Accuracy Evaluation of Digital versus Conventional Impression Techniques for Partially Edentulous Arches: An In Vitro Study

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

By
Amin Marghalani, BDS
May 2016

THESIS COMMITTEE

Thesis Advisor

Panos Papaspyridakos, D.D.S., MS., 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 And Chair of Department of Prosthodontics and Operative Dentistry
Tufts University School of Dental Medicine

Khaled El-Rafie, D.M.D.,
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

Yukio Kudara, CDT, MDT,
Technical Instructor
Department of Prosthodontics and Operative Dentistry
Tufts University School of Dental Medicine

DEDICATION

To my parents, **Abdulrahim Marghalani** and **Salha Bukhari**, for loveing me unconditionally and teaching me that I can overcome anything with hard work in order to achieve my goals.

To my angel and the love of my life, **Alaa Bukhari**, for believing in me, standing beside me, and taking good care of our son **Yasser** and our family.

To my dear family, **Sarah**, **Ahmed**, **Moaz**, **Suad**, and **Sahar**, for constantly showing me your encouragement and support.

To all my relatives and true friends, for always keep pushing me forward.

ACKNOWLEDGMENTS

I am very fortunate to have performed my graduate work at a Tufts University School of Dental Medicine; therefore, I would like to thank many people for their part in my success.

But before that, I am thankful to **Allah** for blessing me much more than I deserve, and for rewarding me with all the gifts and grants, and for providing me the strength throughout my life.

Also, I want to show my gratitude to my home country Saudi Arabia and Umm Al-Qura University for all the help and support they showed me during my education.

I would like to express my most profound gratitude to my Principal Advisor Dr. **Panos Papaspyridakos** for all the time, help and guidance he offered me to complete my Master project. I am very thankful to you for all extra hours you spent with me, counseling me, teaching me, advising me and above all for showing me how to be a pioneer researcher.

I would like also to express my appreciations to Dr. **Hans Peter Weber** for providing me with his great knowledge and wisdom throughout the project.

I am thankful as well to Dr. **Khaled El-Rafie** for always helping me, taking his time in simplifying matters for me and for contributing his great ideas and insightful suggestions to improve this project.

I would like extend my gratefulness to Dr. **Matthew Finkelman**, for or all the time that he spent guiding me, and for his substantial contribution not only for the Statistical Analysis part, but also throughout the whole project.

I would like also to thank Mr. **Yukio Kudara** for his hard work, and continuous help in guiding me through all procedures and technical steps.

Abstract

Statement of Problem: This study addressed the lack of data available on the accuracy of the Omnicam and True Definition digital scanners in partially edentulous patients.

Purpose: The primary purpose of this study was to compare the accuracy of definitive casts acquired from digital implant impressions (digital implant-level impressions with scan bodies and an intraoral scanner) using 2 different Intra Oral Scanners (CEREC Omnicam and 3M True Definition) with conventional implant impressions. A secondary purpose was to compare the difference in the accuracy of definitive casts between the Nobel Biocare and Straumann implant systems.

Materials and Methods: Two partially edentulous mandibular master casts with two internal connection implant analogs with a 30° degree angulation between them (Tissue-Level implant analogs RN, Straumann and Replace Select implant analogs RP, Nobel Biocare) were used as master models (controls). 60 digital models were created from these two master models and assigned to 6 different groups. The first two groups, I and II, were produced by splinted open-tray implant-level impression procedures followed by digitization (n=10). The next two groups, III and IV, were produced by a digital impression procedure with a white light IOS (CEREC Omnicam; Sirona, Germany: n=10). The last two groups, V and VI, were produced by a digital impression procedure with a blue light IOS (True Definition: 3M ESPE, Germany: n=10 each). Accuracy was evaluated by superimposing the digital files of each cast in each test group to the digital file of the control (master cast) using a specific inspection software

(Geomagic Control 2015). Medians ± interquartile ranges were calculated for all groups, and nonparametric tests (Kruskal-Wallis and Mann-Whitney U tests) were used to assess the statistical significance of differences.

Results: The differences between the three impression groups of the Nobel implant system and the master model were statistically significant for all groups ($p < 0.001$), except for the Omnicam scan group (19.79 ± 4.25), and the True Definition scan group (15.36 ± 6.18 μm). The median ± interquartile range for the conventional group was 39.38 ± 17.71. There were significant differences between the three impression groups of the Straumann implant system and the master model ($p = 0.003$) for all groups, except the conventional impression group (21.77 ± 5.24 μm) and the True Definition scan group (16.94 ± 4.60 μm); the median ± interquartile range for the Omnicam group was 26.01 ± 15.03. The difference between the two implant systems for the conventional impression technique was significantly different ($p < 0.001$). The difference between the two implant systems for the Omnicam scanning system was significantly different as well ($p = 0.011$). The difference between the two implant systems for the True Definition scanning system was not significant.

Conclusions: Within the limitations of this study, both the impression technique and the implant system affected the accuracy of the definitive models. The True Definition scanning system exhibited the best results compared to the other two techniques, although not all differences were statistically significant.

Keywords: digital implant impressions, partial arch implant impressions, partially edentulous, digital dentistry, and dental implants, implant fixed dental prosthesis

TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGUERS

Accuracy Evaluation of Digital versus Conventional Impression Techniques for Partially Edentulous Arches: An In Vitro Study

Introduction

Dental implants have been used to treat partially and completely edentulous patients for more than 4 decades, and longitudinal clinical studies have demonstrated their success [1, 2, 3]. Continuous advancements in Computer-assisted design (CAD) and computer-assisted manufacturing (CAM) technology have made these methods viable alternatives to conventional techniques for fabricating fixed implant-supported dental prostheses (IFDPs) for partially and completely edentulous patients, and have gained enormous popularity in implant dentistry over the past 10 years [4, 5, 6].

Passive fit is one of the most significant prerequisites in maintaining a healthy bone-implant interface and is considered one of the critical features for the long term success of IFDPs [7]. Although achieving an absolute passive fit is not yet possible, providing the best possible fit is fundamental to prevent future biologic and mechanical complications that include screw loosening and/or fracture, implant fractures, and prosthetic-component strain and fracture [1,7].

Several studies have attempted to define numerically the acceptable level of misfit (or the best passive fit), but there has been no definitive agreement about the way in which to quantify the acceptable threshold [8]. Numbers ranging from 10 to 150 microns have been reported to be acceptable amounts of discrepancy at the implant–abutment interface. Various techniques have been employed to assess the fit of screw-retained IFDPs, such as the single screw test. Another way to measure the best possible fit is through the introduction of the screw resistance test

developed by Jemt et al. However, clinicians always should strive for the best possible fit of an implant prothesis [7, 8, 9].

Numerous clinical and laboratory procedures have been described to achieve passive fit, and the accuracy of the definitive implant cast, which depends largely on the accuracy of the impression techniques and materials, is one of the most vital [10,11]. Recent systematic reviews of the accuracy of implant impressions for partially edentulous patients have reported that the splinted technique is superior to the non-splinted, while there is no difference between open-tray and closed-tray techniques [7, 10, 11, 12, 13].

On the other hand, we have limited data available regarding the accuracy of digital implant impressions, and only a few studies have reported on the use of digital implant impressions on partially edentulous patients [7, 10, 14]. Digital impression procedures that employ an intra-oral optical scanner (IOS) have numerous advantages in the field of fixed and implant prosthodontics, which include the elimination of tray selection, reduced risks of distortion when taking impressions, pouring, disinfecting, and shipping to the laboratory, and increased patient comfort and acceptance. Further, digital impressions can be sent and stored electronically, which leads to better efficiency and reduced costs [10, 15, 16, 17, 18, 19, 20, 21, 22].

Literature Review

Implant dentistry

The practice of contemporary dentistry is designed primarily to restore patients to a healthy oral condition through a series of evidence-based steps that have predictable results. Edentulism, partial or complete, is a well-known condition, and dentists in general, and prosthodontists in particular, have always strived to restore healthy dentition to patients who have suffered tooth loss using a variety of well-established methods and techniques [23, 24].

The introduction of osseointegration has expanded the ability of the dental profession and widened the scope of treatment options for edentulous patients. Further developments in implantology have led to a long-term, stable, implant-based dental prosthesis that withstands chewing load. Dr. Per-Ingvar Brånemark, a Swedish physician and researcher, first introduced the concept of osseointegration. He called it, "A direct connection between living bone and a load-carrying endosseous implant at the light microscopic level" [23, 24, 25, 26, 27].

Natural teeth have a larger range of movement in their respective sockets compared to endosseous implants, because the latter lack the natural mobility of the periodontal ligament, as endosseous dental implants functionally attach directly to the bone without intervening connective tissues [28]. Therefore, the misfit in implant-supported IFDPs, partial or complete, will lead to more destructive biological and mechanical complications when compared to tooth-supported prostheses, which make

the achievement of passive fit necessary for the survival and long-term success of ossiointegrated implants [28, 29, 30, 31].

Passive fit and misfit

The passive fit of an IFDP is defined as the formation of an even, concomitant contact at the implant-abutment interface surfaces, without inducing any overload within the prothesis or the adjacent bone tissues during functional loading [32]. Clinically, it is more difficult to determine a clear definition of passive fit, although it has been defined in the literature as "a level of fit which will not produce or cause any long-term clinical problem" [33, 34, 35].

The idea of an absolute passive fit between the IFDP framework and the implant is misleading, as it is impossible to achieve, and a degree of inaccurate fit will always persist [32, 35]. Furthermore, the clinical assessment of the framework-implant misfit does not provide a decisive answer with clear-cut numbers and only detects major misfits [33]. Therefore, the argument among clinicians about the importance of achieving a passive fit, and the assumption that only well-controlled fabrication methods are adequate to maintain successful, long-term treatment, continues [36, 37]. Nevertheless, it remains critical to strive for the best possible fit of the IFDP framework and to reduce the risks of misfit [32].

Biologic and technical/mechanical complications and tolerance

As mentioned above, the consequences of misfit in the framework of IFDP may lead to biologic and technical/mechanical complications. Many

systematic reviews have demonstrated that technical/mechanical complications in IFDPs are more common than are biologic complications. Biologic complications can manifest as pain on palpation and percussion, tenderness, bone loss, loss of osseointegration, and implant failure. On the other hand, technical complications include a range of problems that vary from porcelain chipping, loosening, and fracture of the prosthetic screws, fracture of various components in the system, and even implant fracture [38]. Mechanical complications pertain to those associated with prefabricated, machined components, whereas technical complications refer to those associated with laboratory fabricated components.

Biologic tolerance is defined as the ability of the implants that surround bone tissue to tolerate the strains exerted by the implant, without the introduction of any biological complications [32]. Animal studies have found that a remodeling process does take place at the bone surrounding the implant when loaded, but there were no signs of significant clinical, histological, or radiographic loss of osseointegration. Furthermore, different studies of the relationship between misfit and implant marginal bone loss found no correlation between them [39, 40, 41].

Machining tolerance is defined as the gap between the implant system components in rest positions when these components are held in position by their corresponding screws, which can range from 20 to 100 microns without introducing mechanical complications [42]. There are four types of machining tolerance described in the literature: the first is the displacement between the impression coping and the implant; the second is the displacement of the impression coping that results from the impression technique and material; the third is the displacement between the

impression coping and the implant analog, and the fourth is the displacement of the implant analog in the definitive cast due to dimensional changes in the dental stone [43]. Some studies have suggested that machining tolerance can be used to keep the final distortion to a minimum. One of these studies found that the mechanical tolerance related directly to the impression procedures was more than 61 microns. During delivery, the machining tolerance between the final IFDP framework and the implants can make it easier to achieve a passive fit when it is more than, or equal to, the amount of distortion [42, 43, 44, 45].

Misfit measurements

There is no general agreement on the best numerical way in which to define the acceptable level of misfit. The earliest studies suggested that gaps between 10 to 30 microns at the implant-framework interface were acceptable. Later, after more studies that focused on passive fit, that number increased to 150 microns [38, 46]. Clinical evaluation methods evolved from simply measuring numbers to performing tests that are more meaningful via different assessment techniques, none of which is truly reliable on its own, but, when used in combination, can achieve objective results. These methods include the screw resistance test, first presented by Jemt et al [37], which is performed by tightening the screws one by one beginning from the midline, until one of the screws begins to demonstrate resistance. Thereafter, the framework is considered to exhibit a passive fit with the implants if less than an extra half turn is needed to achieve optimum screw seating. The other test is the single screw test, which is carried out by tightening one terminal screw of the framework and then

evaluating the degree of discrepancy observed at the screw on the other end. The next assessment methods are less accurate, because they depend entirely on the clinician's skills. These involve direct visual and tactile examination using the tip of an explorer to verify marginal fit, and alternate finger pressure techniques in which the clinician evaluates whether or not rocking occurs while one end of the prosthesis is pressed. Radiographs can be used to verify seating, but this method depends largely on the angulations captured and the implant system. Finally, some clinicians have reported using disclosing materials, such as pressure indicating paste (PIP), a fit checker, and disclosing wax [32, 38].

Conventional Impression Techniques

The fabrication of an IFDP framework progresses through different clinical and laboratory procedures and the cumulative distortion that develops in all of these procedures results in misfit of the final prosthesis [32]. These steps (collectively called the distortion equation) include:

- Impression procedure, which includes impression material and technique, and implant number and angulation.

- Master cast fabrication, which includes mechanical tolerance of the implant replica, master cast pouring technique, and materials used.

- Wax pattern fabrication, which includes mechanical tolerance between the abutment replicas and definitive cylinders, and the type of wax used.

- Framework fabrication, which includes distortion in investing and casting; recently, however, using CAD/CAM technology to mill the framework has become the predominant method of fabrication, which leads

to the introduction to the equation of all the potential distortion that comes with the milling technique, rather than the investing and casting technique.

- Definitive prosthesis fabrication, which includes porcelain firing.

- Definitive prosthesis delivery, which includes machining tolerance between the final prosthesis and implants, and the mandibular flexure [32, 37, 40, 47, 48].

The accuracy of conventional impression procedures for IFDP fabrication depends largely on the impression technique—whether it is direct (open tray) or indirect (closed tray), splinted or non-splinted, and on the machining tolerance and design of the impression coping. In addition, the impression material type and properties, the impression tray, and implant number, distribution, angulation, and depth are all additional factors that affect the total accuracy of the impression [49].

Direct versus indirect techniques

Implant impression techniques include two main methods used to capture the exact implant position and transfer it to the definitive cast. The first is the direct technique, which uses an open impression tray (thus called because of the windows it has to expose the impression copings). The second is the indirect technique, which uses a closed tray (no window openings) [49, 50, 51, 52].

The direct technique, also called the pickup technique, is an impression technique in which the impression coping is exposed through the tray window for accessibility, where it usually assumes a square shape. Upon removal of the impression tray after the impression material sets, the impression coping is unscrewed and picked up with the tray [49, 50]. This

technique has the advantages of reducing deformity of the impression material during tray removal, diminishing the effect of implant angulation, and eliminating any concern about impression coping repositioning. Nevertheless, rotational distortion has been reported when connecting the implant replica to the impression copings [49, 50, 51, 52].

The indirect technique, also called the repositioning technique, is a technique in which the impression coping is left unexposed in connection with the implant when the impression tray is removed, during which it usually assumes a conical or tapered shape. In this technique, the copings are short and connected to the implants, and remain connected when the impression tray is retrieved. Then, these copings are removed separately from the implants, and connected to the implant replica before repositioning the coping into its corresponding position in the impression [49, 53]. The advantage of the indirect, closed-tray technique is that it is preferable in cases where there is limited inter-arch space, especially in the posterior region, because of the short impression coping. Further, it is easier by comparison to the direct technique because of its resemblance to the natural tooth impression technique. However, a major disadvantage is the distortion of the impression material that accompanies taking angled implant impressions, and leads to inaccurate definitive casts [51, 52].

Several studies have compared the accuracy of the direct and indirect techniques and concluded that, for completely edentulous cases, scientific evidence demonstrates the superiority of open-tray implant impression techniques. For partially edentulous cases, the evidence shows that there is no significant difference between open- and closed-tray implant impression techniques [2].

The introduction of the snap-fit or press fit plastic impression coping provides an alternative to the direct impression technique that has similar accuracy, and at the same time, is as simple to use as is the indirect technique. The snap-fit procedure actually is a combination of both implant techniques, as the impression coping snaps to the implant and then the impression is taken with a closed tray. When the impression material sets and the impression tray is removed, the snap-fit coping becomes fixed to the impression material and pulls out of the implant [32, 54].

Splinting versus non-splinting techniques

Brånemark first recommended splinting the impression copings when taking the implant impression, and used a rigid material to reduce the rotational, horizontal, and vertical distortion of the impression coping. Thereafter, numerous splinting techniques and materials were introduced that have different advantages [55].

Several past studies have reported that many different materials may be used as a rigid splinting material, with auto-polymerizing acrylic resin the most common. This material, which is used first with dental floss or even an orthodontic wire to make a scaffold between the impression copings, is followed by applying the rigid splinting material [34, 35, 56-61]. However, a major disadvantage described is their dimensional instability, in which total polymerization shrinkage of 7.9% occurs within the first 24 hours, with approximately 80% of this shrinkage occuring within the first 17 minutes after mixing. In addition, some residual stresses always persist within the set auto-polymerizing acrylic resin, which lead to more distortion when the

implant impression is removed, because the greater the mass of the acrylic resin, the greater the amount of distortion [34, 35, 56-67].

Several studies have reported that different methods may be used to reduce the residual stresses within the set resin upon removal of the impression; these include: (1) allowing the splinting material to set for approximately 17 min to prevent most of the acrylic resin polymerization shrinkage and reduce implant impression distortion; (2) sectioning the splint material between the impression copings, and then reconnecting the separated pieces; (3) decreasing the total mass of the splint material [47, 64, 66], and (4) luting the prefabricated bars to the impression copings with minimal amounts of resin.

Dual-cured acrylic resin has been used as a splint material to eliminate the implant impression distortion related to shrinkage. Although it produces less shrinkage, the dual-cured acrylic resin does not set completely (up to 25–45% of the material remains inactivated even 24 hours after curing). In edentulous patients with implants, the plaster impression has been used as a splinting material, although it cannot be used in any areas with anatomical undercuts [68, 69].

Most of the studies conducted on the accuracy of splinting versus non-splinting implant impression techniques has reported that the splinting technique is superior for completely and partially edentulous patients. Fewer studies have reported that the non-splinting technique was equally or more accurate [2, 70, 71-90]

Conventional impression materials

Implant impression materials include structural discrepancies that are related to their setting shrinkage, contraction, and water sorption expansion properties with a range of 50 μm [32, 91, 92]. This shrinkage is related primarily to the cross-linking and subsequent rearrangement of their polymer chains. However, it also could be related to the evaporation of volatile components and the release of by-products.

Numerous materials have been used for implant impressions, with the addition of silicone and polyether impression materials reported most commonly. The resilient properties of these materials reduce their deformation by undercuts; they also have improved accuracy, and relative stability that prevent the implant impression copings from moving during pouring procedures [91, 92, 93]. Several studies that compared polyether and impression materials containing silicone, reported no significant differences in dimensional accuracy, and both produced similarly accurate definitive casts for completely and partially edentulous patients [2, 70, 71-77].

Another important factor is the customized tray, which gives the implant impression material the advantage of having a uniform thickness that makes it more accurate and precise. A comparison of customized and stock trays showed that the customized tray was significantly more accurate due to the uniform distribution of the elastomeric impression material, unlike that in the stock tray [94, 95].

Implant angulation and number

Many investigators have reported that the accuracy of implant impressions decreases in partially and completely edentulous patients when the implants are not parallel, which is related primarily to distortion upon removal of the impression. However, an implant angulation up to 15°-20° degrees was shown to have no adverse effects on the accuracy of the implant impression for partially edentulous patients [2]; further, impression accuracy may be inversely affected by the number of implants [2, 32]. A recent study of the effects of implant impression copings stated that when using polyether impression material, long copings produced more accurate definitive models than did short ones [32].

Intraoral optical scanners

The introduction of digital implant dentistry has simplified and improved the workflow in the fabrication of the IFDP framework and changed the relationship between the dentist and the laboratory significantly [15]. Digital intraoral impression systems capture information about intraoral hard and soft tissues in one of two ways: first, they can capture the information as digital images, which the software stitches together to create one large Standard Tesselation Language (STL) file. The second system captures the information as a digital video that also is created as an STL file. Occasionally, powder coating has to be eliminated before scanning to ensure that all of the information is recorded properly [15-19].

Digital impressions are gaining popularity [14]. The advantages of digital intraoral scanners are numerous and include elimination of all of the conventional steps in taking impressions that may lead to distortion, such

as tray selection, shrinkage and expansion of impression materials, disinfection, and shipping to the laboratory; at the same time, they increase patient comfort, reduce storage occupancy, and keep records in optimum condition for patients through electronic storage [11, 14-19]. Another advantage that intraoral scanners introduced to the workflow in CAD/CAM fabrication of IFDP frameworks is the elimination of the initial step of taking an impression, and pouring the cast to be scanned in the lab. Taking a digital impression using an intraoral optical scanner (IOS) helps create a virtual model that uses the digital impression immediately, and eliminates the need for a stone model, which improves the accuracy and fit of the final prosthesis. One study reported better accuracy when using intraoral scanners compared to the traditional CAD/CAM workflow for fabrication of IFDP frameworks [10].

The limitations of digital scanners include their high purchase and maintenance costs, software performance issues, and the steep learning curve required to achieve commercially acceptable levels of productivity.

Since these scanners were first introduced to the market, numerous lines have emerged. First there were 3D digital scanners, which include the Lava Chairside Oral Scanner (3M ESPE), and the iTero Digital Impression System (Cadent) scanner. Then, new digital scanners acquired software that enables them to design and mill prostheses; these include the E4D Dentist (D4D Technologies) and CEREC Bluecam (Sirona Dental Systems) scanners. These new systems allow the fabrication of the final prosthesis on digital master casts created from the digital information captured. Thereafter, further advancements in digital scanners equipped them with continuous image acquisition to replace single image stitching; these

include the TRIOS scanner (3Shape), CEREC Omnicam (Sirona Dental Systems) scanner, and 3M True Definition (3M ESPE) scanner.

A study compared conventional impressions taken with different techniques and an intraoral scanner (Trios, 3shape), and found that the accuracy of digital scans did not differ significantly from the conventional, implant-level, splinted impressions (Polyether) for completely edentulous patients, while both were significantly more accurate than were implant-level, non-splinted conventional impressions [10]. Another study compared an intraoral scanner (Cadent iTero) to a conventional impression (Polyvinyl Siloxane) in partially edentulous arches, and found that at 0° and 15° degrees implant divergence, conventional impressions were more accurate than were digital impressions. There were no significant differences at 30° and 45° degrees of implant divergences [7].

Intraoral digital scanners of dental implants require the use of scan bodies, easy-to-capture plastic components attached to the implants. The accuracy of digital implant scans can be affected by the scan bodies due to discrepancies related to their fit on the implant. An average discrepancy of 39 μm in the fit of the scan bodies was reported, with only 11 μm on the implant replicas [10, 11, 13-19].

Today, the principal intraoral video data acquisition systems on the market are the TRIOS (3shape), CEREC Omnicam (Sirona), and True Definition (3M ESPE) scanners. There are no data available with respect to the accuracy of the Omnicam and True Definition digital scanners, and only one study using the TRIOS digital scanner compared the accuracy of digital implant impressions to conventional impression techniques. Therefore, a study that compares the accuracy of conventional implant impressions with

those of the CEREC Omnicam and the 3M True Definition digital scanners for partially edentulous patients was necessary to provide more information and clinical validation of intraoral optical scanner technology [10].

Purpose of the study

The primary purpose of this study was to compare the accuracy of definitive casts acquired from digital implant impressions (digital implant-level impressions with scan bodies and an intraoral scanner) using 2 different Intra Oral Scanners (CEREC Omnicam and 3M True Definition) with conventional implant impressions. A secondary purpose was to compare the difference in the accuracy of definitive casts between the Nobel Biocare and Straumann implant systems.

Hypothesis

The primary hypothesis was that the conventional splinted open-tray impressions are more accurate than are digital impressions for partially edentulous casts. The secondary hypothesis was that there is no difference in the accuracy of implant impressions made with the two digital implant systems (Nobel Biocare and Straumann).

Variables to be tested

1) Implant impression technique.
2) Implant system.

Outcome

The accuracy of the impressions was determined by comparing the definitive cast obtained with each method to the master cast and calculating the differences in microns.

Clinical implications

This study will help clinicians determine the most suitable impression technique for their practices. It will also help calculate, with the best evidence available, the risks/benefits of using an IOS, which will promote successful and improved clinical practice and patient satisfaction.

Materials and Methods

Master cast fabrication

Two partially edentulous mandibular casts with two internal connection implant analogs (Tissue level implant analogs RN, Straumann, and Replace Select implant analogs RP, Nobel Biocare) were fabricated to simulate a common clinical condition of partial edentulism (Figure 1). These casts were fabricated in clear acrylic resin in a specialized facility so that the two implants were not parallel to each other; instead, the first implant was parallel to the long axis of the teeth, while the second had a 300 angulation (Model Plus Inc., Grayslake, IL). It was not possible to obtain a digital scan of the clear acrylic resin cast, and therefore, a stone cast was fabricated to serve as a master cast (golden reference) by taking an impression using polyether impression material (Impregum: 3M ESPE, St. Paul, MN) and connecting implant replicas to the impression copings. The impressions were poured using a low expansion (0.09%) type IV stone (Resin Rock: Whipmix Corp., Louisville, KY) to create the master casts (control) for all six groups (Figure 2).

Conventional implant impression technique

Custom trays were fabricated after marking the master cast in four areas to standardize the position of the custom tray while taking the open-tray impression. Light-curing acrylic resin (Triad TruTray: Dentsply, Inc., York, PA) was used to fabricate the custom trays, and 2 holes were drilled through them to accommodate the impression coping guide screws in an

open-tray approach. Then, the conventional implant impression procedures continued as follows:

Groups I and II—Splinted, open-tray implant-level impression (n=10): implant-level impression copings were connected to the implant analogs in the stone cast (control) for both implant systems. A splint between the implant impression copings was made with urethane dimethacrylte-based visible light-cured resin (Triad gel: Dentsply Inc.). To standardize the thickness and shape of the splinting material, drinking straws were filled with Triad followed by light curing, and were stored for 24 hours. The resin bars were then sectioned and attached to the impression copings with minimal amounts of Triad [6]. Ten impressions for each group were taken using polyether impression material (Impregum: 3M ESPE, St. Paul, MN). This process was repeated 10 times to produce 10 stone casts for each group.

Digital implant impression technique

Groups III and IV—Digital impression with Active Triangulation technology (n=10): ten repeated digital scans were taken with a white light IOS (CEREC Omnicam: Sirona, Germany) at implant level for each of the two implant systems. Polymer implant impression scan bodies (RC: Straumann, Basel, Switzerland, and RP: Nobel Biocare, Yorba Linda, CA) were connected to the implants on the master cast and hand tightened. After the acquisition of ten repeated digital impressions, the digital scans were exported and saved as STL files.

Groups V and VI—Digital impression with Active Wavefront sampling technology (n=10): ten repeated digital scans were taken with a blue light IOS (True Definition: 3M ESPE, Germany) at implant level for each of the two implant systems. Polymer implant impression scan bodies (RC: Straumann, Basel, Switzerland, and RP: Nobel Biocare, Yorba Linda, CA) were connected to the implants on the control master cast and hand tightened. Powder was sprayed on the scan bodies and test casts prior to digital scanning. After the acquisition of ten repeated digital impressions, the digital scans were exported and saved as STL files.

Digitization of stone casts

Before recording any accuracy measurements, all stone casts were stored for one week at room temperature. Using a high-resolution reference scanner (Activity 880 scanner: Smart Optics, Bochum, Germany) all of the test stone casts from both groups I and II were digitized for comparison with the other digital groups, III-VI. A 3D transformation feature in the reference scanner (Activity 880 scanner) helped to scan and capture the implants' 3D position using a white light camera that can capture multiple pictures and transform them into a 3D image. Before digital scanning with the reference scanner was conducted, plastic scan bodies (Tissue Level RN: Straumann, Basel, Switzerland, and Replace Select RP: Nobel Biocare, Yorba Linda, CA) were placed on the first test cast, after which the scan bodies were removed and placed on the second cast in the same position for scanning. The same procedure of placing the scan bodies in the same position followed by digital scanning was performed with all 10

casts to eliminate the effect of scan bodies. The 2 stone master casts (control) were digitized with the same procedure, and the STL files were saved for comparison.

Superimposition procedures to assess 3D accuracy of STL files

Inspection software (Geomagic® Control™ 2015) was then used to superimpose the STL datasets for each cast in each test group to the STL file of the control (master cast). The primary method used to calculate the difference was the root mean square (RMS) error, which was calculated with the Geomagic® Control™ 2015 software.

Sample size calculation

The software nQuery Advisor (Version 7.0) was used to perform a power calculation. With a significance level of $\alpha = 0.05$, a sample size of $n = 10$ per group was found to result in a greater than 99% power to detect a difference between the impression techniques, assuming the same effect size as observed in Papaspyridakos et al. [10].

Statistical analyses

Descriptive statistics (medians and inter-quartile ranges) were calculated for each group. Nonparametric testing was undertaken due to non-normality of the data. When comparing conventional impressions, Omnicam scans, and True Definition scans to each other, statistical significance was assessed via two separate Kruskal-Wallis tests: one for Nobel Biocare, and one for Straumann. The Mann-Whitney U test alongside the Bonferroni correction was used for post-hoc tests.

When comparing the Nobel Biocare implant system versus the Straumann implant system, statistical significance was assessed via three separate Mann-Whitney U tests: one for conventional, one for Omnicam, and one for True Definition. SPSS Version 22 was used in all analyses.

Results

A summary of the descriptive statistical analysis with the median ± inter-quartile range of the differences among the three impression groups of the Nobel implant system master model is shown in Table 1. The True Definition scan group had the lowest median value (15.36 ± 6.18 μm), while the conventional impression group had the highest value (39.38 ± 17.71 μm). The Kruskal-Wallis test was significant ($p < 0.001$). In post-hoc testing, the difference between the impression groups and the master model was significantly different for all groups, except the Omnicam scan (19.79 ± 4.25 μm) and the True Definition groups (Table 1).

The analysis of the median ± inter-quartile range of the differences among the three impression groups of the Straumann implant system master model is shown in Table 2. The True Definition scan group had the lowest median value (16.94 ± 4.60 μm), while the Omnicam group had the highest value (26.01 ± 15.03 μm). The Kruskal-Wallis test was significant ($p = 0.003$). In post-hoc testing, the differences between the impression groups and the master model were significantly different between all groups, except the conventional impression (21.77 ± 5.24 μm) and the True Definition scan groups (Table 2).

The analysis of the median ± inter-quartile range of the differences in the conventional impression technique for the two implant system groups is shown in Table 3. The Straumann implant system had a lower median value (21.77 ± 5.24 μm) than did the Nobel system (39.38 ± 17.71 μm). The difference between the two systems was significant ($p < 0.001$: Table 3).

The analysis of the median ± inter-quartile range of the differences in the Omnicam scanning technique for both implant system groups is shown in Table 4. The Nobel implant system had a lower median value (19.79 ± 4.25 μm) than did the Straumann system (26.01 ± 15.03 μm). The difference between the systems was significant ($p = 0.011$: Table 4).

The analysis of the median ± inter-quartile range of the differences in the True Definition scanning technique for the two implant system groups is shown in Table 5. The Nobel implant system had a lower median value (15.36 ± 6.18 μm) than did the Straumann system (16.94 ± 4.60 μm). However, the difference between the two systems was not significant ($p = 0.25$: Table 5).

Discussion

In this in vitro study, the first null hypothesis was rejected, as the implant impression technique did have an effect on the accuracy of the definitive casts obtained. The second null hypothesis was also rejected, as the implant system also had an effect on the accuracy of the definitive casts obtained.

Similar to previous studies [10, 96], the 3D difference between the test model and the control model was evaluated by calculating the RMS error. In this method, the Geomagic® Control™ 2015 software uses the "best alignment fit" algorithm to overlap the test and control model scanning images [96]. In this study, we simulated a common clinical condition of partial edentulism of Kennedy's class II (Kennedy's classes II and III being the most common of all classes of partial edentulous patients in the lower jaw), which was replicated with two partially edentulous mandibular models [97]. Two internal connection implant analogs were inserted into the models in the edentulous areas with one implant parallel to the long axis of the teeth, and the second with a 30° degree angulation, as most previous studies have reported that an angulation of 20° degrees or less produces no statistically significant effects [2, 7, 10, 32].

In this study, the means of all groups were comparable to those presented in previous studies (the means and SDs were not reported but medians and inter-quartile ranges instead, because nonparametric statistical tests were used to determine significance) [7, 10]. With the Nobel implant system, the True Definition digital scans were the most accurate, but did not differ significantly from the Omnicam scans, while the

conventional impressions differed significantly from both digital scanners. This suggests a significant improvement in digital scanners, as most recent reports have indicated that conventional impressions were superior to digital scanners in partially edentulous patients [2, 7, 10, 32].

However, in the Straumann implant system, the Omnicam did not perform as well as it did with the Nobel implants, which could be attributed to two factors. First, the Straumann engaging scan bodies available did not have a surface area as great as that of the Nobel engaging scan bodies (Figure 12). Second, conventional impressions for the Straumann implant system were more accurate compared to the Nobel system. Although procedures for both implant systems were standardized when impressions were taken conventionally, there was a significant difference between the two. This could be attributed to the fact that Straumann impression copings were much larger, and had more surface area on which the splinting material could engage; this may have increased the stability of the impression coping-splint complex (Figure 12) [32]. Further, with the Straumann system, there was no significant difference between the conventional impression and True Definition, as opposed to previously reported studies in which conventional impressions performed significantly better than other digital scanners. [2, 7, 10, 32].

Therefore, in this study, when the conventional impression technique was compared with the two implant systems, the Straumann system was significantly more accurate than was the Nobel Biocare system. The larger impression copings may have been a contributing factor [32].

With the Omnicam technique, the Straumann system was significantly less accurate than was the Nobel system. The same explanation

mentioned previously, that the Straumann scan bodies have less surface area and fewer details that make scanning them more difficult likely contributed to this result [10, 32]. However, with the True Definition technique, there was no statistically significant difference between the two systems.

Overall, there was a clear pattern in this study of supremacy of the digital intraoral scanners (except for the Omnicam with Straumann tissue level implants) over the conventional impression technique. These results demonstrate that digital IOSs have improved profoundly compared to those used in recent relevant studies [2, 7, 10]. For example, in 2015, Lin et al [7] compared definitive casts obtained from a conventional impression technique with those obtained with a digital scanner (Cadent iTero) under similar clinical conditions. Their investigation showed that the digital technique produced less accurate models than did the conventional method. One reason for this could be because the new digital scanners (True Definition and Omnicam) are able to acquire continuous images rather than using single image stitching (Cadent iTero). Further, Lin et al's assessment was conducted on physical models of the conventional and digital groups, while in this study, the assessment was conducted on digital models of the groups alone. Thus, the digital technique was used in more steps compared to our study, increasing the chance for more distortion that produces less accurate digital models [7].

It must be highlighted that the maximum 3D deviation with each of the three different impression techniques was less than 56 μm for both implant systems. Specifically, with the Nobel Biocare system, the maximum 3D deviation was 53 μm for the conventional impression group, 33 μm for the

Omnicam group, and 27 µm for the True Definition group. With the Straumann system, the maximum 3-D deviation was 26 µm for the conventional impression group, 55 µm for the Omnicam group, and 38 µm for the True Definition group. Although the differences between conventional and digital impressions were statistically significant from the nominal point of view, they likely are clinically irrelevant. According to the literature, a misfit of less than 56 µm is below the reported threshold for a clinically acceptable fit [3, 4, 25]. The clinical implications indicate that all three impression techniques are adequate clinically for implant impressions.

Fundamentally, dental restorations (single crowns, FPDs, or IFPDs) can be fabricated using an intraoral digital scanner by two different techniques: in the first, the images captured are recorded using an STL file and then transported to the laboratory. Thereafter, a virtual interocclusal record is captured through buccal and facial scans to mount the digital models virtually to fabricate the restoration. The second technique involves fabricating polyurethane working casts that can be mounted physically using regular face-bows and interocclusal records [98].

Rapid prototyping is the term used to describe the digital technology involved in fabricating digitally based, physical casts (polyurethane models). Largely, the process of producing physical models from information and data obtained digitally can be divided into subtractive and additive techniques. Subtractive techniques include laser and electron beam cutting, computer numerical control machining, and electrical discharge machining. Subtractive methods use mechanical machines to cut down material, and a computer that includes data preset for the designed

final product to control these machines; additive techniques include selective laser sintering, SLA, and 3D printing. These techniques manufacture physical models by gradual addition [99, 100, 101].

The accuracy of physical casts (polyurethane models) obtained through rapid prototyping with a digital IOS has not been investigated fully in the past. A recent study showed the significant superiority of models made by (3D) printing (additive technique) over models made by milling (subtractive technique). However, both techniques were within acceptable clinical levels [99].

One final point to mention is that, as the accuracy of digital IOSs continues to improve, another advantage, time efficiency, will make them increasingly superior to the conventional impression technique. A recent prospective clinical study showed the improved time efficiency of digital compared to conventional workflow for an implant-supported single unit restoration, where a total of 16% less time was required in clinical and related laboratory procedures [102].

The study had the following limitations: first, all physical models produced with the conventional impression technique, as well as the master models, had to be scanned by an extraoral scanner to digitize the models' data. Although this extraoral scanner (Activity 880 scanner: Smart Optics, Bochum, Germany) was equilibrated before scanning, it has a margin of error of 10 microns. This is considered a limitation of the Geomagic® Control™ 2015 software analysis. Second, the results of this study cannot be generalized to all clinical contexts of partial edentulism, because we investigated only one common clinical situation in this experiment. Although the results we obtained are correct with respect to

this particular situation, this might not necessarily be true in a different clinical context of partial edentulism with different implant angulations.

Future studies should consider comparing conventional impressions to digital scanners intraorally, because a less controlled environment may have significant effects on the results. In addition, more laboratory and clinical research is recommended to assess the accuracy of the digital technique with and without the production of physical (polyurethane) casts. The accuracy of physical vs. digital casts also should be assessed to determine which technique is more efficient.

Conclusions

Within the limitations of this in-vitro study, we can conclude that:

1) Different impression techniques and implant systems affected the accuracy of the definitive cast generated.

2) When comparing the three different impression techniques within each implant system, in the Nobel Biocare implant system, True Definition scans were the most accurate, but did not differ significantly from Omnicam scans, while conventional impressions were significantly less accurate than were both digital scanners. With the Straumann implant system, True Definition scans were the most accurate, but did not differ significantly from conventional impressions, while the Omnicam scans were significantly less accurate than were both of the previous techniques.

3) When comparing the two implant systems with respect to each impression technique, with the conventional impression technique, the Straumann system was significantly more accurate than was the Nobel Biocare system. With the Omnicam scan technique, Nobel Biocare was significantly more accurate than was the Straumann system. Finally, there was no significant difference between the two implant systems with the True Definition scan technique.

Table 1: Medians and Inter-quartile Ranges of 3-D Deviation (μm) for the Nobel Biocare implant system

Impression Technique	n	Median	IQR	P-value
Conventional	10	39.38 [a]	17.71	
Omnicam	10	19.79 [b]	4.25	< 0.001*
True Definition	10	15.36 [b]	6.18	

* Statistically Significant
Groups that do not show a matched letter exhibited a statistically significant difference

Table 2: Medians and Inter-quartile Ranges of 3-D Deviation (μm) for the Straumann implant system

Impression Technique	n	Median	IQR	P-value
Conventional	10	21.77 [a]	5.24	
Omnicam	10	26.01 [b]	15.03	0.003*
True Definition	10	16.94 [a]	4.60	

* Statistically Significant
Groups that do not show a matched letter exhibited a statistically significant difference

Table 3: Medians and Inter-quartile Ranges of 3-D Deviation (μm) for the Conventional impression technique

Implant System	n	Median	IQR	P-value
Nobel	10	39.38	17.71	< 0.001*
Straumann	10	21.77	5.24	

* Statistically Significant

Table 4: Medians and Inter-quartile Ranges of 3-D Deviation (μm) for the Omnicam scanning technique

Implant System	n	Median	IQR	P-value
Nobel	10	19.79	4.25	0.011*
Straumann	10	26.01	15.03	

* Statistically Significant

Table 5: Medians and Inter-quartile Ranges of 3-D Deviation (μm) for the True Definition scanning technique

Implant System	n	Median	IQR	P-value
Nobel	10	15.36	6.18	0.247
Straumann	10	16.94	4.6	

* Statistically Significant

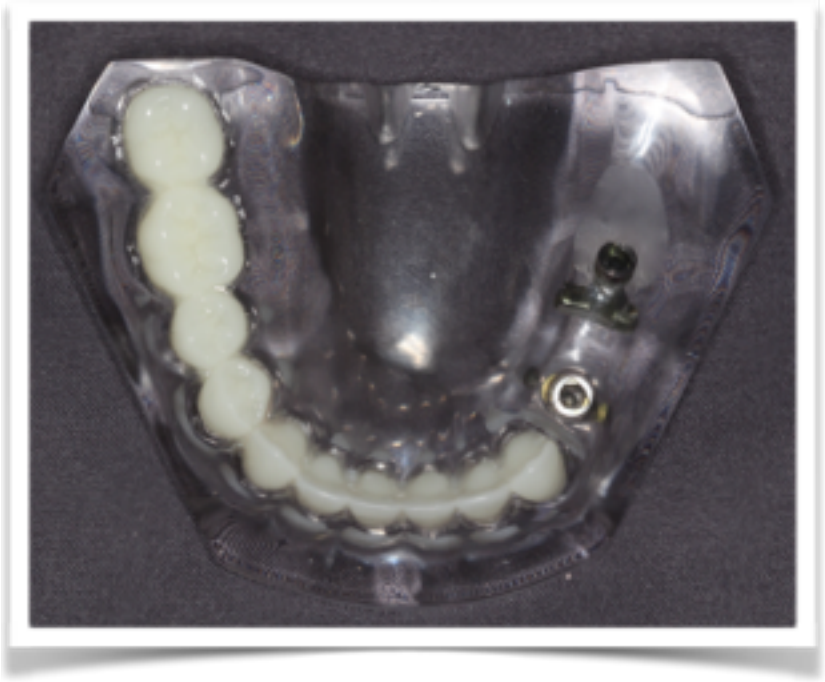

Figure 1: Clear acrylic model with two internal connection implant analogs (Replace Select implant analogs RP, Nobel Biocare)

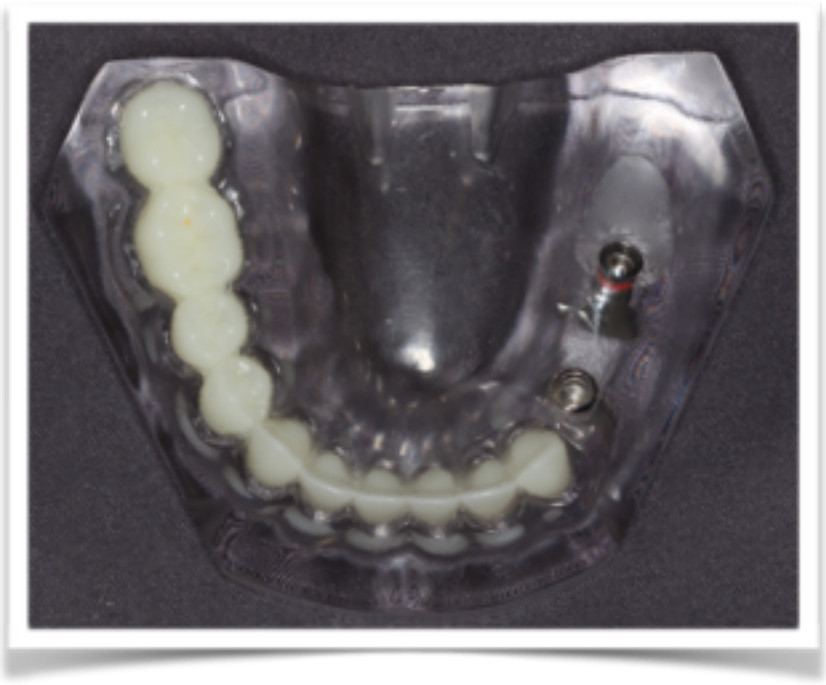

Figure 2: Clear acrylic model with two internal connection implant analogs (Tissue level implant analogs RN, Straumann)

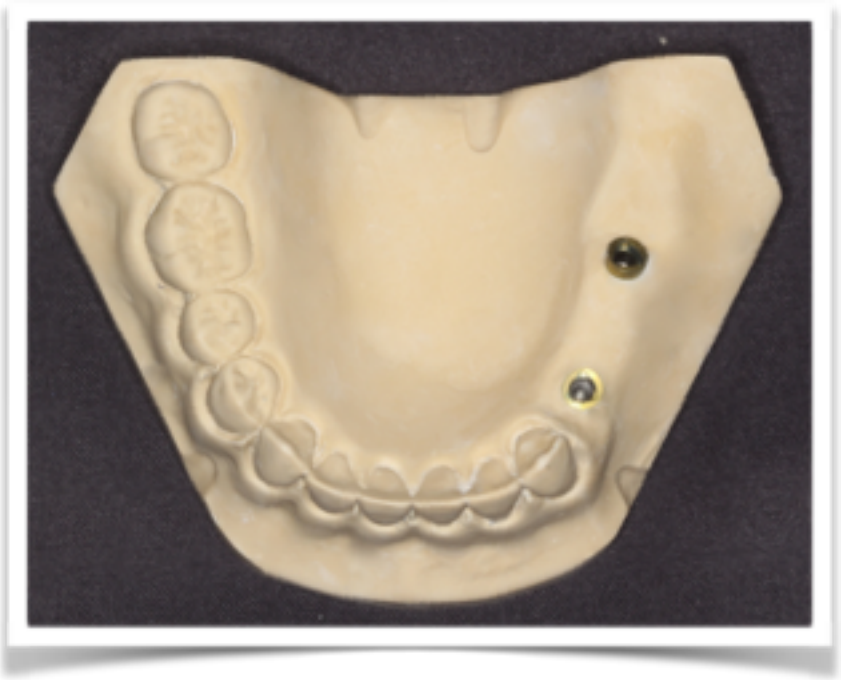

Figure 3: Master model with two internal connection implant analogs (Replace Select implant analogs RP, Nobel Biocare)

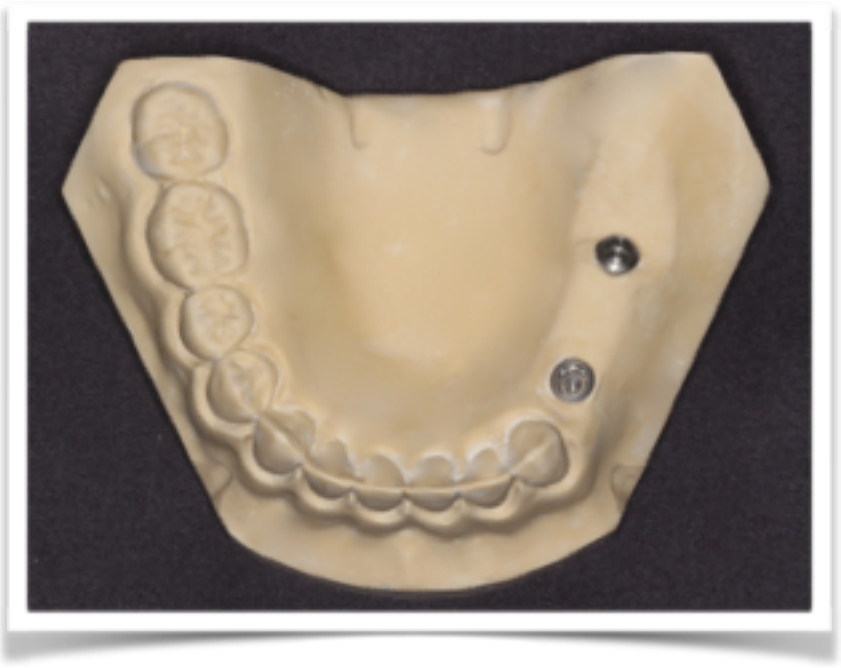

Figure 4: Master model with two internal connection implant analogs (Tissue level implant analogs RN, Straumann.)

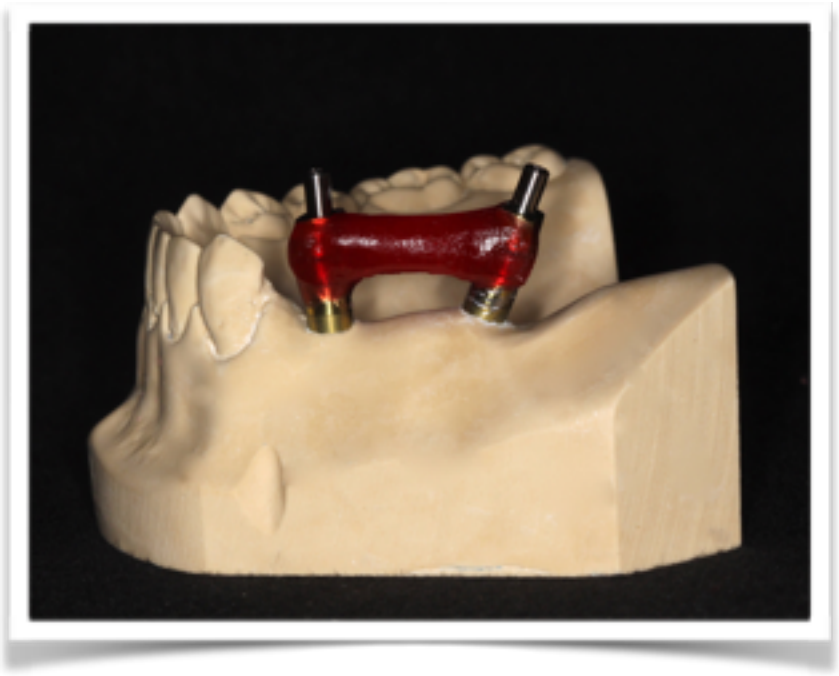

Figure 5: Splinting (Replace Select implant analogs RP, Nobel Biocare)

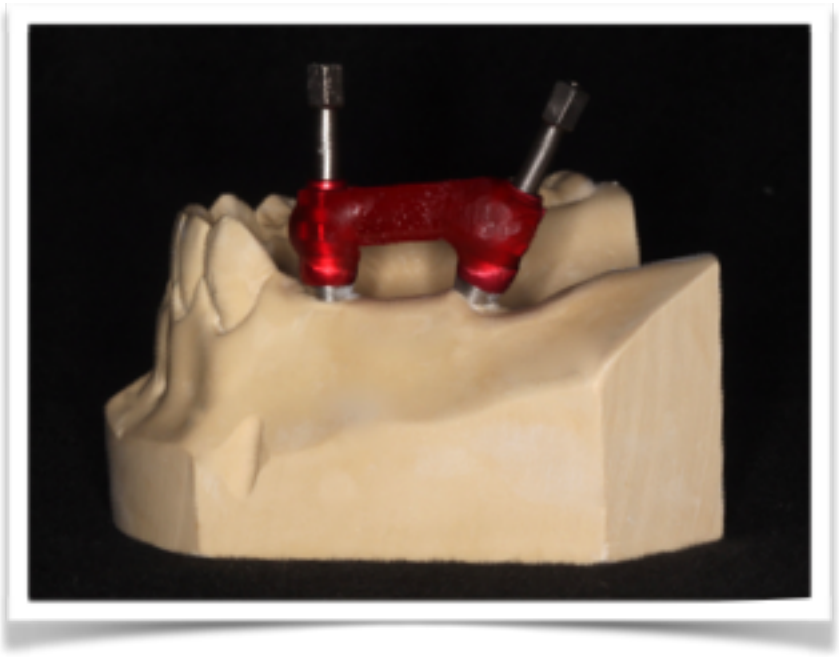

Figure 6: Splinting (Tissue level implant analogs RN, Straumann)

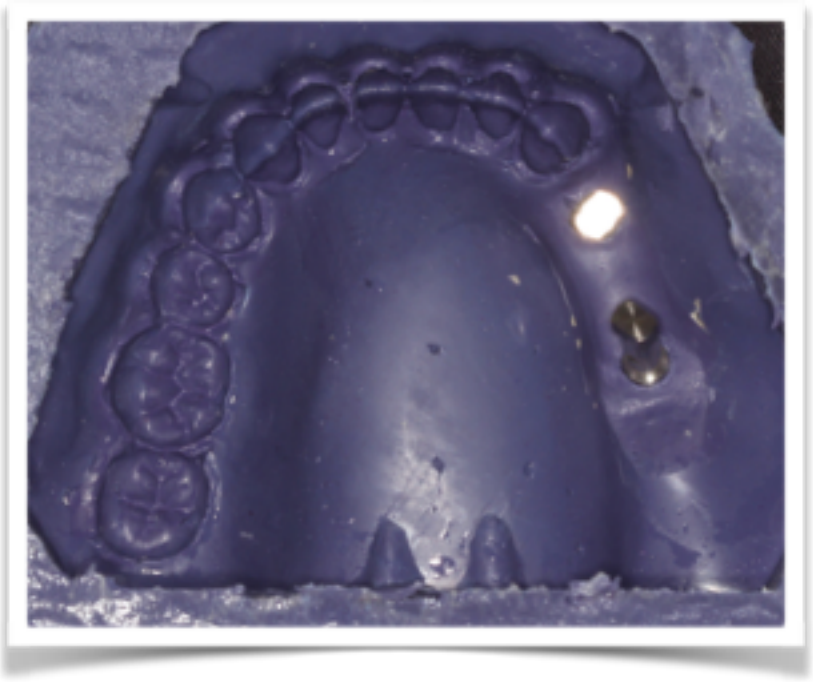

Figure 7: Conventional impressions (Replace Select implant analogs RP, Nobel Biocare)

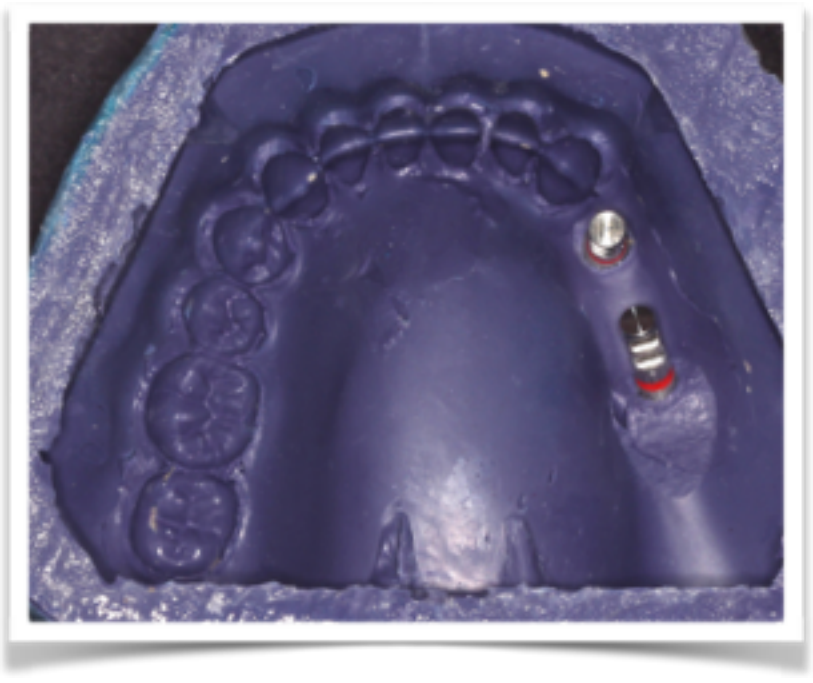

Figure 8: Conventional impressions (Tissue level implant analogs RN, Straumann)

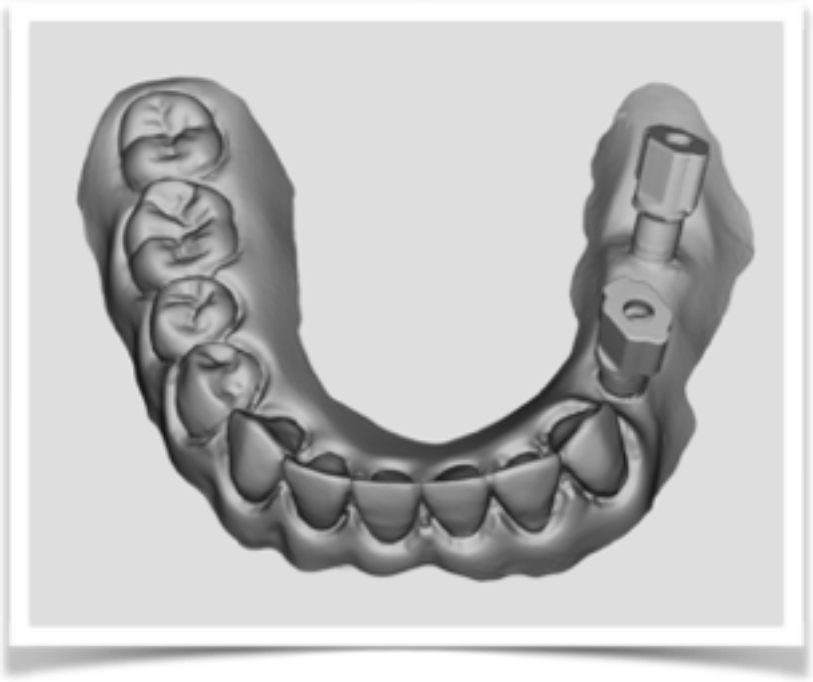

Figure 9: CEREC Omnicam; Standard Tesselation Language files (STL files) (Replace Select implant analogs RP, Nobel Biocare)

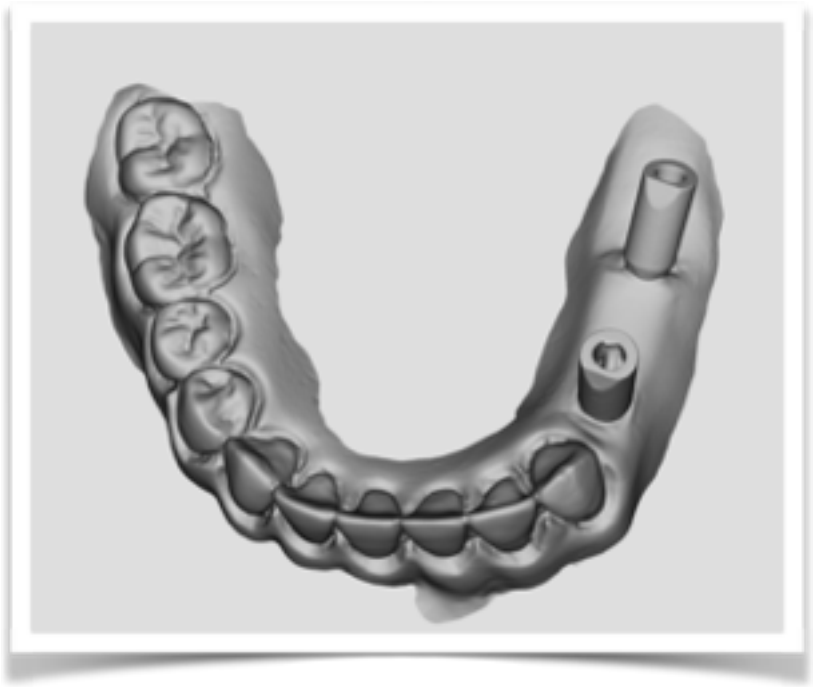

Figure 10: CEREC Omnicam; Standard Tesselation Language files (STL files) (Tissue level implant analogs RN, Straumann)

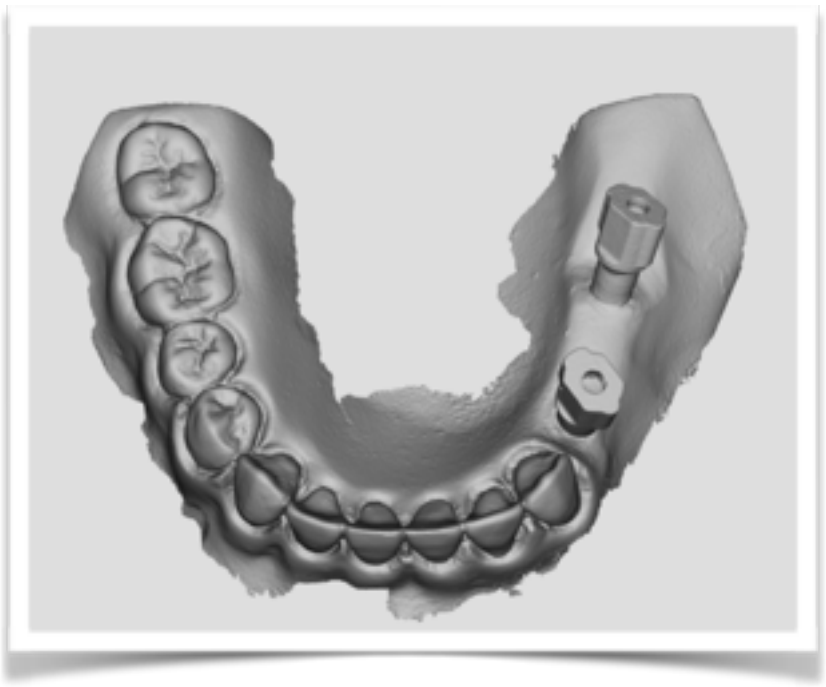

Figure 11: True Definition; Standard Tesselation Language files (STL files) (Replace Select implant analogs RP, Nobel Biocare)

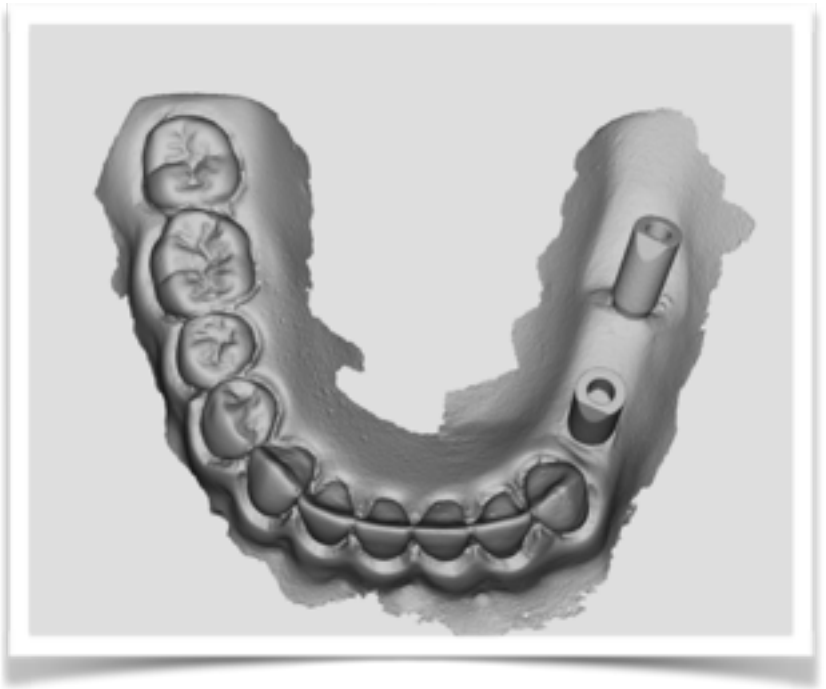

Figure 12: True Definition; Standard Tesselation Language files (STL files) (Tissue level implant analogs RN, Straumann)

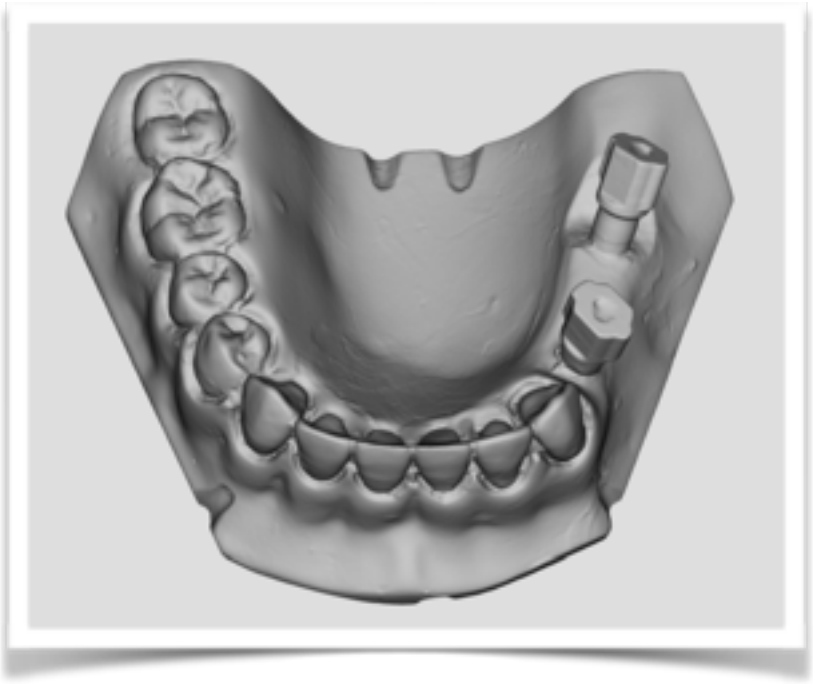

Figure 13: Activity 880 scanner; Standard Tesselation Language files (STL files) (Replace Select implant analogs RP, Nobel Biocare)

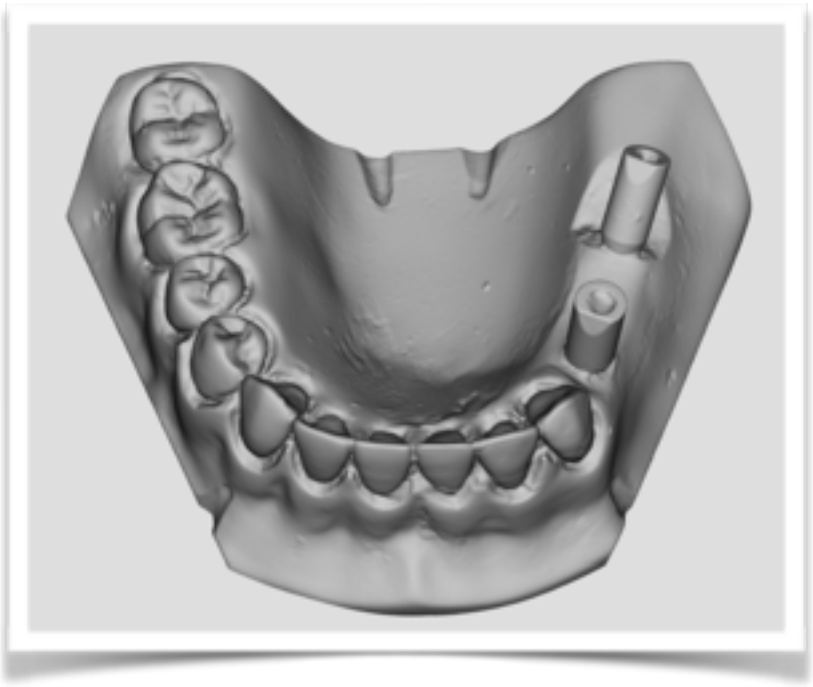

Figure 14: Activity 880 scanner; Standard Tesselation Language files (STL files) (Tissue level implant analogs RN, Straumann)

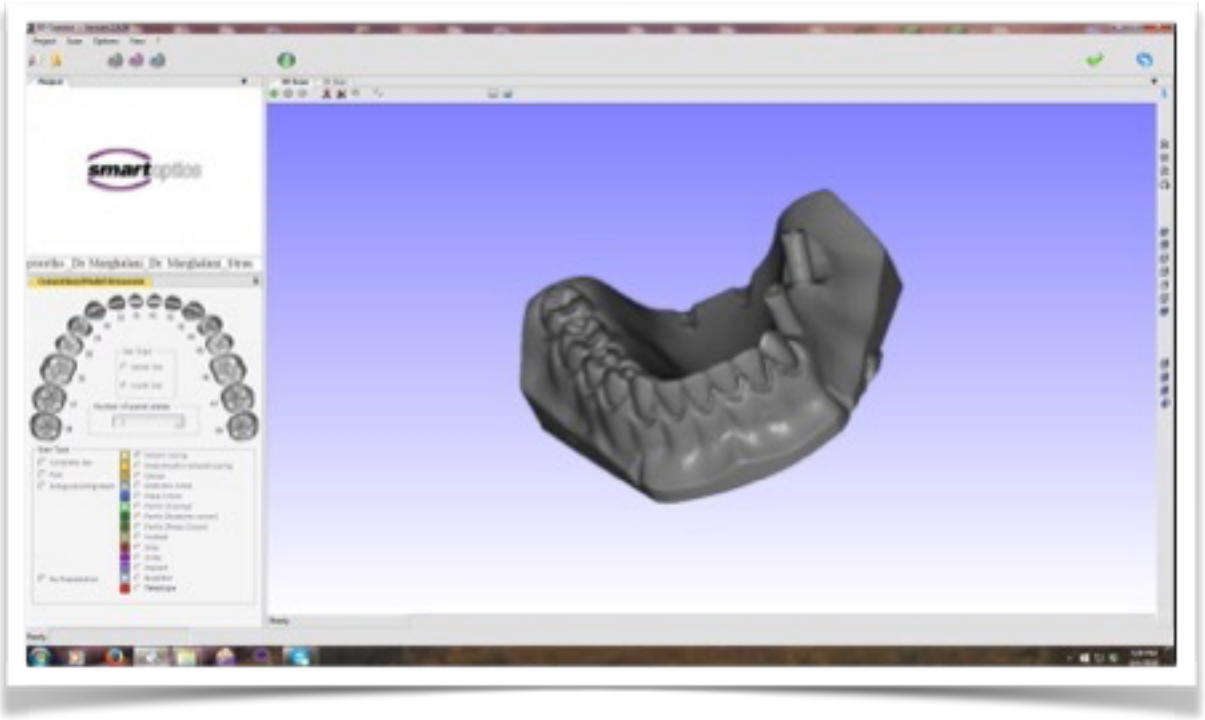

Figure 15: Activity 880 scanner; Data acquisition

Figure 16: Activity 880 scanner

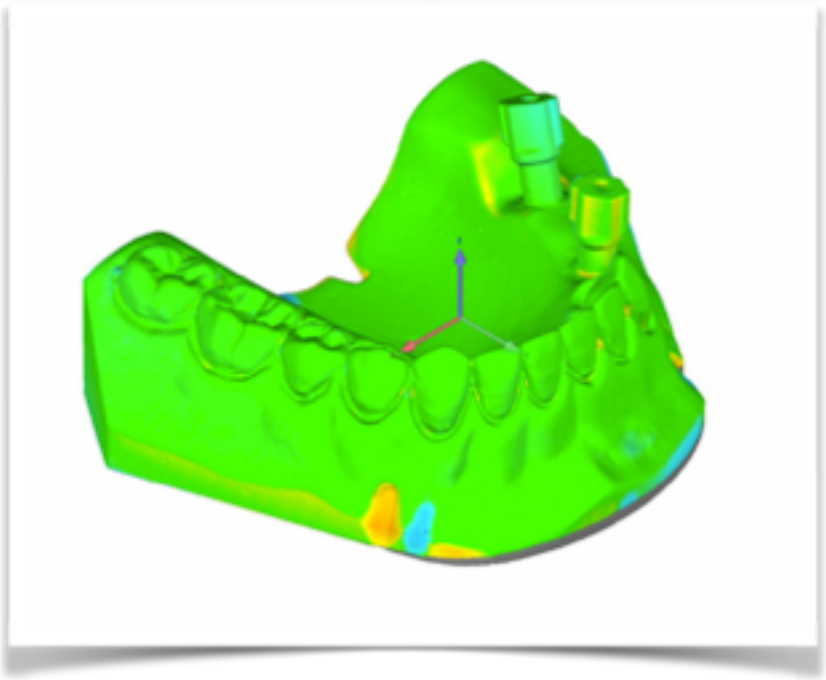

Figure 17: 3-D Accuracy Assessment for conventional impression technique (Replace Select implant analogs RP, Nobel Biocare)

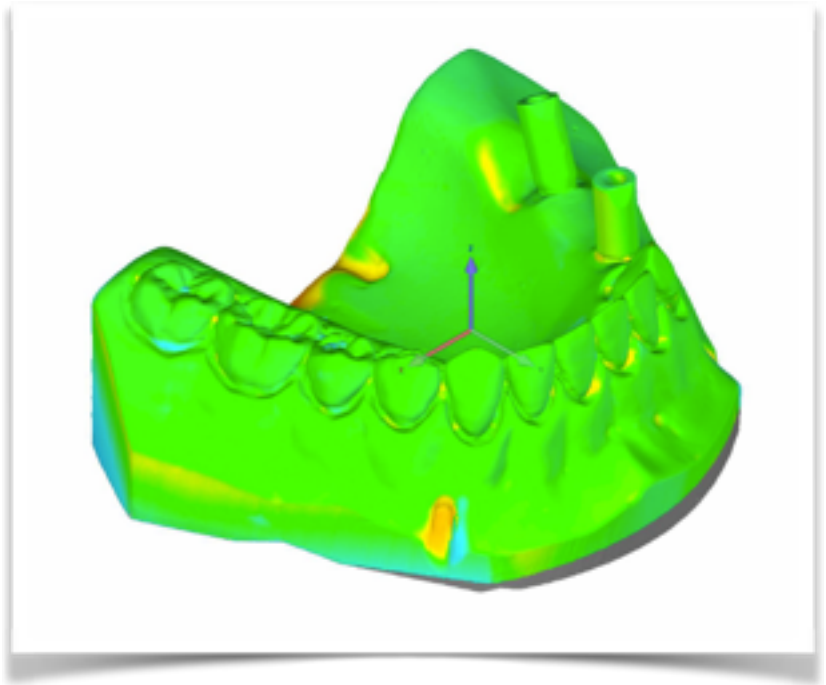

Figure 18: 3-D Accuracy Assessment for conventional impression technique (Tissue level implant analogs RN, Straumann)

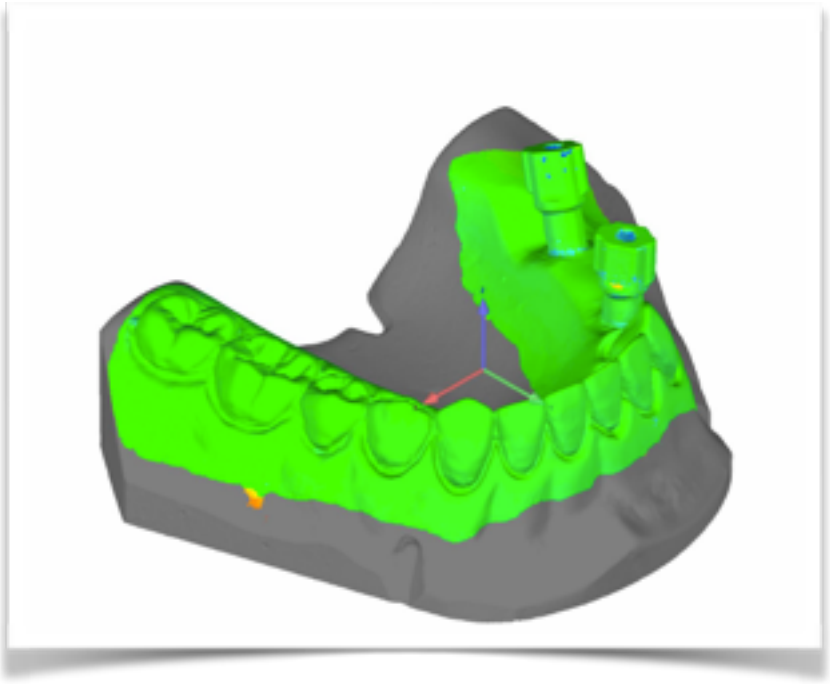

Figure 19: 3-D Accuracy Assessment for Omnicam digital scan technique (Replace Select implant analogs RP, Nobel Biocare)

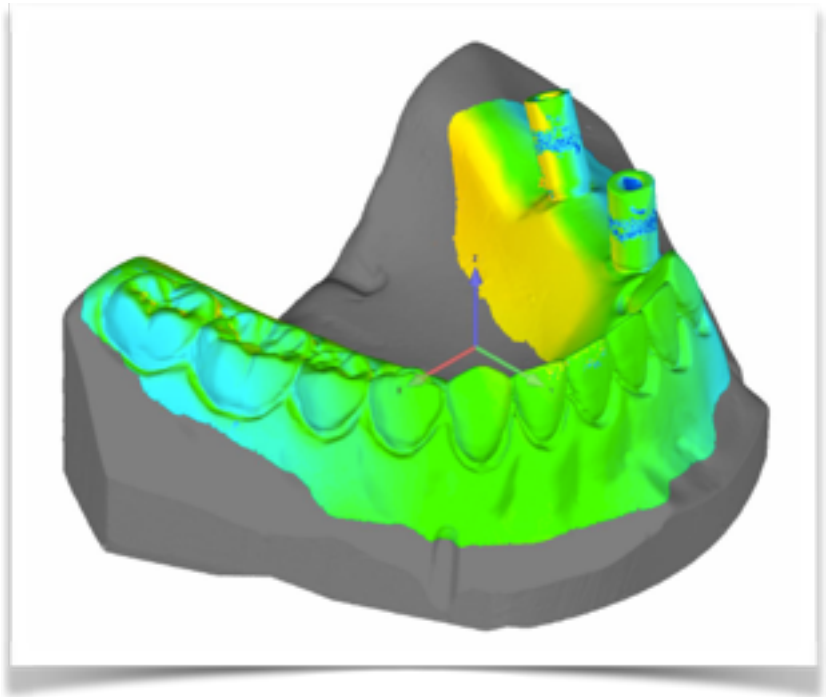

Figure 20: 3-D Accuracy Assessment for Omnicam digital scan technique (Tissue level implant analogs RN, Straumann)

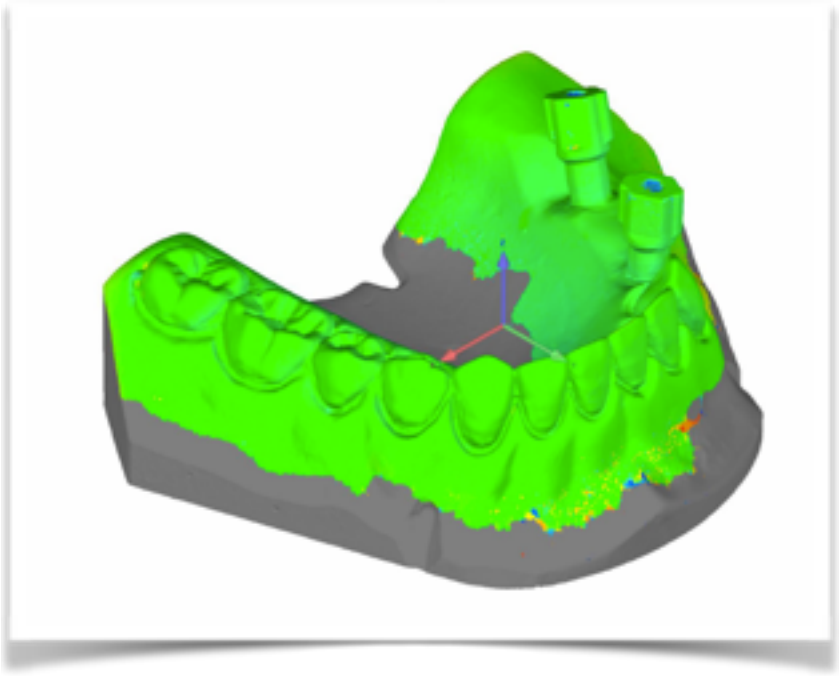

Figure 21: 3-D Accuracy Assessment for True Definition scan technique (Replace Select implant analogs RP, Nobel Biocare)

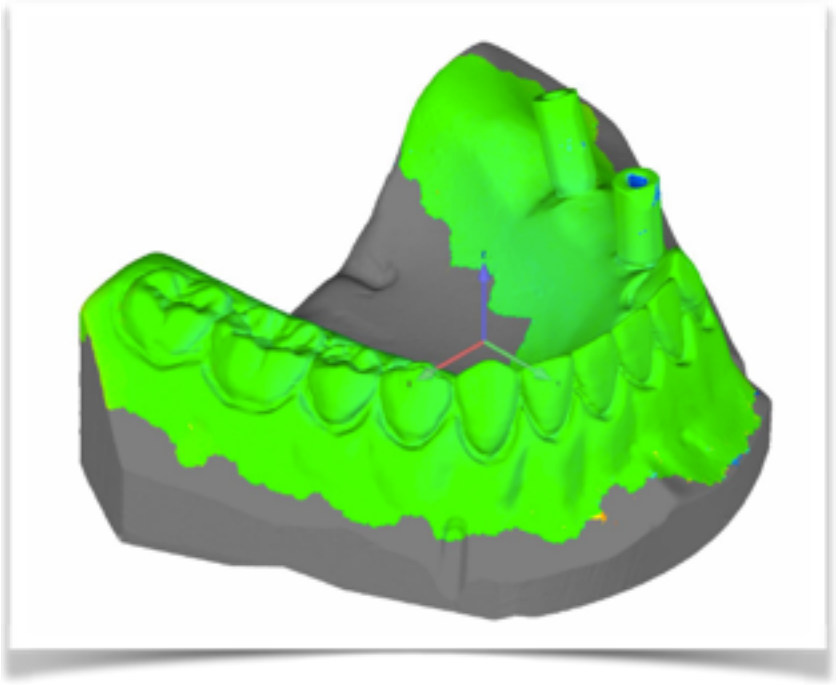

Figure 22: 3-D Accuracy Assessment for True Definition scan technique (Tissue level implant analogs RN, Straumann)

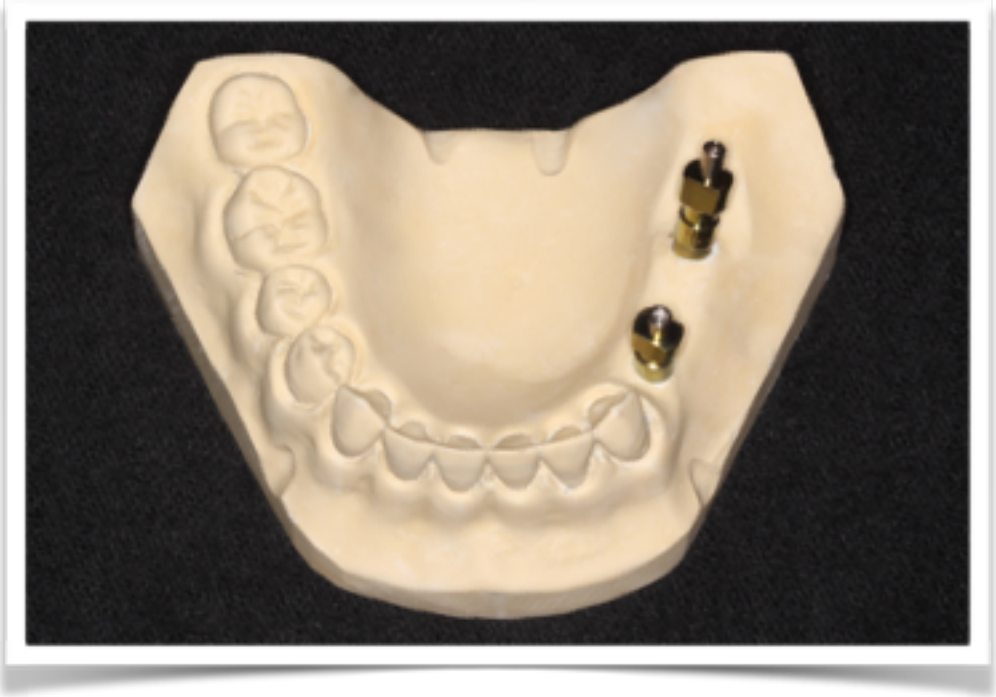

Figure 23: Impression copings (Replace Select implant analogs RP, Nobel Biocare) with smaller surface area.

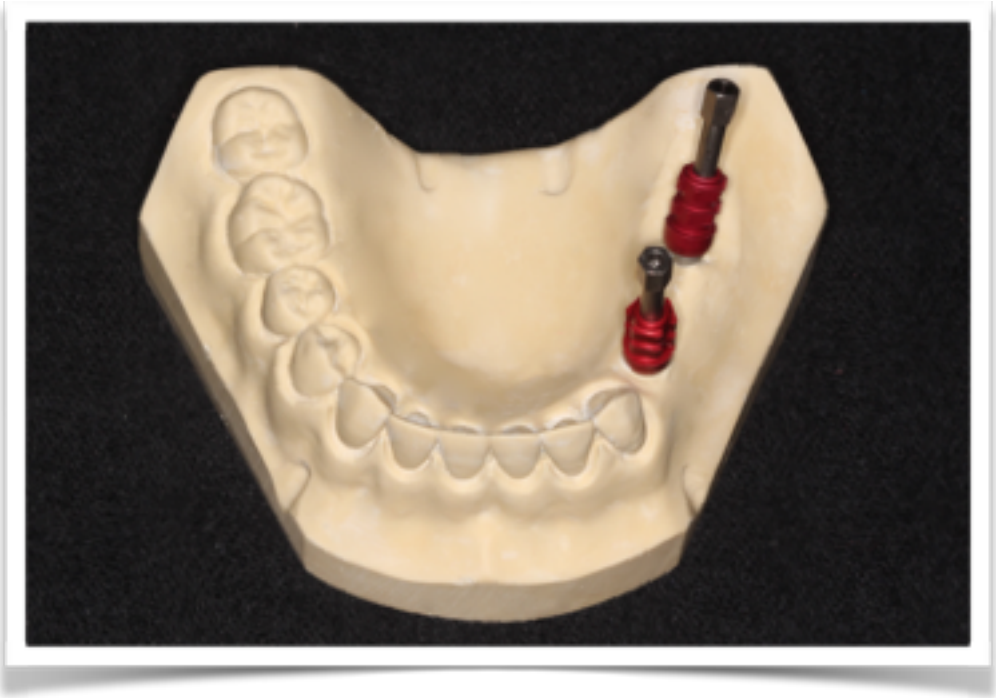

Figure 24: Impression copings (Tissue level implant analogs RN, Straumann) with bigger surface area.

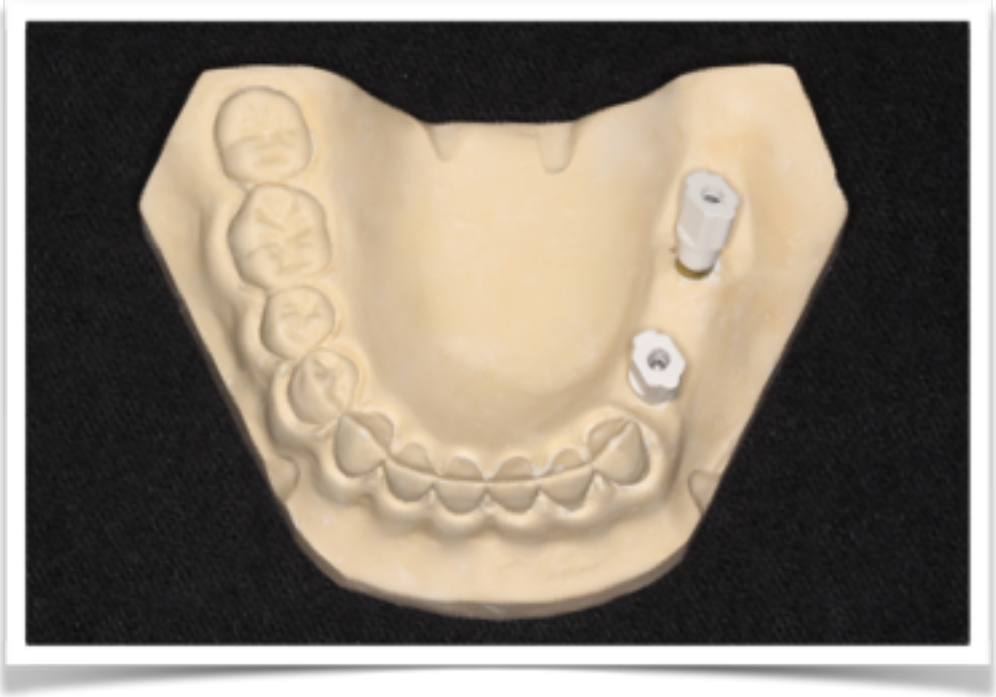

Figure 25: Scan bodies (Replace Select implant analogs RP, Nobel Biocare) with bigger surface area.

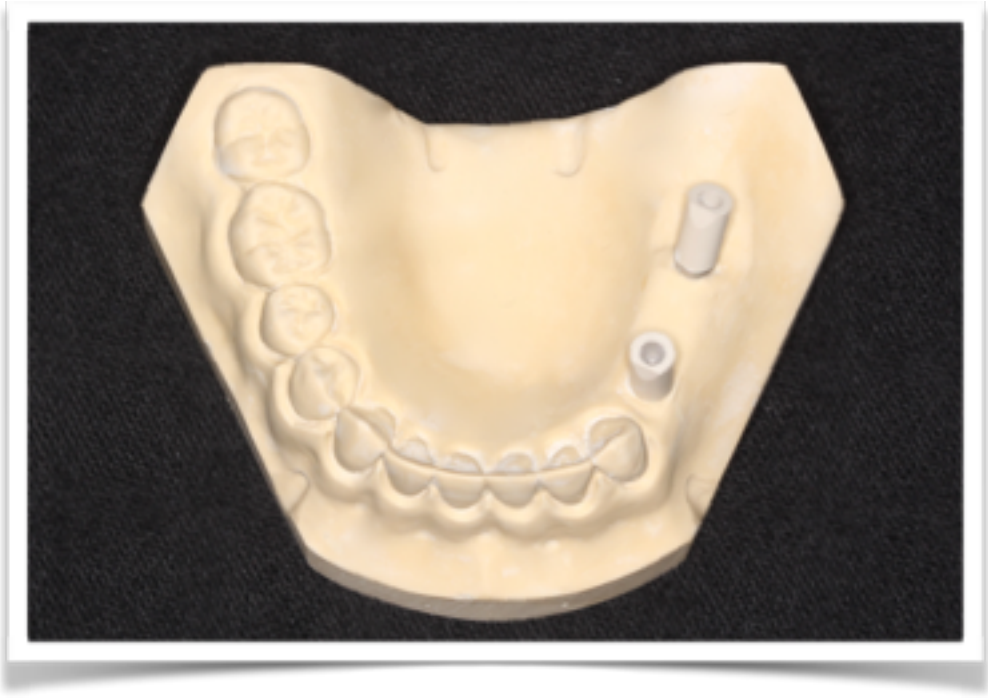

Figure 26: Scan bodies (Tissue level implant analogs RN, Straumann) with smaller surface area.

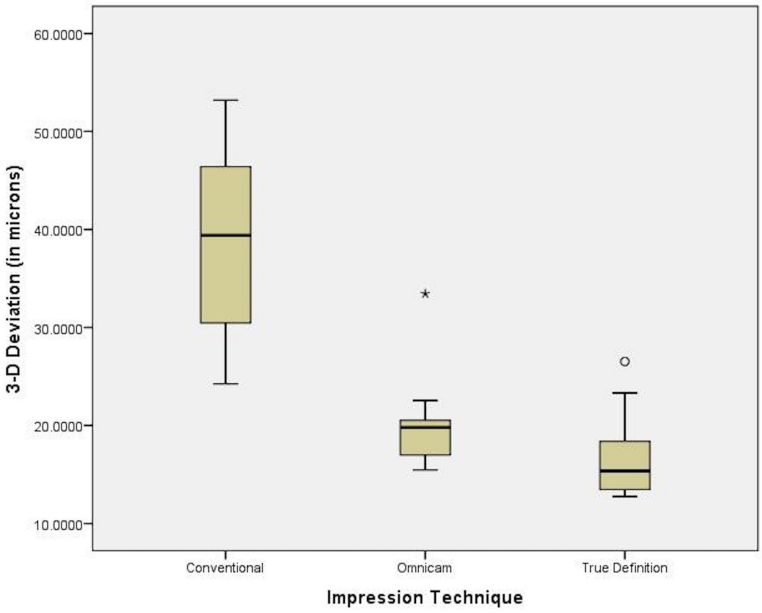

Figure 27: Box-plot chart illustration of the results for all three impression techniques for the Nobel Biocare implant system

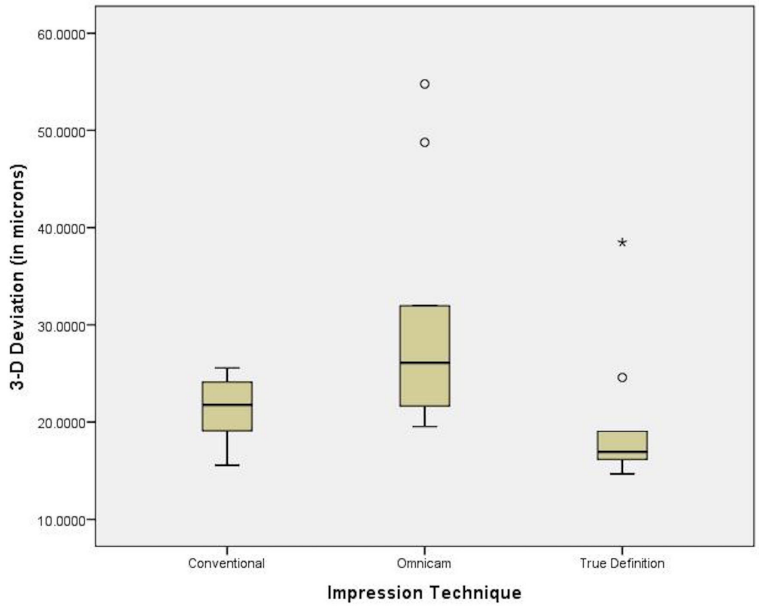

Figure 28: Box-plot chart illustration of the results for all three impression techniques for the Straumann implant system

REFERENCES

1. Kapos T, Ashy LM, Gallucci GO, Weber HP, Wismeijer D. Computer aided design and computer-assisted manufacturing in prosthetic implant dentistry. Int J Ora Maxillofac Implants 2009;24:110- 117.

2. Papaspyridakos P, Chen CJ, Gallucci GO, Doukoudakis A, Weber HP, Chronopoulos, V. Accuracy of implant impressions for partially and completely edentulous patients: a systematic review. International Journal of Oral Maxillofacial Implants 2014a;29: 836–845.

3. Papaspyridakos P, Chen CJ, Chuang SK, Weber HP. Implant loading protocols for edentulous patients with fixed prostheses: a systematic review and meta-analysis. International Journal of Oral Maxillofacial Implants 2014b;29(Suppl): 256–270.

4. Kapos T, Evans C. CAD/CAM technology for Implant abutments, crowns, and superstructures. Int J Oral Maxillofac Implants 2014;29(Suppl):117–136.

5. Jemt T, Hjalmarsson L. In vitro measurements of precision of fit of implant supported frameworks. A comparison between "virtual" and "physical" assessments of fit using two different techniques of measurements. Clinical Implant Dentistry and Related Research 2012;14(Suppl 1): e175–e182.

6. Papaspyridakos P, Lal K. Computer assisted design/computer assisted manufacturing zirconia implant fixed complete prostheses: clinical results and technical complications up to 4 years of function. Clinical Oral Implants Research 2013;24: 659–665.

7. Lin WS, Harris BT, Elathamna EN, Abdel-Azim T, Morton D. Effect of Implant divergence on the accuracy of definitive casts created from traditional and digital implant-level impressions: an In vitro comparative study. Int J Oral Maxillofac Implants 2015;30:102-109

8. Abduo J, Bennani V, Waddell N, Lyons K, Swain M. Assessing the fit of implant fixed prostheses: a critical review. Int J Oral Maxillofac Implants 2010;25:506–515

9. Sahin S, Cehreli MC. The significance of passive framework fit in implant prosthodontics: Current status. Implant Dent 2001;10:85–92.

10. Papaspyridakos P, Gallucci GO, Chen CJ, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. Clin Oral Impl Res 2015; [epub ahead of print]

11. Akalin ZF, Ozkan YK, Ekerim A. Effects of implant angulation, impression material, and variation in arch curvature width on implant transfer model accuracy. Int J Oral Maxillofac Implants 2013;28:149–157.

12. Mpikos P, Tortopidis D, Galanis C, Kaisarlis G, Koidis P. The effect of impression technique and implant angulation on the impression accuracy of external and internal connection implants. Int J Oral Maxillofac Implants 2012;27:1422–1428.

13. Rutkunas V, Sveikata K, Savickas R. Effects of implant angulation, material selection, and impression technique on impression accuracy: a preliminary laboratory study. Int J Prosthodont 2012;25:512–515.

14. Gimenez B, Ozcan M, Martinez-Rus F, Pradies G. Accuracy of a digital impression system based on active wavefront sampling technology for

implants considering operator experience, implant angulation, and depth. International Journal of Oral Maxillofacial Implants 2014;29: 853–862.

15. Joda T, Wittneben JG, Brägger U. Digital implant impressions with the "individualized scanbody technique" for emergence profile support. Clin Oral Implants Res 2014;25:395–397.

16. Lin WS, Harris BT, Morton D. The use of a scannable impression coping and digital impression technique to fabricate a customized anatomic abutment and zirconia restoration in the esthetic zone. J Prosthet Dent 2013;109:187–191.

17. Lin WS, Harris BT, Morton D. Use of implant supported interim restorations to transfer periimplant soft tissue profiles to a milled polyurethane definitive cast. J Prosthet Dent 2013;109:333–337.

18. Wismeijer D, Mans R, van Genuchten M, Reijers HA. Patients' preferences when comparing analogue implant impressions using a polyether impression material versus digital impressions (intraoral scan) of dental implants. Clin Oral Implants Res 2014;25:1113–1118.

19. Galhano GÁ, Pellizzer EP, Mazaro JV. Optical impression systems for CAD-CAM restorations. J Craniofac Surg 2012;23:575–579.

20. Ramsey CD, Ritter RG. Utilization of digital technologies for fabrication of definitive implant-supported restorations. J Esthet Restorative Dent 2012;24:299–308.

21. Lee SJ, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. Clin Oral Implants Res 2013;24:111–115.

22. Moreno A, Giménez B, Ozcan M, Pradíes G. A clinical protocol for intraoral digital impression of screw-retained CAD/CAM framework on

multiple implants based on wavefront sampling technology. Implant Dent 2013;22:320–325.

23. Jayesh RS, Dhinakarsamy V. Osseointegration. J Pharm Bioallied Sci. 2015;7(Suppl 1):S226–9.

24. Novaes AB Jr, de Souza SL, de Barros RR. Influence of implant surfaces on osseointegration. Braz Dent J. 2010;21:471–81.

25. Brånemark PI. The Osseointegration Book - From calvarium to calcaneus. USA: Quintessence Books 2005 ;p. 24.

26. Brånemark PI. Osseointegration and its experimental background. *J Prosthet Dent*. 1983;50:399–410.

27. Abduo J, Bennani V, Waddell N, Lyons K, Swain M. Assessing the fit of implant fixed prostheses: a critical review. *Int J Oral Maxillofac Implants*. 2010;25:506–515.

28. Papaspyridakos P, Lal K, White GS, Weber HP, Gallucci GO. Effect of splinted and nonsplinted impression techniques on the accuracy of fit of fixed implant prostheses in edentulous patients: a comparative study. Int J Oral Maxillofac Implants 2011;26:1267–1272.

29. Ravald N, Dahlgren S, Teiwik A, Gröndahl K. Long-term evaluation of Astra Tech and Brånemark implants in patients treated with full-arch bridges. Results after 12-15 years. Clin Oral Implants Res 2013;24:1144–1151.

30. Jemt T, Hjalmarsson L. In vitro measurements of precision of fit of implant-supported frameworks. A comparison between "virtual" and "physical" assessments of fit using two different techniques of measurements. Clin Implant Dent Relat Res 2012;14(suppl 1):175–182.

31. Buser D, Janner SF, Wittneben JG, Brägger U, Ramseier CA, Salvi GE. 10-year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: A retrospective study in 303 partially edentulous patients. Clin Implant Dent Relat Res 2012;14:839–851.

32. Buzayan MM, Yunus NB. Passive fit in screw retained multi-unit implant prosthesis understanding and achieving: a review of the literature. *The Journal of the Indian Prosthodontic Society* 2014;14(1):16-23.

33. Michalakis KX, Hirayama H, Garefis PD. Cement-retained versus screw-retained implant restorations: a critical review. Int J Oral Maxillofac Implants 2003;18:719–728.

34. Assif D, Marshak B, Schmidt A. Accuracy of implant impression techniques. Int J Oral Maxillofac Implants 1996;11:216–222.

35. Assif D, Marshak B, Nissan J. A modified impression technique for implant-supported restoration. J Prosthet Dent 1994;71:589–591.

36. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants 1991;6:270–276.

37. Jemt T, Book K. Prosthesis misfit and marginal bone loss in edentulous implant patients. Int J Oral Maxillofac Implants 1996;11:620–625.

38. Kan JY, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. J Prosthet Dent 1999;81:7–13.

39. Jemt T, Rubenstein JE, Carlsson L, Lang BR. Measuring fit at the implant prosthodontic interface. J Prosthet Dent 1996;75:314–325.

40. Wee AG, Aquilino SA, Schneider RL. Strategies to achieve fit in implant prosthodontics: a review of the literature. Int J Prosthodont 1999;12:167–178.

41. Sorrentino R, Gherlone EF, Calesini G, Zarone F. Effect of implant angulation, connection length, and impression material on the dimensional accuracy of implant impressions: an in vitro comparative study. Clin Implant Dent Relat Res 2010;12(Suppl 1):63–76.

42. Ma T, Nicholls JI, Rubenstein JE. Tolerance measurements of various implant components. Int J Oral Maxillofac Implants 1997;12:371–375.

43. Kim S, Nicholls JI, Han CH, Lee KW. Displacement of implant components from impressions to definitive casts. Int J Oral Maxillofac Implants 2006;21:747–755.

44. Roberts WE, Smith RK, Zilberman Y, Mozsary PG, Smith RS. Osseous adaptation to continuous loading of rigid endosseous implants. Am J Orthod 1984;86:95–111.

45. Klinberged IJ, Murray GM. Design of superstructures for osseointegrated fixtures. Swed Dent J 1985;28:63–69.

46. Natali AN, Pavan PG, Ruggero AL. Evaluation of stress induced in periimplant bone tissue by misfit in multi-implant prosthesis. Dent Mater 2006;22:388–395.

47. Del'Acqua MA, Arioli-Filho JN, Compagnoni MA, Mollo Fde A Jr. Accuracy of impression and pouring techniques for an implant-supported prosthesis. Int Journal Oral Maxillofac Implants 2008;23:226–236.

48. Duyck J, Naert I. Influence of prosthesis fit and the effect of a luting system on the prosthetic connection preload: An in vitro study. Int J Prosthodont 2002;15:389–396.

49. Lee H, So JS, Hochstedler JL, Ercoli C. The accuracy of implant impressions: a systematic review. J Prosthet Dent 2008;100:285–291.

50. Daoudi MF, Setchell DJ, Searson LJ. A laboratory investigation of the accuracy of two impression techniques for single-tooth implants. Int J Prosthodont 2001;14:152–158.

51. Conrad HJ, Pesun IJ, DeLong R, Hodges JS. Accuracy of two impression techniques with angulated implants. J Prosthet Dent 2007;97:349–356.

52. Carr AB. Comparison of impression techniques for a five-implant mandibular model. Int J Oral Maxillofac Implants 1991;6:448–455.

53. Lee H, Ercoli C, Funkenbusch PD, Feng C. Effect of subgingival depth of implant placement on the dimensional accuracy of the implant impression: an in vitro study. J Prosthet Dent 2008;99:107–113.

54. Akca K, Cehreli MC. Accuracy of 2 impression techniques for ITI implants. Int J Oral Maxillofac Implants 2004;19:517–523.

55. Brånemark PI, Zarb GA, Albrektsson T. Tissue -integrated prostheses. Chicago: Quintessence; 1985. p. 253.

56. Assuncao WG, Filho HG, Zaniquelli O. Evaluation of transfer impressions for osseointegrated implants at various angulations. Implant Dent 2004;13:358–366.

57. Vigolo P, Majzoub Z, Cordioli G. Evaluation of the accuracy of three techniques used for multiple implant abutment impressions. J Prosthet Dent 2003;89:186–192.

58. Vigolo P, Fonzi F. An evaluation of impression techniques for multiple internal connection implant prostheses. J Prosthet Dent 2004;92:470–476.

59. Lee H, So JS, Hochstedler JL, Ercoli C. The accuracy of implant impressions: a systematic review. J Prosthet Dent 2008;100:285–291.

60. Humphries RM, Yaman P, Bloem TJ. The accuracy of implant master casts constructed from transfer impressions. Int J Oral Maxillofac Implants 1990;5:331–336.

61. Herbst D, Nel JC, Driessen CH, Becker PJ. Evaluation of impression accuracy for osseointegrated implant supported superstructures. J Prosthet Dent 2000;83:555–561.

62. Inturregui JA, Aquilino SA, Ryther JS, Lund PS. Evaluation of three impression techniques for osseointegrated oral implants. J Prosthet Dent 1993;69:503–509.

63. Mojon P, Oberholzer JP, Oberholzer JP, Meyer JM, Belser UC. Polymerization shrinkage of index and pattern acrylic resins. J Prosthet Dent 1990;64:684–688.

64. Spector MR, Donovan TE, Nicholls JI. An evaluation of impression techniques for osseointegrated implants. J Prosthet Dent 1990;63:444–447.

65. Hsu CC, Millstein PL, Stein RS. A comparative analysis of the accuracy of implant transfer techniques. J Prosthet Dent 1993;69:588–593.

66. Burawi G, Houston F, Byrne D, Claffey N. A comparison of the dimensional accuracy of the splinted and unsplinted impression techniques for the Bone-Lock implant system. J Prosthet Dent 1997;77:68–75.

67. Naconecy MM, Teixeira ER, Shinkai RS, Frasca LC, Cervieri A. Evaluation of the accuracy of 3 transfer techniques for implant-supported prostheses with multiple abutments. Int J Oral Maxillofac Implants 2004;19:192–198.

68. Assif D, Nissan J, Varsano I, Singer A. Accuracy of implant impression splinted techniques: effect of splinting material. Int J Oral Maxillofac Implants 1999;14:885–888.

69. Eid N. An implant impression technique using a plaster splinting index combined with a silicone impression. J Prosthet Dent 2004;92:575–577.

70. Hariharan R, Shankar C, Rajan M, Baig MR, Azhagarasan NS. Evaluation of accuracy of multiple dental implant impressions using various splinting materials. Int J Oral Maxillofac Implants 2010;25:38–44.

71. Assunção WG, Cardoso A, Gomes EA, Tabata LF, dos Santos PH. Accuracy of impression techniques for implants. Part 1—Influence of transfer copings surface abrasion. J Prosthodont 2008;17:641–647.

72. Assunção WG, Filho HG, Zaniquelli O. Evaluation of transfer impressions for osseointegrated implants at various angulations. Implant Dent 2004;13:358–366.

73. Assunção WG, Tabata LF, Cardoso A, Rocha EP, Gomes EA. Prosthetic transfer impression accuracy evaluation for osseointegrated implants. Implant Dent 2008;17:248–256.

74. Choi JH, Lim YJ, Yim SH, Kim CW. Evaluation of the accuracy of implant-level impression techniques for internal-connection implant prostheses in parallel and divergent models. Int J Oral Maxillofac Implants 2007;22:761–768.

75. Jang HK, Kim S, Shim JS, Lee KW, Moon HS. Accuracy of impressions for internal-connection implant prostheses with various divergent angles. Int J Oral Maxillofac Implants 2011;26:1011–1015.

76. Lee YJ, Heo SJ, Koak Jy, Kim SK. Accuracy of different impression techniques for internal-connection implants. Int J Oral Maxillofac Implants 2009;24:823–830.

77. Kwon JH, Son YH, Han CH, Kim S. Accuracy of implant impressions without impression copings: A three-dimensional analysis. J Prosthet Dent 2011;105:367–373.

78. Cabral LM, Guedes CG. Comparative analysis of 4 impression techniques for implants. Implant Dent 2007;16:187–194.

79. Carr AB. Comparison of impression techniques for a two-implant 15°-degree divergent model. Int J Oral Maxillofac Implants 19 9 2 ; 7 : 4 6 8 – 4 7 5 .

80. Inturregui JA, Aquilino SA, Ryther JS, Lund PS. Evaluation of three impression techniques for osseointegrated oral implants. J Prosthet Dent 1993;69:503–509.

81. De La Cruz JE, Funkenbusch PD, Ercoli C, Moss ME, Graser GN, Tallents RH. Verification jig for implant-supported prostheses: A comparison of standard impressions with verification jigs made of different materials. J Prosthet Dent 2002;88:329–336.

82. Lee HJ, Lim YJ, Kim CW, Choi JH, Kim MJ. Accuracy of a proposed implant impression technique using abutments and metal frame- work. J Adv Prosthodont 2010;2:25–31.

83. Jo SH, Kim KI, Seo JM, Song KY, Park JM, Ahn SG. Effect of impression coping and implant angulation on the accuracy of implant impressions: An in vitro study. J Adv Prosthodont 2010;2:128–133.

84. Howell KJ, McGlumphy EA, Drago C, Knapik G. Comparison of

the accuracy of Biomet 3i Encode Robocast technology and conventional implant impression techniques. Int J Oral Maxillofac Implants 2013;28:228–240.

85. Conrad HJ, Pesun IJ, DeLong R, Hodges JS. Accuracy of two impression techniques with angulated implants. J Prosthet Dent 2007;97:349–356.

86. Eliasson A, Ortorp A. The accuracy of an implant impression technique using digitally coded healing abutments. Clin Implant Dent Relat Res 2012;14(suppl 1): 30–38.

87. Filho HG, Mazaro JV, Vedovatto E, Assunção WG, dos Santos PH. Accuracy of impression techniques for implants. Part 2—Comparison of splinting techniques. J Prosthodont 2009;18:172–176.

88. Rutkunas V, Sveikata K, Savickas R. Effects of implant angulation, material selection, and impression technique on impression accuracy: A preliminary laboratory study. Int J Prosthodont 2012:25:512–515.

89. Gallucci GO, Papaspyridakos P, Ashy LM, Kim GE, Brady NJ, Weber HP. Clinical accuracy outcomes of closed-tray and open-tray implant impression techniques for partially edentulous patients. Int J Prosthodont 2011;24:469–472.

90. Cehreli MC, Akça K. Impression techniques and misfit-induced strains on implant-supported superstructures: an in vitro study. Int J Periodontics Restorative Dent 2006;26:379–385.

91. Assuncao WG, Filho HG, Zaniquelli O. Evaluation of transfer impressions for osseointegrated implants at various angulations. Implant Dent 2004;13:358–366.

92. Rashidan N, Alikhasi M, Samadizadeh S, Beyabanaki E, Kharazifard MJ. Accuracy of implant impressions with different impression coping types and shapes. Clin Implant Dent Relat Res 2009;14(2):218–225.

93. Robert G, Craig JMP. Restorative dental materials. St. Louis: Mosby; 2002.

94. Burns J, Palmer R, Howe L, Wilson R. Accuracy of open tray implant impressions: an in vitro comparison of stock versus custom trays. J Prosthet Dent 2003;89:250–255.

95. Donovan TE, Chee WW. A review of contemporary impression materials and techniques. Dent Clin North Am 2004;48:445–470.

96. Papaspyridakos P, Benic GI, Hogsett VL, White GS, Lal K, Gallucci G.O. Accuracy of implant casts generated with splinted and non-splinted impression techniques for edentulous patients: an optical scanning study. Clinical Oral Implants Research 2012;23: 676– 681.

97. Jeyapalan V, Krishnan CS. Partial Edentulism and its correlation to age, gender, socio-economic status and incidence of various Kennedy's classes– a literature review. Journal of Clinical and Diagnostic Research 2015;9(6):14-17.

98. Alghazzawi TF. Advancements in CAD/CAM technology: Options for practical implementation. J of Prosthodontic Research 2016;60(2):72-84

99. Patzelt SB, Bishti S, Stampf S, Att W. Accuracy of computer-aided design/computer-aided manufacturing generated dental casts based on intraoral scanner data J Am Dent Assoc 2014;145(11):1133–1140

100. Jacobs PF, Reid DT. Rapid Prototyping and Manufacturing: Fundamentals of Stereolithography. Dearborn, Mich Society of

Manufacturing Engineers in cooperation with the Computer and Automated Systems Association of SME 1992;1-24.

101. Horn TJ, Harrysson OL. Overview of current additive manufacturing technologies and selected applications. Sci Prog 2012;95(3):255-282.

102. Joda T, Brägger U. Time-Efficiency Analysis Comparing Digital and Conventional Workflows for Implant Crowns: A Prospective Clinical Crossover Trial. . Int J Oral Maxillofac Implants 2015;30(5):1047-1053.