# Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision

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**Statement of problem.** A new approach to both 3-dimensional (3D) trueness and precision is necessary to assess the accuracy of intraoral digital impressions and compare them to conventionally acquired impressions.

**Purpose.** The purpose of this in vitro study was to evaluate whether a new reference scanner is capable of measuring conventional and digital intraoral complete-arch impressions for 3D accuracy.

**Material and methods.** A steel reference dentate model was fabricated and measured with a reference scanner (digital reference model). Conventional impressions were made from the reference model, poured with Type IV dental stone, scanned with the reference scanner, and exported as digital models. Additionally, digital impressions of the reference model were made and the digital models were exported. Precision was measured by superimposing the digital models within each group. Superimposing the digital models on the digital reference model assessed the trueness of each impression method. Statistical significance was assessed with an independent sample *t* test (α=.05).

**Results.** The reference scanner delivered high accuracy over the entire dental arch with a precision of 1.6 ±0.6 µm and a trueness of 5.3 ±1.1 µm. Conventional impressions showed significantly higher precision (12.5 ±2.5 µm) and trueness values (20.4 ±2.2 µm) with small deviations in the second molar region (*P*<.001). Digital impressions were significantly less accurate with a precision of 32.4 ±9.6 µm and a trueness of 58.6 ±15.8µm (*P*<.001). More systematic deviations of the digital models were visible across the entire dental arch.

**Conclusions.** The new reference scanner is capable of measuring the precision and trueness of both digital and conventional complete-arch impressions. The digital impression is less accurate and shows a different pattern of deviation than the conventional impression. (J Prosthet Dent 2013;109:121-128)

> ## Clinical Implications
> At present, the digital impression cannot fully replace the conventional impression for restorative procedures.

Dental impressions are an important step in restorative dentistry. They transfer the intraoral situation to an extraoral cast, the accuracy of which influences the fit of the restorations, an important factor in the longevity of the final restoration.[1-3]

The current gold standard is the physical impression made with an elastomeric impression material and stock or custom trays, resulting in a physical gypsum cast (conventional impression [CI]). Various techniques for achieving the most accurate results have been described in the literature.[4-6] With the development of computer-aided design/computer-aided manufacturing (CAD/CAM) systems and especially the use of zirconium dioxide for ceramic restorations, the digital model has become increasingly important. For this purpose, the gypsum cast needs to be digitized with an extraoral scanner to create a 3-dimensional (3D) digital model to design and mill the restoration.[7] The latest development in CAD/CAM dentistry is a digital intraoral impression from an intraoral scan of the patient's teeth,[8-10] resulting in a 3D virtual model. If needed, a physical model can be fabricated by rapid prototyping (stereolithography [SLA], 3D printing, or milling) from the intraoral digital impression data.[8,10,11]

A fundamental question, besides

the clinical handling of the devices for the digital intraoral impression and the ease of the following steps in the digital workflow, is the accuracy of this new impression technique. Recent studies evaluating the digital impression describe several issues such as distortion of the digital models, problems with the intraoral conditions, and lower precision compared to conventional impressions.[9,12]

Accuracy consists of precision and trueness (ISO 5725-1).[13] Precision describes how close repeated measurements are to each other.[14] The higher the precision, the more predictable is the measurement. Trueness describes how far the measurement deviates from the actual dimensions of the measured object. A high trueness delivers a result that is close or equal to the actual dimensions of the measured object. Trueness measurements for conventional intraoral impressions with gypsum casts are most frequently linear distance measurements.[5,15-18] This method is restricted by few measurement points, the need for specific geometries with clear reference markers for the measurement,

and the inability to display 3D changes of the dental model such as torsions and axis deviations.[5,18,19]

Three-dimensional examination of the trueness of impressions and gypsum casts are rare in the literature.[20,21] One requirement is knowing the real surface of the object being tested, the tooth or the dental arch, but this requires a reference scanner or access to a well-known reference model.[22] It is possible to measure surface points with high trueness with coordinate measuring machines (CMMs), but these lack scan speed and do not accurately measure freeform surfaces such as fissure lines and interproximal areas because of the geometric size and shape of the tip of the stylus (probe).[23-25] Optical scanners with high accuracy are currently limited to small measurement fields such as single teeth or quadrants.[9,20] Other methods for evaluating trueness include scanning calibrated objects of known dimensions,[22,25] for example, a sphere or a block[23,26] or measuring the marginal fit of the final restoration.[27,28] However, these calibrated objects are small and do not have the

typical morphology of teeth or the dental arch. Evaluating the fit of the final restoration includes the entire fabrication process, not only an assessment of the scanning quality of the preparation.

The purpose of this study was to evaluate the ability of a new reference scanner to achieve high precision and high trueness of complete-arch model scans and compare the accuracy of conventional (CI) and digital (DI) complete-arch impressions. The null hypotheses were that the reference scanner would provide internal mean values of trueness and precision of complete-arch model scans equal to the deviations of conventional impressions and that the digital complete-arch impression (DI) would show mean values of trueness and precision equal to those of the conventional complete-arch impression (CI).

## MATERIAL AND METHODS

A steel reference model (c) of a patient's maxillary dental arch with 2 complete crown preparations and 1 inlay preparation was fabricated (Fig. 1A).
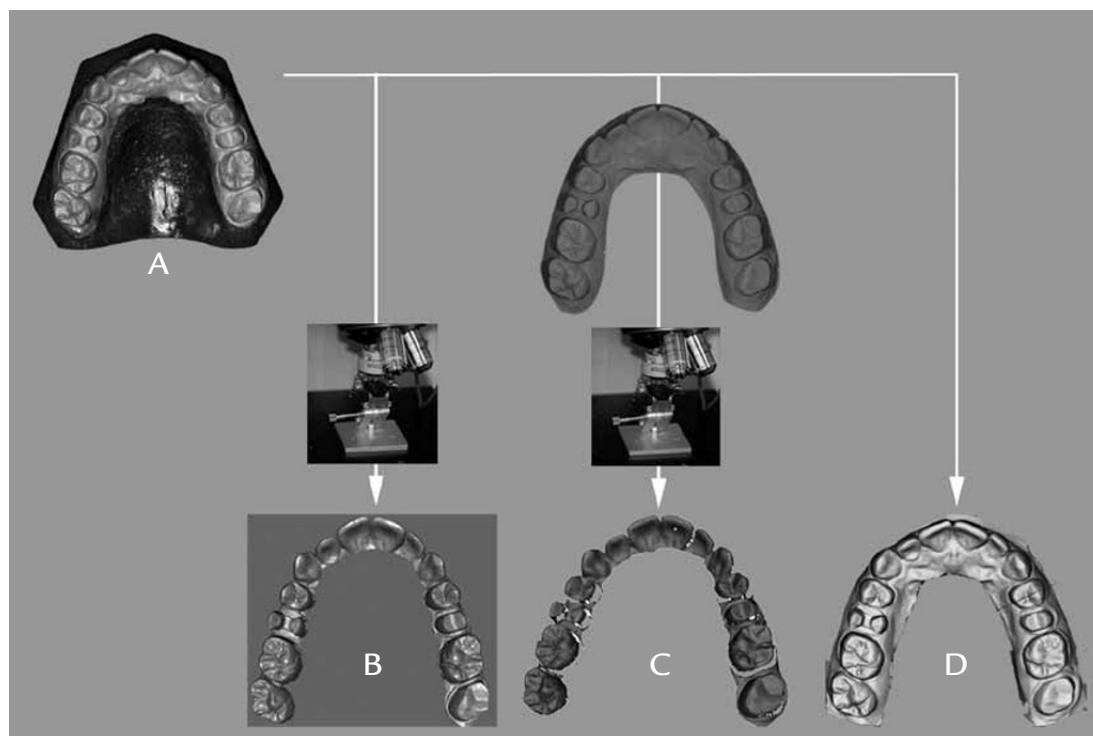


**1** Overview of reference model and impression techniques. (A) Reference model with inlay and complete crown preparations. (B) Reference model scanned with reference scanner. (C) Conventional impression with gypsum cast fabrication and scan of gypsum cast with reference scanner, (D) Digital impression with virtual 3D model.

## Accuracy of the reference scanner

The basis of the new reference scanner was a focus variation technique combined with a high precision objective lens movement over a large measurement field (Infinite Focus Standard; Alicona Imaging, Graz, Austria). The software of the new reference scanner was modified slightly to enhance the stitching quality for large object measurement (IFM software 3.5.0.1; Alicona Imaging). The reference model was scanned with this reference scanner 5 times in the same x-y-z direction. These data sets (Ref_Prec1-Ref_Prec5) were used to calculate the precision of the reference scanner (group Ref Prec). Afterwards, the reference model was scanned 5 times in a rotated position of approximately 90 degrees around the z-axis and inclined 10 to 20 degrees around the x-axis and y-axis. These data sets (Ref_True1-Ref_True5), representing group Ref_True, were used to calculate the trueness of the reference scanner. The point size of each scan was 1.6 × 1.6 µm in the x and y directions and 0.25 µm in the z direction. Scan time for 1 complete-arch model was 21 to 29 hours. Each scan resulted in a data set of approximately 20 million surface points (Fig. 1B).

The Ref_Prec (Precision) data sets (Ref_Prec1 through Ref_Prec5) were superimposed on each other with difference analysis software (IFM software 3.5.0.1; Alicona Imaging) with a best fit algorithm (n=10). The signed nearest neighbor distances of each surface point between the superimposed models were computed. A signed nearest neighbor is the shortest distance from a surface point of model 1 to a surface point of model 2, considering the positive or negative direction relative to the surface normal of model 1. Therefore, the distance can be either positive or negative. The highest and lowest 10% of these differences were not included for comparison. The mean of the remaining 80% of the differences was calculated and divided by 2 (Mi-

crosoft Excel:mac 2011; Microsoft Deutschland GmbH, Unterschleissheim, Germany), resulting in the (90 percentile -10 percentile)/2 as the precision value of this superimposition. A difference image was created (Fig. 3) and saved for visual analysis. The (90 percentile -10 percentile)/2 of all superimpositions was summarized and the mean, median, and standard deviation calculated (Microsoft Excel:mac 11; Microsoft Deutschland GmbH).

The Ref_True (Trueness) scans (Ref_True1 through Ref_True5) were compared to the first nonrotated scan Ref_Prec1 as described above (n=5). The superimposition of the rotated scans reveals any filter effects, that is calibrating errors of the software and matching errors of the measurement process, and represents the validation of the trueness of the scanner.

## Accuracy of conventional impression technique

Five conventional impressions (CI) were made with a vinyl siloxanether impression material (Identium; Kettenbach, Eschenburg, Germany) and metal stock trays (ASA Perma-Lock; ASA Dental SpA, Bozzano, Italy) by using a double mix technique. Polymerization time was 10 minutes and the impression was removed from the model by lifting the tray from the anterior to the posterior. After 8 hours storage at ambient humidity and 23°C room temperature and in a dark environment, the impression was poured with Type IV gypsum (CAM-base; Dentona AG, Dortmund, Germany) and allowed to set without inverting the impression. After 40 minutes, the casts were removed from the impression and stored for 48 hours at room temperature and ambient humidity before scanning with the reference scanner. The casts were scanned with the reference scanner as described in section Ref_Prec (Fig. 1C).

To obtain the CI_Prec (Precision) data, the cast scans were compared

to each other to determine the precision of the conventional impression (n=10). To obtain the CI_True (Trueness) data, the cast scans were compared to the scan of the reference model to determine the trueness of the conventional impression method (n=5). The difference analysis was performed in the same way as described above.

## Accuracy of digital impressions

Five digital impressions (DI) of the reference model were made with the CEREC AC System (Sirona Dental Systems, Bensheim, Germany) by using the CEREC Connect Software 3.82. The reference model was coated with OptiSpray (Sirona Dental Systems) and approximately 20 optical impressions were made to acquire the entire dental arch (Fig. 1D). The resulting model was exported to a standard triangulation language file (STL) describing the 3D object surface and imported into the Alicona IFM Software for comparison to the reference model scanned with the Alicona IFM device.

To obtain the DI_Prec (Precision) data, the digital impressions were superimposed on each other and the differences showed their precision. The superimposition of the digital impressions on the reference model provided the basis for the trueness of the digital impression method and the DI_True (Trueness) data. The difference analysis was performed in the same way as described for Ref_Prec.

To analyze the differences of the mean value, the independent sample *t* test was used in a pairwise comparison of the testing groups. The Levene test was used to assess the equality of variances among the test groups ($\alpha$=.05). No significant differences for all compared groups were found. Statistical differences between the mean values in pairwise comparison of Ref_Prec to CI_Prec, Ref_Prec to DI_Prec, and CI_Prec to DI_Prec for precision and Ref_True to CI_True, Ref_True to DI_True, and CI_True to DI_True for trueness were analyzed with software at $\alpha$=.05
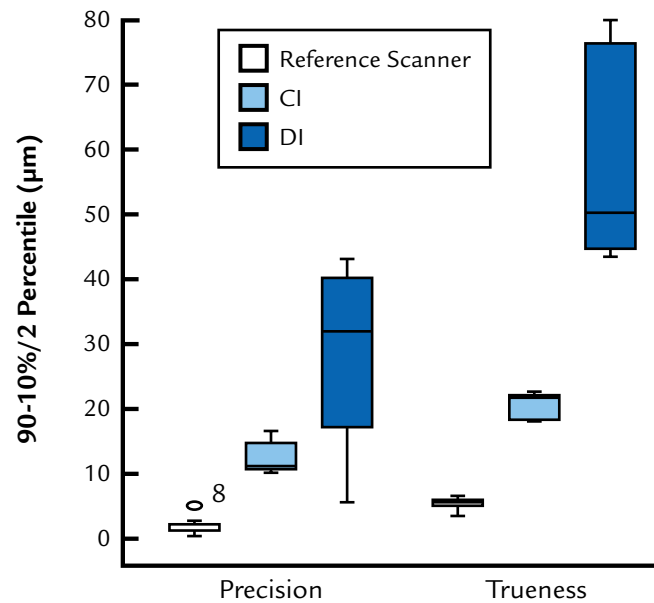
**2** Boxplot of accuracy measurement (precision and trueness) for all groups. All groups show significant differences from each other (*P*<.001). CI: conventional impressions, DI: digital impressions
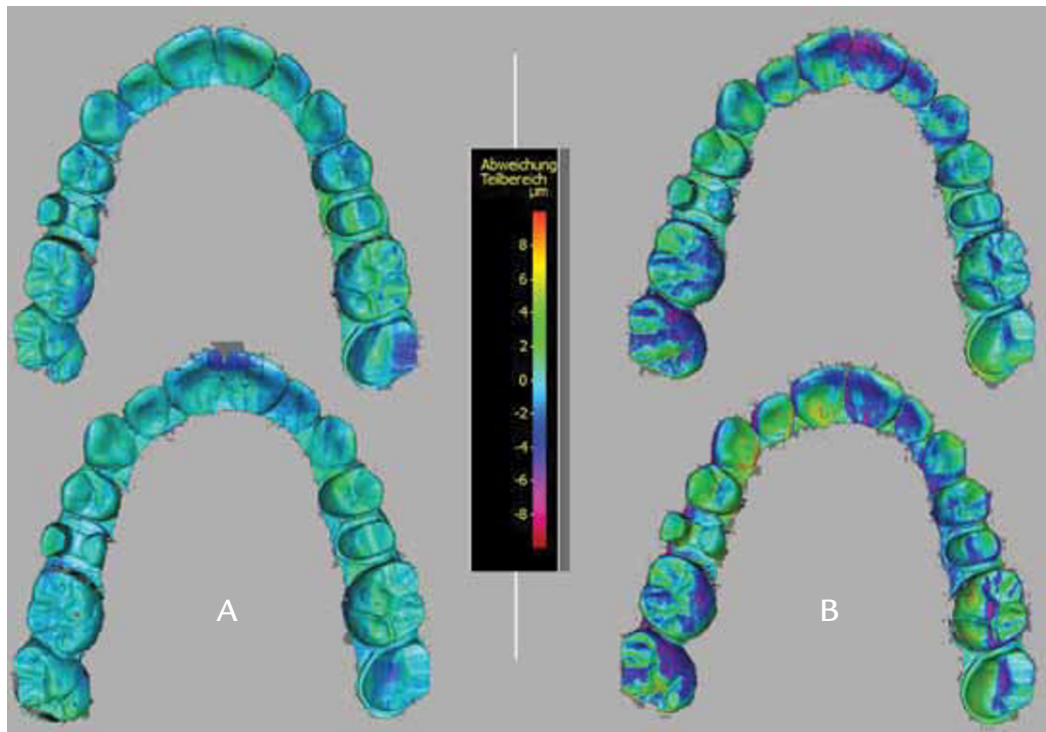


**3** Difference images of trueness and precision of reference scanner. Difference color map is set from -10 µm to +10 µm. Yellow to red color indicates positive deviations, blue to violet shows negative deviation between 2 superimposed models. (A) Precision: Homogenous difference mapping of ±2 µm is visible with local peaks up to ±5 µm in steep inclines. (B) Trueness: Large areas differ up to 4 µm, while steep flanks of anterior and second molar region show some higher differences up to 8 µm.

(IBM SPSS Statistics v19; IBM SPSS, Chicago, Ill). To analyze the differences of the mean value, the independent sample *t* test was used. The Levene test was used to assess the equality of variances among the test groups (α=.05).
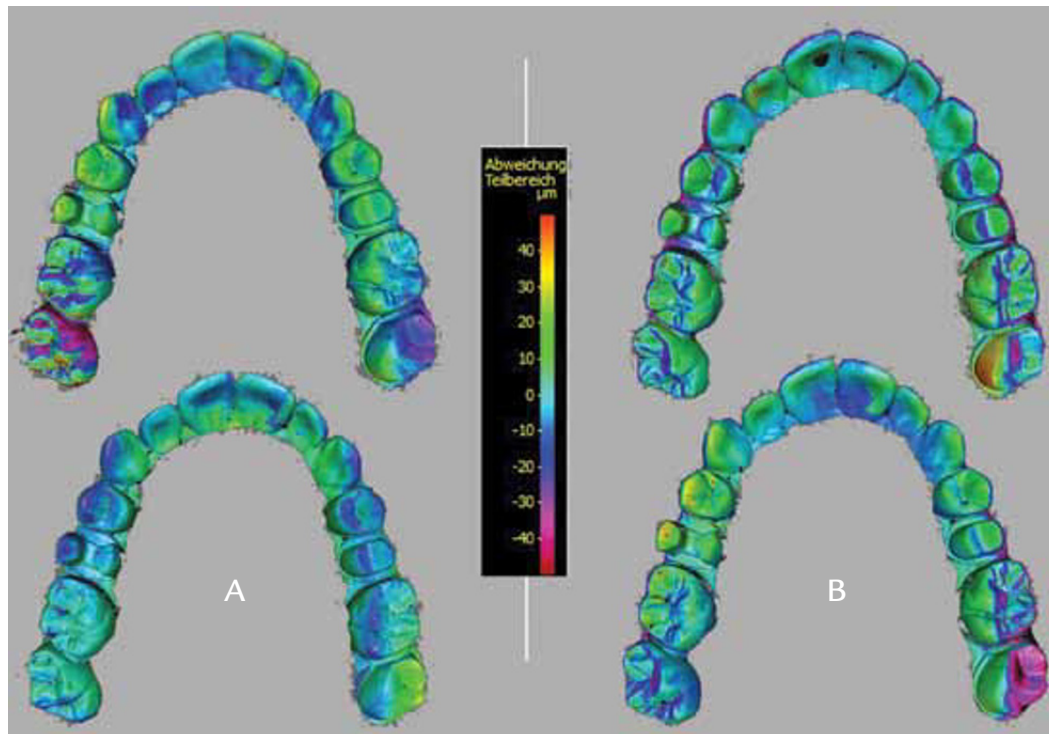
## RESULTS

### Accuracy of the reference scanner

Figure 2 shows the result of the precision and trueness measurements. Group Ref_Prec shows de-

viations between 0.5 µm and 2.5 µm with a mean of 1.6 ±0.6 µm (median: 2.0 µm) over the entire dental arch.

Figure 3A shows the differences between 2 repeated scans in a range from -10 µm to +10 µm. A homogenous deviation over the entire dental

**4** Difference images of trueness and precision of conventional impressions. Color difference map is set from -50 μm to +50 μm. Yellow to red color indicates positive deviations, blue to violet shows negative deviation between 2 super-imposed models. (A) Precision: Difference map of 2 repeated scans. Anterior regions show minimal deviations of up to 20 μm. Distal end of arch shows irregularly occurring deformations of up to 50 μm. (B) Trueness: Gypsum casts show increasing deviation to distal end of dental arch. Distortion in region of second molar of second quadrant is visible.
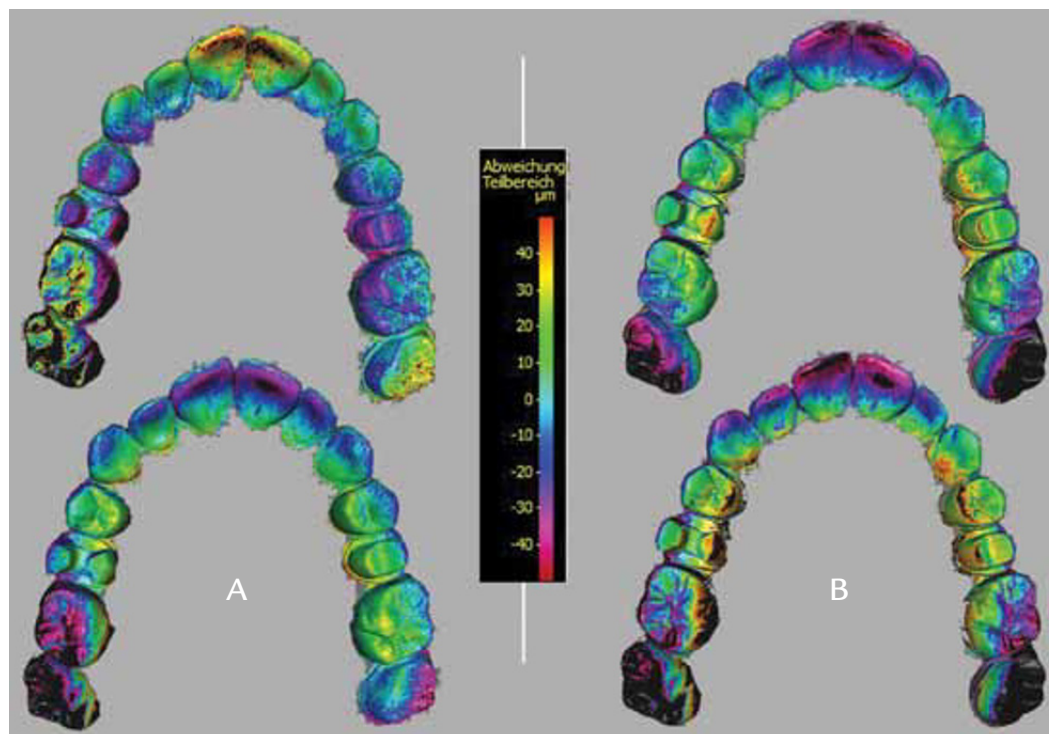


**5** Difference images of trueness and precision of digital impression. Color difference map is set from -50 μm to +50 μm. (A) Precision: Difference image of 2 repeated digital impressions. Irregularly occurring deviations are visible across entire dental arch. Highest differences are located at distal end. Wavelike distortion of dental arch with alternating positive and negative deviations together with rotation of anterior region is visible. (B) Trueness: Systematic distortion along sagittal and transversal axes is visible. Negative deviations are located in anterior and molar region and positive deviations in premolar regions up to 50 μm. Distal end of dental arch differs up to 170 μm.

arch with maximum values of 5 μm on steep oral inclines of the incisor and the second molar is visible. The error is only visible in these particular regions and did not accumulate over larger distances.

Trueness values in group Ref_True ranged from 3.5 to 6.5 μm with a mean of 5.3 ±1.1 μm (median: 5.5 μm). The difference image 3B shows local higher deviation of about 8 μm in the second molar region and at the oral surface of the anterior, again in steep inclines of the tooth surface.

### Accuracy of conventional impression technique

Conventional impressions showed a mean precision (CI_Prec) of 12.5 ±2.5 μm (median 11.0 μm) (Fig. 2) and a trueness (CI_True) of 20.4 ±2.2 μm (median 21.5 μm) (Fig. 2). The low standard deviation showed high reliability for the conventional impression in this in vitro experiment. The independent sample $t$ test revealed a statistically significant difference compared to the accuracy of the reference scanner ($P<.001$).

The visual evaluation of the precision measurement showed small deviations in the anterior and premolar regions of around 10 μm and higher, irregularly occurring discrepancies on the second molar with maximum values of up to 50 μm (Fig. 4A). Trueness difference images showed low deviations in the anterior region. Premolar and molar regions differed more from the reference model. At the distal end of the dental arch, irregular deviations of up to 50 μm occurred.

### Accuracy of digital impression

The digital impressions showed a precision (DI_Prec) of 32.4 ±9.6 μm (median 31.7 μm) and a trueness (DI_True) of 58.6 ±15.8 μm (median 50 μm). The independent sample $t$ test showed statistically significant differences from group CI_Prec and CI_True ($P<.001$).

The differences of the precision measurements showed an irregular deviation pattern. The anterior region was more precise than the posterior, and the highest posterior deviations were located only at 1 side of the model (Fig. 5A).

The visual analysis of the trueness showed a systematic deviation of the virtual 3D models to the reference model, with negative values in the anterior and molar region and positive values in the canine and premolar region (Fig. 5B). Maximum differences of up to 170 μm occurred in the second molar area. The model was distorted along the sagittal and transversal axes on both sides.

## DISCUSSION

The results of this study support the rejection of the first null hypothesis, that the reference scanner would deliver mean internal values of trueness and precision of complete-arch model scans equal to the deviations of conventional impressions ($P<.001$). The reference scanner delivered significantly lower internal mean values of trueness and precision compared to those of group CI. Therefore, the reference scanner is capable of measuring and evaluating the trueness and precision of conventional complete-arch impressions (CI). The second null hypothesis, that the digital complete-arch impression (DI) shows the same accuracy as the conventional complete-arch impression (CI), was rejected ($P<.001$) as the conventional complete-arch impression shows higher precision and higher trueness for this type of impression.

With the increasing possibilities of CAD/CAM systems, including virtual articulation, it is becoming increasingly important to gain accurate data not only from the preparation but also from the entire dental arch for the production of partial or complete removable dental prostheses. Therefore, a fundamentally new method should be established to compare the quality of intraoral or extraoral scanning devices with that of

conventional impression techniques. For that purpose, a new method of measuring dental arch models with a scanner based on focus variation was introduced. A modulated white light is projected onto the model surface, and the reflected light is captured with an objective with a small depth of field (DOF). The system is capable of measuring surfaces within a field of 10×10×10 cm. Different magnification lenses can be used to reduce the spot size and therefore increase the resolution to 50 nm.

For the evaluation of trueness and precision, multiple measurements of a testing object from different directions and angulations were compared. Errors due to filter algorithms and calibration errors of the scanner were disclosed by comparing and superimposing scans from different directions. Only similar linear scale errors in the x-axis, y-axis, and z-axis would be undetectable with this approach. However, this error can easily be avoided by a longitudinal measurement of a calibrated length specimen.

According to the results of these in vitro analyses, the precision (1.6 μm) and trueness (5.3 μm) of the new reference scanner are high for scanning the dental morphologies of a complete-arch model. In comparison, the use of a laser triangulation system as a reference yielded a trueness of about 15 μm when scanning a quadrant (Laserscan 3D Pro).[9,22] No other systems that have the ability to scan morphologically shaped tooth surfaces with such high trueness and precision over an area up to 6 cm[2] and 2 cm in height have been reported. Other studies used geometric forms to verify CMMs and showed high trueness and precision for these devices. However, these CMMs acquire only a small number of points from the model surface. Additionally, for a precise model with CMM, knowledge of the surface shape before scanning is necessary.[25] Also the tip of the tactile probe has a certain diameter, meaning small morphological structures such as fissure lines and

gingival margins cannot be detected with these systems. With the new reference scanner, acquiring the dental surface without prior knowledge of the morphology is possible. Some manufacturers describe the accuracy of their scanners as ranging from 5 µm to 30 µm. However, these values were measured only on small models or geometric testing blocks up to 10 mm long.[20,21,26] In addition, the same scanner may have been used for both reference and testing measurements.[3] Measuring the accuracy of the final restoration to define the impression accuracy is a linear distance measurement and cannot describe 3D deviations of the impression method itself.[27,28]

The new reference scanner provides an accuracy that is significantly ($P<.001$) higher than that produced by conventional and digital impressions. The use of the (90 percentile -10 percentile)/2 is due to the measurement process. There may be scattered surface points with errors and areas with only a low point density. Additionally, the boundary of each scanned model is slightly different, and areas with an inclination higher than 80 degrees cannot be scanned with the reference scanner. In these areas, the difference measurement cannot be relied upon to find the correct nearest signed neighbor. Therefore, the lowest 10% and the highest 10% of the difference values are not considered for comparisons. However with 80% of the scanned surface, the difference analysis represents more model surface than a mean value with root mean square deviation that consists of 66% of the measured differences, a value that was mainly used in other studies.[20,24]

With a trueness of 5.3 µm, the reference scanner is significantly below that of conventional complete-arch impressions and is therefore suitable for these types of measurements. In this study, the trueness of gypsum casts from a vinyl siloxanether impression was 20.4 ±2.2 µm. Indeed, this result can be interpreted as a low deviation across the entire dental arch.

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The greater deviations in the second molar regions may be due to the use of a standard impression tray. Brosky et al[19] also found impressions with larger deformations in a test group with standard impression trays but not located in the same area. They measured mean deviations from 27 µm to 312 µm where most measurements ranged from 27 µm to 83 µm. However, based on the results of a different analysis method comparing a greater percentage of the scanned surface, this result accords well with that of the present study for the trueness of conventional impressions. In contrast, the 3D difference analysis used in this study, showing accuracies of about 10 µm for conventional impression materials, cannot be compared to studies with linear distance measurements.[6,15,17,18]

The digital impressions with the CEREC Bluecam show higher deviations from the reference model, resulting in significantly ($P<.001$) lower precision and trueness compared to the conventional impression group. The pattern of deviation in the sagittal axis in 1 quadrant was also revealed in former studies.[9,12] As purported by the manufacturer, the deviations in the anterior region may be due to the creation of the complete-arch scan by combining 2 overlapping partial scans of both quadrants. The registration area is the anterior region from canine to canine. In the anterior regions, with less structured tooth surface and steep inclines, more error with the optical impression can occur. It is probable that the superimposition process leads to that type of deviation. These 2 errors seem to be systematic and maybe reduced or avoided with further software improvements.

## CONCLUSIONS

Within the limitations of this study, the following conclusions were drawn:
1. The new reference scanner provides accurate measurement results with which to compare conventional and digital complete-arch impression techniques.
2. The trueness and precision of the digital complete-arch impression are less

accurate than of a conventional impression with vinyl siloxanether material.
3) The deviation patterns of conventional and digital impressions are different.

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## NOTEWORTHY ABSTRACTS OF THE CURRENT LITERATURE

# The association of denture stomatitis and partial removable dental prostheses: a systematic review

Emami E, Taraf H, de Grandmont P, Gauthier G, de Koninck L, Lamarche C, et al.
Int J Prosthont 2012 Mar-Apr;25:113-9.

**Purpose:** The aim of this systematic review was to analyze the evidence on the occurrence of denture stomatitis (DS) and potential risk factors in patients wearing partial removable dental prostheses (RDPs).

**Materials and Methods:** MEDLINE, EMBASE, the Cochrane Central Register of Controlled Trials, and the Cochrane Database of Systematic Reviews were searched and complemented by manual searching. Outcome measures were the presence of DS in patients wearing partial RDPs and an assessment of associated risk factors. All types of experimental and observational studies investigating an association between DS and the wearing of partial RDPs were included. Methodologic quality and level of evidence were assessed using valid scales. Two authors performed study selection, data extraction, and quality assessment independently.

**Results:** A total of eight studies met the inclusion criteria. The prevalence of DS in partial RDP wearers ranged from 1.1% to 36.7%. Data on the potential risk factors were not consistent. Despite the heterogeneity and methodologic quality of included studies, an association between DS and the wearing of partial RDPs was found.

**Conclusions:** There is some evidence that the presence of DS is associated with the wearing of partial RDPs. However, because of methodologic limitations and cross-sectional designs of research studies, no cause-effect relationship could be inferred. Future research should provide higher levels of evidence to confirm the etiology of DS in partial RDP wearers.

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