



School of
Dental Medicine

Accuracy Evaluation of Definitive Casts Obtained from
Conventional and Digital Impression Methods for Kennedy
Class IV Partially Edentulous Maxillary Arches:
an in Vitro Study

Thesis submitted in partial fulfillment of the requirement for the degree of Master
of Science

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Table of Contents

Abstract.....	1
Thesis Committee	ii
Acknowledgments	iii
Introduction and Literature Review	3
Aim and Hypothesis.....	8
Materials and Methods	8
Results.....	15
Discussion	16
Conclusion	19
References	20
Appendix A: Tables	27
Appendix B: Figures	29

Abstract:

Purpose: This study compared the accuracy of definitive casts obtained by conventional impressions with those obtained from two different intra-oral scanners (Dental Wings and True Definition).

Material and Methods: Two maxillary partially edentulous clear acrylic casts with teeth # 7, 8, 9, and 10 missing were fabricated to simulate a Kennedy class IV clinical condition. Both casts were outfitted with two internal connection implant analogs in sites # 7 and 10, Bone Level RC implant analogs (Straumann USA, Andover, MA) in one cast, and Nobel Conical Connection RP implant analogs (Nobel Biocare, Yorba Linda, CA) in the other. The study had 6 groups. Groups I and II included casts produced from conventional impressions, which were then digitized (n=10 each). Groups III and IV consisted of digital impressions obtained with a 3Shape True Definition intra-oral scanner (n=10 each). For groups V and VI a Dental Wings intra-oral scanner was used to produce the digital impressions (n=10 each).

Results: For the Straumann implant system, the True Definition intra-oral scanner was the most accurate with a median \pm IQR 3-D deviation of $18.1 \pm 4.7\mu\text{m}$. No statistically significant differences between the three groups ($p = 0.400$) were noted.

For the Nobel Biocare system, the Dental Wings intra-oral scanner was the most accurate with a median \pm IQR 3-D deviation of $15.9 \pm 3.2\mu\text{m}$. A statistically significant difference between the Dental Wings digital impression and the conventional impression group, which had a median \pm IQR of $25.3 \pm 2.9 \mu\text{m}$) was found.

The difference between Straumann and Nobel Biocare casts was significant for Dental Wings digital impressions ($p=0.023$), but not for the other two impression techniques

($p=0.579$ for conventional, $p=0.853$ for True Definition).

Conclusions: Within the limitations of the current study, the Dental Wings intra-oral scanner showed the least 3-D deviation for the Nobel Biocare implant system with a statistically significant difference when compared to the conventional impression method. The True Definition scans showed the least 3-D deviations for the Straumann Bone Level RC system, but no statistically significant differences between the three groups were observed.

Dental Wings digital impressions showed less 3-D deviation values for the Nobel Biocare system than the Straumann system with a statistically significant difference.

Introduction and Literature Review

The success of dental implants has been well documented in the literature. Consequently, implant supported prostheses have become the preferred alternative for tooth replacement in many partially or fully edentulous patients [1,2,3]. Since their introduction in the early 1980s, Computer-Assisted Design (CAD) and Computer-Assisted Manufacturing (CAM) have advanced, and in the past 10 years have been incorporated more and more in dental care and dental technology. Today, digital dental technology provides a viable alternative to the conventional techniques of fabricating fixed implant-supported prosthesis and has gained considerable popularity in implant dentistry [4,5,6].

A passive fit is an important prerequisite for the long-term success of both implants and the final prosthesis [7]. The fit is considered “passive” when the restoration does not create static loads within the prosthetic system or in the surrounding bone tissue. Passive fit is very important for the long term success of both implants and prosthesis, and it helps in minimizing both biological and prosthetic complications[1,7].

Multiple studies have defined passive fit. However, there is no agreement on the acceptable size of the marginal gap [8]. The marginal gap size at the interface between the prosthesis and implant or abutment has been used to describe the level of fit. However, numbers that have been suggested as being acceptable are 10, 30, or 150 microns and have rendered this method as empirical. The screw resistance test proposed by *Jemt* et al. represents another method [5]. If gap closure can be achieved by tighten-

ing an occlusal screw with an extra one half of a turn of a screw, then the fit may be accepted as passive [7,8,9].

Multiple steps and procedures are performed before the final delivery of prosthesis. Obtaining an accurate working model that truly represents the implant location and orientation is a fundamental prerequisite for achieving an accurately fitting prosthesis.

There are several factors that affect the accuracy of a working or master cast such as impression technique, implant type/system, implant-abutment connection type (external vs. internal), stiffness and accuracy of fit of impression posts, implant depth relative to the soft tissue level, and angulation between implants[10,11].

Multiple studies and systematic reviews have evaluated and compared the various techniques for impression taking in partially edentulous patients.

For conventional impressions, it has been well documented that splinting the implant transfer or impression posts with a resin-based material prior to obtaining the impressions leads to superior accuracy of the resulting cast than with non-splinted alternatives for both completely and partially edentulous arches. While for completely edentulous arches open tray techniques have been shown to be more accurate than the closed-tray techniques, no difference has been found for dental arches with posterior partial edentulism [7,10,11,12,13]. However, for the specific indication of maxillary anterior partial edentulism, the current scientific literature does not provide any information.

Implant-prosthetic treatment in the anterior maxilla is defined as advanced or complex [15]. While multiple studies have shown that the success rate of implants placed in the anterior maxilla is similar to other regions of the mouth [16,17], implant placement in the anterior maxilla is challenging because of the anatomy of the alveolar ridge in the area, and the bone remodeling processes after tooth extraction, which especially affect the buccal alveolar bone.

It has been shown that following tooth extraction in the anterior maxilla, resorption of the alveolar bone volume is 25% during the first year and 40-60% after 3 years [18]. Resorption occurs in a palatal direction, which will often lead to palatal placement of the implants relative to the prosthodontically desirable tooth position in the area if no grafting procedures are performed.

If multiple adjacent teeth need to be replaced requiring the placement of two or more implants, there is a high likelihood of having non-parallel implants, both in the mesio-distal and facial-palatal directions. Therefore, the scenario chosen in this study is of a clinical relevance. In their study, Lin et al. [7] chose a Kennedy Class II scenario, i.e., distal extension with implants being adjacent to natural teeth only on their mesial side. In a Kennedy Class IV indication, implants are tooth bound both mesially and distally, which may have an additional negative effect on the accuracy of impressions, casts, and/or prostheses.

This study addressed the influence of two different implant designs – tissue level im-

plants and bone level implants – on the accuracy of conventional and digital impressions. The choice of implant type is usually based on clinician preference. Especially in the anterior maxilla, bone level type implants are more frequently used. They offer multiple advantages, of which the most important are: easier surgical handling in combination with bone augmentation procedures; greater transmucosal running room for proper emergence designs of provisional and final prostheses; and easier customization of final crown margin locations and insertion paths via custom abutments.

In a recent systematic review regarding the incidence of biologic, technical, and esthetic complications of single implant abutments supporting fixed prostheses, Zembic et al. [19] reported a higher incidence of technical complications compared to biological or esthetic complications. This included abutment screw loosening, crown loosening, and chipping of veneering ceramics. However, no differentiation was made between implants placed in the posterior or anterior regions.

Visser et al. [20] evaluated the complications associated with implant retained crowns in the maxillary esthetic region. These authors concluded that esthetic complications were high. In 12% of the cases, a new restoration had to be made due to the inadequate shape or color of the original crown.

As for complications associated with mal-aligned or tilted implants, Chrcanovic et al. [21] in a recent review and meta-analysis concluded that the angulations of dental implants in a mesio-distal direction might not affect implant survival in the maxilla. However, they only evaluated biological complications.

Tiziano et al. [22] in a case series of 35 patients evaluated both biological and prosthetic complications associated with tilted trans-sinus implants.

Patients were either completely or partially edentulous, and the final prosthesis were either full arch fixed prosthesis or 3 unit fixed partial prosthesis. Prosthetic complications associated with tilted implants were screw loosening in 17.5% of cases and porcelain chipping in 30% of the cases.

Many companies are competing to develop the most accurate intraoral impression devices. There are several scanning systems available today that use intraoral video data acquisition:

- TRIOS by 3Shape (3Shape, Copenhagen, Denmark): this system works under the principle of ultrafast optical sectioning and confocal microscopy, which recognizes the pattern being scanned over a range of focus plane positions when maintaining a fixed spatial relation between the scanner and the object being scanned.

- CEREC Omnicam (Dentsply - Sirona, Bensheim, Germany): this system uses the triangulation of light, in which the intersection of three linear light beams is focused on a certain point in 3D space.

- True Definition by 3M ESPE (3M ESPE, St. Paul, MN): this system works with the concept of active wavefront sampling. It is capable of obtaining 3D data from a

single-lens imaging system.

- Dental Wings (Dental Wings, Montreal, QC): this system uses miniaturized 3D scanners in the hand-piece tip, which directly view the teeth and/or implant scan bodies, and surrounding soft tissues from multiple orientations. Captured data are transmitted to an in-office or remote system via DWOS Connect for prosthesis design and production. It is an open system compatible with other CAD software.

Once scanning is complete, the resulting data are saved either as a stereolithographic Standard Tessellation Language (STL) file, or a proprietary encrypted file. An open system uses STL files and will allow the use of any CAM device, while a closed system will generate a proprietary encrypted file that can only be used by specific software and milling devices from the same system.

Digital impressions using intra-oral scanners (IOS) have advantages over conventional impressions in a number of ways: potential reduction of time from dental chair to dental laboratory, digital processing and storage, online communication between dentist and dental technologist, and improved patient comfort [10,15,16,17,18,23,24,25,26].

When evaluating the accuracy of digital implant impressions for partially edentulous patients, limited data are available [7,10,14]. In one study, Ng et al.[33] evaluated the effect of inter-implant angulation on the accuracy of a master model, and compared conventional to digital techniques using the Robocast protocol (Biomet 3i, West Palm

Beach, FL). Implants were placed in the mandibular first premolar and first molar positions simulating a Kennedy class III scenario. Inter-implant angulations of 0, 10, 20, and 30 degrees were studied. The casts obtained using the digital technique were less accurate than those with a conventional impression for all tested inter-implant angulations.

In another study, Lin et al. [7] used the TRIOS intraoral scanner (3Shape, Copenhagen, Denmark) to compare the accuracy of conventional and digital impressions for a fixed dental prosthesis on tissue level implants placed in the posterior mandible, simulating a Kennedy class II scenario with inter-implant angulations of 0, 15, and 30 degrees. At 0 and 15 degrees of implant divergence, the casts generated from digital impressions were less accurate than those from conventional impressions. At 30 and 45 degrees, there was no difference between the two methods [10]. However, little data are available for the Dental Wings and True Definition intraoral scanners at this time, nor are there any studies evaluating the accuracy of digital impressions for the Kennedy class IV scenario with bone level implants placed in the anterior maxilla.

Due to the sparsity of scientific information regarding the accuracy of digital impressions with intraoral scanners other than Trios or for the accuracy of digital impression techniques in partially edentulous indications, it is desirable to evaluate other intraoral scanning systems specifically for partially edentulous indications such as the Kennedy Class IV scenario.

Aim and Hypothesis

The purpose of this study was:

- to compare the accuracy of definitive casts obtained from conventional impressions with digital implant impressions using 2 different intra-oral scanning systems (Dental Wings and 3M True Definition).

- to compare the impression accuracy for two implant systems - Nobel Conical Connection RP and Straumann Bone Level - in the presence of 30° inter-implant divergence.

The proposed hypotheses for this study were:

- 1) Splinted open tray conventional impressions are more accurate than digital impressions of dental arches with anterior partial edentulism and implants of $\geq 30^\circ$ divergence.

- 2) There is no difference in impression accuracy between the two implant systems studied under the conditions stated above.

Materials and Methods

Master Cast Fabrication

Two maxillary partially edentulous clear acrylic casts with teeth # 7, 8, 9, and 10 missing were fabricated to simulate a Kennedy class IV clinical condition. Both casts were outfitted with two internal connection implant analogs in sites # 7 and 10. In one cast, they were Bone Level RC implant analogs (Straumann USA, Andover, MA), in the other No-

bel Conical Connection RP implant (Nobel Biocare, Yorba Linda, CA).

The implant analogs in both casts were placed with a mesiodistal divergence of 30 degrees. The analogs in sites 7 and 10 were tilted 15 degrees distally. One model per implant system was fabricated from clear acrylic in a laboratory specialized in model manufacturing (Model Plus Inc, Grayslake, IL).

It is not possible to scan a clear acrylic model accurately, because the scanning light will reflect from the acrylic surface. A large amount of scanning powder will have to be applied, which would compromise the accuracy. Therefore, a stone duplicate model was fabricated, which served as the master cast in this study.

The master cast was fabricated as follows: impression copings were attached to the implants in the clear acrylic model. Two openings were drilled in the custom tray for access to the impression coping guide screws. The impression posts were splinted with urethane-dimethacrylate-based visible light curing resin (Triad Gel; Dentsply Inc, York, PA). Two layers of baseplate wax (Neowax; Dentsply Trubyte Inc, York, PA) were applied to the master cast to provide an equal thickness of 3 mm for the impression material. Custom tray was fabricated using Triad TruTray (Dentsply Inc, York, PA). Impression was obtained using polyether impression material (Impregum, 3M ESPE, St. Paul, MN). After loosening the impression post screws and separating the impression from the model, implant analogs were screwed to the impression copings and the impression poured using a low expansion (0.09%) type IV die stone (Resin Rock, Whipmix Corp,

Louisville, KY). As mentioned, the resulting cast served as the master model (control model) for all study groups.

The following groups of casts I – VI were created and compared:

GROUP I (n=10): Casts generated from conventional splinted open-tray impressions obtained at the implant level of Straumann Bone Level Regular Crossfit (BL RC) Implants (Straumann USA, Andover, MA)

GROUP II (n=10): Casts generated from conventional splinted open-tray impressions obtained at the implant level of Nobel Biocare Regular Platform (RP) Implants (Nobel Biocare, Yorba Linda, CA).

GROUP III (n=10): Casts generated from digital impressions at the implant level of Straumann BL RC Implants (Straumann USA, Andover, MA) using the True Definition scanner (3M Espe, St.Paul, MN).

GROUP IV (n=10): Casts generated from digital impressions at the implant level of Nobel Biocare RP implants using the True Definition intraoral scanner (3M Espe, St.Paul, MN).

GROUP V (n=10): Casts generated from digital impressions at the implant level of Straumann BL RC Implants (Straumann USA, Andover, MA) using the Dental Wings intraoral scanner (Dental Wings, Montreal, QC, Canada).

GROUP VI (n=10): Casts generated from digital impressions at the implant level of Nobel Biocare RP implants using the Dental Wings intraoral scanner (Dental Wings, Montreal, QC, Canada)

Conventional Impressions - Groups I,II

Fabrication of Custom Trays

For the conventional impressions, custom trays were fabricated using Triad TruTray (Dentsply Inc, York, PA). After connecting the impression posts with the splints, two layers of baseplate wax (Neowax; Dentsply Trubyte Inc, York, PA) were applied to the casts to provide an equal thickness of 3 mm for the impression material. The master model was marked in four different areas with V-shape notches. These mark stops ensured the accurate seating and positioning of the custom tray. Two openings were drilled in the custom tray for access to the impression coping guide screws.

Fabrication of Splints

The impression posts were splinted with urethane-dimethacrylate-based visible light curing resin (Triad Gel; Dentsply Inc, York, PA). Drinking straws were filled with the material in order to standardize the thickness and shape of the splint. After light curing, the splints were stored for 24 h at room temperature and relative humidity of 50%.

The resin bars were sectioned and re-connected to the impression copings with a minimal amount of Triad to reduce dimensional changes of the material in the curing process [6].

Impression and Cast Fabrication

After connecting the impression copings/posts to the implant analogs and fabricating the splints on the control cast as described above, impressions were taken using polyether impression material (Impregum, 3M ESPE, St. Paul, MN). Prior to impression taking, tray adhesive was applied in a thin layer to the intaglio surface of the custom tray. The adhesive was allowed to dry for 15 min. All impressions were made at room temperature, with a relative humidity of 50%. Automatic mixing and dispensing system Pentamix (3M ESPE, St.Paul, MN) was used. Impression material was injected around the impression posts using Impregum Penta Elastomer syringe (3M ESPE, St.Paul, MN). The custom tray was filled and seated using light finger pressure until the marked stops contacted with the respective areas on the master cast. The impression material was allowed to polymerize for 8 min.

To produce the casts from the obtained impressions, a control box was made with addition reaction silicone to create a silicone matrix for pouring the impression with dental stone. This control box was used for pouring all the impressions in order to standardize the amount of stone used for the fabrication of the stone casts as well as the shape and volume of the casts. This process was repeated 10 times to produce 10 stone models for each group.

Digital Implant Impression Technique

Group III and IV - Digital impression with Active Triangulation technology

A blue light intraoral scanner (True Definition: 3M ESPE, St.Paul, MN) was used to obtain ten digital scans of each master cast. All digital impressions were obtained at the implant level. Implant scan bodies (Bone Level RC scan bodies, Straumann USA, Andover, MA) and Regular Platform (RP) scan bodies (Nobel Biocare, Yorba Linda, CA) were attached to the implants on the master cast and hand-tightened. After the acquisition of ten repeated digital impressions per master cast, the digital scans were exported as Standard Tessellation Language (STL) files and stored on an external hard drive.

Group V and VI - Digital impression with Active Wavefront Sampling Technology

A Dental Wings intraoral scanner (Dental Wings, Montreal, QC, Canada) was used to obtain ten digital scans of each master cast representing the two different implant systems in the same manner as described above for Groups III and IV.

Stone Model Digitization

Before conducting any measurements, all stone models from groups I and II were stored for one week at room temperature. Using a high-resolution extraoral scanner (Activity 880 Scanner, Smart Optics, Bochum, Germany), scans were obtained for Group I and II stone models and digitized for comparison with the digital impression groups (III-VI). Scan bodies were attached to the implant analogs (Bone Level RC, Straumann USA, Andover, MA) and Regular Platform (RP) (Nobel Biocare, Yorba Lin-

da, CA). After scanning of the first cast, scan bodies were removed and placed on the second model. The same procedures of placing the scan bodies in the exact same position and scanning them were done for all 10 casts. The resulting STL digital files were saved for the next step in the manner mentioned above. All of the measuring devices were calibrated prior to scanning process according to manufacturer's instructions.

Accuracy Measurements

Geomagic Control 2015 software (3D systems, Morrisville, NC) was used to superimpose the STL digital files from each cast from each test group over the files from the control groups. The method in analyzing the differences was performed by the software through calculating the root mean square (RMS) error.

Power Calculation

A power calculation was performed via nQuery Advisor (Version 7.0). The calculation indicated that a sample size of $n=10$ per group would yield a Type I error rate of 5% and power greater than 99% for the comparison of impression techniques, using the data from a study by Papaspyridakos et al. [10] for anticipated values.

Statistical Analysis

Descriptive statistics were computed that included medians and inter-quartile ranges for each group (splinted open tray conventional impression, Dental Wings digital impressions, and True Definition digital impressions for both implant systems [Straumann Bone Level RC and Nobel Biocare Conical Connection RP]). Analysis of accuracy measure-

ment differences between the three groups within each implant system was conducted via nonparametric testing due to the non-normality of the data. Comparing the impression techniques to each other was done via two separate Kruskal-Wallis tests. Dunn's test alongside the Bonferroni correction was used for post-hoc tests. Three Mann-Whitney U tests were used to compare the Nobel Biocare with the Straumann system, one test for each impression technique. With the exception of tests employing the Bonferroni correction, p-values less than 0.05 were considered significant. SPSS Version 22 was used for all statistical analyses.

Results

The 3-D deviation values for each group were calculated and displayed in table 1.

Median \pm inter-quartile ranges of the 3-D deviation for the Straumann Bone Level RC implant analogs are shown in Table 2a. When comparing the three impression techniques, True Definition was the most accurate ($18.1 \pm 4.7\mu\text{m}$), followed by Dental Wings ($24.3 \pm 19.8 \mu\text{m}$), and lastly the conventional impression technique ($28.9 \pm 28.2 \mu\text{m}$). The Kruskal-Wallis test comparing the groups did not reveal any statistically significant differences ($p = 0.400$).

Median \pm inter-quartile ranges of the 3-D deviations for Nobel Biocare Conical Connection RP implant analogs are shown in Table 2b. When comparing the three impression techniques, Dental Wings was the most accurate ($15.9 \pm 3.2\mu\text{m}$), followed by True Definition ($18.7 \pm 9.9 \mu\text{m}$), and lastly the conventional impressions ($25.3 \pm 2.9\mu\text{m}$). The Kruskal-Wallis test comparing the three groups revealed statistically significant differ-

ences ($p = 0.004$). In post-hoc tests, the only statistically significant difference found was between the Dental Wings and the conventional impression groups ($p=0.001$).

The difference between Straumann and Nobel Biocare systems was significant for Dental Wings ($p=0.023$), but not for the other two impression techniques ($p=0.579$ for conventional, $p=0.853$ for True Definition). Figure 1

Discussion

This study compared the accuracy of definitive casts obtained from conventional impressions to those from two different intra-oral scanning systems, True Definition and Dental Wings. The study is one of the first to compare the accuracy of gypsum models from conventional implant impressions and digital impressions obtained by True Definition and Dental Wings intra-oral scanners. The clinical scenario studied here has not been used in any other study. As mentioned above, other similar studies have used different intra-oral scanners [10] or tissue level implants in different clinical scenarios [28].

The obtained results indicate that the Dental Wings intra-oral scanner was the most accurate for the Nobel Biocare conical connection RP Implant system. In contrast, for the Straumann Bone Level RC Implant system, the True Definition intra-oral scanner was the most accurate. However, within each system, the only statistically significant differences were found for the Nobel Biocare casts when comparing Dental Wings digital scans with the casts obtained with the conventional impression technique.

When comparing digital impressions using True Definition intra-oral scanning, the Straumann system showed a lower 3-D deviation median value than the Nobel Biocare

system. This could be attributed to the design of the scan bodies. The Straumann scan body is cylindrical in shape with no undercuts and much easier to scan. The Nobel Biocare scan body has an undercut in the gingival portion, which makes it more difficult to obtain accurate scans with the True Definition scanner. Nevertheless, it has to be recognized that the observed difference was not statistically significant.

The problem described above was not encountered when using the Dental Wings intra-oral scanner. The hand piece head is small and equipped with little wings. They make it easier to image the undercut areas.

One more difference between the two scanning systems lies in the manner in which each system processes the missing data following every scan. The True Definition scanner will point to the areas that were not properly registered and requests a separate scan to be made for these areas. Following the second scan the system attempts to overlap the two scans. This step may affect the accuracy of the final scan. However, with the Dental Wings scanner, the system will compensate for the missing data by automatically predicting and filling them in by comparison to similar areas that were already captured.

It has to be noted that both scanners require the use of scanning powder, a procedure that is difficult to standardize. During scanning, powder was reapplied in areas that were not recognized by the scanner at each subsequent scan. When the scanning powder is being reapplied some of the areas might get sprayed twice which might affect the accu-

racy.

The 3-D deviation of all impression techniques was less than 150 μm . Klinberg and Murray [35] stated that a 30 μm gap at the implant–abutment interface is acceptable if it is not including more than 10% of the circumference. More recently, Jemt [5] stated that a misfit around 150 μm is acceptable.

The accuracy of a dental impression is determined by two factors: trueness and precision (ISO 5725-1). Trueness represent the deviation from the control or original geometry. Precision represents the deviations within impressions of a test group. This study looked at the accuracy (Trueness) of the three impression techniques.

The control stone master model was digitized using an Extra-Oral scanner (Activity 880 Scanner, Smart Optics, Bochum, Germany). According to the manufacturer the precision of the scanner is 10 μm , which might be considered a limitation of the study, other studies have used different technologies for the digitization of the control model with a precision of 1 μm [36].

One last limitation of the current study is that before each scan with both intra-oral scanners, the scan bodies were removed and replaced again to resemble the case of the conventional impressions were scan bodies were moved between different stone models. This process might lead to some inaccuracy due to the possibility of placing the scan bodies in a different position, and the machinery intolerance of the two implants systems.

Digital impressions using intra-oral scanners, and the utilizing of CAD/CAM technology are a predictable and viable option for the fabrication of implant restorations, from single crown to full arch restoration, including a Kennedy class IV scenario as studied here. A digital work flow can provide a faster and more efficient approach when compared with conventional impression techniques. In one study, intra-oral scanning was 23 minutes faster than obtaining conventional impressions for single crowns, 22 minutes faster for 3-Units FPD, and 13 minutes faster for full arch impressions with 13 abutments. [34].

Conclusions

Within the limitations of the current in vitro study the following can be concluded:

1- For the Straumann Bone Level RC implant system, there was no significant difference between the three impression techniques. However, True Definition intra-oral scanner showed the least 3-D Deviation, while the conventional open tray splinted technique showed the most.

2- For the Nobel Biocare Conical Connection RP implant system, the Dental Wings intra-oral scanner was found to be the most accurate, while the conventional open tray splinted technique was the least accurate.

3- When comparing the two implant systems, impressions obtained with the Dental Wings intra-oral scanner were more accurate for the Nobel Biocare than the Straumann system.

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Appendix A: Tables.

Table 1: 3-D deviation values for all test groups.

	Str Con	Str Ture Def	Str DW	Nob Con	Nob Ture Def	Nob DW
Scan 1	14.008	14.878	28.730	15.507	25.883	30.171
Scan 2	11.745	16.923	17.292	17.709	21.913	13.894
Scan 3	31.838	15.976	16.328	24.734	25.659	14.101
Scan 4	14.139	25.698	24.015	12.532	28.442	45.501
Scan 5	25.927	22.947	14.522	22.357	23.218	22.975
Scan 6	50.576	18.549	36.685	15.760	25.275	22.415
Scan 7	34.836	19.632	18.032	16.583	26.138	17.324
Scan 8	40.562	19.579	44.560	15.893	22.717	20.157
Scan 9	44.970	15.007	37.380	15.828	25.325	15.276
Scan 10	9.958	17.591	24.540	15.935	25.843	15.892

Table 2a:

RMS Error values for Straumann implant analogs (n=10 per group).

	Median	IQR	p
Conventional	28.9	28.2	0.400
True Definition	18.1	4.7	
Dental Wings	24.3	19.8	

Table 2b:

RMS Error values for Nobel Biocare implant analogs (n=10 per group).

Groups that do not share a letter exhibited a statistically significant difference.

	Median	IQR	p
Conventional	25.3 ^a	2.9	0.004
True Definition	18.7 ^{ab}	9.9	
Dental Wings	15.9 ^b	3.2	

Appendix B: Figures.

Figure 1: The difference between Straumann and Nobel Biocare casts was significant for Dental Wings digital impressions ($p=0.023$) but not for the other two impression techniques ($p=0.579$ for conventional, $p=0.853$ for True Definition).

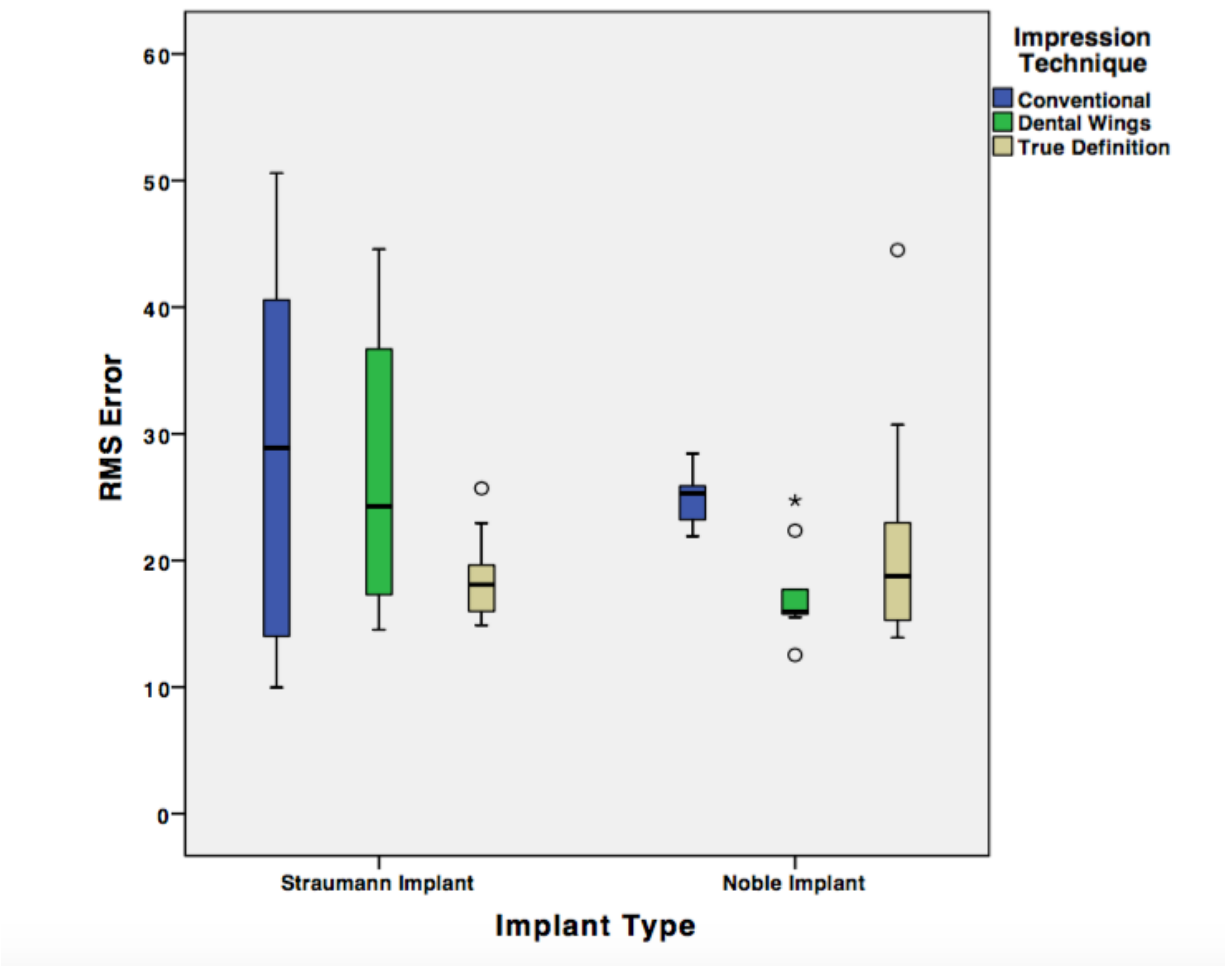


Figure 2: (A) Clear acrylic master model for Nobel Biocare Conical Connection RP Implant Analogs. (B) Stone Duplicate of the same model.

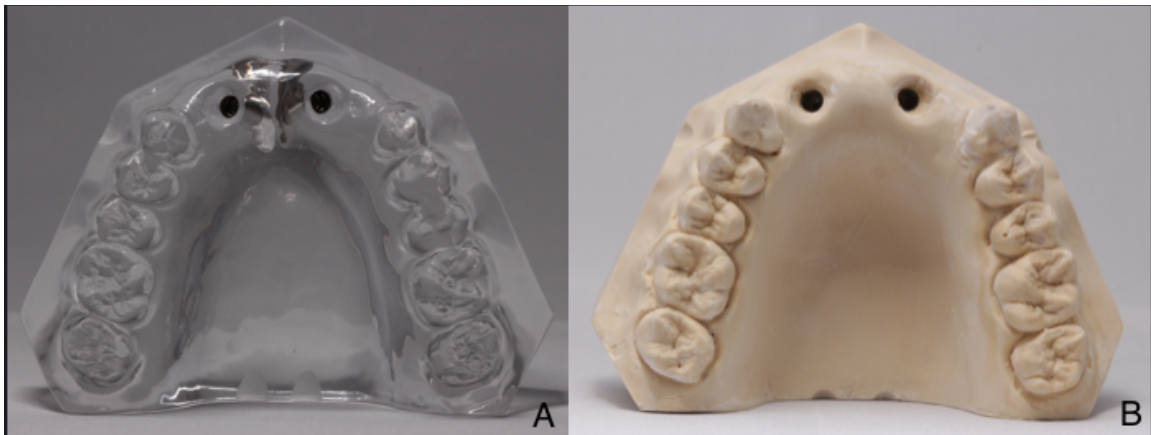


Figure 3 : Scans produced by different scanners for the Straumann Bone Level RC Master model. (A) Activity 880 extra-oral scanner (B) Dental Wings intra-oral scanner (c) True Definition intra-oral scanner.

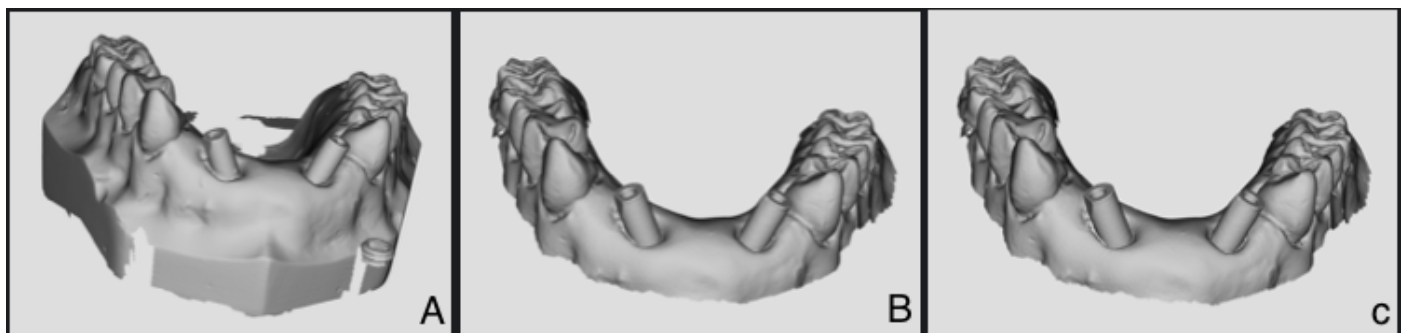


Figure 4: Geomagic 3D Comparison report of the Best Fit Alignment between Dental Wings intra-oral scanner and the control master model.

