Accuracy of computerized and conventional impression-making procedures for multiple straight and tilted dental implants

The 1st Innovation Award for the scientific research “Accuracy of computerized and conventional impression-making procedures of multiple straight and tilted dental implants”

EAED Spring Meeting; 2 to 4 June 2016; Copenhagen, Denmark

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Abstract

Purpose: To compare the accuracy of implant impressions using computer-aided impression-making technology and a conventional approach in a standardized setting in vitro, and to verify the effect of implant angulation (40 to 45 degrees) on the accuracy of digital and conventional impression-making procedures.

Materials and methods: Four different edentulous mandibular reference models (RMs) were manufactured. Two straight (RM1); four straight (RM2); two straight and two tilted (RM3); and six straight (RM4) dental implants were placed, simulating four different clinical scenarios. The computer-aided impressions (n = 5 for each RM) were made using an intraoral scanner (IOS) (True Definition, 3M ESPE). Polyether (n = 5 for each RM) and vinyl polysiloxane (n = 5 for each RM) impression materials were utilized for the conventional approach. The collected data were analyzed in terms of trueness. The statistical analysis was performed using one-way analysis of variance (ANOVA).

Results: The overall differences of interimplant distance, identified in mean values, were statistically significant among the different impression-making groups in RM1, RM3, and RM4. The data analyses of overall interimplant angle deviations yielded statistically significant differences in all four RMs. However, the deviations obtained with both impression-making approaches did not exceed an interimplant distance threshold of 100 μm, and an interimplant angle of 0.5 degrees, which seems to be clinically acceptable.

Conclusion: Within the limits of this in vitro study, the accuracy of the computer-aided and conventional impression-making approaches for straight and tilted dental implants was comparable, and might be clinically considered for full-arch, multiple-implant restorations. However, further clinical studies are required to verify the feasibility of different IOSs (with and without scanning powder application), different implant systems, and multiple implant configurations.

Introduction

The fabrication of a framework for multiple implants requires highly precise clinical and laboratory procedures. Implant frameworks are fabricated today utilizing either conventional procedures and materials or computer-aided techniques. Conventional procedures have been applied for years in routine dental practice and are widely discussed in the literature. However, every step of the conventional workflow (eg, individual impression tray fabrication, tray adhesive material, impression material/procedure, impression disinfection, fabrication of the master cast, modeling of the wax pattern, investing of the wax pattern, metal casting, etc) generates a certain amount of error, which can either be accumulated or compensated for, yet cannot be fully automated.\(^1\),\(^2\) Obviously, the accuracy of conventional implant impression-making procedures is one of the most critical factors that significantly impacts the quality and fit of implant restorations.

On the other hand, the introduction of digital technologies in dentistry has enhanced the capability to examine, diagnose, and treat dental patients by improving the accuracy of data acquisition, enhancing treatment planning and restoration design, and speeding up the manufacturing process.\(^3\) However, it is still unknown whether conventional procedures can be substituted, or even improved upon, by using computer-aided impression-making technologies. In recent years, the application of computer-aided impression-making technologies has gained significant interest.\(^4\)-\(^6\) Digital impressions were found to be favorable because of the potential to correct the entire impression without the need to repeat the whole procedure,\(^4\) and to avoid the unpleasant taste of conventional impression materials.\(^6\) Thus, patients are more comfortable with the convenience of computer-aided impression-making procedures.\(^5\),\(^7\) It was also shown that these procedures allow for a more time-efficient workflow than conventional impression procedures.\(^8\),\(^9\)

Despite the rapid development of digital technologies, it is not surprising that the possibility for error always exists in every reconstruction process of three-dimensional (3D) objects. The source of such errors is related, but not limited, to a noncalibrated or poorly calibrated scanning device or scanning technology,\(^10\) operator inexperience,\(^11\)-\(^13\) hand shaking or incorrect IOS wand position relative to the object,\(^14\) incorrect scanning method,\(^15\) scanning length,\(^13\),\(^16\) patient movements, improper scanning powder application,\(^15\),\(^17\) and/or the presence of saliva on the scanning surface. If not compensated for properly, such errors may obviously impact the overall quality of implant restorations. Therefore, several concomitant questions arise and need to be answered: Does a computer-aided impression-making approach result in a restoration of similar or even improved quality compared with conventional impression-making procedures? Does the number of implants affect the accuracy of the digital impression? If not, would the location or angulation of the implants affect the overall accuracy? And how would this compare with the accuracy of conventional impressions? The answers to these questions would provide clinicians with important information about...
the applicability of digital impression-making procedures in cases of different multiple implant configurations in edentulous jaws.

The main aim of this in vitro study was to evaluate the accuracy of implant impressions in terms of distance and angle using a computer-aided impression-making technology and a conventional approach in a standardized setting. A further aim was to verify the effect of an implant angulation of 40 to 45 degrees on the accuracy of digital and conventional impression making by means of trueness measurements.

Materials and methods

Reference models

Four different edentulous mandible reference models (RMs) were manufactured from polymethylmethacrylate material (ProBase Cold, Ivoclar Vivadent). Two (RM1), four (RM2), four (RM3), and six (RM4) implants (Osseotite 2 Certain Implants, BIOMET 3i) of 4 mm in diameter and 10 mm in length simulated four different clinical scenarios:

- RM1: Two straight implants were placed interforaminally in the former area of the second incisors (Fig 1a).
- RM2: Four straight implants were placed interforaminally in the former area of the second incisors and the first premolars (Fig 1b).
- RM3: Two straight implants were placed interforaminally in the former area of the second incisors, and two laterally tilted implants were placed in the former region of the first premolars, with an angulation of 40 to 45 degrees (Fig 1c).
- RM4: Six straight implants were placed in the former area of the second incisors, first premolars, and first molars (Fig 1d).

The RMs were stored in a cool, dark, well-ventilated room with a temperature of 21 ± 1°C, a relative humidity of 55 ± 3%, and an air pressure of 761 ± 5 mmHg.

Digital impression-making approach

Two different impression-making approaches, namely a computer-aided and a conventional approach, were applied. The computer-aided impression was taken using an intraoral scanner (IOS) (True Definition, software version 4.0.3.1, 3M ESPE) using the double gingival scanning method. This scanner is based on a wavefront sampling technology. Three
optical lenses inserted in the scanning wand are able to capture 60 images per second. Based on the ‘3D-in-motion’ video technology, it is possible to generate 10,000 data points per image. The images are taken in three dimensions and matched together in real time to create the 3D digital object. The system requires scannable abutments (scanbodies) and scanning powder. The latter prevents the effect of reflection and functions as a connector in the image overlapping process. The high-precision scanbodies used in the present investigation were manufactured from polyetheretherketone (PEEK) (Createch Medical) and were 4.1 mm in depth x 8 mm in height. The high-resolution 3M scanning spray (3M ESPE) applied consists of 50% to 60% titanium dioxide, 30% to 40% zirconium oxide, and 5% to 10% zinc stearate. The size of the scanning powder particles is given by the manufacturer as approximately 20 μm.

All scans were made on the same day in the same room under the same ambient conditions with a 5 min pause between each scan. The scanbodies were hand-screwed onto each implant analog, and a light dusting with scanning powder was performed only once, before starting the scanning process. The scanbodies were not removed until all the scans were completed.

A double gingival scanning method was applied according to the manufacturer’s recommendations, as follows: Following the specifications, the alveolar ridge was first scanned from the fourth to the third quadrant without capturing the attached scanbodies. After the scanning process was stopped and saved, the alveolar ridge was scanned once again, from the third to the fourth quadrant, then stopped again. To continue the scanning process from one quadrant to the other, the wand was rotated clockwise (in the fourth quadrant) or counterclockwise (in the third quadrant) at the buccal area of the first premolars. The scanbodies were digitized separately in detail, and the scan process was stopped after each of them. Special attention was given to the IOS wand position while scanning: it was aligned to the alveolar ridge, parallel to the scanning surface, and the required focal distance was maintained. Each reference model was scanned five times, and three operators executed approximately 30 scans before the investigation began (Fig 2).

Conventional impression-making approach

For the conventional approach, two different impression materials were used:
Polyether impression material (Impregum Penta Medium Body, 3M ESPE).

Vinyl polysiloxane impression material (Imprint 4 Penta Heavy and Regular, 3M ESPE).

Both materials are hydrophilic and applicable for implant impression making. The impressions were taken by three operators using anatomically customized individual open trays and conventional fixed (non-splinted) pick-up copings of 4.1 mm in depth x 7.5 mm in height (Certain EP Pick-Up Coping, Biomet 3i) (Fig 3).

The individual open trays were manufactured from a light-curing custom tray material (Megatray, Megadenta), and 3 mm of space relief was provided for the impression material with buccolingual stoppers. The stoppers ensured a stable tray position for each impression. The custom trays were made 2 weeks before taking the conventional impressions. Afterwards, two tray adhesive materials were used: 3M ESPE Polyether Tray Adhesive was used for the polyether impression material, and 3M ESPE VPS Tray Adhesive was used for the VPS impression material (Fig 4).

All conventional impressions were made within 3 days in the same room under the same ambient conditions that exactly corresponded to the conditions under which the computer-aided impression-making was performed (Fig 5).

Each impression was placed into a 2% disinfection solution consisting of didecyldimethylammonium chloride, glutaral, and glyoxal (Picodent Tauchdesinfektion, Picodent) for 10 min, then rinsed under cold running water for approximately 15 s. After 30 to 45 min, the impressions were poured with a type 4 stone (Pico-stone M, cream color brown, Picodent), which according to the manufacturer has an expansion of < 0.1%
(Fig 6). To avoid bubbles in the cast, each impression was briefly pre-rinsed with cold water, and air dried before pouring. Gypsum powder (200 g) and distilled water (44 ml) were used to produce each cast. The vacuum mixing time was 40 s. After 60 min, the stone casts were separated from the impression material and slightly shaped with a trimmer device.

Data analysis

Both the computer-aided and conventional impression-making procedures were applied as the test methods and were compared with reference data. To obtain data of the 3D position of each implant in all four RMs and the test stone casts, an industrial coordinate measuring machine (CMM) (Createch Medical) was used. CMM (Crysta-Apex, Mitutoyo America Corporation) is a computer-controlled tactile measuring device with an accuracy certified by the National Entity of Accreditation (Geneva, Switzerland). The maximum permissible error for a length measurement is 1.9 + 3L/1000 μm according to the ISO 10360-2:2009 geometrical product specifications.¹⁸

The 3D position of each implant was defined by x-, y-, and z-coordinates in space, and each 3D interimplant distance and angle was calculated (‘zero method’). The interimplant distance is the distance between the center of the reference implant, which was always the most posterior implant in the fourth quadrant, and the center of every further implant (Fig 7a). The interimplant angle is the angle between the axis of the reference implant and the axis of every further implant (Fig 7b). The differences between the datasets of the distances and angles in the RMs and the digital/ conventional impressions were calculated by subtraction.
The digital scans made with the IOS were converted into Standard Tessellation Language (STL) format. The final STL file of the whole digital scan was prepared and analyzed using 3D evaluation software (Geomagic Qualify 2012, Geomagic). The 3D analyses were performed after the implant analogs and scanbodies were separated from the surrounding structures.

The collected data from the digital and conventional impressions were analyzed in terms of trueness, which comprises a comparison between the reference and the test datasets (Fig 8).  

**Fig 7 (a)** 3D inter-implant distances found between the center points of the reference implant and the center point of every further implant. (b) 3D inter-implant angles found between the axis of the reference implant and the axis of every further implant.

![Diagram](image)
Statistical analyses were performed to investigate distance and angle accuracy discrepancies between the implants in the four RMs. Means, medians, and standard deviations were computed for a descriptive statistical analysis. Using a robust form of Levene’s test statistic for the equality of variances, mean was replaced with median (proposed by Brown and Forsythe) for each model. One-way analysis of variance (ANOVA) was used to compare the differences of the group means, and box plots were prepared for a graphical representation. All calculations were performed with the statistical software Stata 13.1 (StataCorp). The threshold of statistical significance was set to $P < 0.05$.

Results

RM1

The overall differences in interimplant distance, identified in variability between Impregum and IOS, Imprint and IOS, and Impregum and Imprint were not statistically significant. The difference found in mean values was statistically significant only between Imprint and IOS (Tables 1 and 2a).

The data analyses of the overall interimplant angle deviations yielded statistically significant differences only in mean values between Imprint and Impregum, and Imprint and IOS, without any statistically significant difference in variability (Tables 3 and 4a).

RM2

The overall differences in interimplant distance identified in variability and in mean values between Impregum and IOS, Imprint and IOS, and Impregum and Imprint were not statistically significant (Tables 1 and 2a).

The data analyses of overall interimplant angle deviations yielded statistically significant differences in mean values between Impregum and IOS, and Imprint and IOS, but the differences in variability were not statistically significant among the three groups (Tables 3 and 4a).

Table 1  Comparison of the overall interimplant distance deviations for each RM for all the impression-making approaches

<table>
<thead>
<tr>
<th>Impression-making approach</th>
<th>RM1</th>
<th>RM2</th>
<th>RM3</th>
<th>RM4</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOS</td>
<td>18.47 ± 19.83 μm</td>
<td>9.48 ± 16.04 μm</td>
<td>35.78 ± 24.22 μm</td>
<td>31.11 ± 27.05 μm</td>
</tr>
<tr>
<td>Polyether impression material – Impregum</td>
<td>14.27 ± 15.67 μm</td>
<td>12.22 ± 16.93 μm</td>
<td>19.78 ± 21 μm</td>
<td>44.03 ± 45.66 μm</td>
</tr>
<tr>
<td>Vinyl polysiloxane impression material – Imprint</td>
<td>11.04 ± 14.22 μm</td>
<td>12.74 ± 12.5 μm</td>
<td>4.87 ± 21.34 μm</td>
<td>16.86 ± 24.52 μm</td>
</tr>
</tbody>
</table>
Table 2  Comparison of variability and mean values in the overall analysis of interimplant distance deviations for (a) RM1 and RM2, and (b) RM3 and RM4

(a)

<table>
<thead>
<tr>
<th>Material</th>
<th>RM1 P value (mean)</th>
<th>RM1 P value (variability)</th>
<th>RM2 P value (mean)</th>
<th>RM2 P value (variability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregum vs IOS</td>
<td>0.153</td>
<td>0.617</td>
<td>0.533</td>
<td>0.792</td>
</tr>
<tr>
<td>Imprint vs Impregum</td>
<td>0.262</td>
<td>0.203</td>
<td>0.736</td>
<td>0.368</td>
</tr>
<tr>
<td>Imprint vs IOS</td>
<td>0.047</td>
<td>0.379</td>
<td>0.905</td>
<td>0.197</td>
</tr>
</tbody>
</table>

(b)

<table>
<thead>
<tr>
<th>Material</th>
<th>RM3 P value (mean)</th>
<th>RM3 P value (variability)</th>
<th>RM4 P value (mean)</th>
<th>RM4 P value (variability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregum vs IOS</td>
<td>0.006</td>
<td>0.237</td>
<td>0.104</td>
<td>0.004</td>
</tr>
<tr>
<td>Imprint vs Impregum</td>
<td>&lt; 0.0001</td>
<td>0.344</td>
<td>0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>Imprint vs IOS</td>
<td>0.010</td>
<td>0.035</td>
<td>0.074</td>
<td>0.789</td>
</tr>
</tbody>
</table>

Table 3  Comparison of the overall interimplant angle deviations for each RM for all the impression-making approaches

<table>
<thead>
<tr>
<th>Impression-making approach</th>
<th>RM1</th>
<th>RM2</th>
<th>RM3</th>
<th>RM4</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOS</td>
<td>0.04 ± 0.05 degrees</td>
<td>0.17 ± 0.14 degrees</td>
<td>0.22 ± 0.19 degrees</td>
<td>0.24 ± 0.22 degrees</td>
</tr>
<tr>
<td>Polyether impression material – Impregum</td>
<td>0.03 ± 0.04 degrees</td>
<td>0.07 ± 0.1 degrees</td>
<td>0.04 ± 0.04 degrees</td>
<td>0.15 ± 0.25 degrees</td>
</tr>
<tr>
<td>Vinyl polysiloxane impression material – Imprint</td>
<td>0.07 ± 0.09 degrees</td>
<td>0.08 ± 0.07 degrees</td>
<td>0.16 ± 0.16 degrees</td>
<td>0.06 ± 0.06 degrees</td>
</tr>
</tbody>
</table>
The overall differences in interimplant distance, identified in mean values, were statistically significant among the three groups (Impregum vs IOS, Imprint vs IOS, and Impregum vs Imprint). However, the difference found in variability was significant only between Imprint and IOS (Tables 1 and 2b).

The overall differences in interimplant angle, identified in variability and mean values, were statistically significant between Impregum and IOS, and Impregum and Imprint. However, there was no significant difference in variability and mean values between Imprint and IOS (Tables 3 and 4b).

### Table 4

Comparison of variability and mean values in the overall analysis of interimplant angle deviations for (a) RM1 and RM2, and (b) RM3 and RM4

(a)

<table>
<thead>
<tr>
<th>Material</th>
<th>RM1 P value (mean)</th>
<th>RM1 P value (variability)</th>
<th>RM2 P value (mean)</th>
<th>RM2 P value (variability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregum vs IOS</td>
<td>0.667</td>
<td>0.89</td>
<td>0.002</td>
<td>0.8</td>
</tr>
<tr>
<td>Imprint vs Impregum</td>
<td>0.041</td>
<td>0.46</td>
<td>0.576</td>
<td>0.6</td>
</tr>
<tr>
<td>Imprint vs IOS</td>
<td>0.038</td>
<td>0.547</td>
<td>0.003</td>
<td>0.372</td>
</tr>
</tbody>
</table>

(b)

<table>
<thead>
<tr>
<th>Material</th>
<th>RM3 P value (mean)</th>
<th>RM3 P value (variability)</th>
<th>RM4 P value (mean)</th>
<th>RM4 P value (variability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregum vs IOS</td>
<td>&lt; 0.0001</td>
<td>0.0004</td>
<td>0.056</td>
<td>0.715</td>
</tr>
<tr>
<td>Imprint vs Impregum</td>
<td>0.001</td>
<td>0.0001</td>
<td>0.078</td>
<td>0.039</td>
</tr>
<tr>
<td>Imprint vs IOS</td>
<td>0.078</td>
<td>0.968</td>
<td>0.001</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

RM3

The overall differences in interimplant distance, identified in mean values, were statistically significant among the three groups (Impregum vs IOS, Imprint vs IOS, and Impregum vs Imprint). However, the difference found in variability was significant only between Imprint and IOS (Tables 1 and 2b).

The overall differences in interimplant angle, identified in variability and mean values, were statistically significant between Impregum and IOS, and Impregum and Imprint. However, there was no significant difference in variability and mean values between Imprint and IOS (Tables 3 and 4b).

RM4

The overall differences in interimplant distance identified in the variability between Impregum and IOS, and Impregum and Imprint, as well as in mean values between Impregum and Imprint, were statistically significant. No further statistically significant differences in interimplant distance were identified (Tables 1 and 2b).

The overall differences in interimplant angle were found to be significant between Imprint and IOS in variability and mean values. A statistically significant difference between Imprint and Impregum was found only in variability. There were no further statistically significant differences found (Tables 3 and 4b).
The datasets of RM2 (four straight implants) and RM3 (two straight and two tilted implants) were compared with regard to distance deviations for all three impression-making approaches. Statistically significant differences in overall variability between RM2 (15 datasets) and RM3 (15 datasets) were found in the Imprint group ($P = 0.007$). There was no statistically significant difference for the IOS ($P = 0.543$) or the Impregum approaches ($P = 0.443$), while the difference in the overall mean values between both RMs was statistically significant only in the IOS group ($P < 0.0001$) (Fig 9).

The datasets of RM2 and RM3 were also compared regarding angle deviations for all three impression-making approaches. Statistically significant differences in overall variability between RM2 (15 datasets) and RM3 (15 datasets) were found in the impression-making group with Imprint ($P = 0.004$), but not with IOS ($P = 0.168$) or Impregum ($P = 0.127$).

The overall mean values showed a statistically significant difference only for the Imprint group ($P = 0.018$) (Fig 10), which was similar to the variability data.

**Discussion**

This in vitro study examined the accuracy of implant impression making comparing computer-aided and conventional approaches as well as straight and tilted implants in a standardized setting. The results showed some statistically significant differences in variability and mean deviations between the different approaches and RMs. Nevertheless, the obtained deviations with both impression-making approaches did not exceed an interimplant distance threshold of 100 μm, and an interimplant angle of 0.5 degrees. Unfortunately, there are no data available in the literature that clearly define the clinically acceptable error for distance and angulation of implant impressions.

The deviations obtained cannot be generalized because the results represent the capacity of only one implant.
system and one IOS. Moreover, a light dusting with scanning powder was necessary to prevent surface reflections, enhance data acquisition, and improve the stitching of the images. Several studies in the literature have analyzed the influence of scanning powder application on the accuracy of scans. It was stated that computer-aided impression making without surface pretreatment may reduce the risk of powdering errors and, therefore, scanning distortions. In contrast, a laboratory study utilized and compared different IOSs and found no evidence to suggest that scanning powder negatively affected the dimensional object accuracy. It should also be taken into consideration that neither the possible error of digital model generation nor the manufacturing of the restoration are included in the present study, and should be further investigated.

A number of in vitro studies have shown that digital data acquisition is a valid alternative to a conventional impression-making procedure. However, a critical evaluation of the available literature yields contradictory results. In fact, an in vivo study showed that the accuracy of the intraoral scanning procedure was no substitute for the conventional method, and could not ensure the manufacturing of a passive-fitting prosthesis.

However, important methodological differences in the accuracy assessment methods used in the various studies have to be taken into account. The most popular accuracy evaluation method – the so-called best-fit algorithm or, in other words, general overlapping of the reference and test objects – was basically used in most of the studies that analyzed the accuracy of a computer-aided impression-making method. The superimposition of two datasets (ie, the reference and the test) means the superimposition of two different point clouds. Each cloud has a different reference system; for instance, the CMM (or other reference scanner) versus the IOS. Finding the best-fitting overlap of clouds with a different reference system leads to alignment and measuring uncertainty.

The methodological alternative applied in this study, the so-called ‘zero method’ considers the center point of the chosen implant as the reference, and obtains the linear distances or angulations between the implants in the specific model. This method avoids an alignment of the datasets, as in the best-fit algorithm, and provides the exact deviation in distance or angulation. Such measurements cannot be broken down into the x-, y-, and z-coordinates of the other reference system because it would introduce the aforementioned error of the averaging process when matching different data clouds. Instead, it compares the exact distances and angles (found with the coordinate measurements) by mathematical subtraction and without manipulating the data. For this reason, high-precision PEEK scanbodies with a cylindrical form were chosen for the present study due to their favorable mechanical and chemical properties. Although such scanbodies do not provide any rotational information, the computer-aided design/computer-aided manufacturing (CAD/CAM) framework on multiple implants does not require an antirotation lock.

The present study attempted to provide practical information about the
possibility of manufacturing a screw-retained framework on multiple implants using a digital intraoral impression. The results obtained from the conventional approach could have been influenced by the non-splinted impression-making technique, impression separation strain, and the stone cast manufacturing procedure. In contrast, the inaccuracies in the digital method could have been caused by the IOS technology, scanning method, scanning powder application, scanning length, and hand shaking. Moreover, the operator’s ability, as well as mechanical tolerances between each scanbody (digital approach) or pick-up coping (conventional approach), could also have led to accuracy errors.

Finally, it should be taken into consideration that the in vitro environment does not fully correspond to in vivo conditions such as the presence of saliva, patient movements, mobile areas of mucosa, or difficulties in accessing some areas of the mouth. These factors may contribute to the inaccuracy of both conventional and digital impression-making procedures.

Conclusion

Within the limits of this in vitro study of one IOS and two conventional impression materials, the accuracy of the computer-aided and conventional impression-making approaches for straight and tilted dental implants seems to be clinically acceptable and may therefore be considered for full-arch, multiple-implant restorations. Further clinical studies are required to verify the feasibility of different IOSs for fabricating digital impressions of different multiple-implant systems.

Acknowledgments

The authors would like to thank Dr Sebastian BM Patzelt (DMD, MSc, Dr med dent habil, PhD) for his support during this in vitro study, Mrs K Vach for the preparation of the statistics, 3M ESPE for providing the IOS and the digital training course (special thanks to Alberto Alvarez) as well as for sponsoring the conventional impression materials, BIOMET 3i for providing the dental implants, and Createch Medical for manufacturing the scanbodies and for performing the high-accuracy measurements.
References


