D CLIPTM printer, CA, USA] (Figure 6).

**ACCURACY ASSESMENT PROCEDURES**

**Radiographic assessment**

Radiographs were taken for each prototype including the master cast to assess the accuracy of fit on each screw-retained abutment. Prior to taking each radiograph, the prototype torqued to 15 Ncm to simulate the clinical scenario (table 2).

**Laboratory Analysis; Accuracy of Fit Assessment**

A prosthesis was fabricated on the master cast (Figure 6,7). The Variobases (Variobase for bridge for SRA, Straumann) were cemented to the prototypes using cyanoacrylate cement (Figure 6). The accuracy of the fit of the prototypes was tested on master casts. Two experienced blinded clinicians tested the accuracy of fit of the framework on all prototypes using the screw-resistance test. For each prototype to be tested, the prototype was placed on the SRAs, the prosthetic screws were placed and hand-tightened in a sequence from one terminal abutment to the another. If complete seating required more than quarter a turn of the screwdriver after initial resistance was felt, it was deemed a misfit.

## STATISTICAL ANALYSIS

A sample size calculation was conducted using R v. 4.1.1 (R Core Team, Vienna, Austria). The anticipated accuracy rates for Carbon M2 and Form 3b were based on the findings of Papaspyridakos et al. [63] The calculation determined that to detect a difference of 20% in the accuracy rates between these printers, a sample size of n=31 per group was adequate to obtain 80% power in conjunction with a Type I error rate of .05.

Using SPSS (IBM Corp), Descriptive statistics (frequencies and percentages) will be calculated for each group. Chi square will be used to assess statistical significance. The significance level will be set at $\alpha$=.05. SPSS version 28 (IBM Corp., Armonk, NY, USA) will be used in the analysis.

## Result

Using SPSS (IBM Corp, Armonk, New York, NY), descriptive statistics were calculated for each of the 2 groups. The Accuracy of fit for Carbon and Form lab printers were measured by Chi square test for the association between groups and fit assessment (Table 1,2). Agreement between the two blinded experienced clinicians (KR and PP) were assessed with Cohen's kappa score of 1, indicate complete agreement. The screw-resistance test performed in the Carbon group, 25 out of 31 printed prototypes had an acceptable fit (80.65%) and 6 prototypes misfit (19.35%) (Table 1). Similarly, acceptable fit was observed in the Form 3b lab group 26 out of 31 prototypes (83.87%) and 5 prototypes exhibit misfit (16.13%) (table 1).

Chi square test indicated that there was no statistically significant association between groups and accuracy of fit as the p-value being 0.7396 >0.05. Out of the 62 printed prototype prostheses by the 2 printers, 51 (82.26%) had an acceptable fit and 11 prototypes misfit (17.74%) (Table 1,2).

## Discussion

The purpose of this in vitro study was to assess if completely digitally fabricated printed prototypes present with accurate fit for maxillary all-on-6 case scenario and to compare the accuracy between the two 3D printers. The findings of this study showed that out of the 62 digitally fabricated prosthesis prototypes from the double digital scanning, 51(82.26%) presented with accurate fit under in vitro assessment. The accuracy of fit ranged from 80.65% (25/31) for Carbon M2 to 83.87% (26/31) for Form 3b printers' group. The hypothesis of this study was accepted as the two printers (Form lab 3b, Carbon M2) exhibit similar accuracy of fit on a reference cast and statistically no significant difference between the two printers in comparison to each other. Even though 11 of 62 fit failures were unacceptable, these findings show how important it is to make verification jig, even during full digital workflow.

The study compared two 3D printing technologies: stereolithography technology (SLA) as used in the Formlabs form 3b printer and CLIP technology (Continuous Liquid Interface Production™) in M2 Carbon printer. Another in vitro study was conducted to determine the degree of accuracy of 3D printed dental casts using CLIP and DLP technology.[55] The intraclass correlation coefficient (ICC) was calculated to measure the level of accuracy of the dental casts produced using the CLIP technology printer. The study found that casts produced with the CLIP technology showed significantly less variation than those produced with the DLP printer.[55} In another in vitro study using DLP and SLA printing technology, 20 casts were printed with 2 implants placed 5° apart in the anterior maxilla as the reference cast. The Build angle was 45° for both printers, according to this study the DLP shows the least deviation and SLA shows the highest deviation.[64]

However, according to this study, the 3d deviation is within acceptable parameters and the 3d printed models are within the acceptable range.

There are several AM (additive method of manufacturing) related factors reported in the literature that may influence the accuracy of a printed object, such as: Build angle, Resolution and Printer speed.

Regarding the building angle, an in vitro study evaluated the impact of the building angle on the accuracy of a 3D dental restoration.[64] The build angle was 45°, allowing for parallel implant platform placement to the build platform. Based on numerous printing trials, the authors reported consistent results with no deviations from the build angle. As far as the CLIP printing method is concerned, another in vitro study showed that the printer failed to print on 45° after multiple attempts.[65] Therefore, according to the literature, the angle of the building is 180° for M2 Carbon Printer.[55] In our study the building angles were 45° for SLA printer and 180° for CLIP printer.

In 3D printing, resolution becomes more complicated because it involves three dimensions: the 2D horizontal plane, X, Y, and the vertical Z plane, which represents the thickness of the layer and is preset by the manufacturer, Therefore, the choice of printer must be based on the printer's performance in all three planes. The X and Y planes of SLA printers are determined by the diameter of the laser beam produced. On the other hand, CLIP printer photosensitive resin material is projected in a continuous rapid series of UV light images. The resin hardens by being exposed to UV light. [55, 65]. In another in vitro study, the resolution was set at 100 µm for 3 printers (M2 Carbon, Formlabs Form 3b+, BEGO Varseo S) except Straumann P30+ was 50 µm. The author found that M2 Carbon printer had a better accuracy in comparison with other printers.[65] In this study the resolution for the Carbon M2 printer and Form lab 3b+ was set on 100µm of layer thickness for better resolution. There is no statistical difference between the two printers in our study were the two printers exhibit similar accuracy.

Another factor to reflect is the printing speed, as the literature disclosed no reference of the effect of printing speed on the accuracy of the model. However, Abdeen et al,[65] found that the printing speed of M2 Carbon printer is faster than Formlab 3b+ printer as Five models produce per cycle in comparison to 3 model for Formlab 3b+ printer. Which consistence with this study as more prototypes produces per cycle by M2 Carbon than Formlab 3b+ printer.

A recent study by Papaspyridakos et al, evaluated the accuracy of complete digital workflow for fabricating printed prototypes in all-on-4 case scenario generated from three different printers. (63) The finding of this study indicates accuracy of fit ranges from 87% of Sprintray pro95 printer to 100% for the Form 3b+ and M2 Carbon printers. The authors of the study highlighted that errors during the wash and cure original, during alcohol bath cleaning step and post processing could lead to accumulation of errors resulted in 87% accuracy of fit for Sprintray pro95 printer in comparison to 100% accuracy of fit for the Form 3b+ and M2 Carbon printers. In the present study, the same digital workflow protocol applied in all-on-6 case scenario fabricating prototypes from two different printers (Form 3b+ and M2 Carbon). However, The accuracy of fit ranges from 80.65% for M2 carbon to 83.87% for Form 3b+printer which is less accurate in comparison to Papaspyridakos et al study. It can only be hypothesized that that Increased number of implants in all-on-6 case scenario, the angulation divergent between implants and angulation of printing for prototypes lead to less accuracy. Also, the offset clearance for the titanium inserts in the designing phase of prototypes was not accurate could of lead to inaccuracy in our study.

As far as the practical lab accuracy evaluation component is concerned, the test method chosen was the screw resistance test. The primary reason for selecting the screw resistance test over other test methods, such as the one screw test, is the clinical relevance that the screw resistance test has over the one screw test. The results revealed that 6 out of 31 of Carbon printer prototypes show misfits on reference cast and 5 out of 31 of From lab 3b printer shows Misfit on master cast with not statistically significant chi square test p-value $0.7396 > 0.05$. Therefore, the hypothesis was accepted as both printers exhibit similar accuracy.

The radiographic fit analysis showed gaps or apparent misfits in the printed prototypes of both groups, consistent with screw resistance test. However, some of the misfit prototypes was not detected completely in the radiographs. One of the possible explanations, and perhaps one of the limitations of this study, is that the printed resin material is very flexible. In contrast to the traditional prothesis, printed resin prototypes may enable the analogs to move within the cast due to the torquing of the prosthetic screw at 15Ncm. Cyanoacrylate is used to hold the abutment titanium in place, but some degree of displacement within the resin material can't be completely ruled out. In this study, the type of resin used, and the post print process were done according to the manufacturer's instructions to minimize error. Further efforts done to standardize and minimize errors included the following:

- The same IOS (TRIOS) was used to take the digital impressions of all prototypes.
- The screw-resistance test was completed by two blinded experienced clinicians, and both arrived at the same result for each prototype.

- All the laboratory work, including preparing the master cast, taking the digital impressions, using the EXCOCAD software and completing the superimposition in EXOCAD, and taking all the radiographs, was done by a single operator.
- The same technique and sequence of scanning was done for all digital impressions.
- The same 6 scan bodies were used for all Impression.
- While taking the radiographs, a radiographic ring positioning system was used, and the same exposure parameters were set for all casts.

. Possible limitations of this study include the following:

- The use of an intra-oral scanner in a laboratory setting, thus eliminating factors such as saliva, tongue, space issue, and location of implant, which are known to affect scanning quality and accuracy of the digital impression.
- Another limitation may be that only 2 3D printers were used in the study; these may be more inaccurate in terms of accuracy compared to other printers on the market. Also, in term of the flexibility of the resin material used in printed prototype prostheses can also be a limiting factor, even if the prototypes are thick enough.
- Only one clinical scenario was tested representing an all-on-six cases.

**Clinical implications**

The study investigated a common clinical scenario of an edentulous maxilla with six implants. The finding of this study shows that 11 out of 61 prototypes printed with misfits and both printers had similar and acceptable accuracy, which can be helpful to aid in fabricating fixed prothesis.

However, the fact that 11 out of 62 prototypes were misfits highlights the importance of verification jig for full arch cases in complete digital workflow. This can be done through different techniques for example, intraoral splinting of impression comping then connecting implant analogs before pouring the verification cast or utilizing the converted prosthesis and connecting the analogs and pour it to create the verification cast. The verification cast will be utilized to ensure prosthesis passivity, quality assessment and aid in titanium cementation processes for prosthetic restorations. The precision of fit of prototypes and definitive prosthesis are essential for long term success, as it has been shown that complications with IFCDPs are frequent and time dependent, even when all prosthodontic procedures are performed according to strict protocols. [25]

Further research and clinical studies needed to evaluate the accuracy of digitally fabricated prosthesis. This will give valuable data on the clinical fit and, enable clinicians to measure the degree of misfit of the framework.

## CONCLUSION

Within the limitations of this in-vitro comparative study of a completely edentulous maxilla with six abutment-level implants, the following conclusions may be drawn:

- Fifty-one (82.26%) out of the 62 digitally fabricated prototypes from double digital scanning presented with accurate fit under in vitro assessment.
- The accuracy of fit ranged from 80.65% (25/31) for M2 Carbon printer group to 83.87% (26/31) for Form 3b printer group.

Radiographic evaluation did not demonstrate any variation in comparison to the screw resistance test on all the groups.

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*APPENDICES*

## APPENDIX A: Tables

### Table 1: A

| Table of Group by Fit Y/N | | | |
|---|---|---|---|
| Group (Group) | Fit Y/N (Fit Y/N) | | |
| Frequency<br>Percent<br>Row Pct<br>Col Pct | 0 | 1 | Total |
| Carbon | 6<br>9.68<br>19.35<br>54.55 | 25<br>40.32<br>80.65<br>49.02 | 31<br>50.00 |
| Form lab | 5<br>8.06<br>16.13<br>45.45 | 26<br>41.94<br>83.87<br>50.98 | 31<br>50.00 |
| Total | 11<br>17.74 | 51<br>82.26 | 62<br>100.00 |

| Statistic | DF | Value | Prob |
|---|---|---|---|
| Chi-Square | 1 | 0.1105 | 0.7396 |

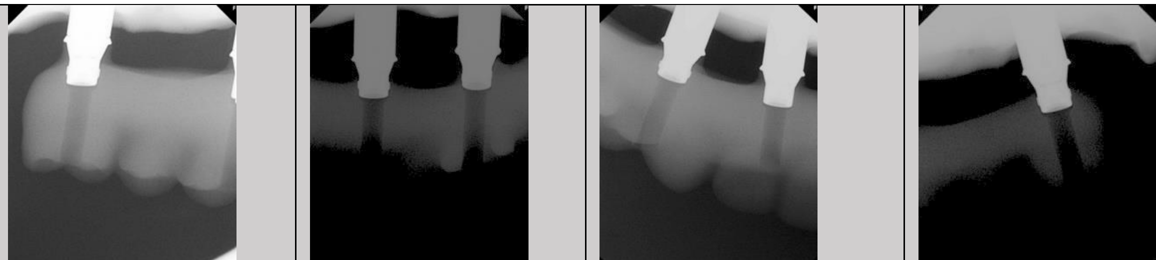
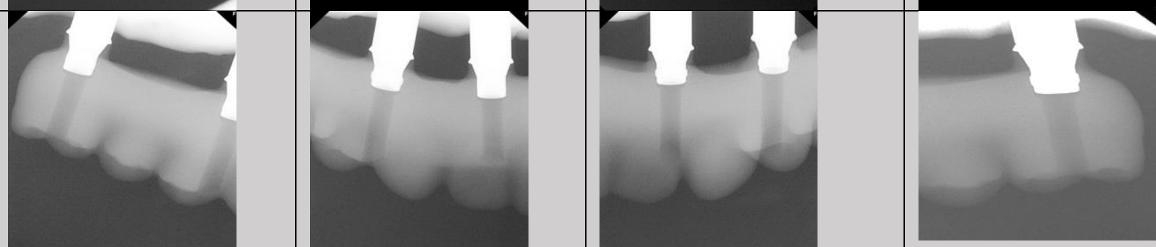
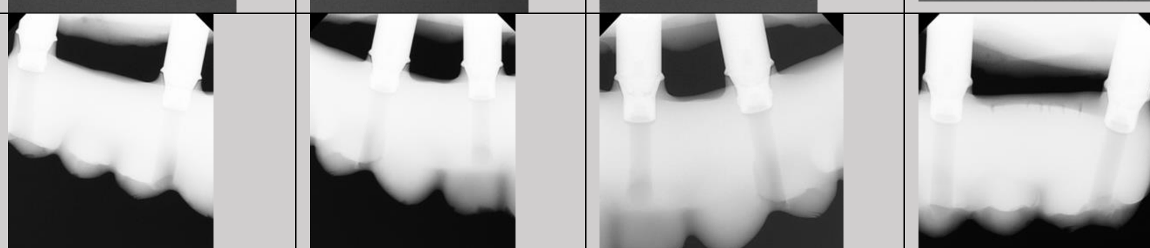
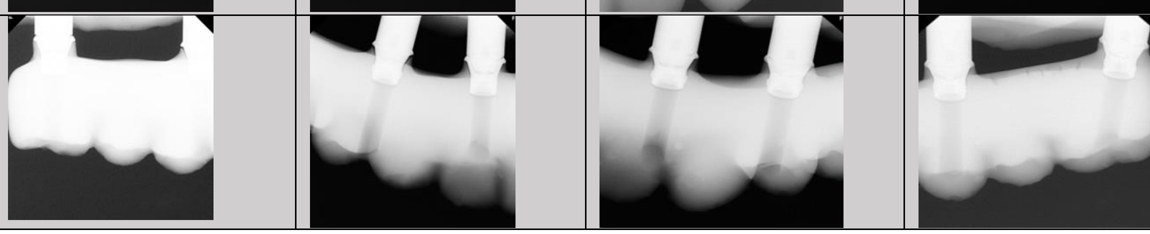
- The p-value of the chi square test, the p-value being >0.05 shows that there was no statistically significant association between group and accuracy if fit.

Table 1: B

| Group | Misfit | Acceptable Fit |
|---|---|---|
| Carbon M2 | 6 | 25 |
| Form3B Formlabs | 5 | 26 |
| Total | 11 | 51 |

Screw-resistance test (groups: Carbon M2, Form3B Form 3b).

Table 2:

| Groups | |
|---|---|
| **A** |  |
| **B** |  |
| **C** |  |
| **D** |  |

Radiographs of prototypes corresponding to the number of the implants showing the junction between the abutment and prosthesis (Form 3B+, M2 Carbon):
A. misfit M2 Carbon printed prototype, B. acceptable M2 Carbon printed prototype, C. acceptable Form 3b+ printed prototype, D. misfit Form 3b+ printed prototype.

# APPENDIX B: Figures

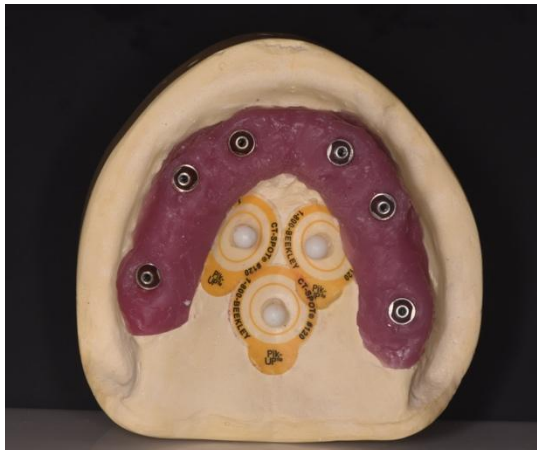


Figure 1. Master cast of an edentulous maxilla with six implants with Screw-retained abutments (Straumann, SRAs) and fiducial markers, prior to digital scans.

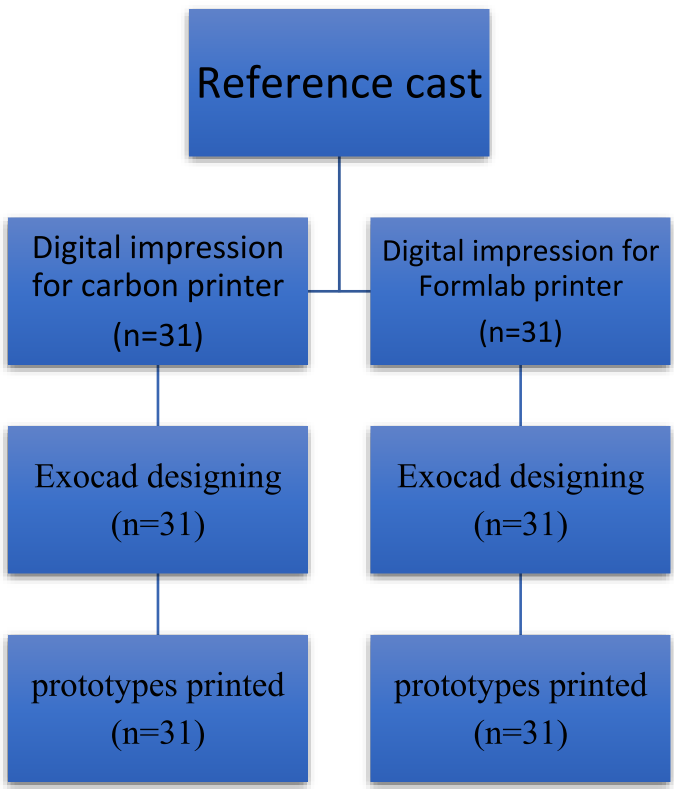



Figure 2. Study flowchart

Figure 3. The TRIOS 4 (3 Shape) Intra-Oral Scanner IOS

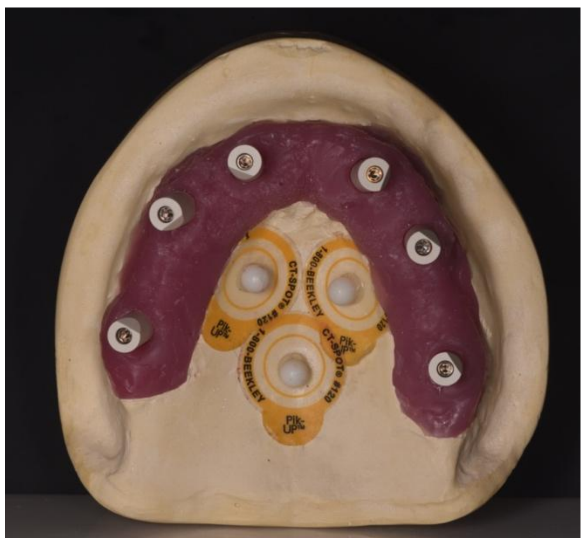
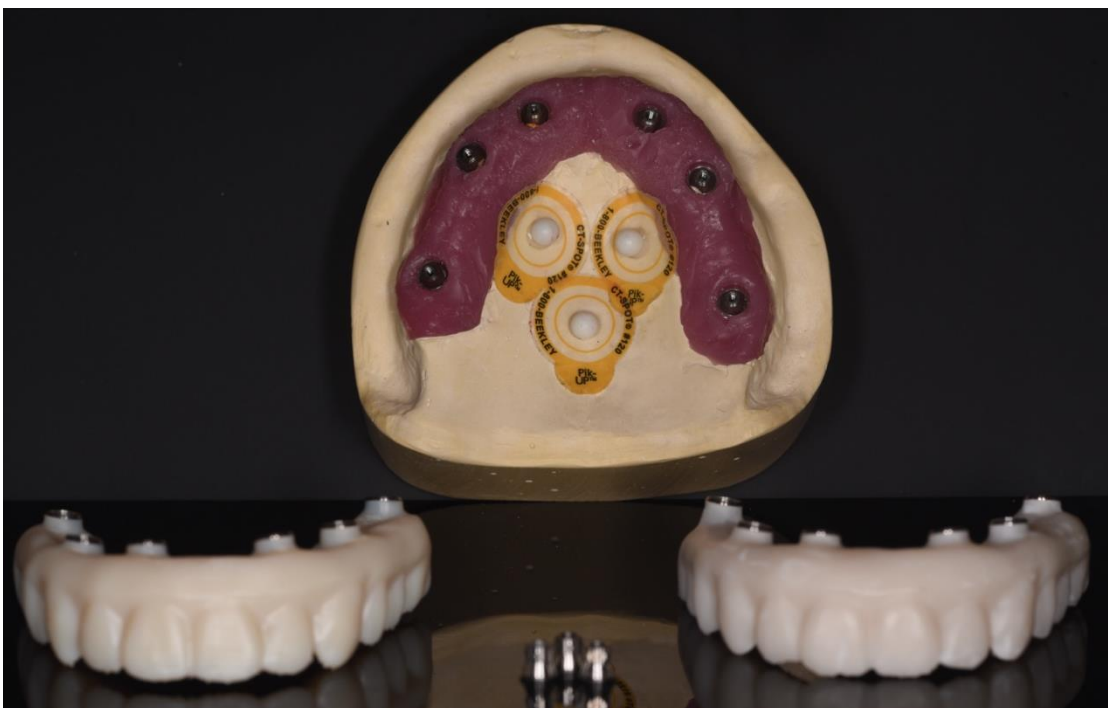



Figure 4. Master cast with CARES Mono scan bodies attached to the SRAs prepared for scanning procedure.


A B

Figure 5. The 3D printers used in the study. A; Form3B by Formlabs, B; Carbon M2



A B C

Figure 6. The printed prototypes in the study. A; Form 3B+ prototype, B; The titanium inserts (Variobase for bridge for SRA, Institute Straumann AG, Basel, Switzerland), C; Carbon M2 prototype.


Figure 7. Digitally fabricated prosthesis prototype placed on the master cast.

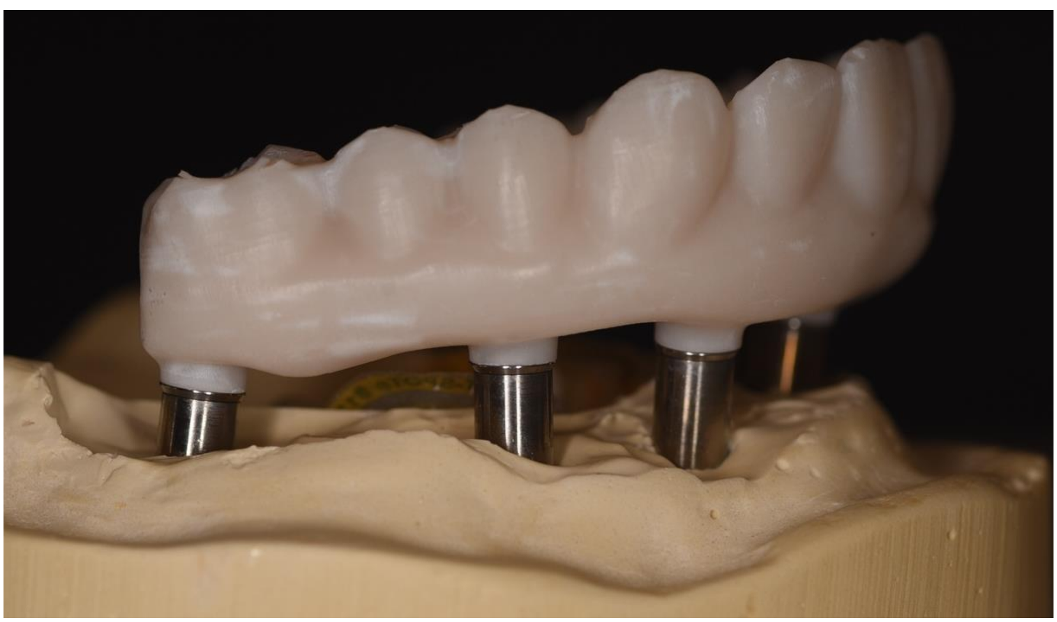


Figure 8. Accurate fit with the adequate seat of the prototype onto the multiunit abutments (SRA) of the master cast.

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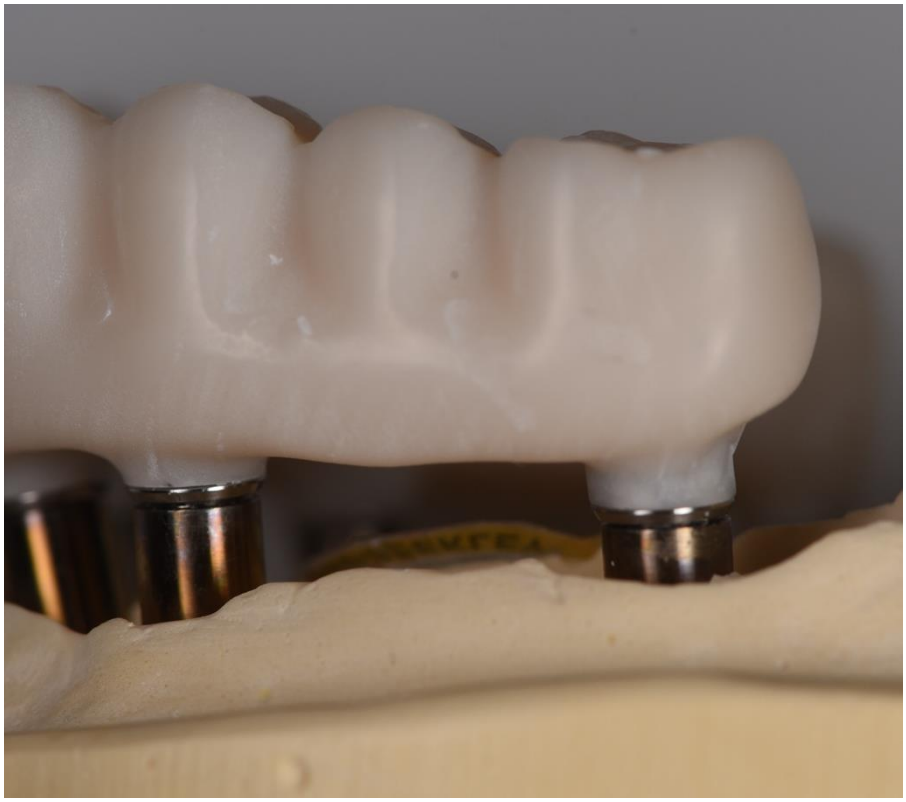

Figure 9. Non-accurate fit is shown with the gap between the printed prosthesis prototype and multiunit abutments (SARS).