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In Vivo Accuracy and Precision in Prosthodontics

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Abstract

Nedelcu, R. 2020. In Vivo Accuracy and Precision in Prosthodontics. *Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Medicine* 1625. 51 pp. Uppsala: Acta Universitatis Upsaliensis. ISBN 978-91-513-0840-1.

Background: There has been a dramatic increase in commercially available intraoral scanners (IOS) in the last decade, offering to replace indirect digitization of models (MOD) fabricated from impressions (IMPR). IOS has benefits of less patient discomfort and a faster workflow to fabricate fixed dental prosthesis (FDP), and implant-supported prostheses (IFD). However, *in vivo* evidence is lacking not only for IOS, but also for MOD, FDP and IFD fit.

Aims: Paper I: to evaluate *in vitro* finish line distinction and accuracy in seven IOS and one MOD. To assess parameters of resolution, tessellation, topography, and color. **Paper II**: to evaluate a method of acquiring an *in vivo* reference measurement in dentate subjects and analyse accuracy and precision of IOS and MOD. **Paper III**: to evaluate an *in vivo* reference-measurement method in fully edentulous maxillae with full-arch implant treatments and to analyse accuracy of MOD and fit of existing IFD. **Paper IV**: to analyse precision and accuracy of IOS using different acquisition protocols compared to the reference-measurement in Paper III.

Material and Methods: Paper I: A model with a crown preparation was reference-scanned with an industrial scanner, (ATOS), scanned with seven IOS and the MOD of an IMPR was digitized. Best-fit Alignment and 3D Compare Analysis was followed by descriptive analysis. **Paper II:** A reference-scan was acquired with ATOS. Subjects were scanned with IOS and one MOD of an IMPR was digitized. Accuracy and precision were evaluated after Best-Fit Alignment and 3D Compare Analysis. **Paper III**: A reference-measurement of implant positions was acquired with ATOS. MOD from IMPR was digitized and IFD scanned. Datum and Relative Point System Alignment was followed by accuracy and precision analysis. **Paper IV**: Subjects in Paper III were scanned with IOS using three different protocols, followed by accuracy and precision analysis.

Results: Paper I: There were considerable differences between IOS depiction of finish line and finish line accuracy. **Paper II**: IOS presented varying results for impressions in up to ten units. No differences were found for MOD. **Paper III**: IFD was significantly less accurate than MOD. **Paper IV**: Differences were found between scanning protocols. Compared to Paper III, IFD was less accurate. No differences were found for MOD.

Conclusion: There are relevant differences between IOS when scanning subgingival preparations. Some IOS are better suited for long-span scans. Some IOS can be used for full-arch impressions for IFD in the maxilla, however, adequate soft-tissue management is crucial.

Keywords: accuracy, precision, in vivo, digital impression, intraoral scanner, polyether impression, implant impression, framework misfit, fully edentulous

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To Andreas, for believing in me
To Ingela and Pontus, for understanding me
To Hans, for teaching me

To my family,
for being there for me

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I Nedelcu, R., Olsson, P., Nyström, I., Thor, A. (2018) Finish line distinctness and accuracy in 7 intraoral scanners versus conventional impression: an in vitro descriptive comparison. Paper subtitle. *BMC Oral Health*, 18(1):27–38

II Nedelcu, R., Olsson, P., Nyström, I., Rydén, J., Thor, A. (2018) Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: A novel in vivo analysis method. *J Dent*, 69:110–118

III Nedelcu, R., Olsson, P., Thulin, M., Nyström, I., Thor, A. In vivo accuracy and precision of full-arch implant-supported restorative workflow. Part 1: impression, models and restorations. (Submitted manuscript).

IV Nedelcu, R., Olsson, P., Thulin, M., Nyström, I., Thor, A. In vivo accuracy and precision of full-arch implant-supported restorative workflow. Part 2: Intraoral scanning using different protocols (Submitted manuscript).

Contents

Abbreviations

ATOS	ATOS Core 80 5 MP Scanner (reference scanner)
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CMM	Coordinate Measurement Machine
FDP	Fixed Dental Prosthesis
IFD	Implant-supported Fixed Denture
IOS	Intraoral Scanner(s)
RPS-Alignment	Relative Point System Alignment
STL	Standard Tessellation Language (file format)
TRIOS-BL	TRIOS baseline scanning protocol
TRIOS-DF	TRIOS assisted scanning with dental floss
TRIOS-SP	TRIOS assisted scanning using a splint method

Introduction

Scope of the Thesis

Dental impressions play a central part in oral prosthetics. It is used to fabricate models for planning and executing treatments from removable dentures to tooth- and implant-supported crowns and bridges. The process of pouring and setting the negative imprint of teeth and soft tissues into a stone model usually requires the models to be transported to a dental laboratory for processing. To shorten the working time to fabricate tooth-supported fixed dental prosthesis (FDP) alternative digital impressions using intraoral scanners (IOS) were developed over thirty years ago (Rekow, 1987).

During the last decade, there has been a dramatic increase in the number of commercially available IOS offering to replace conventional impressions with digital impressions (Renne et al., 2017). The dental profession has since been amidst a technological shift by digitizing the last major steps in the prosthetic workflow.

Although there is no absolute accepted value for marginal misfit in final restorations, or a full understanding of associated risks with poor fit especially on implants, there is an innate strive to uphold the highest possible fit in the restorative workflow (Hjalmarsson, Ortorp, Smedberg, & Jemt, 2010; Katsoulis, Takeichi, Sol Gaviria, Peter, & Katsoulis, 2017). For IOS to succeed and become the replacement of choice for impressions, it is imperative that the technology can offer at least the same or better clinical results as well-established methods.

The core foundation in medicine and dentistry is based on offering treatments and methods that are evidence-based. Such research is not always available, even for long-standing treatments (Djulbegovic & Guyatt, 2017). This has created the need for a broader interpretation introducing 'proven experience' to allow for clinical reasoning. However, the term has been under increased scrutiny as it does not identify who's experience, and if that population's viewpoint is in line with a consensus. Furthermore, the decision of treatments must include and account for the patient preferences and values, leading the way for evidence-based practice (Djulbegovic & Guyatt, 2017; Greenhalgh, Howick, Maskrey, & Evidence Based Medicine Renaissance, 2014).

It is evident that flourishing social media and numerous internet-based discussion groups has become a method of acquiring information among clinicians. A search on popular video-sharing websites will divulge an abundant number of treatments on display with unfiltered testimonials of IOS integration in advanced and complex treatments. This often leaves the viewers in awe, but there is little or no scientific evidence supporting the procedures or methods described.

A major limitation for investigating the quality of IOS clinically is the challenge in acquiring reliable reference measurements due to the restrictive nature of the oral cavity. Thus, most of the research is performed *in vitro*, eliminating the clinical reality and potentially oversimplifying the test. *In vivo* data of IOS could support clinicians with both benefits and limitations and allow for better understanding of the technology. Research on conventional impressions, FDP and implant-supported fixed denture (IFD) is equally lacking regarding *in vivo* studies and is much needed to put the IOS results in a context.

The scope of this thesis was to primarily develop a methodology to assess the performance of IOS and conventional impressions *in vivo*, and where applicable, the subsequent final restoration. Furthermore, to develop better understanding of the technical differences between IOS systems and the clinical effects of specific IOS properties.

The thesis is based on four papers. **Paper I** evaluates seven IOS regarding specific properties *in vitro* which have the potential to affect the quality of the scan and compares the results to a conventional impression. **Paper II** evaluates an *in vivo* method developed to acquire a reference measurement of dentate subjects to which IOS and conventional impressions can be compared. **Paper III** used an adaptation of this method *in vivo* to acquire a reference measurement and to investigate conventional impressions in full-arch restorations on implants and the fit of previously manufactured IFD. **Paper IV** compares three different IOS scanning protocols *in vivo* on the same subjects as Paper III, making the results directly comparable between the two papers. To our knowledge, the method used in Papers II, III and IV provides unique results where there is no prior *in vivo* data.

The intention of the combined studies was to provide results for conventional and digital impressions ranging from single teeth, to extensive dentate conditions and advanced implant impressions *in vivo*, and to offer a workflow for an industry-standard 3D analysis method.

History of Dental Impressions

It is believed that impressions were used for the first time over 250 years ago using soft beeswax and cast in plaster of Paris to create a positive model replicating the anatomy in the subject (Guerini, 1909). The use of models made it possible to diagnose, plan and simplify the process of manufacturing restorations without the patient being present. In the coming decades different materials where tried, from gutta-percha, to actual plaster being allowed to set in the mouth for edentulous patients.

In the 1920s, modelling plasters became available (Wilson, 1919), and by this time, it was common to use impression trays to stabilize the impression material and limit the deformations upon removal. Reversible hydrocolloid, a gel-like material based on algae, was developed in 1936 and despite its cumbersome handling, it offered superior impressions, even by today's standard. Due to World War II, algae from Japan could not be procured and non-reversible hydrocolloid materials were introduced as a substitute. However, the quality was poorer than reversible hydrocolloids (Starcke, 1975). These alginate materials still exist today and are used mainly for diagnostic models, calling for fast-setting impressions in situations that commonly do not require the highest accuracy.

Early modern elastomeric impressions based on polysulfide and silicon were introduced in the middle of the nineteen-fifties. Following these materials, elastic polyether materials were introduced, and later polyvinylsiloxane, both being the principal impression materials currently in use (Starcke, 1975).

CAD/CAM in Brief

Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) were introduced in dentistry in the early 1970s, with the first experimental crowns manufactured a decade later (Duret, Blouin, & Duret, 1988). With advancements in technology, treatments were over time no longer limited to single units, but offered complex multi-unit restorations on teeth and implants, (Andersson et al., 1989; Andersson, Razzoog, Oden, Hegenbarth, & Lang, 1998; Katsoulis et al., 2014; Russell, Andersson, Dahlmo, Razzoog, & Lang, 1995). An essential part of the workflow was the digitization of gypsum models poured from traditional conventional impressions using dental laboratory scanners (Persson, Oden, Andersson, & Sandborgh-Englund, 2009).

IOS in Brief

Parallel to the development of CAD/CAM, IOS systems became available, which could digitize the dental status in situ, completing the full digital workflow and eliminating the need for impressions in specific cases (Rekow, 1987). Historically, the most successful IOS was the CEREC system, which was limited to single-tooth restorations and came as an integral part in a proprietary workflow accompanied by an in-house milling machine (Fasbinder, 2010; Mormann, 2006). The system eliminated the need to send a conventional impression to a dental laboratory for pouring the stone models, the waiting for the material to set, the digitization of the model in the dental laboratory, the sending of the scan files to a milling centre and the time needed to return the milled restorations. Instead, the milling machine was brought into the dental practice together with sintering equipment, thus completing the digital workflow. Early CEREC systems were however limited to milling intaglio surfaces (Otto & De Nisco, 2002), but with 3D software and hardware developments, it was possible to mill restorations for multiple teeth during early 2000s (Ender, Wiedhahn, & Mormann, 2003), and shorter bridges since 2009, (Kurbad & Schnock, 2009; Schneider, 2016).

Since the late 2000s, there has been a rapid increase in the number of commercial IOS. Modern IOS can capture data of full dental arches and provide an in-situ digitization that could be used for fabrication of extensive restorations. Most systems no longer limit the user to a proprietary workflow with specific focus on final restoration, but offer the clinician and dental technician control of the acquired data for third-party CAD/CAM manufacturing, (Beuer, Schweiger, & Edelhoff, 2008).

With technological hard- and soft-ware advancements, the turnover time of IOS is relatively short as new generations of scanners appear every three to four years. The trend has also been very clear where IOS has moved from scanners using still-image acquisition, frequently with a titanium dioxide powder coating, to non-coating video acquisition and inclusion of true-to-colour renderings, (Ender, Attin, & Mehl, 2016; Nedelcu & Persson, 2014; Ting-Shu & Jian, 2015).

Digital impressions have been attributed to several benefits over conventional impressions. It reduces the worry in patients from not being able to breathe, anxiety when a gag reflex occurs during impressions-taking, and stress from the general state of helplessness (Gjelvold, Chrcanovic, Korduner, Collin-Bagewitz, & Kisch, 2016; Mangano, Gandolfi, Luongo, & Logozzo, 2017). IOS offers practical benefits of being able to interrupt a scan at any given time due to discomfort and makes it possible for the clinician to rescan specific areas instead of having to retake a full conventional impression.

Even though the speed of most IOS have not reached that of the active time it requires to take an alginate impression for a study model, the difference can be seen as negligible, and the patient preference is still towards IOS (Burhardt, Livas, Kerdijk, van der Meer, & Ren, 2016; Renne et al., 2017). However, when impressions are used for a prosthetic treatment, the speed of the IOS supersedes that of the slower conventional impressions (Joda & Bragger, 2016a), and can shorten the overall time of impression and the manufacturing of a single tooth restoration (Gjelvold et al., 2016; Joda & Bragger, 2016b; Muhlemann, Kraus, Hammerle, & Thoma, 2018). Other benefits with IOS include the possibility of sending files electronically within moments, the elimination of storage for models, enhanced communication with dental technicians and a powerful visual tool in explaining and involving the patient in the treatment (Mangano et al., 2017).

Accuracy & Precision

Varying terminology exists in the science of metrology for explaining intra and inter-system variations. The studies conducted in this thesis have adopted the commonly used terminology in the field of engineering (Nedelcu & Persson, 2014), defining *accuracy* as the ability of a measurement to match the actual value or accepted reference value and *precision* as the ability of a measurement to be consistently reproduced. Accuracy is thus affected by systematic effects, and precision by random effects.

This stands in contrast to the ISO 5725 where accuracy implies the total displacement of a result from a reference value, due to random *as well as* systematic effects. What the studies in this thesis refer to as accuracy is presented as the invented term *trueness* in the ISO 5725 standard. The existence of multiple definitions of the widely used term accuracy is somewhat confusing.

The ISO 5725 standard has been used extensively mainly by one research group (Ender, Attin, et al., 2016; Ender & Mehl, 2011, 2013, 2015; Ender, Zimmermann, Attin, & Mehl, 2016), and has since been followed by several others (Patzelt, Emmanouilidi, Stampf, Strub, & Att, 2014; Renne et al., 2017).

2D and 3D Analysis

There are numerous publications on two-dimensional (2D) comparisons in dentistry, with examples commonly found in marginal crown fit of restorations (Tsirogiannis, Reissmann, & Heydecke, 2016). Although the findings provide quantitative data, the readings are performed usually through measurements of sliced samples at specific locations. Thus, the linear method may limit the analysis of data and has the potential shortcoming of introducing bias as to how the points are selected and if the points are representative in the analysis.

A method commonly used in engineering to investigate accuracy, eliminating shortcomings of 2D measurements, is three-dimensional analysis (3D). A frequent application is that of assessing manufacturing processes where a product is measured and compared to its original CAD file (Raja V, 2008). Another application is a reference-measurement of a reference-model, thus defining a ground truth, to which either a process or a secondary measurement device can be compared. The reference-measurement is frequently made with a Coordinate Measurement Machine (CMM) or an industrial optical scanner. The reference systems have in common that they must have an expected accuracy and precision that supersedes that of the method to be tested to have any validity for assessment of accuracy.

CMM

Examples of applications of CMM in dentistry can be found in 3D analysis of impressions and model fabrication in implant-supported treatments (Bergin, Rubenstein, Mancl, Brudvik, & Raigrodski, 2013), and assessments of the manufacturing process of frameworks based on a reference model (Eliasson, Wennerberg, Johansson, Ortorp, & Jemt, 2010; Hjalmarsson et al., 2010). These studies are based on specific geometries, such as implants or cylinders in frameworks, which are suitable for reference measurement using a CMM.

Optical Scanner

Optical scanners are widely used in measurements of free-form shapes in engineering (Y. Li & Gu, 2005; Makem, Ou, & Armstrong, 2012). The method offers faster processing speed and does not carry the limitation of the physical size of the probe of the CMM, making it ideal when scanning surfaces such as narrow interdental spaces *in vitro*. This method has been frequently adopted within the field of dentistry when investigating impressions and IOS based on free-form shapes such as teeth. A common approach is a reference-measurement of a model, after which conventional impressions can be taken and the model scanned with IOS. The datasets are imported into 3D metrology software whereupon a mathematical best-fit alignment is conducted between the reference-scan and the digitized models from the conventional impression or the IOS. To visualize the accuracy, deviations are displayed in a colour histogram, and in some cases annotations are made to evaluate deviations in specific areas (Ender & Mehl, 2011, 2013, 2015; Mehl, Ender, Mormann, & Attin, 2009; Nedelcu & Persson, 2014; Patzelt et al., 2014; Persson et al., 2009; Raja V, 2008; Renne et al., 2017).

Free-form Shape versus Geometries

3D Compare Analysis comes with certain shortcomings which several publications have addressed somewhat improperly. This is not mainly due to the method itself but rather the application of the software to a methodology it is not originally intended for. Software packages for 3D inspection allows for specific regions of interest to be aligned by best-fit-alignment algorithms. This ensures that the alignment does not take in consideration the full surface which may contain areas of little or no importance. However, the statistical data extracted from the subsequent 3D Compare Analysis will include all surfaces, and if not addressed properly, will inadvertently affect the overall accuracy being reported. This is the reason why scan-cropping of free-form shape may be critical and part of the solution. Yet, if the objects to be aligned contain specific geometries, such as circles and planes in a scan-body used in IOS for scanning implants, then these geometries, also referred to as *datums*, can be identified and robustly aligned through a Relative Point System Alignment (RPS-Alignment). This method eliminates certain issues seen in free-form shape analysis and is described in **Paper III** and **Paper IV** in this thesis.

IOS Specifics

Some earlier studies comparing IOS and conventional impressions have found IOS to demonstrate a statistically significantly lower accuracy (Ender & Mehl, 2013, 2015). Recent review articles have however concluded that there are great benefits with IOS, although, the literature does not support the use of IOS in long-span restorations on teeth or implants (Mangano et al., 2017). Study design, execution and models used for assessing IOS makes it difficult to compare results between existing studies, even when conducted under optimal laboratory conditions. Several factors may influence the measured data from IOS.

IOS Acquisition Technology

IOS uses varying acquisition technologies, ranging from active triangulation with light emitting diode (LED) or laser, to parallel confocal technology.
Visual inspection of STL files exported from IOS can show sizeable variations in the underlying 3D mesh and especially triangle density. Little is known how resolution (triangle density) affects accuracy or precision (Nedelcu & Persson, 2014). Low mesh resolution may result in poor accuracy for a small surface, such as an abutment, but could still show high accuracy for a full arch scan in a dentate subject.

The accuracy in older IOS can be directly linked to the method of acquisition and the interaction with the material properties of the object being scanned. A key finding in older IOS generations shows that IOS based on triangulation and laser technology results in a higher degree of interpolation and poorer results (Nedelcu & Persson, 2014). Recent publications on substrate effect of scans shows that parallel confocal technology has an overall higher accuracy than active triangulation with LED, but there appears to be great improvement in newer generations of IOS systems not only for specific technologies, but for IOS systems as a whole (Dutton et al., 2019; Mangano et al., 2017).

Light Dynamics

Material properties in combination with scanner technology and light dynamics can affect accuracy. Results have displayed sizeable differences using non-coating IOS systems in translucent materials, where an increase in translucency resulted in lower accuracy (H. Li, Lyu, Wang, & Sun, 2016; Nedelcu & Persson, 2014). Yet several studies evaluating IOS *in vitro* have used a range of materials, from gypsum and polyurethane, acting as near to perfect diffusers, to metal, having a high level of specular reflection (Ender & Mehl, 2015; Patzelt et al., 2014; Seelbach, Brueckel, & Wostmann, 2013). These material properties may either oversimplify the clinical reality of non-coating scanners, or contrarily put the non-coating scanners to great disadvantage when scanning metal and are vastly different from naturally translucency of teeth. Still, little is known regarding the influence from opacity, iridescence, surface gloss, and fluorescence which vary individually between human teeth, as does the effect of tooth age, thickness and colour of the enamel and underlying dentine (Xiong, Chao, & Zhu, 2008). It would be favourable to use materials with a translucency and refraction index close to enamel and dentine to mimic natural light dynamics seen in teeth during *in vitro* investigations (Nedelcu & Persson, 2014).

Scanning Strategies and Human Factor

Factors, such as different scanning strategies based on the scan pattern during the scan have varying results *in vitro*. Investigations of shorter spans have shown little, or no difference between scanning patterns, whilst full-arch scans have shown measurable differences (Gimenez, Ozcan, Martinez-Rus, & Pradies, 2014; Muller, Ender, Joda, & Katsoulis, 2016). It is unclear how these findings translate into the clinical environment. This is especially the case with the introduction of Artificial Intelligence (AI) in some scanners.

Previous studies have shown that the experience of the operator can influence the accuracy of IOS scans even *in vitro* (Gimenez et al., 2014). This ought to be of even greater importance when scanning *in vivo*, as parameters such as handling of soft-tissues and controlling substrates, such as saliva, blood and gingival crevicular fluid play a significant presence that may further affect the accuracy of the scans.

Image-stitching and Non-attached Tissues

Any *in vitro* study will further carry a vital difference compared to clinical reality as the models will not take in account non-attached tissues that may interfere during the clinical procedure, such as: the sulcus, lips, floor of the mouth or tongue. IOS uses pattern recognition to stitch multiple images with partial overlapping areas into full models (Nedelcu & Persson, 2014). The scans will, voluntarily or not, include a certain amount of data of non-attached tissues. Movement between measurements in the underlying surfaces may cause improper stitching of measurements. It is practically impossible to realistically simulate this effect *in vitro*.

There are few *in vivo* studies on IOS versus conventional impressions. Studies focusing on precision gives a quantifiable inter-system error, but does not take in consideration the accuracy (Ender, Attin, et al., 2016; Ender, Zimmermann, et al., 2016).

It would be preferable to evaluate accuracy of IOS *in vivo* as it would expose the systems to real conditions. The challenge lies in being able to create a reliable reference-scan. A first novel approach to evaluating accuracy of IOS and conventional impressions *in vivo* has utilized a transfer guide with known properties and allowed for bonding of spheres with known positions to the teeth (Kuhr, Schmidt, Rehmann, & Wostmann, 2016). However, the accuracy analysis is only conducted at the location of the spheres.

It is not only IOS that lack *in vivo* accuracy data. Conventional impressions have still not been thoroughly validated *in vivo* for the same reasons.

Aims

Paper I

It is undeniable that there have been great technological improvements in IOS during the last decade which are directly dependent on the general ad-vancements in computer technology. This has allowed not only for faster scanning speed, but also a change from image to video acquisition (Nedelcu & Persson, 2014). Previous studies have found considerable variations in scanning speed between systems and different generations of IOS from the same manufacturer (Renne et al., 2017). These results show differences in accuracy which can be expected with systems from multiple manufacturers using varying technologies and system age. One specific parameter not pre-viously investigated is the acquisition of the finish line distinctness between IOS. Fig. 1 shows an example from clinical practice of a crown preparation with retraction cord in place that should offer no challenge for a convention-al impression in displaying the finish line and the emergence profile. Yet, the 3D render of the acquired data shows the area to be somewhat blurred, not offering the expected distinct details.

Specific Aims Paper I

- Visualize inter-system variations of supragingival and subgingival finish line distinctness in seven IOS systems and a conventional impression.
- Investigate finish line accuracy.
- Analyse mesh resolution (triangle density), tessellation (level of triangle regularity), topography (variations in height), and the effect of colour for finish line identification.

Paper I evaluates the specific localized deviations at the finish line which would otherwise be lost when investigating the overall accuracy and precision, as these deviations constitute only a small part of the full dataset.

A **B**

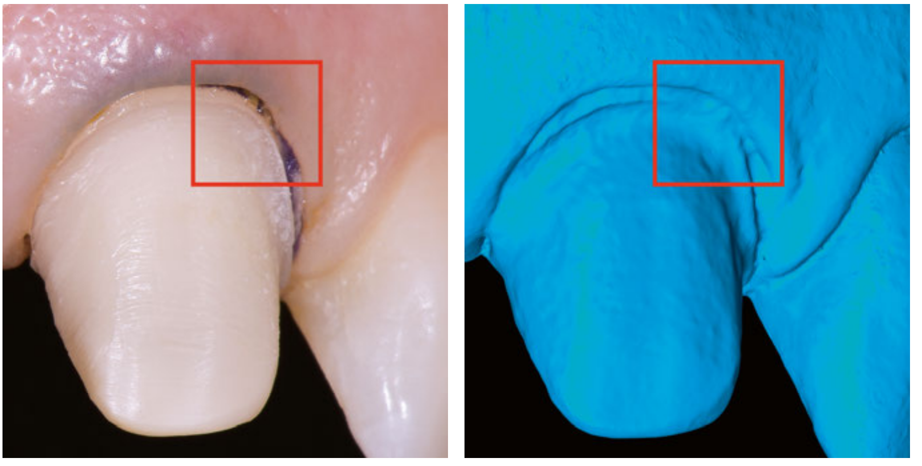

Figure 1. **A**. Clinical photograph of a preparation with retraction cord. **B**. Subsequent 3D rendering from an IOS displayed at approximately the same angle. The red box displays a particular section of the finish line with poor distinction in the IOS versus photograph.

Paper II

Although IOS was initially intended for single-tooth restorations, the systems offer the possibility to scan full-arches. However, the use of IOS for manufacturing long-span FDP or IFD does not have support in the literature (Mangano et al., 2017). Further, *in vivo* data is lacking both for IOS and conventional impressions regarding accuracy.

Specific Aims Paper II

- Investigate if a methodology developed by our research-team could be used for reference-measurement *in vivo* in dentate subjects.
- Evaluate the precision of the reference-scanner and dental laboratory scanner.
- Analyse accuracy of IOS and conventional impressions.
- Explore the possibility of scanning a scan-body with an ATOS reference-scanner without coating.

Paper III & IV

Manufacturers offering both implants and milled frameworks as part of their product portfolio have taken a cautious approach and suggested scanning cases for single-crowns and short bridges with IOS. The traditional impression method for full-arch implant-supported restorations have relied on impression copings for conventional methods with or without splinting between the copings (Fig.2 A). Yet, digital impressions have been used in rather extensive cases of full-arch impressions for several years using scan-bodies (Fig. 2B) for fabricating IFD (Fig. 2C), (E. Gherlone et al., 2016; E. F. Gherlone, Ferrini, Crespi, Gastaldi, & Cappare, 2015).

A **B**

C

Figure 2. **A**. Impression copings attached to implants for conventional open-tray impressions. **B**. Scan-bodies attached to implants for digital impression with IOS. **C**. Example of IFD with framework in milled titanium.

Paper III and **IV** uses the *in vivo* methodology developed and assessed in **Paper II** to investigate previously undertaken IFD treatments with conventional impressions.

Specific Aims Paper III

- Evaluate if the methodology from Part II could be used *in vivo* to create a reference-measurement in subjects with full-arch implant-supported treatments.
- Investigate the precision of a reference- and a laboratory scanner.
- Analyse the accuracy of the used in the manufacturing of the existing IFD, and the accuracy of a new model fabricated from a new conventional impression.
- Analyse the accuracy of the previously manufactured IFD from *in vivo* impressions.

Specific Aims Paper IV

- Analyse the accuracy of IOS using the reference-measurement from Paper III.
- Investigate the use of three different scanning protocols of IOS.
- Analyse if scanning four implants is more accurate than six implants
- Compare the results from conventional impressions and IFD from Paper III to the results from IOS.

Ethical approval

While ethical approval was not needed for the *in vitro* study in Paper I, ethics approval was required for *in vivo* studies II, III and IV.

The study in Paper II was conducted in connection with treatment for single-implant restorations in accordance with ethical approval from the Regional Ethical Review Board, Uppsala University, Dnr 2015/324.

The study in Papers III and IV was conducted on subjects recruited at a private specialist implant centre, Uppsala Käkkirurgiska Centrum (UKKC), Uppsala and in accordance with ethical approval from the Regional Ethical Review Board, Uppsala University, Dnr 2016/020.

Informed written consent was obtained from all participants prior to enrolment..

Paper I

Materials and Methods

Model and ATOS reference-scan

A model with screw-attached teeth and hard gingiva was prepared for a crown treatment of an upper right lateral. The finish line was supragingival with two specific subgingival areas, distobuccal (DB) and mesiopalatal (MP), where the preparation was placed at the bottom of the sulcus (Fig. 3). The model was scanned with an industrial-grade scanner (ATOS).

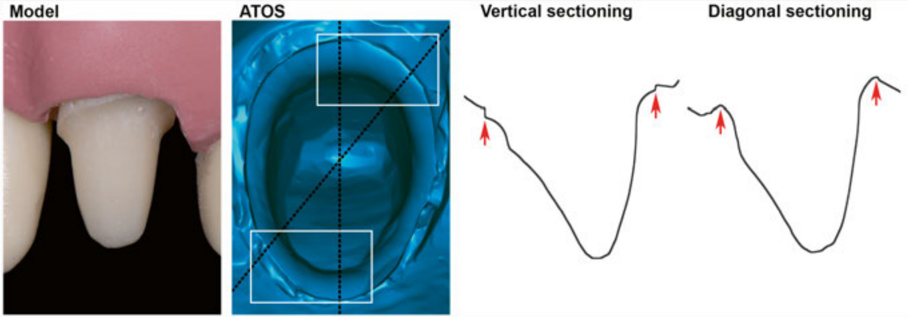

Figure 3. Model with preparation. ATOS reference-scan with rectangular demarcation of subgingival areas DB (upper) and MP (lower). Dotted lines display the sections for the vertical and diagonal sectioning with finish line in relation to the artificial gingiva.

IOS and conventional impression

The model was scanned ten times with seven IOS: 3M True Definition (3M), Carestream CS3500 (CS3500), Carestream CS3600 (CS3600), Dentalwings Intraoral Scanner (DWIO), Omnicam (OMNI), Planscan (PLAN) and Trios (TRIOS). The tenth file from each system was exported as STL. One impression was taken, and the poured model was scanned with a dental laboratory scanner (IMPR) and exported as STL.

Imaging and 3D Compare Analysis

STL files were imported into 3D inspection and metrology software. High resolution snapshots were exported of the surface rendering at a predefined occlusal viewing angle (OVA) (Fig. 4).

ATOS reference file, IOS and IMPR scan were cropped with a reproducible methodology in OVA. 3D Compare Analysis was performed on the cropped IOS and IMPR.

Image processing and analysis

Manual measurements were marked with an arrow depicting the longest distance from periphery to the demarcation margin of > 50 and <-50 µm towards the centre of the preparation.

To evaluate the effect of colour, screenshots were taken for CS3600 and PLAN. OMNI and TRIOS screenshots were taken in proprietary dental laboratory software used for exporting STL files.

Results

Despite the descriptive nature of the analysis and its subjective element, there are variations between scans that present a clear separation.

Resolution

The ATOS reference-scanner presented the highest resolution, near twice that of TRIOS, which in turn had a triangle count of 1.6-3.1 times higher than any other IOS and 1.3 times higher resolution than IMPR (Fig. 4).

Tessellation

The mesh of 3M and DWIO presented a higher level of tessellation uniformity close to the finish line compared to other systems.

Topography

Image analysis revealed some topographic deviations in 3M and TRIOS that were not present in other systems.

Finish line distinctness

TRIOS showed the highest overall finish line distinctness and margin accuracy. PLAN, DWIO and 3M showed the lowest finish line distinctness, with PLAN and 3M also having the lowest resolution. DWIO on the other hand, had the second highest resolution among IOS (Fig. 4).

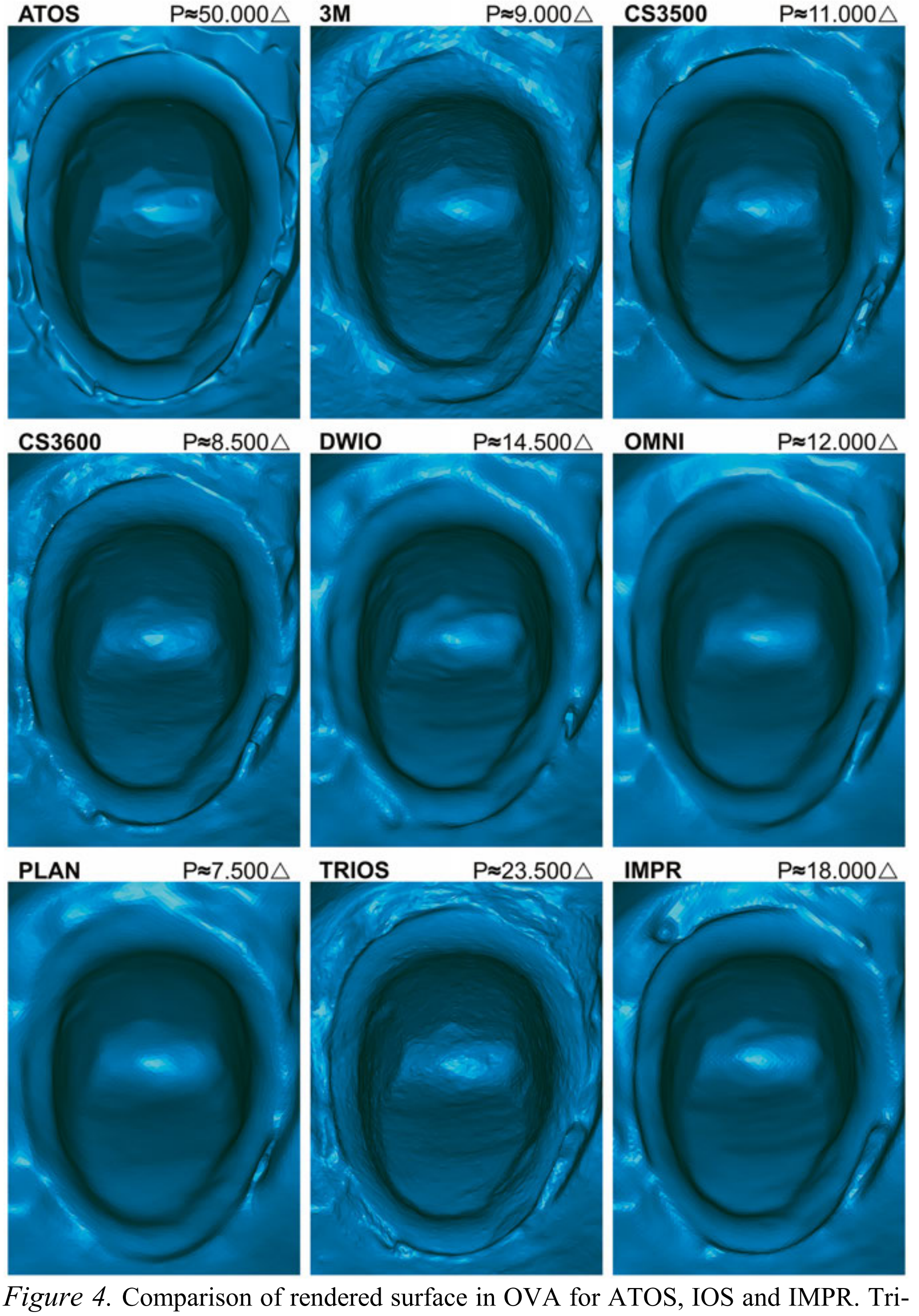

Figure 4. Comparison of rendered surface in OVA for ATOS, IOS and IMPR. Triangle count (P) refers to the mesh depicting the preparation without surrounding soft tissues.

Finish line accuracy

TRIOS and CS3600 had the highest finish line accuracy with deviations below ±25 µm. IMPR displayed deviations above ±50 µm but did not reach further than 30-50 µm from the periphery. DWIO, 3M and PLAN showed 3D deviations above 100 µm and reaching between 192 µm to 680 µm from the periphery.

Colour

The contrast from colour scans in CS3600, OMNI and TRIOS increased the ease of finish line identification, however PLAN showed excessive colour-bleed and did not enhance the finish line distinctness.

Discussion

TRIOS provided the highest triangle count, highest level of finish line distinctness and shared the highest level of finish line accuracy with CS3600. Both scanners surpassed IMPR. DWIO and PLAN offered a low finish line distinctness and finish line accuracy, and 3M presented an increased level of deviations in the subgingival areas of above ±100 µm. These IOS held a higher level of deviations from the periphery of the finish line. Unlike all IOS, PLAN showed mostly negative deviations. These deviations in finish line accuracy were at least two-fold over margin fit of restorations in a recent review, which takes in consideration the full workflow and all contributing factors (Tsirogiannis et al., 2016).

Overall resolution did not appear to be the only contributing factor to finish line distinctness and finish line accuracy. Non-uniform tessellation in combination with localized higher resolution in areas with an increased 3D topographical variation provided the best finish line distinctness and finish line accuracy. Scanner dependent topography variations in TRIOS and 3M, which could be seen as noise, did not appear to reach levels of clinical concern.

Colour provided contrast that could enhance finish line identification in some scanners.

Paper II

Materials and Methods

Subjects

Five subjects referred for implant treatment of a missing first or second premolar in the upper jaw participated after informed consent (Fig. 5). Implants were installed using a one-stage-surgery protocol and allowed to heal for twelve weeks.

Figure 5. Example of dentate subject with one missing premolar.

Reference-scan

Four reference-bodies in the shape of hemispheres in Alumina (Al2O3) milled to 3 mm in diameter, were bonded buccally on laterals and second premolars in the upper jaw. Due to anatomical and physical variations, adaptations were made where one reference-body was shifted one tooth position unilaterally. The reference-bodies were numbered as position one to four from right premolar (Pos. 1), to left premolar (Pos. 4). The teeth and reference-bodies were carefully coated. A scan-body was attached to the implant.

The head and neck of the subjects were fixated using an orthopaedic vacuum pillow. An optical industrial-grade scanner (ATOS) was used to scan the buccal aspect of the dentition using 5-7 sequences. Three complete scans were conducted on each subject after which the scans were post-processed and exported as STL.

IOS scans

The upper jaw was scanned three times with: Trios 3 (TRIOS), CEREC Omnicam (OMNI) and 3M True definition (3M) using proprietary coating on the latter. Files were exported in STL file format.

Impression

Scan-bodies were removed, and impression-copings were attached to the implants. An impression was taken, and the model poured. A laboratory scanner (D1000) was used to scan the models with an attached scan-body. Files were exported in STL file format.

3D Compare Analysis

Files were imported into 3D inspection and metrology software, and after best fit alignment using the reference-bodies only, a 3D Compare Analysis was performed. Surface annotations of 2 mm diameter were placed on each reference-body and data extracted.

Precision

ATOS reference-scans and D1000 scans were cross-compared to each other. For each subject, the IOS-scans 3M, OMNI and TRIOS were cross-compared.

Accuracy

For each subject, the first ATOS reference-scan was used for accuracy evaluations of all IOS, and for the first D1000 model scan (IMPR).

Results and Discussion

Precision evaluation of ATOS reference-scanner

The deviations of the ATOS scanner were a mean of 0.6 µm, median of 0.5 µm, minimum of -4.0 µm and maximum of +4.8 µm. Examination of reference-scans showed localized artefacts, most likely due to the coating spray. Although the ATOS system is mainly used in industrial applications, the precision was deemed high also in this clinical application.

Precision evaluation of D1000 laboratory scanner

Deviations of the D1000 laboratory scanner were: a mean of 0.5 µm, median of 0.9 µm, minimum of -1.7 µm and maximum of +4.8 µm. The results were comparable to the ATOS reference-scanner used *in vivo*. Unlike the ATOS, the D1000 operated under optimal conditions.

Accuracy evaluation of IOS scans and conventional impression

Accuracy of 3M and TRIOS were found to be statistically significantly higher than OMNI. No significances were found for IMPR when compared to any of the IOS. OMNI showed higher positive deviations in the posterior area compared to the anterior, and negative contracted area in the frontal region (Fig. 6). These finding support the use of IOS clinically when scanning up to ten units without extensive edentulous areas. However, there are variations between IOS as previously reported. A previous *in vivo* study has shown IMPR to be superior, followed by 3M and TRIOS. OMNI presents the lowest accuracy (Kuhr et al., 2016) and similar results have been reported in an *in vitro* study (Patzelt et al., 2014).

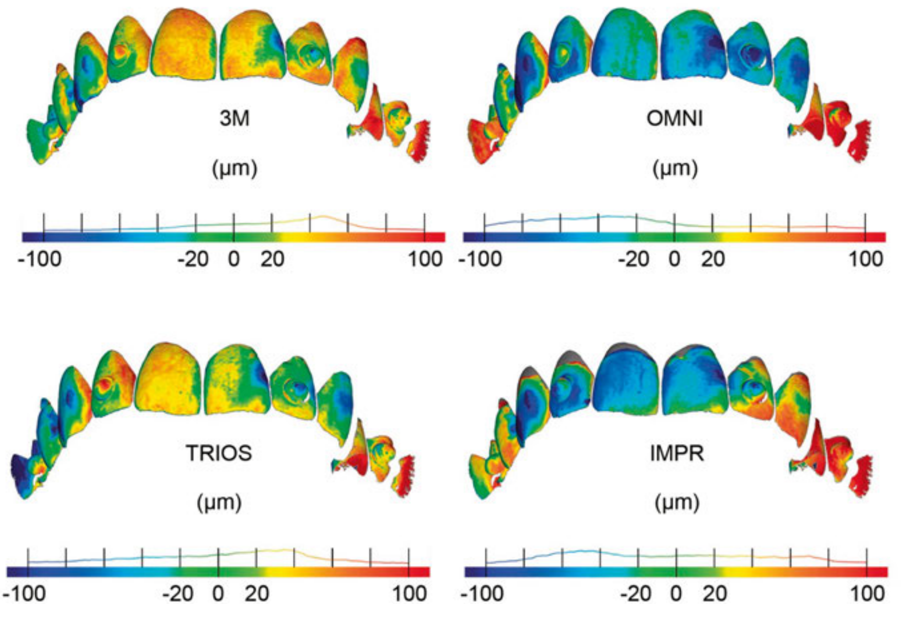

Figure 6. Representative 3D Compare Analysis of IOS and IMPR and colour histogram depicting deviations with settings at nominal ±20 µm and critical level at ±100 µm.

Precision evaluation of IOS scans

No statistically significant differences were found regarding precision. The inter-system variations were considerable with a clear expansion / contraction, generally in the posterior areas (see plots in original publication). It is unclear if this is caused by software algorithms, scanning pattern, the operator, incorrect stitching due to anatomical conditions or capture of non-attached tissues, all of which may affect the overall quality of the scan.

Paper III & IV

Materials and Methods

Subjects

Seven subjects participated after informed consent. The inclusion criteria were previous treatment with IFD based on CAD/CAM on six implants with hexagonal regular platform connection (RP), and without abutments.

Previous treatments had been provided by three different specialists in oral prosthetics, using different dental laboratories and manufacturing processes. The restorations had been in function between 33 and 73 months.

Upon removal of the bridge, one subject presented failed osseointegration of two implants. A second subject had converging implants and the posterior implant and its contralateral were excluded.

The subjects were split into two groups. The first group consisted of all subjects with six stable implants (6P), (n=5). A second group combined these subjects' central four implants with the subjects where only four implants were included (n=7).

Workflow

The full workflow is depicted in Fig. 7 for **Paper III** and Fig. 8 for **Paper IV**. The studies were executed in parallel and share the same reference-measurement. The order of the workflow was executed as listed below.

1. Acquisition

Reference-scan REF, (Paper III and Paper IV)

Upon removal of existing implant-supported bridges, scan-bodies were attached, and for each subject, three reference-scans were performed with an ATOS scanner using multiple sequences.

IOS scan - TRIOS, (Paper IV)

Pre-test scans were performed on the first subject with two different IOS. One system could not consistently produce a digital impression due to stitching anomalies and was excluded. The second system, Trios 3 (TRIOS), managed to process the scan.


1 Acquisition
2 Virtual Model
3 Datum Alignment
REF
MOD1
MOD2
BRIDGE
4 AVAN
5 Global Alignment
6 RPS Alignment
RPS Position 4
Dev. 0.027
ΔX -0.016
ΔY 0.008
ΔZ 0.02

Figure 7. Workflow Paper III. **1**. Acquisition of scan-bodies for reference scan (REF). Conventional impression to fabricate MOD2. Scan of BRIDGE with analogues mounted. **2**. Virtual models of REF, scanned MOD1 used to fabricate original FDS, MOD2 based on impressions and BRIDGE. **3**. Datum Alignment of scan-body with indirect alignment of analogues for REF. Direct Datum Alignment of analogues for 3D print models MOD1 and MOD2. Datum alignment of analogues to BRIDGE. **4**. AVAN. Exported aligned analogues for each model of REF, MOD1, MOD2 and BRIDGE. **5**. Consistent geometry-based Global Alignment. **6**. Example of RPS Alignment with deviations for each position, Resultant, DeltaX, DeltaY an DeltaZ

For each subject, using the TRIOS system, three baseline scans were undertaken of the scan-bodies and inter-implant tissues (TRIOS-BL). Three scans were performed using dental floss around scan-bodies, creating a cross-pattern in the inter-implant gap (TRIOS-DF). Three scans were conducted using a bis-acrylic composite to splint the scan-bodies (TRIOS-SP).

The scans did not use the common two-step approach of first capturing soft-tissues and secondly capturing the scan-body as the subjects were edentulous.

All scans used a modified scanning pattern, capturing scan-bodies and inter-scan-body tissues from the palatal to an occlusal aspect. The rationale for this modified approach was to limit any interaction from non-attached buccal tissues near the scan-bodies due to the resorbed dental arches.

Conventional impressions – Model Scans MOD1, MOD2, (Paper III)

After removing scan-bodies and attaching impression-copings, a conventional impression was taken, and models were manufactured. Scan-bodies were attached to original models used to manufacture the implant bridge and scanned with a dental laboratory scanner three times (MOD1). The model from the new impressions were similarly processed three times (MOD2).

Bridge scan – BRIDGE, (Paper III)

Implant analogues were attached to the subject's bridge. A thin coating of a titanium-dioxide was applied to the highly reflective analogues using an air-brush technique and the bridge was scanned with ATOS.

2. Virtual Models

Virtual models were extracted from ATOS for REF and BRIDGE as STL files. To mimic the standard manufacturing workflow, virtual scan-bodies were aligned in the proprietary software. A virtual 3D model was generated for TRIOS-BL and TRIOS-DF to extract the actual position of implants. Due to interference of splint material in TRIOS-SP scans, the files were exported without 3D print workflow.

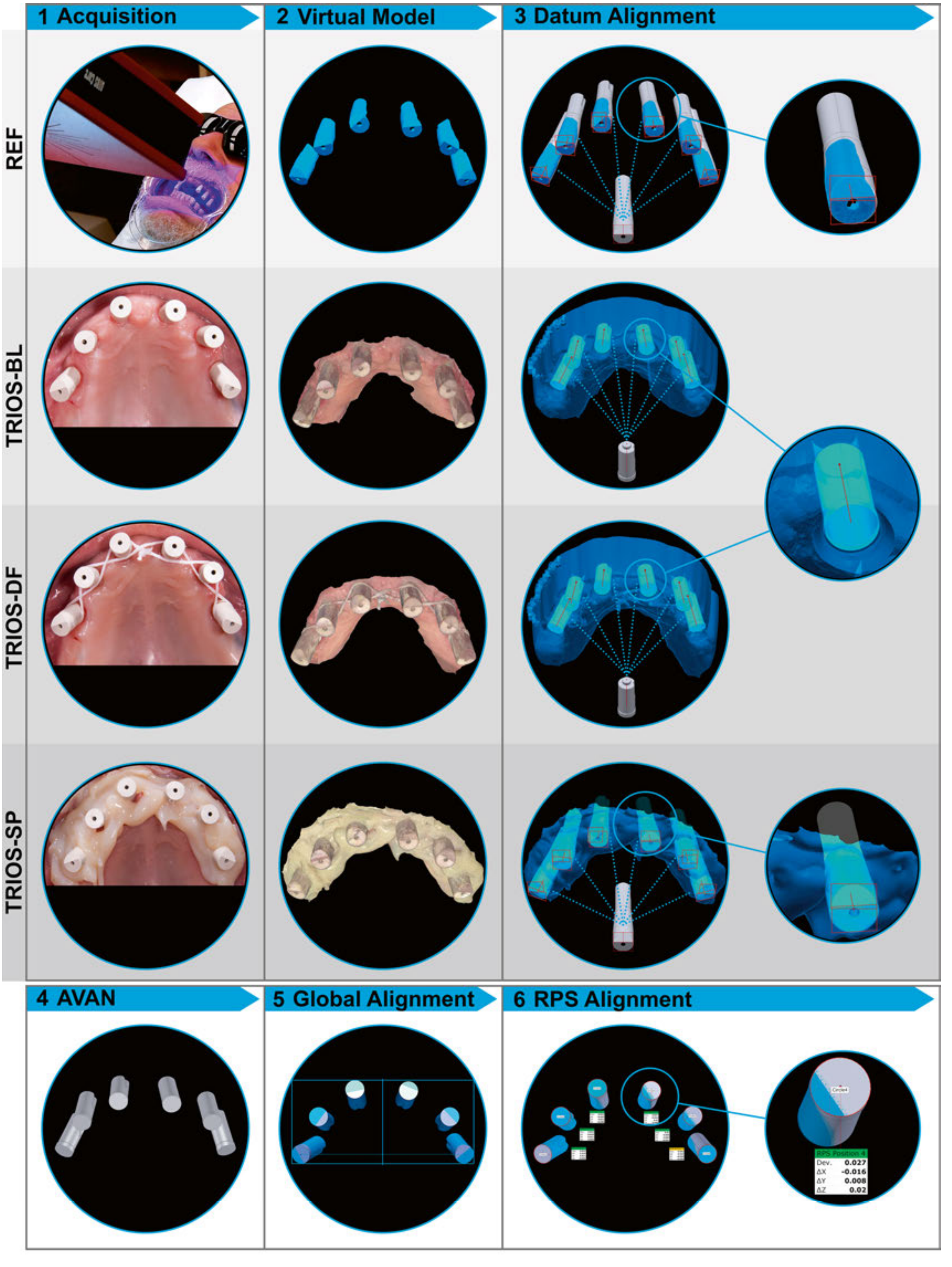
1 Acquisition
2 Virtual Model
3 Datum Alignment
REF
TRIOS-BL
TRIOS-DF
TRIOS-SP
4 AVAN
5 Global Alignment
6 RPS Alignment
RPS Position 4
Dev. 0.027
ΔX -0.016
ΔY 0.008
ΔZ 0.02

Figure 8. Workflow Paper IV. **1.** Joint REF acquisition for Paper III. Scan using three different protocols, TRIOS-BL, TRIOS-DF and TRIOS-SP. **2**. virtual models of REF, TRIOS-BL, TRIOS-DF and TRIOS-SP. **3**. Direct Datum Alignment of analogues for proprietary 3D print models TRIOS-BL and TRIOS-DF. Datum Alignment of scan-body with indirect alignment of analogues for TRIOS-SP. **4**. AVAN. Exported aligned analogues for each model of TRIOS-BL, TRIOS-DF and TRIOS-SP. **5**. Consistent geometry-based Global Alignment. **6**. Example of RPS Alignment with deviations for each position, Resultant, DeltaX, DeltaY an DeltaZ.

3. Datum Alignment

Specific geometrical features, *datums*, such as planes and axis of cylinders were identified in CAD files of scan-bodies and analogues and the mesh of the virtual models. A Datum Alignment matched those geometrical features for each implant position using either analogue or scan-body combined with an analogue.

4. AVAN – Aligned Virtual Analogue

Datum Aligned CAD analogues (AVAN) for each model was exported, thus defining the inter-implant position in the 3D space for each scan.

5. Global Alignment

A Global Alignment was executed of AVAN files defining the models in the 3D planes using a consistent geometry-based protocol and making it possible to compare the deviations based on Cartesian axes together with a combined linear Resultant.

6. RPS alignment

Intra- and intersystem RPS-Alignments were performed where each platform in a file set as *reference* was paired to its equivalent platform in a secondary file *measured data,* to be analysed

Results and Discussion

Precision of REF, MOD1, MOD2 and BRIDGE scans

There were statistically significant differences between the precision of ATOS used to scan REF and BRIDGE, and the dental laboratory scanner used to scan MOD1 and MOD2 in both 6P and 4P groups. The precision was the highest for REF with 9.3 µm ± 1 µm for 6P and 7.0 ± 0.9 µm for 4P for the Resultant.

Although the precision being statistically significantly lower for REF than the scan of BRIDGE using the same scanner, the reference scans were performed *in vivo*. All scanners showed a precision of lower than 10 µm.

Precision of TRIOS-BL, TRIOS-DF and TRIOS-SP

All TRIOS protocols showed statistically significantly lower precision than REF, however, the precision was consistently higher for 4P group than 6P group as the deviations for the bilateral posterior implants were notably higher for protocol TRIOS-BL and TRIOS-DF.

Similar results of flaring in the posterior region was seen in Paper II, and the probable cause being that any error from stitching the measurements will be amplified by the distance from the occurrence. This specific deviation did not appear in the TRIOS-SP group.

Accuracy

There were mostly no statistically significant differences between MOD1, MOD2, TRIOS-BL and TRIOS-DF for the Resultant and the three axes. TRIOS-SP presented lower accuracy than TRIOS-BL. TRIOS-BL and TRIOS-DF were statistically significantly different for Resultant and several axes to BRIDGE, which in turn presented the lowest accuracy by a factor of two.

Although studies using a similar methodology are limited, an *in vitro* study found comparable results for the impressions and the fabrication of models as MOD1 and MOD2 (Bergin et al., 2013). Similarly, an *in vitro* study using a somewhat similar design for assessing IOS scans of six implants presented comparable results to TRIOS (Vandeweghe, Vervack, Dierens, & De Bruyn, 2017).

The TRIOS-SP protocol was chosen to evaluate if the method could limit the risk of scanning non-attached tissues and to investigate if the technique could have a positive effect on the adaptive focal depth of the used scanner. TRIOS-SP failed to show higher accuracy than TRIOS-BL. On the contrary, the accuracy was found to be lower on several axes. The reason was most likely caused by the depth of which the scan-body had to be placed on several implants, leaving only a limited height for the splint material. The visible interference from the material caused the alignment of scan-bodies to fail in the proprietary software, and 3D print files could not be created. Similarly, the non-proprietary Datum Alignment showed more misfit.

Manufacturing Accuracy

When comparing the scan MOD1 of the model originally used to manufacture the IFD, BRIDGE displayed a similar statistically significant difference as when compared to REF.

The findings of BRIDGE presenting the lowest accuracy is comparable to previous *in vitro* studies which found the framework manufacturing to be the process that affects the overall misfit the most (Abduo, Lyons, Bennani, Waddell, & Swain, 2011).

Comparable *in vitro* studies evaluating IFD on five implants have shown a lower misfit than presented in this *in vivo* study (Eliasson et al., 2010; Hjalmarsson et al., 2010). However, the results of the misfit is well within the suggested upper limit of 150 µm (Lie & Jemt, 1994).

General Discussion

This thesis has evaluated IOS and conventional impressions in several settings. The methods described offers the opportunity for the first time to compare accuracy *in vivo* in both extensive dentate and edentulous subjects with treatments requiring full-arch implant-supported restorations. Furthermore, it assesses the quality of manufactured IFD and the accuracy of the full workflow. The initial *in vitro* study presented in Paper I shows that there are considerable differences between scanners that appears to be not only dependent on hardware and scanner technology but must be based partially on decisions in the design of the software algorithms.

Although there are clear differences between IOS, the studies presented promising results in line with conventional impressions for some IOS. However, the *in vivo* IOS studies were conducted in the maxilla which may not be directly transferable to the mandible where more challenging anatomy is present. On the other hand, new advancements in artificial intelligence, AI, and machine learning, may improve the quality of the scans, but also separate the systems further based on their software.

Conclusions

Conclusion Paper I

There are sizable differences between intraoral scanners and impressions regarding finish line distinctness and accuracy which may have a clinical impact. Some scanners perform better than conventional impressions, whilst others provide lower quality scans.

The finish line distinctness and accuracy are not directly linked to scanner resolution, but varies depending on factors such as subgingival preparation, tessellation and local finish line resolution.

Variations in topography exist but have little or limited effect.

Although colour information captured by some scanners can facilitate the identification of the preparation margin, one scanner based on laser-technology and separate colour sensor failed to superimpose the data correctly.

Clinicians should critically evaluate each scan and understand the limitations of the operated scanner when challenging subgingival conditions apply.

Conclusion Paper II

The described methodology can be used for assessing accuracy of IOS and conventional impressions *in vivo* in up to five units bilaterally from midline.

Accuracy varied between intraoral scanners and conventional impressions. 3M and TRIOS presented a higher accuracy than OMNI. IMPR overlapped both groups. However, the deviations were within a similar magnitude.

Intraoral scanners can be used as a replacement for conventional impressions when restoring up to ten units without extended edentulous spans.

Conclusion Paper III

Conventional impressions taken in polyether material without splinting in an open tray can provide accuracy *in vivo* in the same range as *in vitro*.

The deviations seen in CAD/CAM frameworks were twice as high as that of impressions *in vivo*.

Shorter IFD on four implants manufactured on conventional impressions offers a marginally higher accuracy than IFD on six implants.

Conclusion Paper IV

TRIOS-BL showed better accuracy and precision than TRIOS-DF and TRIOS-SP. The use of splint in TRIOS-SP failed to show any benefit.

Scanning four implants for shorter restorations were significantly more accurate than scanning six implants.

TRIOS-BL showed no difference from models manufactured from conventional impressions in Part III

Similar to models based on impressions in Part III, TRIOS-BL was more accurate than the final restoration.

Future Works

As the *in vivo* methodology presented in this thesis have never been applied in previous studies, it is essential that the methodology and results are further validated. This could be performed using alternative industrial scanners as well as comparing the systems with the promising technology of stereophotogrammetry.

The assessed splint-technique, TRIOS-SP in Paper IV, failed to show better accuracy mainly due to the limited height of the scan-bodies. The protocol still offers a theoretical advantage when scanning edentulous subjects with atrophied mandibles using IOS. Further investigations with increased height of scan-bodies would prove whether this method is usable in the most challenging conditions.

Lastly, it would be beneficial to compare *in vivo* results with *in vitro* based on the same subject's models. Such a test would not only use the identical IOS systems and analysis methodology, but it would have identical conditions of inter-implant spacing and angulations. Furthermore, it would validate if the results from previous *in vitro* research on IOS are clinically relevant and meaningful in extensive cases, or if more complex and time-consuming *in vivo* studies are required to address these aspects in prosthodontics.

It is undeniable that IOS is on the path to overtake the conventional impression and will play a central part in oral prosthetics, oral and maxillofacial surgery and orthodontics. In combination with CAD/CAM and virtual planning, the systems offer advanced treatment possibilities and rapid manufacturing which the traditional approach cannot compete with. With the current PhD thesis, a foundation has been offered in methodology and analysis, and also towards meeting the need for clinical evidence.

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Sammanfattning

Inom tandvården används ofta avtryckstagning för att skapa modeller i gips av patientens tänder, tandkött och delar av käkarnas form i över- och underkäke. Det är mycket viktigt att avtrycket återspeglar verkligheten, inte minst när kronor och broar ska tillverkas. Målet för vårdgivare och industri är att alltjämt förbättra tekniken eftersom passform kan påverka hållbarhet och prognos vid behandlingar.

CAD/CAM-teknik har sedan flera decennier gjort det möjligt att med hög noggrannhet kunna fräsa fram tandersättningar med god passform. Processen har varit beroende av gipsmodeller som framställts från avtryck, vilka i sin tur har digitaliserats med skannersystem på tandtekniska laboratorier.

Tandvården står nu inför ett stort tekniksprång genom ett pågående teknikskifte till intraoral skanning. Tekniken innebär att tänder och implantat kan skannas på plats i munnen. Den nya tekniken visar snabbhet, precision och patientkomfort och syftar till att ersätta den traditionella avtryckstagningen med avtrycksmassa. Genom intraoral skanning kan arbetsflödet från avtryck till fräsning ske helt digitalt och därmed åtminstone i teorin eliminera felkällor i den traditionella avtryckstagningen, desinfektionsprocessen, transporten och gipsframställningen.

Med intraorala scanners så kommer nya utmaningar i och med munhålans egenskaper. Ett exempel är att handhållna intraorala skanners måste klara av att kartlägga områden där det finns en rörlighet i underlaget (slemhinnan), vilket speciellt sker i områden där det saknas flera tänder. Detta går inte att utvärdera på syntetiska modeller utanför munnen eftersom skannersystemen inte utsätts för verklighetstrogna svårigheter. Ytterst få studier existerar som utvärderar intraorala skannrar på plats i munhålan, (*in vivo*), inte heller traditionella avtryckstekniker finns utvärderade annat än på laboratoriemodeller. Orsaken är främst svårigheten att i munnen kunna mäta och erhålla en referensmätning i form av en tre-dimensionell referensfil som kan anses utgöra ”sanningen”, mot vilken det går att utvärdera önskade behandlingsscenarion. Denna avhandling beskriver en ny metodik för att utvärdera systemen på plats i munhålan, vilket sannolikt genererar mer realistiska resultat än studier på syntetiska modeller.

Denna avhandling baserar sig på följande fyra delarbeten:

Delarbete I utvärderade i laboratoriemiljö skillnaden mellan sju olika skannersystem och traditionellt avtryck för framställning av en krona. Specifika systemegenskaper kartlades med beskrivande analys för att bättre förstå teknikskillnader avseende bland annat upplösning och färg. Studien visade att det fanns intraorala skannersystem som var både bättre och sämre än vanliga avtryck, men att det framförallt fanns större skillnader mellan systemen vid återgivning av specifika områden som kan påverka prognosen för behandlingen.

Delarbete II utvärderade ett mätsystem för att kunna ta fram en referensmätning av patientens tänder i överkäken. Tre intraorala skannersystem jämfördes mot traditionell avtryckstagning och resultaten visade även här på skillnader mellan systemen. Samtliga system var inbördes jämförbara med traditionell avtryckstagning.

Delarbete III och Delarbete IV utvärderade en vidareutvecklad mätmetod för referensmätning av patienter som saknar samtliga tänder i överkäken och som tidigare erhållit implantatbehandlingar. Mot denna referens jämfördes både intraoral skanning med olika hjälpmedel, traditionellt avtryck och den tidigare framställda implantatbrons passform. Intraoral skanning visade goda resultat och att den var jämförbar med konventionell avtryckstagning vid implantatbehandlingar i helt tandlösa överkäkar. Även när den tidigare framställda bron jämfördes med referensmätningen i munnen och den gipsmodell som använts för framställningen av bron, så visade mätningar på en generellt god passform.

Sammantaget visar intraorala skanners lovande resultat även om det finns specifika skillnader mellan system.

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