Evaluation of the Accuracy of Three Different Materials Used to Fabricate Dental Implant Verification Jigs

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Hesham S. Al-Madani, B.S

THESIS COMMITTEE

Thesis Advisor

Panos Papaspyridakos, D.D.S., M.S., Ph.D., Assistant Professor
Department of Prosthodontics and Operative Dentistry
Tufts University School of Dental Medicine

Committee Members

Hans Peter Weber, D.M.D., Dr.Med.Dent., Professor
Department of Prosthodontics and Operative Dentistry
Tufts University School of Dental Medicine

Yong-jeong Kim, D.M.D., M.S., Associate Director
Department of Prosthodontics and Operative Dentistry
Tufts University School of Dental Medicine

Khaled El Rafie, D.M.D., F.A.C.P., Clinical Instructor
Department of Prosthodontics and Operative Dentistry
Tufts University School of Dental Medicine

Matthew Finkelman, Ph.D., Associate Professor
Department of Public Health and Community Service
Tufts University School of Dental Medicine

ABSTRACT

Aim & Hypothesis: The accuracy of transferring dental implant position from the patient's mouth to the master cast is important to achieve long-term successful treatment. All implant-supported prosthesis casts need to be verified before fabrication of the framework. The primary aim of this study was to assess different materials in terms of their performance in transferring the implant position by comparing the dimensional accuracy of test casts fabricated by using verification jigs made of GC resin, test casts fabricated by using verification jigs made of Triad light cure resin, and test casts fabricated by using verification jigs made of Fixpeed resin with the control cast. The secondary aim was to compare the accuracy of test casts fabricated by using parallel and angulated implants within each material (within each group). The hypotheses were that the test casts fabricated by using Triad light cure verification jigs would be more accurate than the test casts fabricated by using Fixpeed resin verification jigs and the test casts fabricated by using GC resin verification jigs and that parallel implants would have more 3-dimensional accuracy than angulated implants.

Materials & Methods: A PMMA blank representing an edentulous mandibular arch was prepared, and 5 internal connection implants (Straumann Tissue Level RN, Basel, Switzerland) were placed. The implant distribution included three implants in the anterior region, and two implants in the posterior region. The three implants in the anterior region were parallel to each other and the two implants in the posterior region were distally tilted bilaterally 20 degrees. Verification jigs were fabricated with three different materials by using prefabricated bars, representing three different groups. Every group included 15 specimens. These 45 verification jigs were fabricated from the master model to make 45 verification jig casts (test casts) using low expansion type IV (Resin Rock) stone for three different groups of 15 specimens each (n=15). Distortion was recorded as root mean square.

Results: After comparing the three groups in this study the results were: Group 1 (GC Resin) had a mean (SD) value of 36.59 (12.47) μm; Group 2 (Fixpeed Resin) had a mean (SD) value of 35.9 (10.13) μm; Group 3

(Triad Gel) had a mean (SD) of 34.12 (7.10) μm. One-way ANOVA showed no statistically significant difference between groups (P=0.790). For the second analysis, which was the comparison of parallel and tilted implants within each group (GC Resin, Fixpeed Resin, and Triad Gel), Group 1 (GC Resin) parallel had a mean (SD) value of 35.65 (12.30) μm; tilted had a mean value of 38.00 (13.02) μm. In Group 2 (Fixpeed Resin), parallel had a mean (SD) value of 33.85 (8.77) μm; tilted had a mean of 39.05 (12.62) μm. In Group 3 (Triad Gel), parallel had a mean (SD) value of 33.28 (7.47) μm; tilted had a mean (SD) value of 36.03 (7.12) μm. Data were normally distributed for Groups 1 and 3 (GC Resin and Triad Gel), but not for group 2 (Fixpeed Resin). The difference between parallel and tilted was significant for all three groups: GC Resin (P=0.024; paired t-test), Fixpeed Resin (P=0.002; Wilcoxon signed-rank test), and Triad Gel (P=0.002; paired t-test).

Conclusions: There were no statistically significant differences between the three materials in regards to the 3-D distortions of the test casts fabricated by using GC Resin, Fixpeed Resin, and Triad Gel verification jigs. The 3-D distortion value in comparison between parallel vs. tilted implants showed that parallel implants had significantly less 3-D distortion compared to 20 degrees tilted implants.

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Introduction

Oral rehabilitation of partially and completely edentulous patients with dental implants is currently routine procedure and clinical studies have proven the longitudinal effectiveness of this treatment modality [1, 2]. Due to the fact that endosseous implants are functionally ankylosed with direct contact to the bone, they lack the inherent mobility of the periodontal ligament. Hence, they cannot accommodate distortions or misfit at the implant-abutment interface [3]. Although absolute passive fit of implant fixed complete dental prostheses (IFCDPs) is not yet attainable, it is still unclear what degree of prosthesis misfit will lead to biologic or technical complications [4, 5]. Screw loosening and/or fracture, implant fractures and prosthetic components strain and fracture have been related with prosthesis misfit [6, 7].

The clinical fit of an implant prosthesis at the implant-abutment junction is directly dependent on the accuracy of impression technique and cast fabrication [3-5]. Hence, an accurate implant impression is necessary, in order to generate an accurate definitive cast. An accurate definitive cast is the milestone for the fabrication of an accurately fitting prosthesis. The advent of computer-assisted design/computer-assisted manufacturing (CAD/CAM) technology improved the framework fabrication procedures and increased the precision of fit of implant prostheses [8, 9].

Accuracy of transferring the correct 3-D position of the dental implants from the patient's mouth to the working cast is needed to have long-term success, because inaccurate implant impressions can lead to a misfit of the implant-supported prosthesis, which can result in complications and/or implant failure. Up to now, a variety of methods and techniques have been used to transfer the implant position to the master cast [10].

One of the techniques of confirming the accuracy of the implant impression and generated cast is the implant verification jig. The benefit of using a verification jig is confirming that the working cast is accurate and hence, an accurately fitting prosthesis can be fabricated. The level of clinically acceptable misfit is currently unknown. Jemt & Book reported that a range from 91 to 111 μm for one-piece abutment-level implant-supported fixed complete dental prostheses (IFCDPs) is acceptable [5]. Papaspyridakos et al. showed that for an external connection implant system used in a clinical study a 3-D misfit ranging from 59 to 72 μm of 3-D misfit can be considered as maximum discrepancy resulting in acceptable clinical fit with one-piece implant-supported fixed complete dental prostheses (IFCDPs) [10].

There are varies materials that have been used to fabricate verification jigs, namely, heat cured acrylic resin, light cured acrylic resin, and self curing acrylic resin. Currently, there is no consensus as to which is better. The objective of the present in vitro study was to compare the accuracy of verification jigs made using three different materials.

Literature Review

1. Passive Fit of Implant-Supported Frameworks

Definitions of Passive Fit:

Passive fit of implant-supported prostheses defined as an even contact between the implant-abutment junction with no stress and no adverse occlusal loads being applied on the implants, the prosthetic components and the supporting bone.

Many authors have defined passive fit of implant-supported frameworks, but these definitions are not based on strong scientific evidence. According to Branemark, implant framework passive fit was defined as a gap between framework and abutments of < 10 μm [14]. According to Patterson, passive fit is achieved when no gap is present between superstructure and abutment after the screws are torqued [15]. According to Jemt, passive fit was defined when the gap between abutments and superstructure is less than 150 μm, and no more than half a turn is needed in order to torque the prosthetic screws from 10Ncm to 15 Ncm [16]. Klineberg and Murray defined passive fit when a framework presented with gap up to 30 μm at the implant-abutment junction [17]. Jemt and Book reported that a range from 91 to 111 μm for one-piece abutment-level implant-supported fixed complete dental prostheses (IFCDPs) is acceptable [5]. For one-piece implant-level IFCDPs, Papaspyridakos et al. reported that the maximum discrepancy resulting in acceptable clinical fit ranged from 59 to 72 μm [10]. However, there is no consensus regarding the acceptable 3-D misfit, and further studies are necessary.

Causes of Framework Misfit

Several factors may affect the accuracy of fit of implant-supported frameworks, such as impression making, impression techniques, impression materials, die materials, framework materials and fabrication methods, and technician/dentist skills [18,19].

Additional factors may enhance the risk for a framework misfit, namely the length of the framework span; increasing the framework span length will likely increase the degree of misfit, also increasing the number of implants could be another factor that can cause a framework misfit [20, 21]. Clelland et al. reported that marginal gaps up to 500 μm were not detectable by using an explorer and tightening the screws of the 2-implant-supported framework to 10 Ncm was enough to close the gap [21]. However, the finite element study reported that the presence of 111 μm vertical gap had a significant impact on stress distribution in implant components and surrounding bone. [22].

There is no solid evidence clinically or radiographically that indicates framework misfit can cause bone loss. According to Kallus et al. in a 5-year retrospective study done on 236 patients with IFCDPs, gold abutment screw loosening was associated with poor framework fit [23]. An animal study by Carr et al. reported similar results with no difference in bone comparing two amounts of misfit, 38 μm and 345 μm without occlusal loading [24]. Jemt and Book performed a clinical and radiographic study on two groups of patients with maxillary implant-supported fixed complete dental prostheses (IFCDPs). The first group showed a mean gap of 111 μm, and the second group showed a mean gap of 91 μm. The first group of the study was prospectively followed and the second group was retrospectively evaluated. The findings showed no correlation between framework misfit and loss of marginal bone [5].

Several studies mentioned the presence of a biological tolerance between bone and implants [25]. Previous studies also suggested techniques in order to minimize the misfit during the fabrication of a screw-retained implant-supported framework by using different impression methods, verification jigs [26], low fusing metal casting [27], casting a framework in sections [28], master reference casts [28], and CAD/CAM technology [8,9].

2. Methods to Assess the Framework Misfit

There are various methods for assessing the fit of screw-retained implant prostheses, but the single screw test (SST) remains a simple and popular method to be used for both clinically and in the dental laboratory [16,34]. For the quantitative assessment of vertical gaps, some *in vitro* studies have employed microscopic measurements [42]. Qualitative assessment of the vertical microgap was performed with the single screw test (SST) in the present study [43,44,55-59]. Some studies have emphasized the importance of vertical fit, while other studies have reported that the rotational misfit may be more detrimental [43,44,58,59].

Single screw test (SST) and digital bitewing radiographs are used to assess the clinical fit in everyday clinical practice. Radiographs are taken perpendicularly to the implant abutment-framework interface, in order to eliminate the effect of x-ray tube inclination to radiographic detection of marginal misfit, since inclination of more than 15 degrees may skew the readings and hinder detection of marginal gaps [34,43,44,58,59]

Clinicians have been using different techniques to evaluate the degree of misfit in implants framework, but none of these techniques have been set as standard method. The accuracy and

specificity of each of these methods can be affected by several factors [34]. According to jemt, the single screw test (SST) is a useful method to evaluate the framework fit by tightening the screw at one terminal implant and observing any misfit or marginal opening at the other abutments on the non-screwed side [16]. This technique can be improved to evaluate the framework misfit when combined with direct vision, tactile sensation, and radiographs. According to Henry, the alternate finger pressure method can be used to detect any movement or rocking of framework by applying pressure at each end of the framework alternatively [29]. According to Adell et al. the alternate finger pressure technique may be combined with the observation of saliva movement in order to enhance the accuracy of the aforementioned method [30]. An explorer can be a useful tool for tactile sensation and direct vision, but is not easy to evaluate the framework misfit if it is hidden by soft tissue; however, using magnification and ample lighting can enhance this method [29,31,32]. Several factors can affect the sensitivity of this technique such as the clinician's visual accuracy, the explorer tip size and the marginal location.

Periapical and bitewing digital radiographs are routinely used in order to assess framework fit at the implant-abutment interface [33]. Radiographs must be taken perpendicular to the implant-abutment interface, in order to eliminate the effect of x-ray tube inclination to radiographic detection of marginal misfit, since inclination of more than 15 degrees may skew the readings and hinder detection of marginal gaps [33].

In detail, Jemt's the single screw test (SST) requires that the clinician tighten at 15 Ncm the prosthetic screw of the most distal left terminal implant of the screw-retained framework, standardizing the side of tightening. The single screw is unscrewed if the framework is seated passively and then the procedure is repeated at the other terminal implant. The vertical fit

interfaces between implant abutment/framework are measured on both sides and are termed screwed and non-screwed side [16].

Jemt introduced the screw resistance test (SRT) on the basis that 150 μm is an arbitrary acceptable vertical discrepancy and is half the distance between prosthetic gold screw threads [16]. The protocol consisted of tightening every gold screw individually until initial finger resistance was achieved. A misfit was diagnosed if more than half a turn (180°) was needed to torque the prosthetic gold screw from 10 to 15 Ncm [16].

In detail, Jemt's screw resistance test (SRT) for assessment of framework fit includes tightening the prosthetic screws, one by one, starting with one of the intermediate implants on one side of the midline. This first screw is brought down until the first resistance is observed. At this point, the position of the screwdriver is identified before the screw is completely tightened. The clinicians are instructed to use a tightening force of 15 Ncm. A maximum of half a turn (180°) is allowed for final tightening of the prosthetic screw. The next tightened screw is the prosthetic screw closest to the midline on the other side of the first screw, using the same technique. The remaining intermediate screw is then tightened and eventually the two terminal prosthetic screws are tightened [16]. Jemt considered a framework to have misfit if more than one half turn is needed to achieve final torque [16].

Disclosing media or materials have been utilized to evaluate the framework fit, such as pressure indicating past, fit checker and elastomeric materials [32]. Additionally, 3-D photogrammetric systems have been utilized to detect up to 10 μm discrepancies. Also measurable thickness materials can be utilized to detect the framework fit such as shim stock and dental floss [25]. Most of the aforementioned methods and techniques mentioned are done chairside by the dentist [34].

Strain gauge analysis is another method that may be utilized to assess the framework fit in the laboratory. In detail, the strain gauge contains wires arranged in pattern, which will be attached to the framework. These wires can detect sensitive strains caused by misfit of the framework. However, this technique has a weak point, in that the wires measure the strain only where the strain gauges are attached [35]. An additional method to assess the framework fit is the photogrammetric technique, which was introduced by Lie and Jemt [19]. In detail, this method is based on 3-dimensional orientation measurements, utilizing a small camera with a modified lens to produce three images of each object from one shot. This method provides 3-dimensional accuracy by measuring a small gap as 30 μm [19]. A coordinate measuring device has been used in some research laboratories to evaluate and measure implant framework fit. This technique utilizes a three axes probe for X, Y, and Z planes. The coordinate measuring device measures the distances and heights of each implant analog or the framework dimensions and then calculates the data by utilizing computer software with precision up to the level of 1 μm [36].

3. Factors Affecting the Fit of the Framework

Misfit at the implant-abutment junction has been suggested to result in complications, including screw loosening/fracture, ceramic veneer fracture, and potentially implant fracture and crestal bone loss [5,7, 9,18]. Hence, every attempt should be made to ensure that an accurate master cast is produced in order to generate an accurately fitting implant-supported fixed complete dental prostheses (IFCDP).

Several factors affect the fabrication of the implant-supported framework. They are divided into clinical factors and laboratory factors. Clinical factors include impression techniques and materials as well as the clinician's experience. Laboratory factors include cast fabrication techniques and materials, framework fabrication and materials, as well as the technician's experience.

3.1. Accuracy of Impression Materials and Techniques

An accurate implant impression is necessary in order to generate an accurate definitive cast, which is the basis for the fabrication of an accurately fitting prosthesis. Several clinical and laboratory variables, from impression making to machining tolerance, improper connection of the impression copings and analogs, dimensional changes of the impression materials and stone, can influence the accuracy of the fit. The impression materials should be biocompatible, easy to use and dimensionally stable, have high tearing resistance, acceptable color and taste, and be compatible with die materials [37]. Several impression materials have been used clinically for implant impressions such as polyvinyl siloxanes, polyether, impression plaster, and polysulfide, due to their dimensionally stability, the accuracy of recording fine details of the intraoral anatomy, and high tear strength. Polyether is the preferred impression materials by many clinicians. According to Wee et al. polyether has the highest torque value. It was reported that implant casts fabricated using polyether were more accurate than casts generated from other impression materials [38]. According to Assuncao et al. condensation silicone has the least accuracy compared to polysulfide, high viscosity addition silicone, and polyether. They reported that both polyether and high viscosity addition silicone are the most accurate impression

materials [39]. Several authors found no difference in accuracy between polyether and vinylpolysiloxane (VPS) [38,39,40].

3.2. Impression Techniques

3.2.a. Stock Tray Versus Custom Tray

The purpose of an impression tray is to provide retention and stability for the materials and the impression. It is always assumed that custom trays provide better impressions and more accurate casts compared to stock trays. According to Burns et al. custom trays are better than stock trays for picking up an implant impression due to the rigidity, which prevents distortion, and maintain a consistent thickness of the impression materials [41]. Stock trays can be used but may produce an inaccurate impression due to their flexibility and may not maintain the consistent thinness of the impression materials [41].

3.2.b. Closed Tray Versus Open Tray Impressions

There are several implant impression techniques being described in the literature [42]. Firstly, in the closed tray technique tapered impression copings are used. The impression copings are screwed onto the implants. Then, the impression will be taken, and the impression copings will be removed from the patient's mouth and transferred to the impression by hand. Finally, the laboratory analogs will be connected to the impression copings followed by pouring the working cast. The second technique is the open tray technique. In this technique screw retained

impression copings are used and picked up in the impression. A window is opened in the impression tray allowing access to the impression copings after the impression has set. In a recent systematic review by Papaspyridakos et al. one clinical study *in vitro* reported better accuracy with the open-tray versus the closed-tray technique for full arch implant cases [42]. For partially edentulous indications, the majority of *in vitro* studies showed better accuracy with open-tray vs. the closed-tray technique, but the only clinical study reported no difference [42].

3.2.c. Splinted Versus Non-Splinted Impressions

Different splinting materials have been used clinically to splint the impression copings, such as polymethyl methacrylate (PMMA), dental floss, metal bars, prefabricated PMMA resin bars, composite resin and light cured resin. In an in vitro study, Mojon et al. measured the polymerization shrinkage of Duralay Resin, which they found to be 7.9% on the first day. Out of this amount of shrinkage, 80% happened within 17 minutes. This is why sectioning the resin is recommended and suggested in several studies [42, 57]. The purpose of the splinting technique is to connect the copings with resin to stabilize and prevent any movement during and after impression making.

A recent systematic review by Papaspyridakos et al. reported that for completely edentulous patients, most *in vitro* studies and all three clinical studies demonstrated better accuracy with the splinted vs. the non-splinted technique. For partially edentulous patients, one clinical study and most *in vitro* studies showed better accuracy with the splinted versus non-splinted technique [42].

The open-tray technique was more accurate than the closed-tray for completely edentulous, but for partially edentulous patients there seemed to be no difference. The impression material (polyether or polyvinylsiloxane) had no effect on the accuracy of implant impressions [42].

3.3. Die Materials

Several die materials have been utilized to fabricate casts. Dimensional stability, strength, accuracy, resistance to abrasion, ability to reproduce fine details, ease of use and safety are requirements of a good die material [37]. Gypsum materials are the most commonly used to fabricate casts. Gypsum materials contain calcium sulfate dehydrate. At a certain temperatures the dehydrate converts to hemihydrate [45].

There are five types of dental gypsum according to the American Dental Association: Type I impression plaster, Type II plaster model, Type III dental stone, Type IV dental die stone of high strength and low expansion, and type V dental die stone of high strength and high expansion [46].

All gypsum products have measurable linear expansion, which is specified by the American Dental Association. Each type has a different setting expansion, which can be measured after two hours from initial mixing [46]. In a study by Heshmati et al. the investigators evaluated the setting expansion of type IV and V dental stone after 120 hours from the initial mixing. They reported that most of the dental stone materials completed their setting expansion after 96 hours, while most of the expansion happened in the first two hours. The expansion of type IV and V gypsum after the initial two hours was between 22% -71% of the total expansion [47].

Several studies have compared dimensional changes of implant casts fabricated from different types of gypsum products. One of these studies done by Wee et al compared three different die materials, namely Resin rock, Vel-mix and Die keen. They reported that Resin rock had the least dimensional changes compared to Vel-mix and Die keen; therefore, Resin rock was recommended by the authors to fabricate implants restorations casts [48,49].

3.4. Implant Angulation

The effect of implant angulation on the accuracy of implant casts fabricated by different impression techniques was recently investigated in a systematic review [42].

As far as completely edentulous patients are concerned, six *in vitro* and three clinical studies reported on accuracy outcomes with angulated implants [42]. Three clinical studies did not focus on the details of implant angulation but reported that the splinted technique was clinically better than non-splinted or closed-tray techniques with angulated implants. Three of the six *in vitro* studies reported that the splinted technique was more accurate when dealing with angulated implants. One *in vitro* study reported that for a buccal angulation of 10º the impressions were more accurate with polyether than PVS, whereas another *in vitro* study for the same 10º buccal angulation showed no difference between polyether and PVS impressions [42].

Another *in vitro* study reported on the effect of implant angulation on an eight-implant edentulous maxillary arch with four internal connection and four external connection implants with a bilateral split-mouth design. They reported that implant impression accuracy was affected by angulated implants, especially at 25ºangulation. No studies were found assessing the effect of

internal vs. external connection or implant vs. abutment level on implant impression accuracy [42].

Regarding partially edentulous patients, three *in vitro* studies reported on three-implant scenarios with internal or external connections and reported that angulation up to 15° did not affect accuracy, but the clinical significance is unknown [42]. The splinted technique was better at angulation of 30° and 40° according to the results of one study. Three *in vitro* studies reported on four-implant scenarios with internal or external connections and reported that angulation up to 5° did not affect accuracy and that for angulations more than 20° the splinted technique was better [42].

4. Fabrication Implant-Supported Framework Techniques

There are two techniques to fabricate implant-supported frameworks. The first method for fabrication of an implant-supported framework is the conventional casting technique. There are several factors that affect this technique such as investing materials, investing temperatures, investing technique, casting technique, and the pattern materials [50]. Several metals have been used for casting and fabrication of implant frameworks, such as high noble alloy, noble alloy and base metal. High noble has limitations, which include high flexibility, so it is not recommended for long span frameworks. Noble alloy and base metal are more favorable to dentists and technicians, for their lower price, rigidity and accuracy of fitting. The increasing cost of gold makes precious alloys more expensive and not affordable for patients [51]. Base metal is the alternative metal to noble alloy, because it is less expensive. However, some patients develop an

allergy to base metal, which could be contraindicated for these particular patients. Another disadvantage of using base metal is the fact that it is not easy to cast, cut and solder as well as finish and polish [51]. Usually, frameworks done by conventional casting require cutting and soldering or laser welding to improve the accuracy of implant framework fit [52].

The second technique to fabricate implant-supported frameworks is with the use of CAD/CAM technology. The introduction of the CAD/CAM to dentistry made several procedures accessible and affordable for clinicians, technicians and patients. In this technique implant-supported frameworks are milled out of titanium or zirconia and are less expensive compared to conventional casting techniques with precious alloys. The CAD/CAM workflow includes scanning, designing and milling [53]. Kapos et al. reported that CAD/CAM frameworks demonstrate the most accurate fit and are the easiest to fabricate [8, 9, 51].

5. Assessing the Accuracy of the Master Cast with Verification Jigs

Several techniques have been used and recommended by authors to verify the accuracy of the master cast. According to Henry, the use of a verification jig can improve the accuracy of the master cast [29]. Another study by Ercoli et al. investigated differences in full-arch implant-supported framework fit fabricated on casts with or without verification jigs. They found that the frameworks fabricated on casts using verification jigs fit passively in all patients, while frameworks fabricated without the use of verification jigs did not demonstrate passive fit (only 2/12 presented with accurate fit) [54].

Aim and Hypothesis:

1. The aims of this study were:

- To compare the dimensional accuracy of test casts fabricated by using verification jigs made of GC resin, test casts fabricated by using verification jigs made of Triad light cure resin, and test casts fabricated by using verification jigs made of Fixpeed resin with the control cast.
- To compare the accuracy of test casts fabricated by using parallel and angulated implants within each material (within each group).

2. Hypotheses:

- The test casts fabricated by using Triad light cure verification jigs are more accurate than the test casts fabricated by using Fixpeed resin verification jigs and the test casts fabricated by using GC resin verification jigs.
- Parallel implants have more 3-dimensional accuracy than angulated implants.

Materials and Methods

A PMMA blank representing an edentulous mandibular arch was prepared and five internal connection implants (Straumann Tissue Level RN, Basel, Switzerland) were placed (Figure 1). The implant distribution included three implants in the anterior region, and two implants in the posterior region. The three implants in the anterior region were parallel to each other and the two implants in the posterior region were distally tilted bilaterally 20 degrees (Figure 1).

Verification jigs were fabricated with three different materials by using prefabricated bars (Figure 2), representing three different groups. Every group included 15 specimens.

These 45 verification jigs were fabricated from the master model to make 45 verification jig casts (test casts) using low expansion type IV (Resin Rock) stone for three different groups. The groups consisted of the following:

-Group 1 (PMMA – polymerizing resin)

Fifteen verification jigs were made using PMMA resin (GC Pattern resin). Five temporary non-engaging abutments were tightened to the implants at implant-level at 15 Ncm (Figure 3), and then they were splinted together with a prefabricated bar made of PMMA resin using a small amount of the same resin to connect the temporary abutments (Figure 4). After complete polymerization, the jig was untightened and then removed in order to fabricate the working cast. Analogs were tightened to the verification jig and then a test cast was poured with low expansion stone (0.09%)(Figure 5). This procedure was repeated 15 times in order to fabricate 15 test casts.

-Group 2 (PMMA – polymerizing resin).

Fifteen verification jigs were made using PMMA resin (Fixpeed Pattern resin). Five temporary non-engaging abutments were tightened to the implants at implant-level at 15 Ncm (Figure 3), and then they were splinted together with a prefabricated bar made of PMMA resin using a small amount of the same resin to connect the temporary abutments (Figure 6). After complete polymerization, the jig was untightened and then removed in order to fabricate the working cast (Figure 6). The same procedures above have been done to fabricate the test casts.

-Group 3 (Triad gel – visible light cured material).

Fifteen verification jigs were made using Light cure resin (Triad gel, DENTSPLY international, Inc.). Five temporary non-engaging abutments were tightened to the implants at implant-level at 15 Ncm (Figure 3), and then they were splinted together with a prefabricated bar made of light cure resin using a small amount of the same resin to connect the temporary abutments and cured with the light-curing device (Figure 7). After complete resin polymerization, the jig was untightened and then removed in order to fabricate the working cast (Figure 7). The same procedures above have been done to fabricate the test casts.

For the 3-D accuracy measurements, polymer scan bodies were placed on the implants and a digital scanner was used in order to capture the position of 3-D implant positions (Figure 8). The resultant Standard Tessellation Language (STL) files were superimposed with the control STL file from the master cast. This way, we assessed the 3-D deviations in order to have an accurate comparison between the original position and the position of the implants in the verification jig casts.

Digital Scanner

The Smart optic 880 digital scanner was used for the present study (Figure 9). The smart optic 880 scanner features a 3-D transformation tool that helped to scan the implants' position in 3-D orientation. This scanner utilizes a white light camera, which has the ability to capture details and capture many pictures and transform it to a 3-D image. The Smart optic 880 has a precision up to the level of 10 μm. Mimics and Geomagic software specially developed for medical image processing. Mimics and Geomagic software has a set of tools developed to deliver a precise digital data from a 3-D scan for accurate measurements. Mimics and Geomagic has accuracy as small as1μm. Both software were involved to overlap the scanning datasets of each cast of each test group to the scanning dataset of the control (master model). The primary method to calculate the difference was root mean square (RMS) error, which was obtained by Mimics software.

Accuracy Measurements with Digital Scanning

One digital scan of the master cast (Figure 10) at the implant-level was obtained with the high-resolution reference scanner with 10 μm precision (Smart Optics 880 scanner, Bochum, Germany) and used as control (reference) for comparison with the scans of the casts of the three test groups I to III (Figures 11,12,13). For all digital scans, the same polymer scan bodies (Scan bodies RN, Straumann, Basel, Switzerland) were moved from their mandibular corresponding position in cast 1 to cast 15 of each test group in order to eliminate the effect of scan body variances. An operator blinded to the type of casts performed all scanning procedures. In order to capture the 3-D orientation of the implants in each test cast and their 3-D deviations, the digital

STL volumes from the 3 test groups were registered using a surface based registration algorithm. The cumulative 3-D discrepancies were calculated by comparing of all deviations x-, y-, z-axis for each implant in five specific points (occlusal, mesial, distal, buccal, and lingual) with superimposition software (Mimics) for data comparison. After the master cast had been scanned along with the polymer scan bodies, the data were transferred as an STL file to Geomagic software. The same procedure was performed for each test cast. After the data were transferred to Geomagic software, the scan of the test cast was superimposed on the scan of the master cast (Figures 14,15,16). After all 45 test casts had been superimposed; the STL data were transferred to Mimics software for the 3-D measurements. Each implant had five points marked in order to measure x-, y-, z-axis for each point. Then the root mean square (RMS) was calculated for each point.

Power Calculation

A power calculation was conducted using nQuery Advisor (Version 7.0). Based on the results of Danesh et al. [11] and Gibbs et al. [12], and assuming equal dimensional accuracy between Fixspeed and GC Resin, an effect size of $\Delta^2 = 0.29$ was used. Given this effect size, a sample size of n = 15 per group was adequate to obtain a Type I error rate of 5% and a power of 88%.

Statistical Analysis

Descriptive statistics were calculated for each group (Triad, GC Resin, and Fixspeed). Differences in accuracy between the three groups were analyzed via one-way ANOVA. The difference in accuracy between parallel and distally tilted implants in each group was analyzed via the paired t-test (for normally distributed results) or the Wilcoxon signed-rank test (for non-normally distributed results). P-values less than 0.05 were considered statistically significant. SPSS Version 22 was used in the analysis.

Results

Raw data of the RMS values for the total 3-D distortion are presented by group in Table 1a. The mean, SD and the p-value of the outcome were calculated and presented in Table 1b as follows: Group 1 (GC Resin) had a mean (SD) value of 36.59 (12.47) μm; Group 2 (Fixpeed Resin) had a mean (SD) value of 35.90 (10.13) μm; Group 3 (Triad Gel) had a mean (SD) of 34.12 (7.10) μm. One-way ANOVA showed no statistically significant difference between groups (P=0.790).

For the second analysis, which was the comparison of parallel and tilted implants within each group (GC Resin, Fixpeed Resin, and Triad Gel), the raw data for the 3-D distortion are presented in Table 2a. Descriptive statistics (mean, SD, range, and inter-quartile range [IQR]) of the RMS results are presented in Table 2b. In Group 1 (GC Resin), parallel had a mean (SD) value of 35.65 (12.30) μm; tilted had a mean (SD) value of 38.00 (13.02) μm. In Group 2 (Fixpeed Resin), parallel had a mean (SD) value of 33.85 (8.77) μm; tilted had a mean (SD) of 39.05 (12.62) μm. In Group 3 (Triad Gel), parallel had a mean (SD) value of 33.28 (7.47) μm; tilted had a mean (SD) value of 36.03 (7.12) μm. Data were normally distributed for Groups 1 and 3 (GC Resin and Triad Gel), but not for group 2 (Fixpeed Resin). The difference between parallel and tilted was significant for all three groups: GC Resin (P=0.024; paired t-test), Fixpeed Resin (P=0.002; Wilcoxon signed-rank test), and Triad Gel (P=0.002; paired t-test)(Table 2b). In this study each implant had a 3-D distortion measurement; all measurements are displayed in Table 3. Implants one and five (20 degrees distally tilted) had more 3-D distortion in most casts than parallel implants (two, three and four).

Discussion

Achieving total passive fit with screw-retained implant-supported prostheses is a factor to long-term success, but impossible to achieve clinically. According to several authors, the fit of implant-supported one-piece prostheses could be acceptable clinically if the discrepancy of the fit ranges from 59 to 72 μm [10], from 91 to 111 μm [5], or less than 150 μm [16].

Several factors can increase/decrease the accuracy of fit of the implant-supported prostheses, such as impression technique and materials, framework materials and technique, cast materials and fabrication, and clinician/technician skills. The most important step to achieve a passive fit restoration is the accuracy of the implant transfer technique; several techniques have been mentioned and suggested in the literature. According to Papaspyridakos et al. the accuracy of the splinted impression technique is better than that of the non-splinted technique [42]. According to Ercoli et al. frameworks fabricated with verification jigs had better accuracy of fit than frameworks fabricated without verification jigs [54].

The verification jig is one of several techniques to increase the accuracy of fit of the implant-supported prostheses. Several materials have been used to fabricate the verification jigs. In this study we used three materials to compare which one has better dimensional accuracy. The test casts fabricated from verification jigs with Triad Gel had a lower mean 3-D deviation than the Fixpeed Resin and GC Resin test casts, but the results were not statistically significant. On the other hand, the result of comparing between parallel and tilted implants within each group indicated that parallel implants have significantly more 3-dimensional accuracy than angulated implants.

The effect of implant angulation on the accuracy of implants casts fabricated with different methods has not been fully investigated yet. Most of the studies published in the past investigated how to improve the implant cast accuracy for the ideal condition, with parallel implants and excluded the implant angulation as a variable. Only a few studies have assessed the effect of angulated implants on the accuracy of the implant casts with no definitive conclusions drawn [62]. In this study the implant angulation had been tested to mimic the clinical situation as possible.

Several studies reported no significant differences in the accuracy of implant casts for implant angulation up to 15 degrees [63]. Another in vitro study reported that angulation of implants more than 20 degrees affects the accuracy of the fabricated implants casts [64].

Framework fabrication for implant-supported prosthesis requires an accurate master cast. Accuracy of the master cast is affected by factors such as the impression material, the impression technique, the machining tolerance, and the stone expansion.

In the present study, resin modified type IV die stone (Resin Rock) with dimensional expansion of 0.09% was used to pour all stone samples, because of its compressive strength and low linear expansion [48,49]. Studies have compared the linear dimensional accuracy of seven die materials and reported that Resin rock was dimensionally more accurate than other die materials. In the present study, the materials used to fabricate the verification jigs were GC Pattern Resin, Fixpeed Resin, and Triad Gel.

GC Pattern Resin and Fixpeed Resin are a polymethyl-methacrylate (PMMA) resin, which is

also a self-cured resin. All acrylic resin materials exhibit some polymerization shrinkage. It has been shown that 80% of polymerization shrinkage of PMMA occurs within 17 minutes at room temperature and that after 24 hours no significant shrinkage will happen [57]. In the present study the effect of polymerization shrinkage of the GC Pattern Resin and Fixpeed Resin verification jigs was minimized by using bars pre-fabricated 24 hours prior to the splinting procedures. Therefore, the only shrinkage that would affect the accuracy of GC Pattern Resin and the Fixpeed Pattern Resin verification jigs was the shrinkage of the added resin used to connect the pre-fabricated resin bars to the temporary abutments. A small amount of additional resin was used to splint the bars and the temporary abutments.

Triad Gel is a urethane-dimethacrylate resin (UDMA) that does not contain methylmethacrylate monomer. It is also a light cured resin. It has less polymerization shrinkage compared to PMMA acrylic [32]. The linear shrinkage of Triad Gel is approximately 0.38% [60]. Others reported that Triad has a linear shrinkage as small as 0.2% [61]. The small dimensional changes of Triad Gel seem favorable and its good handling proprieties make it a good material for fabrication of verification jigs.

CAD/CAM technology is extensively used for implant framework fabrication due to the superior fit and decreased cost compared to the "wax and cast" technique using noble alloys. These frameworks require an accurate cast prior to scanning and are not designed to be cut and soldered. In the clinical practice, distortion of an implant impression may happen due to the presence of undercuts, improper seating of the impression, angulation of implants, the depth of implant placement, number of implants, and handling of the impression by the technician. In these situations, a dentist can benefit from the use of a verification jig to assess the accuracy of the master cast, to correct the master cast, or to make a new impression.

In regards to the methodology of accuracy assessment, several methods have been employed to measure and quantify the 3-D discrepancies on the x-, y- and z-axis between the implant casts produced with different impression techniques including computerized coordinate measuring machine, traveling microscope, computerized tomography (CT) scan and recently optical scanning and digitization. The use of an optical scanner seems to improve the accuracy of the measurement outcome of this study [5]. The Activity 880 3-D scanner was used because of the ability to capture many pictures and transform them into a single 3-D image. This scanner utilizes white light, and has a purported precision up to the level of 10 μm, according to the manufacturer. Mimics and Geomagic superimposition software were used in this study because of their ability to measure a distortion as small as 1 μm compared to conventional measuring methods. Another advantage of using Mimics and Geomagic software is the ability to calculate the outcome by using the RMS error.

In regards to the machining tolerance and its effect on accuracy assessment, it has been shown that paired prosthetic components may be rotationally displaced during connection to their respective parts and this displacement cannot be controlled by the clinician. The machining tolerance differs between different implant systems and is an unknown variable in the accuracy measurements. Hence, errors occur during connection of impression copings to the implants intraorally and to the implant analogs in the laboratory, respectively. Additionally, errors occur during connection of the scan bodies to the implants prior to digitization. To eliminate the effect of the scan bodies on the accuracy assessments, the same scan bodies were always placed at the same corresponding implant positions.

According to the results from this study which reported that there is no significant differences between the three materials used to fabricate the verification jig, any materials could be used to fabricate the verification jig when encountering full arch implant restorations with a suggestion of using a prefabricated bar to minimize the materials shrinkage and to reduce clinical time.

In this study a PMMA model of five implants had been prepared to be the master/reference cast. The implants used were internal connection (Straumann Tissue Level RN, Basel, Switzerland), which is a different situation from an abutment level impression or other implant brands. Additional studies should be done with different implant system and connection types. Every implant system has a different design and different machining tolerance. For each implant system and materials to fabricate a master cast, manufacturers' instructions must be followed to eliminate/minimize errors.

Limitations of the Study

There are several limitations in this study that must be addressed. Firstly, the inconsistency of GC and Fixpeed resin mixing technique might have skewed the results. It is hard to recreate the same amount of monomer to polymer ratio during mixing of the materials. The amount of monomer to polymer does affect the amount of shrinkage observed [64]. A second limitation of this study is the fact that a single non-blinded investigator performed the experiment, which can lead to some errors and bias. A third limitation is that the study was done in vitro, which is very different from the clinical setting. All of these limitations could affect the accuracy of the results of this study.

CONCLUSIONS

1- There were no statistically significant differences between the three materials in regards to the 3-D distortions of the test casts fabricated by using GC Resin, Fixpeed Resin, and Triad Gel verification jigs.

2- The 3-D distortion value in comparison between parallel vs. tilted implants showed that parallel implants had significantly less 3-D distortion value compared to 20 degrees tilted implants.

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Appendices

Appendix A: Tables

Appendix B: Figures

Appendix A: Tables

Table 1a:

Measurement of the distortion of each cast for group 1 (GC Resin), group 2 (Fixpeed Resin), and group 3 (Triad Gel) in µm.

GROUP 1 (GC PATTERN)		**GROUP 2 (FIXPEED PATTERN)**		**GROUP 3 (TRIAD GEL)**	
CAST NUMBER	DISTORTION	CAST NUMBER	DISTORTION	CAST NUMBER	DISTORTION
1	38.38	1	45.69	1	30.39
2	39.07	2	38.68	2	30.00
3	11.65	3	39.75	3	28.60
4	56.07	4	39.21	4	32.81
5	41.08	5	56.56	5	32.94
6	19.20	6	39.44	6	32.43
7	47.25	7	38.41	7	33.92
8	38.80	8	38.27	8	52.35
9	38.74	9	36.49	9	29.52
10	38.56	10	11.74	10	36.70
11	40.53	11	24.54	11	29.79
12	12.39	12	32.39	12	28.55
13	41.34	13	28.01	13	48.78
14	40.18	14	28.93	14	30.30
15	45.63	15	40.45	15	34.76

Table 1b:

Mean values, median, and SD for group 1(GC Resin), group 2 (Fixpeed Resin), and group 3 (Triad Gel) in µm.

Group	**N**	**Mean**	**SD**	**Min**	**Max**	**P-value[§]**
1	15	36.59	12.47	11.65	56.07	**.790**
2	15	35.90	10.13	11.74	56.56	
3	15	34.12	7.10	28.55	52.35	
Total	45	35.53	9.96	11.65	56.56	

[§] One-way ANOVA

Table 2a:

Measurement of the distortion of each cast between the parallel and tilted implants for group 1 (GC Resin), group 2 (Fixpeed Resin), and group 3 (Triad Gel) in µm.

GROUP 1 (GC PATTERN)			**GROUP 2 (FIXPEED PATTERN)**			**GROUP 3 (TRIAD GEL)**		
CAST NUMBER	DISTORTION		CAST NUMBER	DISTORTION		CAST NUMBER	DISTORTION	
	PA	TL		PA	TL		PA	TL
1	35.88	42.14	1	35.58	43.34	1	27.96	34.04
2	37.58	41.31	2	38.98	41.22	2	28.13	32.81
3	10.23	13.78	3	39.02	39.51	3	26.21	32.2
4	52.14	61.97	4	47.73	69.81	4	28.27	33.36
5	39.72	43.13	5	38.56	41.38	5	31.55	34.71
6	18.60	20.13	6	36.56	41.18	6	30.52	36.57
7	50.01	43.10	7	36.44	41.03	7	31.09	34.44
8	38.26	39.63	8	34.52	39.44	8	32.46	36.12
9	38.91	38.48	9	10.96	12.92	9	50.43	55.23
10	37.48	40.19	10	23.60	25.97	10	29.59	29.42
11	39.75	41.7	11	31.02	34.44	11	35.70	38.20
12	12.43	12.33	12	27.06	29.45	12	30.07	29.37
13	39.95	43.44	13	27.95	30.41	13	28.61	28.47
14	39.68	40.93	14	40.84	52.98	14	49.14	48.25
15	44.17	47.83	15	38.98	42.67	15	39.60	37.32

Table 2b:

Mean values, minimum, maximum, and SD for group 1 (GC Resin), group 2 (Fixpeed Resin), and group 3 (Triad Gel) in µm for Parallel and tilted implants.

		PA				TL				
Group	N	Mean	SD	Median	IQR	Mean	SD	Median	IQR	P-value
1	15	35.65*	12.30	38.91	4.07	38.00*	13.02	41.31	49.64	.024*ᵡ
2	15	33.85*	8.77	36.44	11.03	39.05*	12.62	41.03	59.89	.002*ʎ
3	15	33.28*	7.47	30.52	7.43	36.03*	7.12	34.44	26.76	.002*ᵡ

* Statistical significance P ≤0.05.

ᵡ Paired t-test.

ʎ Wilcoxon's signed ranks test for dependent variables

Table 3:

Measurement distortion for each implant in each cast for group 1 (GC Resin), group 2 (Fixpeed Resin), and group 3 (Triad Gel).

Cast #	Implant #	Group 1 Distortion (GC Resin)	Group 2 Distortion (Fixpeed Resin)	Group 3 Distortion (Triad Gel)
1	1	41.86	52.68	31.78
	2	34.90	44.82	27.86
	3	35.90	34.44	26.28
	4	36.86	43.26	29.76
	5	42.42	53.28	36.30
2				
	1	41.45	45.78	33.88
	2	37.70	38.90	28.90
	3	36.38	29.38	28.26
	4	38.66	38.48	27.24
	5	41.18	40.90	31.74
3				
	1	15.60	42.06	32.74
	2	10.60	40.16	25.00
	3	9.96	34.32	26.86
	4	10.14	41.86	26.78
	5	11.96	40.38	31.66
4				
	1	64.54	40.46	34.52
	2	49.26	37.58	32.88
	3	58.92	39.12	29.94
	4	48.24	40.36	31.84
	5	59.40	38.56	34.90
5				
	1	43.58	72.26	37.50
	2	40.68	46.62	31.86
	3	37.72	51.16	28.98
	4	40.78	45.42	30.72
	5	42.68	67.36	35.64
6				
	1	23.28	40.54	34.42
	2	23.56	38.76	33.38

	3	20.28	36.90	28.22
	4	11.96	38.78	31.68
	5	16.98	42.22	34.46
7				
	1	40.00	41.12	33.60
	2	52.38	38.68	32.58
	3	51.10	33.80	32.88
	4	46.56	37.22	31.92
	5	46.21	41.24	38.64
8				
	1	40.98	40.80	44.54
	2	37.58	37.74	52.22
	3	36.02	33.54	48.28
	4	41.18	38.04	50.80
	5	38.28	41.26	65.92
9				
	1	41.10	41.26	29.22
	2	39.62	34.56	30.44
	3	39.34	34.04	27.62
	4	37.78	34.98	30.72
	5	35.86	37.62	29.62
10				
	1	35.46	13.68	39.04
	2	38.94	12.28	37.88
	3	33.84	10.46	33.90
	4	39.68	10.16	35.34
	5	44.94	12.16	37.36
11				
	1	42.62	26.66	29.90
	2	41.24	20.84	30.34
	3	37.68	25.54	28.40
	4	40.34	24.42	31.48
	5	40.78	25.28	28.84
12				
	1	12.74	36.94	27.10
	2	12.20	32.90	29.82
	3	11.68	27.76	27.12
	4	13.42	32.42	28.90
	5	11.92	31.94	29.84
13				
	1	42.92	28.94	49.36
	2	41.38	27.04	49.40

	3	38.86	27.04	45.64
	4	39.62	27.10	52.38
	5	43.96	29.96	47.14
14				
	1	42.78	31.18	32.26
	2	40.30	28.26	27.76
	3	38.28	25.44	29.08
	4	40.48	30.16	27.98
	5	39.08	29.64	34.46
15				
	1	48.48	42.56	34.60
	2	45.44	40.76	33.78
	3	41.82	34.32	32.68
	4	45.26	41.86	32.92
	5	47.18	42.78	39.80

Appendix B: Figures

Figure 1:
Master cast with 5 internal connection implants (Straumann Tissue Level RN, Basel, Switzerland).

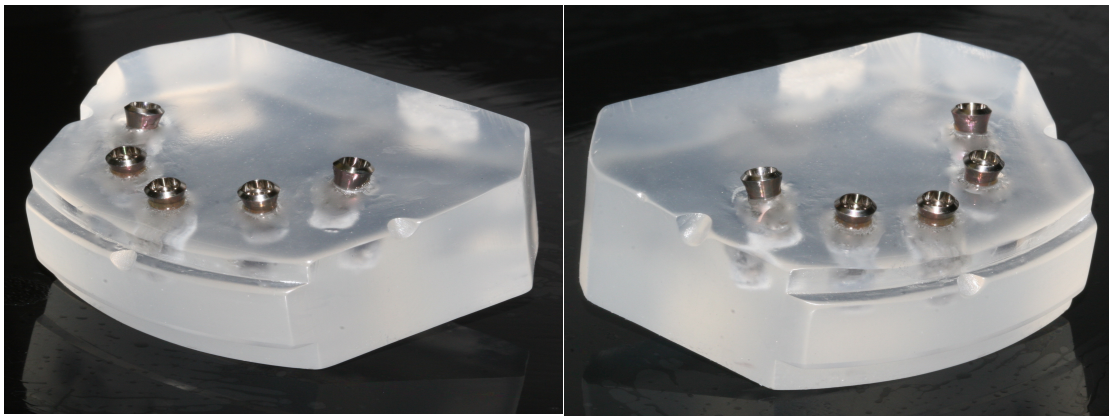

Figure 2:
Prefabricated bars for the three materials (GC resin, Fixpeed resin and, Triad gel).

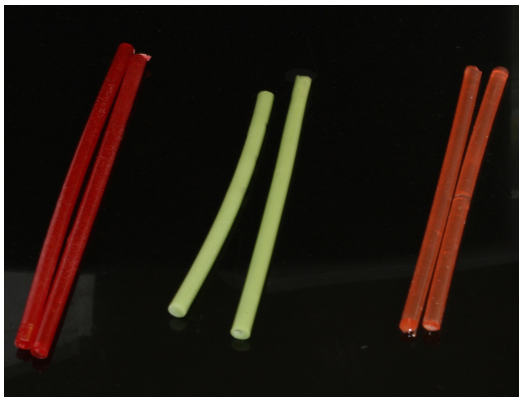

Figure 3:
Master cast with 5 temporary abutments.

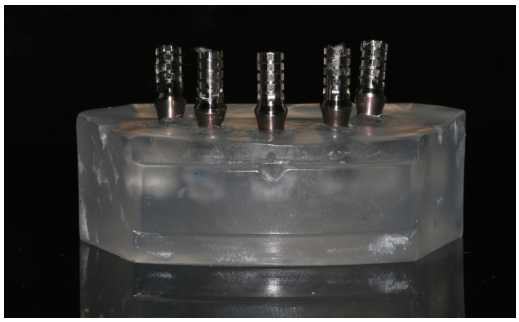

Figure 4:
Master cast with temporary abutments connected with GC resin, and GC resin verifecation jigs with lab analoges.

Figure 5:
Working cast

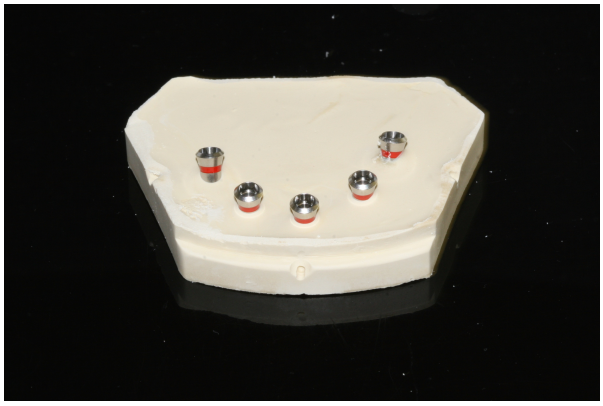

Figure 6:
Master cast with temporary abutments connected with Fixpeed resin, and Fixpeed resin verifecation jigs with lab analoges.

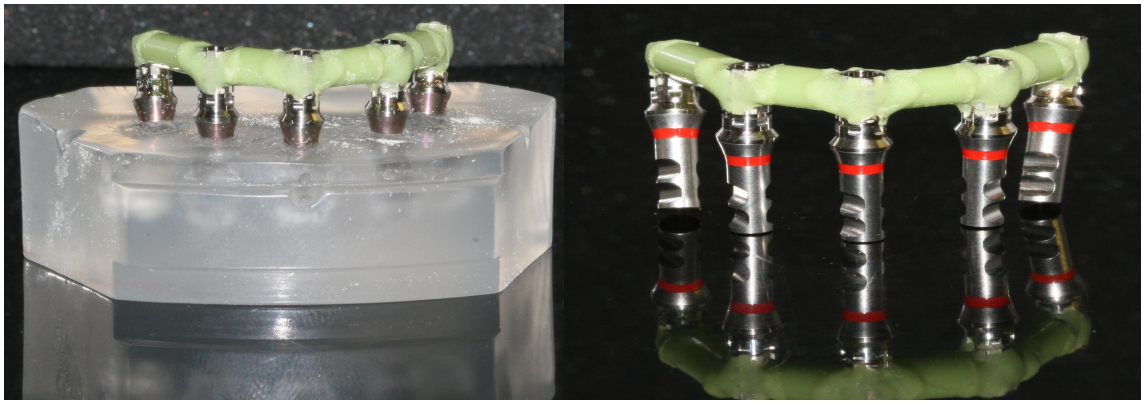

Figure 7:
Master cast with temporary abutments connected with Triad gel, and Triad gel verifecation jigs with lab analoges.

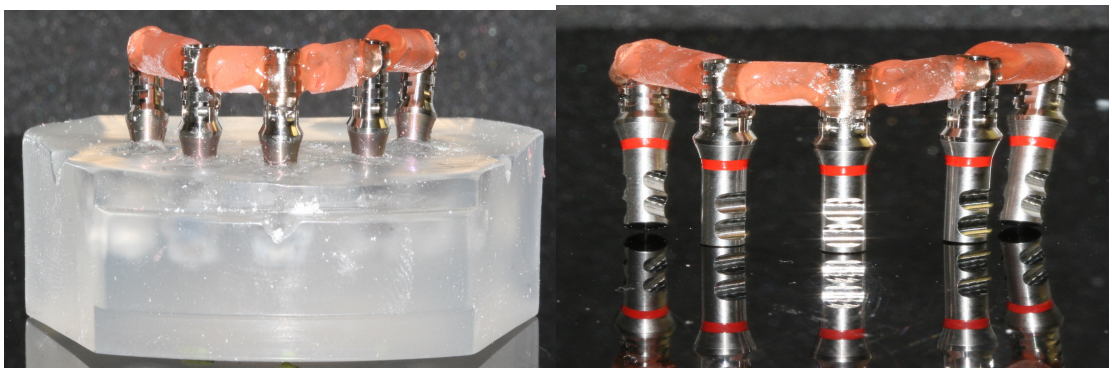

Figure 8:
Master cast with polymer scan bodies.

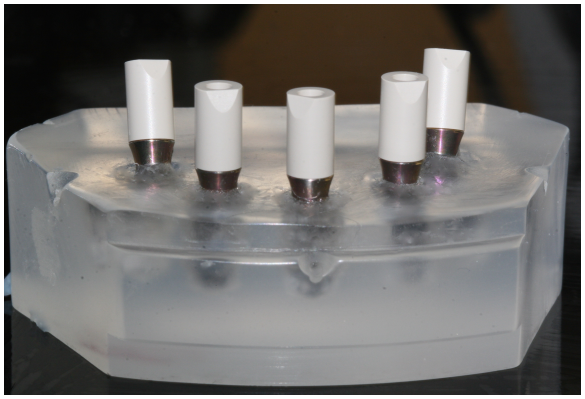

Figure 9:
Smart Optics 880 scanner, Bochum, Germany.

Figure 10:
Scan of the master cast

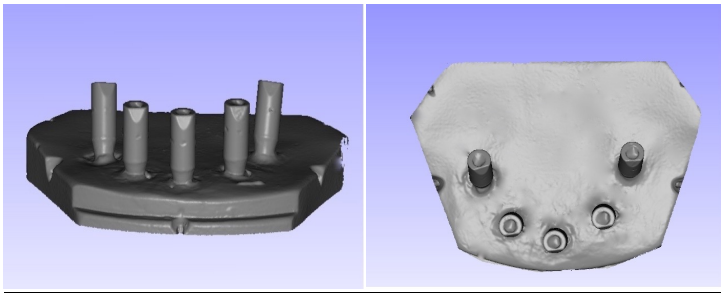

Figure 11:
Scan of test cast generated by using verification jig made out of GC resin (group 1).

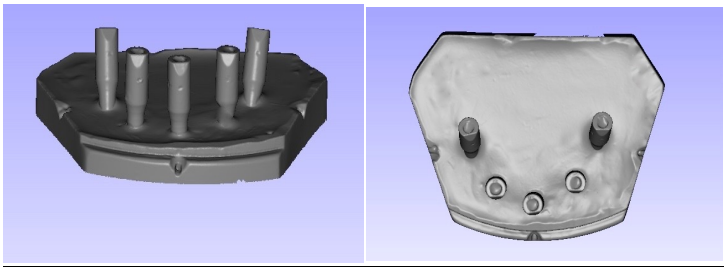

Figure 12:
A scan of test cast generated by using verification jig made out of Fixpeed resin (group 2).

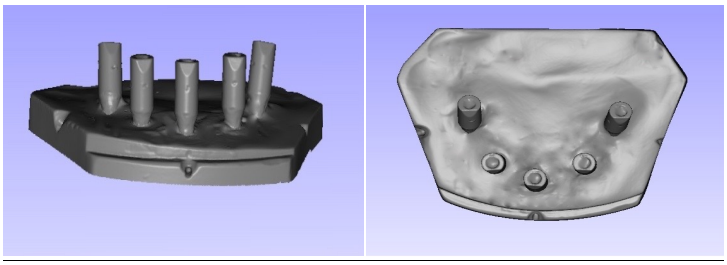

Figure 13:
A scan of test cast generated by using verification jig made out of Triad gel (group 3).

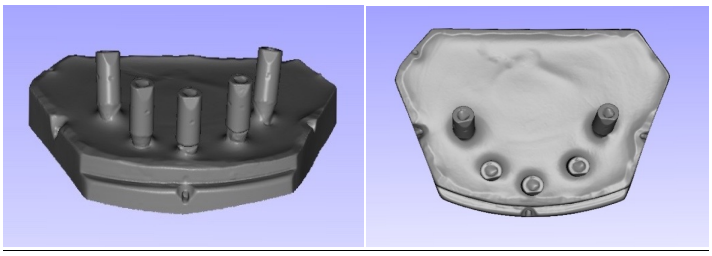

Figure 14:
Superimposition for Group 1.

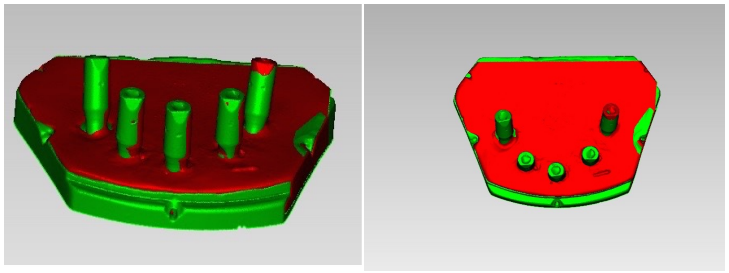

Figure 15:
Superimposition for Group 2.

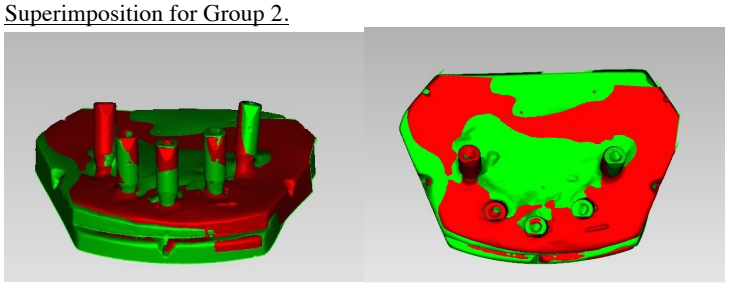

Figure 16:
Superimposition for Group 3.