The accuracy of different digital impression techniques and scan bodies for complete-arch implant-supported reconstructions

Thesis

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By

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Abstract

Statement of problem. While the accuracy of digital implant impressions in single unit and short span situations has been demonstrated, the effect of various scan bodies and scan techniques on the accuracy and scan time in completely edentulous situations is not well understood.

Purpose. The purpose of this study was to evaluate the effects of 4 different scanning techniques and 5 different commercially available intraoral scan bodies on the trueness (distance and angular deviation), precision (variance amongst the scans) and scan time in a completely edentulous situation with 4 implants.

Materials and Methods. Five different intraoral scan body systems were evaluated: AF (IO-Flo, Atlantis Denstply Implants), NT (Nt-Trading GmbH & Co. KG), DE (Dess-USA), C3D (Core3Dcentres NA), and ZI (Zimmer Biomet Dental), and 4 different scanning techniques were evaluated: unmodified master model (NO), glass fiduciary markers placed on the edentulous ridge (GB), pressure indicating paste brushed over the ridge and palate (PP), and floss tied between the scan bodies (FL). Five identical polyurethane edentulous maxillary models with 4 parallel dental implant analogs (TSV 4.1, Zimmer Biomet Dental) in the first molar and canine positions. The scan bodies were attached to the models and the entire surface was scanned using a calibrated structured blue light industrial scanner (Carl Zeiss Optotechnik GmbH) to generate a master
reference model. Five consecutive digital impressions were made of the model using an intraoral scanner (Trios, 3Shape A/S) and 1 of the 4 techniques (n=5) assigned at random. The test scans were superimposed over the master reference model using a best fit algorithm, and then the distance deviation and angular deviation of the scan bodies was calculated. Scan time was also recorded. A two-factor ANOVA was used to examine the effect of scan body and technique on the trueness and on scan time, with subsequent Tukey or Bonferroni-corrected Student’s t-tests. Precision was evaluated by tests for homogeneity of the variances between groups. An alpha level of 0.05 was used for all statistical tests. Reliability for the entire study was evaluated using the intraclass correlation coefficient.

**Results.** The overall reliability of the study according to intraclass correlations was 0.999. In terms of trueness, no statistically significant interaction was found between the effects of scan body and technique on the distance deviation (F=1.28, P=.246), however, scan body (P=.031) and technique (P=.001) each had a significant effect independently. A statistically significant interaction was found between the effects of scan body and technique on angular deviation (F= 4.31, P=<.001). Testing for the homogeneity of variances demonstrated significant differences between the precision of the groups in terms of both distance deviation (P≤.013) and angular deviation (P≤.003). No statistically significant interaction was found between the effects of scan body and technique (F=1.73, P=.076) on scan time, however, scan body alone was found to have a significant effect (P<.0001).
**Conclusions.** The accuracy (trueness and precision) of complete-arch digital implant impressions using ISBs were affected by both the scan body and scan technique when using an intraoral scanning system. The ZI scan body had significantly less distance deviation while splinting scan bodies with floss led to significantly more distance deviation. The scan techniques with different surface modifications was not found to improve scan accuracy. Use of different ISBs led to significant differences in scan time.
Dedication

This manuscript is dedicated to my parents, Mike and Margaret, for their endless love and support, and to my wife, Kristen, who was instrumental in encouraging me to pursue my passion in dentistry.
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I gratefully acknowledge my advisor, Dr. Burak Yilmaz and committee members, Dr. Edwin McGlumphy, Dr. William Johnston, and Dr. Jeremy Seidt for their continued interest and assistance in this project. I would also like to thank the American Academy of Fixed Prosthodontics and the Tylman Research committee for their support, as well as the corporations and product representatives who kindly donated their scan bodies to be used in this project. I am also grateful for the engineering and metrology support that I received from Mr. Rob Glassburn and Mr. Grant Wall. Without each of you, this project would not have been possible.
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**Fields of Study**

Major Field: Dentistry
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Chapter 1. Introduction

The use of implant-supported prostheses in the replacement of natural missing teeth is a reliable and effective treatment option.\textsuperscript{1} Accurate dental impressions are a crucial step in any implant treatment.\textsuperscript{2} Inaccurate transfer of the implant position can lead to an ill-fitting prosthesis, which may put unnecessary strain on the various prosthetic components in the system and ultimately result in complications.\textsuperscript{3,4} Impression procedures for osseointegrated implants traditionally involve the use of impression or transfer copings which are inserted into the implant fixture at the time of the impression and captured in conjunction with the surrounding teeth and mucosa using impression trays and elastomeric impression materials such as polyvinylsiloxane or polyether. With the advent of computer-aided design and computer-aided manufacturing (CAD-CAM) technology, however, it is now possible to skip this step in its entirety and utilize a completely digital workflow when fabricating implant-supported restorations.\textsuperscript{5}

The digital workflow can be either direct or indirect in nature.\textsuperscript{6,7,8} The indirect workflow involves making a conventional implant impression which is then digitized in the laboratory using a benchtop extraoral optical scanner (EOS) and laboratory scan bodies, while the direct workflow includes the use of intraoral scan bodies (ISBs) and an intraoral scanning (IOS) device to generate a digital impression directly from the patient’s mouth. Both EOS and IOS technology use a variety of principles to capture raw
data in the form of point clouds including confocal microscopy, triangulation, interferometry, wavefront sampling, structured light, laser, and video. A difference in technology has been shown to lead to differences in accuracy.

By definition, accuracy consists of two parameters: precision and trueness. Precision describes how close repeated measurements of the same object are to each other, while trueness describes how far the measurement deviates from the actual dimensions of the measured object. Both are important considerations in the digital implant dentistry workflow and should be optimized by not only the scanning devices, but also the scan bodies themselves. Since IOS devices can only capture part of an object at a time, the images must be stitched together using proprietary processing algorithms in order to reconstruct the scanned surface 3-dimensionally, which inherently introduces small inaccuracies that can propagate downstream as the digital workflow continues.

The first digitally scannable implant components were introduced in 2004 and utilized an innovative coded healing abutment called Encode, which provided 3-dimensional information on the implant location in relation to the adjacent teeth, opposing dentition, and surrounding soft tissues (Zimmer Biomet Dental). In 2008, new types of digital technology were introduced and shown to be valid alternatives to traditional impression-making procedures. The first scannable impression copings were released shortly after and termed “scan bodies” by the manufacturer (Straumann Holding AG). Today, almost all major implant manufacturers, as well as numerous third-party companies, offer ISBs. Commercial ISB design is highly variable and their influence on accuracy is not completely understood.
In single unit and short span situations, digital implant impressions using ISBs are shown to have similar accuracy as their conventional impression counterparts. In completely edentulous situations, however, decreased accuracy has been shown. While the overall quality of the digitized data depends heavily on the specific IOS system, another important factor that can affect the accuracy of digital implant impressions using ISBs is the surface topography and characteristics of the surface(s) to be scanned. The quality of a digitized surface reconstruction, and any subsequent measurements, is generally accepted to be shape-dependent, whereas the type of material affects the number of points acquired. Primary geometries, for example, are easier to digitize than secondary and tertiary geometries. Dull, smooth and opaque surfaces are more easily scanned than shiny, rough or translucent ones which can be especially challenging in the mouth, where saliva tends to create reflective surfaces and the hard and soft tissues have a variety of textures.

When attempting to scan an edentulous arch with ISBs, one specific challenge that exists is the limited number of quality reference points between the scan bodies. When common reference points are limited, the images may not be stitched together properly or parts of the scan may be mistaken as redundant data. Thus, techniques have been proposed to overcome this limitation by increasing the number of reference data points in an edentulous arch by modifying the surface and topography of the edentulous ridge. To date, however, no study has evaluated the effects of using these techniques in a completely edentulous situation.
The purpose of this in vitro study was to compare 4 different scanning techniques (conventional intraoral digital scan, a novel scan body splinting technique, and two mucosa surface modification techniques) and 5 different ISBs to evaluate their effects on the accuracy (trueness and precision) and scan time in a completely edentulous situation. The first null hypothesis of this study was that different scanning techniques and scan bodies would not affect the trueness of the scans. The second null hypothesis was that different scanning techniques and scan bodies would not affect the precision of the scans. The third null hypothesis was that different scanning techniques and scan bodies would not affect the scan time. The results of this study may be important in identifying differences in the accuracy and scan time of various scan bodies and digital impression techniques, and help the clinician understand if specific scan body designs or scanning techniques are beneficial in a completely edentulous situation.
Chapter 2. Materials and Methods

This study consisted of fabrication and digitization of the master reference model, data acquisition and digital impressions, surface alignment and registration, measurement of 3-dimensional (3D) distance deviation and angular deviation and statistical analysis. Five different ISB systems were evaluated: AF (IO-Flo, Atlantis Dentsply Implants), NT (Nt-Trading GmbH & Co. KG), DE (Dess-USA), C3D (Core3DCentres NA), and ZI (Zimmer Biomet Dental) and 4 different scanning techniques were evaluated: unmodified master model (NO), glass fiduciary markers placed on the edentulous ridge (GB), pressure indicating paste brushed over the ridge and palate (PP), and floss tied between the scan bodies (FL) (Figure 1 and Figure 2).
Figure 1. Five commercially available ISB systems were used in this study: Atlantis I-Flo (AF), Core3D (C3D), Nt-Trading (NT), Dess-USA (DE), Zimmer Biomet (ZI)
Figure 2. Identical polyurethane master models simulating an edentulous maxilla were fabricated with 4 implants positioned for a complete-arch prosthesis and scanned with 4 techniques: No modifications (NO), Glass Beads (GB), PIP Paste (PP), Floss (FL).

Five identical polyurethane edentulous maxillary models with a soft tissue replica were fabricated with 4 parallel dental implant analogs (TSV 4.1, Zimmer Biomet Dental) in the first molar and canine positions placed 3 mm below the model’s surface. The distance between the 2 middle implants was approximately 20 mm, and approximately 14 mm from the middle implant to posterior implant. Four identical ISBs from 5 different manufacturers were attached to the implants giving a total of 5 master models. The scan bodies were inserted and torqued into place following the manufacturer recommended guidelines.
Each reference model was scanned and its surface reverse engineered using an ISO17025 calibrated structured blue light industrial scanner (COMET L3D, Carl Zeiss Optotechnik GmbH). The digitized model was saved as a stereolithography (STL) file to serve as the master reference model (MRM). Due to the nature of the scanner technology, an anti-reflective powder spray was applied to the models prior to scanning that had an approximate thickness of 2 µm. The scanner’s uncertainty was reported to be less than 11 µm (www.3d-engineering.net).

Five consecutive digital impressions (n=5) were made of the master model using an intraoral scanner (Trios, 3Shape A/S) and each of the 4 techniques in a temperature and humidity-controlled environment. The scanner used the principle of confocal microscopy and has a reported accuracy of 4.5 µm. Groups were scanned in a randomized order generated by a computer software program (Excel, Microsoft Corp). A standardized scan path was utilized per the manufacturer’s recommendation, which consisted of scanning the occlusal surface, then buccal surface, then palatal. All scans were timed from start to finish and a scan was considered complete once the scan body surfaces were captured entirely and no major holes in the reference model were present.

All test scans were then superimposed over the MRM using the best fit algorithm of an industrial metrology software program (Polyworks, Innovometric Software Inc.) which excluded the scan bodies. As a result, only unchanged features of the STLs, such as the palate, ridges, and model base were used in the superimposition to minimize any alignment errors or averaging of data in the measured portion of the scan bodies (Figure 3).
A best-fit algorithm was used to align the surfaces of the MRM and test STL. A coordinate system was created and used throughout the entire inspection to measure the 3D distance deviation and angular deviation of the scan bodies. For the positional deviations, a cross section was created 2.25 mm from the top of each scan body and their center point was located and compared to the corresponding point on the MRM giving positional changes in the X, Y, and Z direction. The scan bodies used for each measurement were labeled 1 through 4 and the same labels were used for every inspection (Figure 4).
Figure 4. A coordinate system was created and the scan bodies used for each measurement were labeled 1 through 4.

The distance deviation was calculated by entering the raw data into the distance formula to generate the 3D distance deviation for each scan body and then averaged amongst the 4 scan bodies on the model. To determine the angular deviation, cylinders were fit to each scan body using the same computer software program and a central axis was generated for each. The nominal axis from the MRM was considered to be at an angle of zero, and the resultant 3D angle between the MRM and test model was recorded, and then averaged, to generate the angular deviation amongst the 4 scan bodies.
A two-factor analysis of variance (ANOVA) was conducted that examined the effect of scan body and technique on each of the following: distance deviation, angular deviation, and scan time. For each ANOVA, the main effects were scan body and technique, and the analyses included their interactions. An alpha level of 0.05 was used for all statistical tests. A Tukey test was used to more completely resolve the statistically significant effects for distance deviation and time, while a Bonferroni-corrected T-test was used for angular deviation.

Precision was defined as the degree of variance within groups of scans, while trueness was defined as the amount of average distance and average angular deviation between the corresponding scan bodies in the test scan and the MRM. In terms of precision, 4 tests (Levene, O’Brien, Brown and Forsythe, and Bartlett) were utilized to evaluate the homogeneity of the variances among the scan body and technique subgroups. The overall reliability of the study method was evaluated using intraclass correlation (ICC) according to Shrout and Fleiss.29
Chapter 3. Results

The total number of measurements in the raw dataset was 1152 and 48 measurements were missing due to post-processing errors in the scanner software. Intraclass correlation for reliability for the raw data set was found to be 0.999.

The raw data for distance deviation, angular deviation and scan time is shown in Figures 5-7 and the results of the ANOVAs are shown in Table 1.

Figure 5. Means and 95% confidence intervals of distance deviations for every combination of scan body and technique.
Figure 6. Means and 95% confidence intervals of angular deviation for every combination of scan body and technique.
Figure 7. Means and 95% confidence intervals of scan time for every combination of scan body and technique.

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Dfnum = degrees of freedom of the numerator
Dfden = degrees of freedom of the denominator

Table 1. ANOVA results comparing interactions between both scan body and technique on distance deviation, angular deviation and scan time.
According to the Tukey adjustment, ZI showed significantly less distance deviation than AF ($P=0.041$) and FL showed significantly more distance deviation than GB ($P=0.008$), PP ($P=0.013$), and NO ($P=0.002$) (Figure 8 and 9).

![Figure 8. Least square means of distance deviation for each technique as derived from analysis of variance.](image)

Figure 8. Least square means of distance deviation for each technique as derived from analysis of variance.
A significant difference in precision with regards to distance deviation was noted by the tests for homogeneity of the variances ($P \leq 0.013$), however, subsequent pairwise comparisons could not resolve these differences any further.

In terms of angular deviation, a total of 70 clinically relevant pairs were evaluated, and 11 statistically significant pairs were identified (Table 2).
A significant difference in precision was noted for the angular deviation as well ($P \leq .003$), with subgroup AS-FL being significantly less precise than both ZI-GB ($P = .021$) and ZI-PP ($P = .022$). With regards to scan time, simple main effects analysis demonstrated a statistically significant difference in the means of the scan time between the following scan bodies: C3D and NT ($P = .0004$), DE and ZI ($P = .017$), and NT and ZI ($P < .0001$) The mean scan times were significantly faster for the ZI group (2.11 minutes) when compared to the DE (2.54 minutes) and NT (2.77 minutes) group, and the mean scan time for the C3D group (2.19 minutes) was significantly faster than the NT group (2.77 minutes) (Figure 10).

Table 2. Bonferroni-corrected t-test as used to investigate differences between statistically significant pairs for angular deviation in degrees.
Figure 10. Least square means of scan time for each scan body as derived from analysis of variance.
Chapter 4. Discussion

This study analyzed the accuracy and scan time using one IOS system in combination with 4 different intraoral scan techniques and 5 different ISB systems. The first null hypothesis was rejected as both scan body and technique had significant effects on both the distance and angular deviation of the scans. The second null hypothesis was rejected as a significant difference in the variances amongst groups was found. The third null hypothesis was also rejected as the scan body system was shown to have a significant effect on the scan time.

With the introduction and implementation of CAD-CAM technology in implant dentistry, a completely digital workflow may be possible using ISBs and IOS devices when fabricating implant supported prostheses, thus eliminating the need for a physical cast entirely. The current study, however, demonstrated significant differences in the trueness and precision of the resulting scans when 4 different scanning strategies and 5 commercially available ISBs were utilized. All scan bodies and scan techniques resulted in a distance deviation greater than 170 µm and an angular deviation greater than 0.5 degrees. Since passive fit is an important goal for any implant-supported prosthesis, an accurate impression, free from distortion, is crucial. While not the aim of the current study, it is possible that scans from the current study may lead to a prosthesis with
varying degrees of misfit, some of which may be beyond a clinically acceptable range.\textsuperscript{30,31}

IOS devices and digital impressions have been well studied in dentistry. A recent systematic review concluded that digital impressions are a clinically acceptable alternative when fabricating tooth-borne and implant-supported crowns as well as short span fixed partial dentures.\textsuperscript{17} Despite this, differences in scanner accuracy have been well-documented.\textsuperscript{10,32,33,34,35,36,37,38,39,40} In addition to the specific technology, the quality of the processing and compensating algorithms can also influence the accuracy of a digital impression.\textsuperscript{18} In the current study, even different scanning techniques using the same IOS led to significant differences in accuracy. The FL technique demonstrated the highest distance deviation, suggesting that it is not beneficial in terms of accuracy to attach the scan bodies in efforts to improve the stitching process. The scanner used in the present study operates on the principle of confocal microscopy and has a reported accuracy to be as low as 4.5 \textmu m.\textsuperscript{10} This measurement, however, should be interpreted with caution as many accuracy measurements are generated by scanning small calibrated objects which differs from scanning large objects like the dental arch.\textsuperscript{41} For complete arch impressions with ISBs, multiple studies have found the scanner used in the current study to be one of the most accurate.\textsuperscript{34,37,38}

Early studies reported the accuracy of scanning the 3-dimensional position of osseointegrated implants using ISBs to be between 14-21 \mu m\textsuperscript{15} and more recent studies show that the accuracy between digital impressions using ISBs and conventional impressions to be similar.\textsuperscript{17,32,42,43,44} For multiple implants, the mean distance error and
angular deviation has been demonstrated to be as low as 11 µm and 0.05 degrees respectively.\textsuperscript{39,45} For complete arch implant impressions, however, higher amounts of inaccuracies have been shown, ranging in distance deviations of 47 – 226 µm.\textsuperscript{37,38,46} The current study demonstrated results within this range. Previous studies indicate that the distance between the ISBs, the depth of the implant, the ISB visibility, location within the scan, and the operator’s experience can affect the accuracy of digital implant impressions with multiple ISBs.\textsuperscript{34,39,47} In addition to these factors, the results of this study also suggest that the scan body itself may influence the accuracy of the scan.

Few studies have investigated the influence of the scan body on scan accuracy. While one study has shown positioning discrepancies with increasing amounts of torque, another study has demonstrated different levels of fit within the implant fixture and analog with repeated disconnection.\textsuperscript{45,48} The present study attempted to account for this by torquing the scan bodies into place using a calibrated driver per the manufacturers recommendations and designing the study so that no disconnection and reattachment of the components was necessary. Only one study has specifically investigated the relationship between scan body geometry and shape on the scan accuracy and found significant differences in the 3D positioning and angular deviation between 2 commercially available ISBs.\textsuperscript{49} This is in agreement with the current study as different scan bodies were found to have a significant effect on the accuracy. The ZI group (mean 170.91 µm) was found to have significantly less distance deviation from the master model than the AF group (mean 209.20 µm). While both scan bodies are fabricated from polyetheretherketone, the scan body used in the ZI group was shorter and had a simpler
shape with fewer undercuts, while the scan body in the AF group was one of the tallest scan bodies and had a more complicated design. The AF group also demonstrated higher angular deviations, which may imply that a shorter and simpler shaped scan body closer to the tissue is beneficial in complete arch situations. Simpler shaped scan bodies from the ZI group were also scanned significantly faster, suggesting that certain shapes and geometries are easier to digitize than others.

To the authors’ knowledge, this is the first study that attempted to incorporate different scanning techniques and different scan bodies in a completely edentulous situation. One study showed improved accuracy using a scan strategy that incorporated an artificial landmark in a partially edentulous situation, however, the study did not utilize ISBs, which can vary significantly in shape, size, and surface from natural teeth. While all 3 null hypotheses were rejected, the scan techniques included in this study, which incorporated modifications to the tissue surface, did not demonstrate improved accuracy when compared to the scan technique with no modifications.

Despite the significant findings in this study, limitations do exist. It is possible that the FL technique showed significantly higher distance deviation because the floss was in direct contact with the scan body’s unique scan region, which may have interfered with the IOS’s ability to digitize the scan body’s surface. As an in vitro study, the scanning environment, while standardized, was different from the oral cavity and required the use of a physical model fabricated out of materials, which may reflect light differently. The use of an anti-reflective powder was also necessary when performing the master scan with the industrial scanner, which may have also lead to inaccuracies in the
measurement process. Another limitation of the study is that the scan bodies were attached directly to the implant fixtures, which may vary from the clinical scenario in which multi-unit abutments are present. To date, however, very few scan bodies are available for abutment level digital impressions. In addition, the model was scanned by a single operator using a scan path, which has yet to be validated for completely edentulous situations. While the occlusal-buccal-palatal path utilized in this study has been studied and recommended by the manufacturer for complete-arch scans in dentate and partially dentate patients, no guidelines currently exist for the completely edentulous patient. As a result, it is possible that different scan paths could lead to different results in complete arch situations. Lastly, the present study only attempted to evaluate the data acquisition step of the workflow, and did not investigate what effect this may have on the downstream processes, such as the processing and production of the definitive restoration. Future studies should be directed towards evaluating the influence of various scan body features on the accuracy of the resulting scans, identifying an ideal scanning protocol for a completely edentulous situation involving ISBs, and evaluating whether or not inaccurate scans lead to an ill-fitting prosthesis when using the completely digital workflow.
Chapter 5. Conclusion

Within the limitations of this study:

- The accuracy (trueness and precision) of complete-arch digital implant impressions using ISBs was affected by both the scan body and scan technique when utilizing one specific IOS system.
- The ZI scan body had significantly less distance deviation while splinting scan bodies with floss led to significantly more distance deviation.
- Scan techniques with different surface modifications resulted in similar distance deviations as the technique without any modifications.
- Use of different ISBs led to significant differences in scan time.

When performing complete-arch digital implant impressions with 4 implants, clinicians should choose the ISB and scan technique carefully, as ISB and scan technique can significantly affect the accuracy of the scan when using the test scanner. Certain ISBs may be scanned faster than others.


