Trueness and Precision Achieved With Conventional and Digital Implant Impressions: A Comparative Investigation of Stone Versus 3-D Printed Master Casts

Keywords

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ABSTRACT

Objective: To analyze implant casts obtained from intraoral optical scanning and conventional impressions. Materials and Methods: Ten optical scans (test) and ten conventional polyether impressions (control) were obtained from a two-implant reference model. Ten casts each were manufactured additively or from stone. All casts were digitized and virtually superimposed to the digital reference (trueness) applying a best-fit algorithm, and secondary analysis for intra-group comparisons (precision). The signed nearest neighbor distance of each surface point (FDI:24/26) was computed and deviations of the three-dimensional vectors (X,Y,Z) analyzed. The groups were compared with the Wilcoxon's rank sum test. Results: The printed casts had mean deviations of 106.0µm and the stone casts 187.9µm compared to the reference. Controls had significantly higher deviations and dispersion (p<0.001). The printed casts showed mean intra-group deviations of 149.8µm and the stone casts 181.2µm without significant differences (p=0.162). There was no statistically significant difference in any of the vector analyses (X:p=0.105, Y:p=0.089, Z:p=0.123). Conclusion: Optical scanning seems to be an alternative to conventional impressions in terms of trueness and precision of implant master casts, simulating the scenario of a three-unit implant-supported fixed dental prosthesis. Digitally manufactured master casts might serve as reliable reference for the final restorations.

INTRODUCTION

Digital workflows have gained clinical relevance in implant prosthodontics over the last years.[1] Especially, intraoral optical scanning (IOS) has become a valuable alternative to the well-established conventional impression technique with elastomeric impression materials.[2] The gathered data of IOS can be stored as a standard tessellation language file (STL) and used for production of 3-D printed models and further CAM-processing of implant restorations.[3,4] Compared to single implant crowns, more complex multiunit implant cases still require physical implant master casts for the production process of the prosthesis.[4]

To guarantee high accuracy of the prosthetic restoration it is important that transfer of the intraoral situation to the workflow is flawless. In the conventional workflow each step bears a risk of error that may result in inaccurate casts. As the digital workflow consists of fewer steps between impressions and the fabrication of the cast, possible sources of error may be eliminated or minimized, but the 3-D printed casts themselves present a different set of limitations.[5,6] To achieve the needed accuracy of 3-D printed implant casts, several factors have to be taken into consideration. The technology used for the additive manufacturing of the master casts, and thus the type of 3-D printer, affect the accuracy and reproducibility. It has been shown, that printers using direct light processing (DLP) performed better than other printing methods. The mechanism is based on that of stereolithography, where the liquid photopolymer resin is selectively exposed to light and converted into solid form.[4,7] Additional factors, such as postprocessing and storage, also influence the accuracy of the printed casts.[6,8] The accuracy of implant analog position is impacted by the individual retention design of the used implant system. In contrast to implant analogs for conventional stone casts, the insertion of the analogs in printed resin casts occurs after the models are polymerized. Different features in the model allow the precise positioning of the analogs, with each design exhibiting its advantages and disadvantages. The analog holder offset as well as the potential wear of the model-analog interface due to repeated removal, impact the accuracy of the implant analogs, and thus the implant master cast.[4]

For comparison of different workflows, precision and trueness must be distinguished. Precision describes the reproducibility of multiple measurements; whereas trueness reflects how close the measurements are to the actual correct dimensions of the measured object. Accuracy is defined as precision and trueness together.[2]

The number of studies investigating the accuracy of full-arch digital master casts has been increasing in the last few years.[6,9,10] Nowadays, 3-D printed models are frequently used in dentistry and have to meet different requirements, depending on the dental discipline. In orthodontics, digital models are used for cast analysis or rapid prototyping-based therapies with splints, which both allows a wider tolerance level for clinical acceptability than master casts for prosthetic reconstructions.[6,11]

Several *in-vitro* investigations have proven the accuracy of fully dentate 3-D printed dental models.[11,12] However, the digital workflows for fully dentate situations totally differs for implant models. Digital workflows for the production of implant dental models are more complicated considering a large number of different manufacturers, the error rate when placing the scanbodies, and the manually insertion of laboratory implant analogs. Thus, up to date, only limited data is available in the dental literature comparing conventionally and digitally fabricated master casts for processing of three-unit implant-supported fixed dental prostheses (iFDPs).[13]

Still not all factors influencing the accuracy of 3D-printed implant models have been clarified, and therefore, the aim of this *in-vitro* investigation was to analyze implant master casts obtained from IOS and conventional impression taking. The Null-Hypothesis was that there is no difference in trueness and precision comparing stone cast versus 3-D printed casts *(Figure 1)*.

MATERIAL AND METHODS

REFERENCE CAST

An epoxide resin reference model (Px Extrarock) of a partially edentulous maxilla, with two soft tissue level type implants in tooth sites 24 and 26 (Straumann TL RN Ø 4.1 / TL WN Ø 4.8) was fabricated and represented the baseline situation *(Figure 2a)*. The cast was digitized, using a high-precision scanner (DWS 7-Series), for obtaining a reference data set.

CONTROL GROUP - CONVENTIONAL IMPRESSION

For control, ten conventional full arch open-tray polyether impressions (Impregum™) were taken from the reference model with implant-specific impression transfer posts and prefabricated trays. For the open impression technique two holes were drilled manually in each tray at the implant positions. The impressions were obtained as monophase impressions following the manufacturer's instructions *(Figure 2b)*. The impressions were stored in a dark environment for 24 h; and then poured with type-III stone (Selenor Extra Export).

TEST GROUP - DIGITAL IMPRESSION

Ten full arch IOS (TRIOS® 3) were taken with implant-specific scanbodies (CARES® Mono Scanbodies) from the reference model *(Figure 2c)*. The scan strategy followed the recommendations of the IOS manufacturer. Based on the obtained STL-files, corresponding implant master casts were CAM-processed and 3-D printed (SHERA model-plus UV grey) with the Straumann DLP printer CARES® P-Series P30.

TRUENESS AND PRECISION

All casts from control and test workflows were digitized with screwed-in scanbodies using a dental laboratory scanner (DWS 7-Series). The gathered STL-files were virtually superimposed to the digital reference cast (trueness) applying a best-fit algorithm, *(Figure 3a)* and secondary analyzed for inner-group comparisons (precision) *(Figure 3b)* with the Final Surface software®. The signed nearest neighbor distance of each surface point between the superimposed casts was calculated. The shortest distance from a surface point of cast 1 to a surface point of cast 2 was defined as signed nearest neighbor. The distance can be either positive or negative considering the direction relative to the surface of cast 1.[2] Approximately 180'000 distances were computed per match. For visual assessment of the deviation pattern a screenshot of each superimposition was saved.

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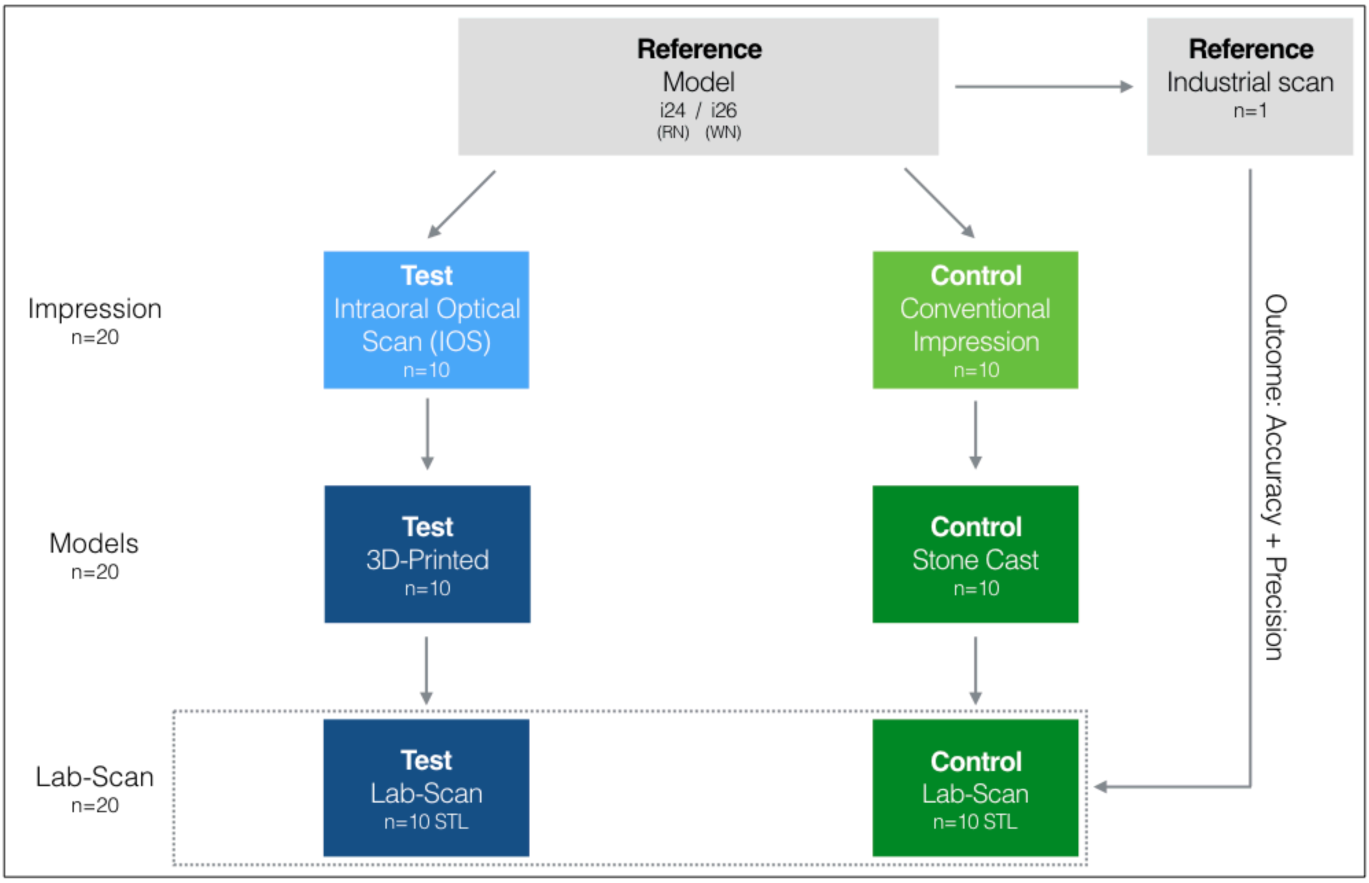

Figure 1: Study flow-chart for test and control workflows

Figure 2a-c: Reference cast (2a); conventional full-arch polyether impression (Impregum™) (2b); and STL-file of the digital impression (TRIOS® 3) (2c)

Additionally, the deviation of the position of the implant analogs in tooth sites 24 and 26 were computed (stone cast to the reference cast and the 3-D printed cast to the reference cast, respectively). The 3-D position of the posterior implant analog (tooth site 26) was matched with the position of the corresponding implant analog of the reference. That position served as origin of the coordinate system (X-, Y- and Z- axis were set to zero). Represented by 3-D vectors (nx, ny nz), the deviation of the position of the implant analog 24 was then computed in reference to point zero.

STATISTICAL ANALYSIS

A power analysis was performed. The required sample size to detect a significant difference of accuracy between test and control with a 5%-level of significance and a power of 80% would have been 6x model measurements per group. Based on the defined sample size calculation, n=10 comparisons to the reference cast were performed, and n=9 inner-group comparisons, respectively.

The statistical analysis was performed with the software package R, Version 3.5.1 (R Core Team 2013). Deviations to both reference cast (n=10) and the first stone cast or 3-D printed cast (n=9) were analyzed descriptively computing means, medians, standard deviations, and inter quartile distances for both groups separately. The same statistics were calculated for deviations of the 3-D vectors for each dimension (X, Y, Z). Control and test groups were compared with the Wilcoxon's rank sum test for two independent samples, using a non-parametric test rather than a t-test.

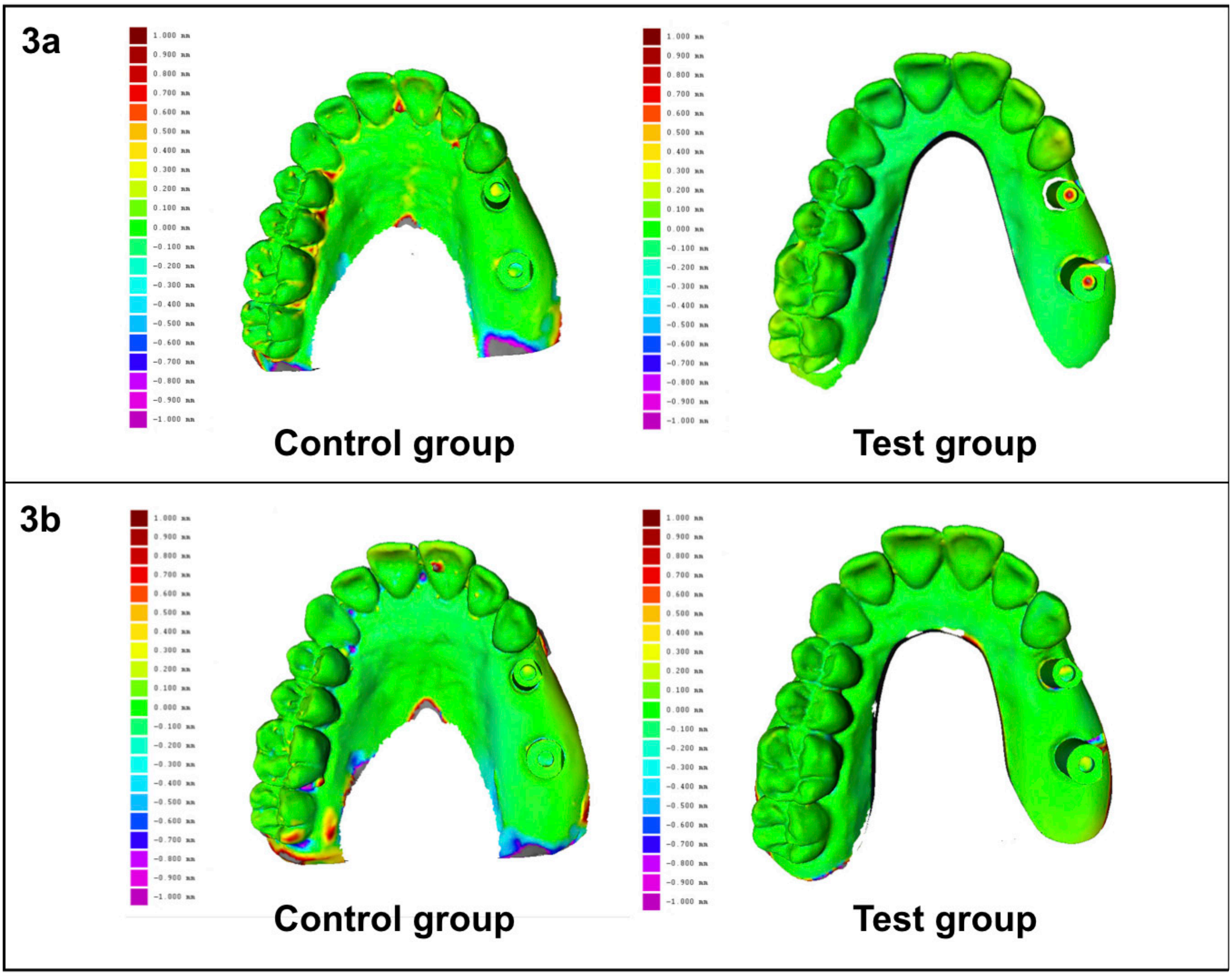

Figure 3a-b: Superimposition of control impressions and test IOS with the reference cast (trueness); and inner-group comparison (precision). Color graded from -1000 µm (purple) to +1000 µm (dark red)

RESULTS

TRUENESS

The mean deviation values for the trueness of the control group (stone cast) and the test group (3-D printed casts) to the reference are shown in Table 1 and Figure 4a. The control group revealed higher deviation values and a higher dispersion. The Wilcoxon-Test demonstrated a statistically significant difference in the standard deviation of both groups ($p < 0.001$) *(Table 1, Figure 4a)*.

PRECISION

Table 2 and Figure 4b reveal the mean inner group deviations of both the test and the control group. There was no statistically significant difference between both groups comparing precision ($p = 0.162$) *(Table 2, Figure 4b)*.

Table 1. Table for trueness analysis comparing deviations of 3-D printed casts (test) and stone casts (control) to the reference cast in µm.

Group	Mean	Median	Standard deviation	IQR
Cast	187.90	181.20	52.05	63.26
Print	106.00	104.40	10.16	6.13

3D-VECTOR ANALYSIS

Table 3 and Figure 5 demonstrate the 3-D error of the implant analog positioning in the printed casts and the stone casts, respectively. The highest positioning errors were in the z-axis (vertical position). The Wilcoxon-Test showed no statistically significant difference in any of the vector analysis (x-axis: $p = 0.105$, y-axis: $p = 0.089$, z-Axis: $p = 0.123$) *(Table 3, Figure 5)*.

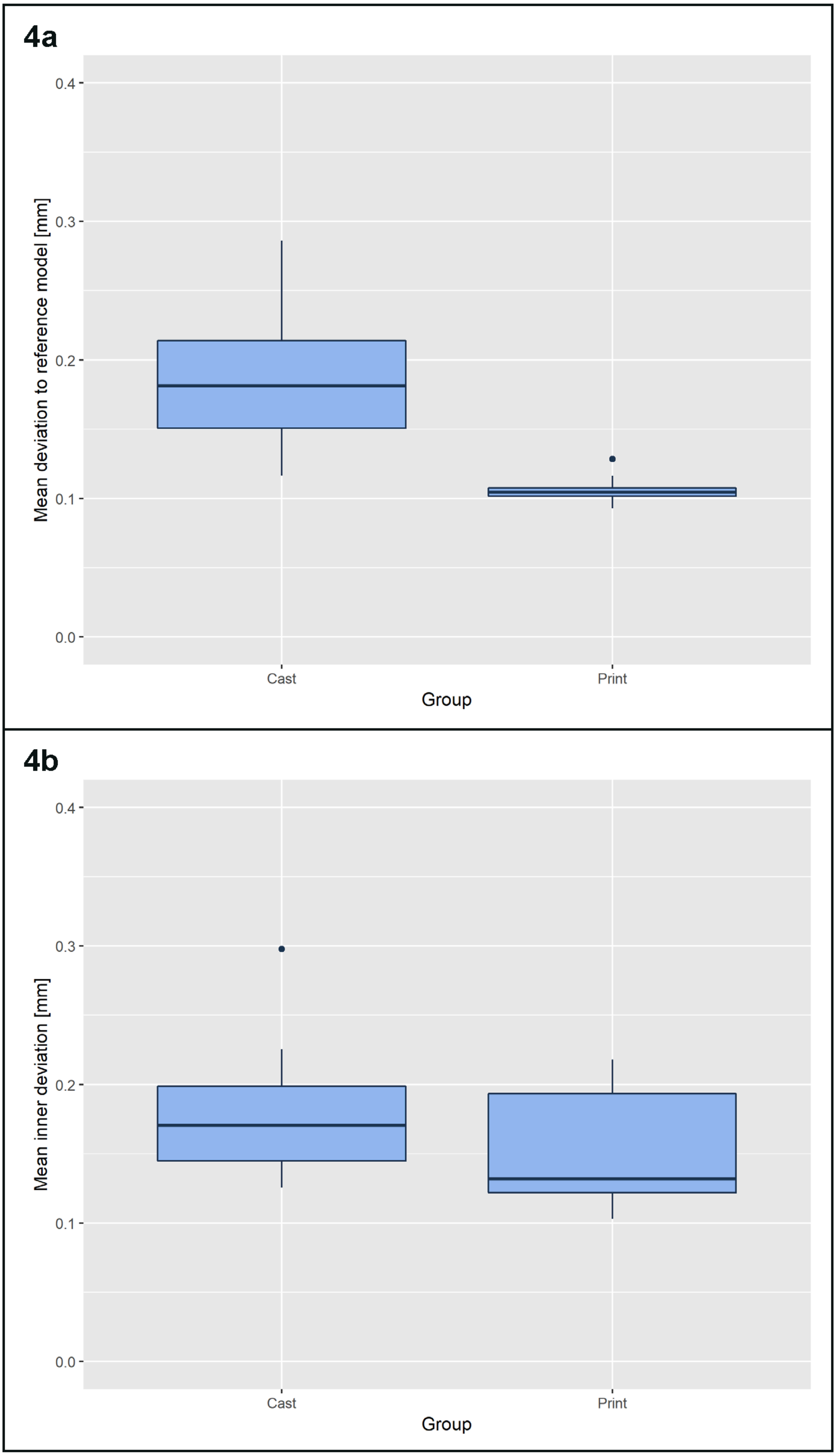

Figure 4a-b: Boxplots for trueness analysis (4a) and inner-group precision analysis (4b) comparing deviations of 3-D printed casts (test) and stone casts (control) to the reference cast

Table 2. Table for inner-group precision analysis comparing the deviations of 3-D printed casts (test) and stone casts (control) in µm.

Group	Mean	Median	Standard deviation	IQR
Cast	181.20	170.50	53.76	54.02
Print	149.80	131.90	43.77	71.38

Table 3. Table for the vector analysis in µm.

Group	Mean	Median	Standard deviation	IQR
X Cast	-26.41	-26.42	23.76	34.43
X Print	-7.45	-13.85	20.63	27.24
Y Cast	35.15	38.12	18.20	31.39
Y Print	8.65	7.04	53.71	60.56
Z Cast	2.26	3.27	71.40	66.73
Z Print	50.16	65.63	79.67	107.57

DISCUSSION

In prosthodontics, trueness and precision of the impression taking process is of substantial importance. The correct transfer of the oral situation into a master cast is the key for the final restoration. A misfit of the iFDP may lead to technical and biological complications. Technical complication may include screw loosening, framework fracture or loss of retention. Whereas biological complications include excessive bone resorption on the implant-bone interface and even loss of osseointegration due to strain generated by the fixation of the inaccurately fitting iFDP. As the implant-bone connection lacks the resilience of the periodontal ligament and the movement of the implant is limited to 50 µm to 150 µm, the passive fit of an iFDP is of crucial importance.[14] No guidelines on the acceptable threshold for the misfit of implants and their superstructure are currently available, however further studies are needed.[15]

Not only the trueness and precision of the implant positions but also capturing the full dental arch is important. In the present laboratory investigation, the following hypothesis "no difference in trueness and precision comparing implant stone cast versus 3-D printed master casts" was tested. The trueness of the 3-D printed casts was significantly higher ($p < 0.001$); however, analysis of the precision revealed no statistically significant difference. Therefore, the Null-hypothesis was rejected regarding the full arch impression. Focusing on the 3-D implant position in isolation, no statistically significant difference between the stone casts and 3-D printed casts could be found. Thus, for the analysis of the 3-D positioning of the implant analogs in tooth sites 24 and 26 the Null-hypothesis could be confirmed.

In contrast to the present findings, in previously published *in vitro* investigations, the intraoral scans (CEREC Bluecam®, CEREC Omnicam®, Cadent iTero®, Lava™ COS) demonstrated higher local deviations of the dental full arch and thus a lower accuracy than conventional impression methods. The trueness values ranged from 11.5 µm to 60.2 µm.[10] The digital impressions produced less accurate CAD/CAM milled implant master casts than the conventional way. A 3-D error of the implant position could be observed for the conventional and digital technique compared to the reference cast. The mean standard deviation error of 116 ±94 µm for the digital and 56 ±29 µm for the conventional way was recorded.[16]

In vivo studies showed that the digital impression techniques were significantly less accurate and demonstrated a higher standard deviation compared to high precision of conventional impressions in regard of full-arch scans.[5,17] In addition, the trueness of the IOS depended largely on the correct scanning strategy.[10] In terms of precision, the digital impression system achieved better results than conventional impression techniques.[17] Another clinical investigation compared the precision of the implant analog position in CAD/CAM manufactured master casts and conventionally fabricated stone casts. Casts produced with the conventional workflow were more precise related to the implant analog position compared to the digital manufactured casts. The mean precision values of the implant position in the digital casts were 88.6 ±46.0 µm for the Trios 3Shape scanner and 32.7 ±11.6 µm for conventional impressions. Based on those findings, the digital implant casts could not serve as reliable reference for the final restoration and a model-free approach should be considered.[18] In the present study, the greatest errors could be shown in the vertical positioning of the implant analogs (z-axis), although not statistically significant and thus not clinically relevant. The fixation of the analog in the 3-D printed casts might not be that accurate, although the laboratory implant analogs showed higher positional accuracy than other systems.[4]

The interpretation of the gathered results of in vitro investigations, and subsequently, the translation into clinical routine is a challenging task. The behavior of the impression materials and the IOS in the oral cavity and the influence of saliva, anatomic conditions and the soft tissue could not be investigated. Besides the power analysis, additional limitation might be a small number of impressions and scans, test group n=10 and control group n=10, respectively. Furthermore, only one scanner system (TRIOS® 3, 3Shape) was used for this investigation.

The higher deviation and dispersion values of the control group may have been caused by torn out interproximal areas and compression and stretching within the material. Even though an isolation was applied to the reference cast, high forces had to be applied to remove the trays from the epoxide resin cast. Furthermore, the mixing and casting process with gypsum is technique sensitive.

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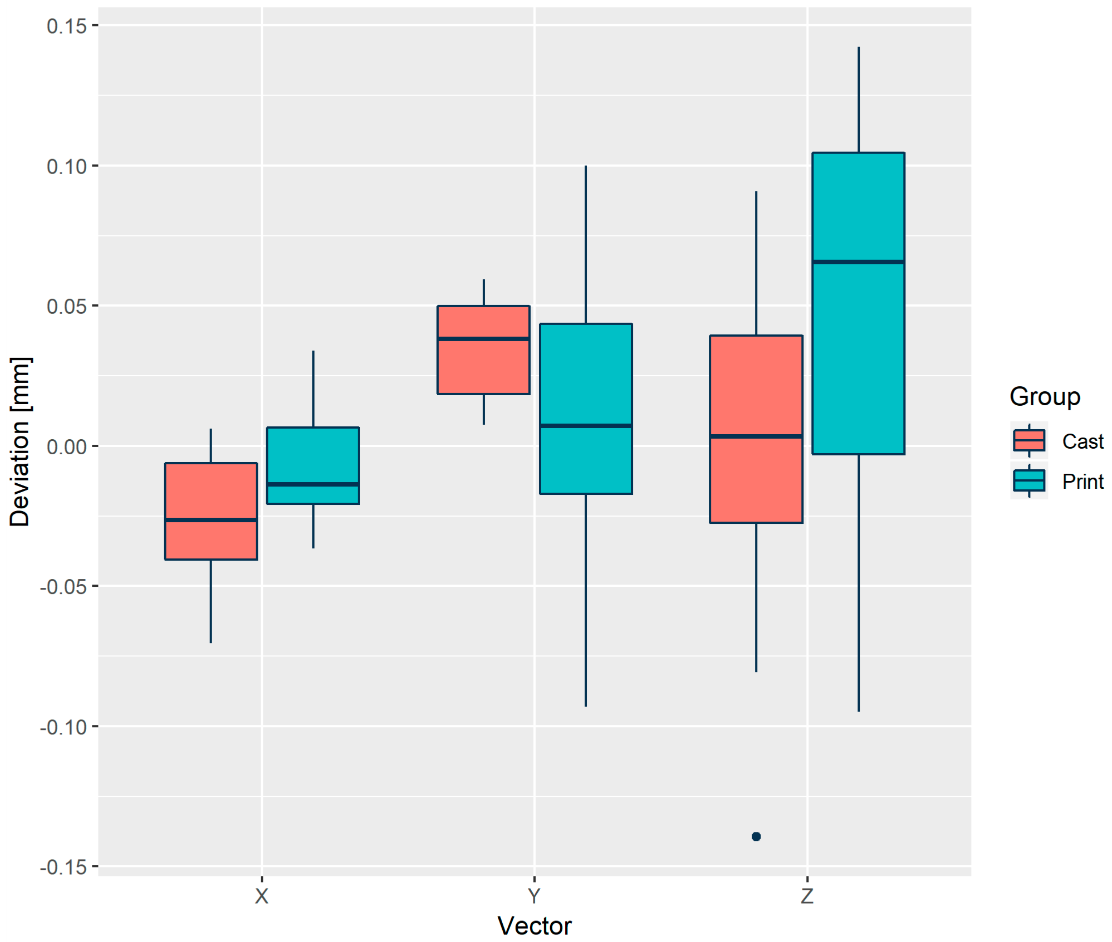

Figure 5: Boxplot for the vector analysis

The digital workflow in implant-prosthodontics may achieve a favorable cost-benefit ratio and is potentially more time efficient.[1,19] There is only limited evidence comparing the clinical benefits of the digital workflow with the conventional non-digitized workflow in fixed implant prosthodontics.[1,20] The digital impression method has no disadvantage in accuracy for the fabrication of single crowns, short FPDs and implant-supported single-unit reconstructions. However, for full-arch FPDs the conventional impression methods should be used.[21]

The current *in vitro* investigation demonstrated significantly higher values of trueness and a slightly higher reproducibility of digital full arch impressions compared to conventional impressions. Regarding the 3-D position of the implant analogs no difference in trueness could be shown.

The digital workflow seems to be a viable alternative to the conventional way producing implant master casts. Further clinical studies are needed to confirm those initial results for the manifestation of clinical guidelines.

CONCLUSION

The results of this study indicated that 3-D printed implant master casts showed higher values of trueness and a comparable reproducibility to conventional master casts. The digitally manufactured master casts appeared to be a reliable alternative to conventional impressions in terms of trueness and precision of implant master casts simulating the clinical scenario of a three-unit implant-supported fixed dental prosthesis (iFDPs).

MANUFACTURERS' DETAILS

- Epoxide resin reference model (Px Extrarock, PX Dental SA, Marin, Switzerland)
- Implants (Straumann TL RN Ø 4.1 / TL WN Ø 4.8, Institut Straumann AG, Basel, Switzerland)
- High-precision scanner (DWS 7-Series, Dental Wings, Chemnitz, Germany)
- Polyether impression material (Impregum™, Penta™, 3M, Saint Paul, MA, USA)
- Implant-specific impression transfer posts (Institut Straumann AG, Basel, Switzerland)
- Prefabricated trays (3M™ ESPE™, Saint Paul, Minnesota, USA)
- Type-III stone (Selenor Extra Export, Zeta, Industria Zingardi, Novi Ligure, Italy)

- Intraoral scanner (TRIOS® 3, 3 Shape, Copenhagen, Denmark)
- Implant-specific scanbodies (CARES® Mono Scanbodies, Institut Straumann AG, Basel, Switzerland)
- Printed casts (SHERA model-plus UV grey, Shera, Lemförde, Germany)
- 3-D printer (CARES® P-Series P30, Institut Straumann AG, Basel, Switzerland)
- Dental laboratory scanner (DWS 7-Series, Dental Wings, Chemnitz, Germany)
- Final Surface software® (GFal, Berlin, Germany)
- Statistical analysis (R Core Team 2013, software package R, Version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria)

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CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

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