In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions

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ABSTRACT

Statement of Problem. Digital impression systems have undergone significant development in recent years, but few studies have investigated the accuracy of the technique in vivo, particularly compared with conventional impression techniques.

Purpose. The purpose of this in vivo study was to investigate the precision of conventional and digital methods for complete-arch impressions.

Material and Methods. Complete-arch impressions were obtained using 5 conventional (polyether, POE; vinylsiloxanether, VSE; direct scannable vinylsiloxanether, VSES; digitized scannable vinylsiloxanether, VSES-D; and irreversible hydrocolloid, ALG) and 7 digital (CEREC Bluecam, CER; CEREC Omnicam, OC; Cadent iTero, ITE; Lava COS, LAV; Lava True Definition Scanner, T-Def; 3Shape Trios, TRI; and 3Shape Trios Color, TRC) techniques. Impressions were made 3 times each in 5 participants (n = 15). The impressions were then compared within and between the test groups. The cast surfaces were measured point-to-point using the signed nearest neighbor method. Precision was calculated from the (90%–10%)/2 percentile value.

Results. The precision ranged from 12.3 µm (VSE) to 167.2 µm (ALG), with the highest precision in the VSE and VSES groups. The deviation pattern varied distinctly according to the impression method. Conventional impressions showed the highest accuracy across the complete dental arch in all groups, except for the ALG group.

Conclusions. Conventional and digital impression methods differ significantly in the complete-arch accuracy. Digital impression systems had higher local deviations within the

complete arch cast; however, they achieve equal and higher precision than some conventional impression materials.

CLINICAL IMPLICATIONS

The accuracy of complete-arch impression casts differs significantly between conventional techniques and digital impression systems. Local deviations are greater in casts generated using digital impression systems; however, digital systems show adequate accuracy across the complete arch. As digital impression systems continue to improve, they may prove to be an equivalent or better alternative to conventional impression techniques.

INTRODUCTION

Intraoral impression is a basic technique in dental practice that is used to generate an imprint of the oral situation. A variety of procedures are based on the intraoral impression, including therapeutic planning, diagnostics, patient communication, cast fabrication, and production of restorations and appliances.[1-9] The accuracy of intraoral impressions is especially critical for fabricating well-fitting restorations.[4,10,11] Two factors influence the accuracy: trueness, which describes the deviation of the impression geometry from the original geometry, and precision, which describes the deviation between repeated impressions rather than to the original geometry (ISO 5725-1).[11,12] Precision reflects the degree of deviation between impressions within a test group.[3]

The current gold standard for a complete-arch intraoral impression is the conventional impression made with rigid impression trays and elastomeric impression material. Several impression materials and techniques have been investigated in vitro and show a high level of accuracy [13-16]; however, only a few in vivo studies have been conducted.[2,17,18] The trueness of conventional impressions is commonly tested by measuring the change in linear distance between an original master model and a gypsum cast derived from the impression.[4,14,15,19,20] This procedure cannot be performed intraorally; therefore, many in vivo studies use an indirect approach and verify the impression trueness by measuring the fit of the definitive restoration based on that impression.[2,21-25] Repeated impressions can be made from one dental arch and compared to show the precision of the impression procedure.[3,21]

The past 30 years have seen the development of the digital intraoral impression technique.[6,10,27-29] This method replicates the intraoral situation using a 3-dimensional (3D) camera to capture the data in a digital format. Restorations can then be directly produced by computer-aided design and computer-aided manufacturing (CAD/CAM) software and computer numerical control (CNC) milling machines.[6,26,30] Contrary to conventional impression methods, digital intraoral impression does not require pouring. A physical stone cast is not necessary but can be produced using rapid prototyping technology.[31] However, the accuracy of digital impression for different clinical applications is controversial, even though several studies show that digital and conventional impressions produce restorations of equal quality.[2,21,22,26] The conventional linear distance measurement is limited to certain geometric forms. To assess the accuracy of impression materials, the clinical situation should be optimal.[32] Thus, the accuracy of digital casts is best evaluated by superimposing the impression on the original geometry.[13,33-36] In this procedure, deviations between the impression and the original master geometry at each surface point are determined from computed 3D distances.[18,34-38] A highly accurate reference scan can be used in in vitro studies to scan the master geometry, which is then compared with the test groups.[34,39] In clinical practice, however, the original master geometry of the intraoral surface is unknown. One approach is to define one impression as the reference and compare it against all other impression techniques.[4] However, this limits the ability to detect impression deviations because deviation from the master scan may be caused by errors in either the master scan or the digital impression. Because of these limitations, the accuracy of digital impressions has been mostly investigated in small regions of the dental arch or on geometrical forms.[18,26,38-40] Recently, a highly accurate method has been established for measuring the dental morphology of in vitro complete-arch impressions in clinical practice.[12,41] It uses a specially adapted highly accurate scanning protocol to measure complete-arch geometry. This method is able to compare conventional and digital impressions generated from the same geometry. A few studies have attempted to assess the accuracy of both digital and conventional complete-arch dental impressions using this method.[34,38,42]

Based on these earlier studies, the purpose of the present study was to evaluate the precision of several conventional and digital methods for generating complete-arch dental impressions in a clinical in vivo situation. In addition, the deviation was visually analyzed to determine the typical deviation pattern associated with each impression method. The null hypothesis was that no significant differences would be found between conventional and digital impression methods.

MATERIAL AND METHODS

Five participants with a complete dentition were recruited from a voluntary collective. Written informed consent was obtained from all study participants. The study was approved by the institutional review board. The maxillary or mandibular jaw was randomly selected (coin toss) in each participant to test all impression methods. For each impression group, 3 impressions were made of each jaw. The impression methods and associated procedures are summarized in Tables 1, 2.

Conventional impressions

Standard perforated metal stock trays (ASA Permalock; ASA Dental) were used to generate the conventional impressions. The optimal tray was selected by testing a stock tray in the oral cavity while ensuring adequate space for the impression material. Tray adhesive was applied if needed. The impressions were performed as suggested by the manufacturer by 2 experienced dentists (1 of them was A.E.).

The conventional impressions were made using the following materials: polyether (POE; Impregum; 3M ESPE); vinylsiloxanether (VSE; Identium; Kettenbach); direct scannable vinylsiloxanether (VSES; Identium Scan, Kettenbach); and irreversible hydrocolloid (ALG; Blueprint Cremix; Dentsply Intl).

For the POE, VSE, and VSES groups, a tray adhesive was applied to the impression tray. The POE, VSES, and ALG impressions were obtained as monophase impressions according to the manufacturer's instructions. The VSE impression was obtained using a 2 viscosity impression technique with heavy- and light-body material (Table 1).

All impressions were disinfected for 10 minutes (Impresept; 3M ESPE). After 8 hours of storage, the VSE, POE, and ALG groups were poured in Type IV dental stone (Cam-Base; Dentona AG). The impression trays were removed from the stone cast after 40 minutes, and the stone casts were stored for 48 hours at ambient temperature and humidity.

The casts were scanned with the reference scanner (Infinite Focus; Alicona Imaging) using a highly accurate protocol for scanning large objects.[12] The scan data were exported in the stereolithography (STL) data format. The impressions from the VSES group were trimmed with a scalpel at the marginal and palatal areas to ensure optimal visibility of the occlusal and proximal tooth surfaces. Impressions from the VSES group were extraorally digitized with a laboratory scanner (iSeries; Dental Wings Inc). This protocol is able to generate digital STL data from a direct impression scan without the need to pour an intraoral impression (VSES-D). Subsequently, the impressions were scanned with the reference scanner (Infinite focus) after sputtering the surface (SCD 030, Bal-Tec) to generate the digital data set for group VSES.

Digital impressions

The following digital impression systems were evaluated: CEREC Bluecam (CER; Sirona Dental Systems); CEREC Omnicam (OC; Sirona Dental Systems); Cadent iTero (ITE; Cadten LTD.); Lava COS (LAV; 3M ESPE); True Definition Scanner (T-Def; 3M ESPE); 3Shape Trios (TRI; 3Shape); and 3Shape Trios Color (TRC; 3Shape).

The impressions were generated according to the manufacturer's instructions (ITE, LAV, T-Def, TRI, and TRC) or using in-house protocols (CER, OC). The oral surfaces were pretreated with a matting powder (Sirona OptiSpray; Sirona Dental Systems) in the CER group and a dusting powder (Lava COS Powder; 3M ESPE) in the LAV and T-Def group. The scan data were directly exported from the acquisition unit (CER, OC), exported after being uploaded to a communication portal (TRI and TRC), or subjected to postprocessing (ITE, LAV, T-Def) and then exported as an STL data file (Table 2).

After receiving all STL data sets, the impressions in each test group were superimposed using CAD qualify software (Geomagic Qualify 12; 3DSYSTEMS) according to a best-fit algorithm. The casts were trimmed to the dental arch and 1 mm of attached gingiva. All scanning artifacts attributed to soft tissue were removed. The trimmed casts were again saved in the STL file format.

To compare the impressions within each test group, the scan data were superimposed using special diagnostic software (Oracheck 2.01; Cyfex AG), which uses a best-fit algorithm to match 2 surfaces, and the differences were analyzed. The distance and direction between the STL vertex point of cast 1 and the closest surface point of cast 2 was calculated using the signed nearest neighbor method. This procedure was repeated for each STL triangle point in cast 1. Depending on the STL resolution of the digital casts, the software computed between 60 000 and 90 000 distances per impression match. The distance data were saved as a CSV file and imported into a statistical program (SPSS v21; IBM Corp). The 10% and 90% percentile-values of the measured distances were calculated. The differences between the 2 matched casts were measured by calculating the (90%–10%)/2 percentile, which indicated that 80% of the cast 1 surface showed less deviation compared with cast 2. The (90%–10%)/2 percentiles of all superimpositions (n=15) of each test group were computed, and the mean, median, and standard deviation were calculated (SPSS v21; IBM Corp.). In addition, a difference map of each match was saved as a screenshot for visual analysis of the deviation pattern.

All (90%–10%)/2 values were analyzed with a statistical program (IBM SPSS Statistics v21; IBM Corp). Normal distribution was determined using the Kolmogorov-Smirnoff test. The Levene test was used to assess the equality of variances for all test groups (α=.05). Statistical differences between the test groups were analyzed using 1-way ANOVA with the post hoc Bonferroni test (α=.05).

RESULTS

The deviation data were normally distributed in each group according to the Kolmogorov-Smirnov test. The Levene test did not indicate any equality of variances (P<.05). According to the 1-way ANOVA, the mean precision values were statistically different among the groups. The results of the statistical analysis are detailed in Tables 3, 4, and boxplots of each group are shown in Figure 1.

The precision of all the groups is shown in Table 3 and Figure 2. The highly precise conventional impression materials in groups VSE (17.4 ±5.1 µm), VSES (18.3 ±8.8 µm), VSES-dig (36.7 ±3.8 µm), and POE (34.9 ±8.8 µm) did not differ significantly (*P*< .05). In contrast, the conventional impression group ALG showed the significantly lowest precision (162.2 ±71.3 µm). The digital impression groups CER (56.4 ±15.4 µm), OC (48.6 ±11.6 µm), TRI (47.5 ±21.4 µm), TRC (42.9 ±20.4 µm), T-Def (59.7 ±29.4 µm), and ITE (68.1 ±18.9 µm) did not differ significantly in precision for the complete-arch impressions ($P > 0.05$). Group LAV (82.8 ±39.3 µm) was significantly less precise than groups TRC, POE, VSES-dig, VSES and VSE. The digital impression groups TRC, TRI, and OC reached the same high precision level as conventional impression groups VSE, VSES, VSES-dig, and POE. Table 4 shows the significance levels among all groups.

Figure 2 shows the typical deviation pattern between repeated complete-arch scans within the test groups. The conventional impressions in the VSE and VSES groups showed minimal deviation (≤40 µm) across the incisal edges of the anterior teeth and at the buccal surface of the premolars (Fig. 2 A, B). In the VSES-dig group, when the impressions from the VSES group were repeated and digitized with an extraoral scanner, greater deviation was observed, especially at the inclined tooth surfaces (Fig. 2C). The conventional impressions in the POE group showed larger local deviations of ≤100 µm in the cast. Negative deviations were observed at the oral surfaces and positive deviations at the buccal surfaces, indicating a slight distortion of the posterior teeth (Fig. 2D). In contrast, the ALG group showed irregular local deviations at different areas; deviations were at least 100 µm and reached 500 µm in some areas (Fig. 2E).

The CER group showed local deviation (≤80 µm) at one end of the dental arch and generally displayed a slight distortion towards the distal end (Fig. 2F). In the OC group, local deviations were detected at the interproximal and cervical areas and measured ≤100-µm. High deviation was also observed at the distal end of the dental arch (Fig. 2G). The digital casts in the LAV group showed high deviation (>100 µm) within 1 quadrant (Fig. 2H). The cast comparison in the T-Def group revealed a similar deviation pattern, but of lower magnitude (Fig. 2I). In contrast, the ITE group showed a diagonal shift in the digital cast, with negative deviations in the premolar and distal molar regions (Fig. 2K). In the TRI group, 1 quadrant began to deviate, beginning at the canine region, toward the distal end of the cast but remained ≤100 µm at the distal tooth (Fig. 2L). A similar deviation pattern was observed in the TRC group (Fig. 2M).

In general, the digital impression systems with high frame rates (video-based systems and the OC, LAV, T-Def, TRI, and TRC groups) began to deform distal to the anterior region of the dental arch. Single images based on the digital impression system (CER, iTer) primarily showed local deviation with increasing deformation toward the distal end of the cast. In contrast, while the conventional impressions showed local deviation, the deviation did not increase in magnitude toward the distal arch.

DISCUSSION

The purpose of this study was to assess the precision of digital and conventional complete-arch impressions in vivo. With the increase in the use of CAD/CAM, not only in the restorative dentistry but also in surgery, orthodontics, diagnostics, and treatment planning, digital impression making must meet a high level of accuracy beyond the preparation site. In order to eliminate the conventional impression and stone cast, digital impressions must perform at least at the same level of quality and accuracy as current conventional techniques.[6] Based on the results of the present in vivo study, the null hypothesis that the conventional and digital impression systems are equally accurate must be rejected. Thus, no differences were found among the groups

This study revealed significant differences in precision according to the method used to obtain the complete-arch impression. Large differences were visible in the conventional impression materials and in the digital impression techniques. Conventional impressions using vinylsiloxanether material (VSE, VSES) showed the highest precision, while those using the irreversible hydrocolloid (ALG) showed the lowest precision. The digital intraoral impression systems resided in between these extremes; the digital systems were significantly less precise than the highly precise conventional impression materials. The precision across the complete arch scans did not differ significantly among the various digital impression systems. All of the digital systems showed a larger standard deviation compared with the high precision conventional impression materials.

The anterior region has little geometric information and was particularly difficult to scan with the digital intraoral cameras. Error propagation in this region leads to increased deformation toward the distal end of the dental arch. Additionally, optimal scanning is necessary to generate quality results.[39] Several studies have evaluated the trueness and precision of digital impressions by focusing on single or partial fixed dental prosthesis preparations.[11,16,26,35,44] In these small areas of the dental arch, digital impressions are highly accurate and better than conventional impression methods.

When the complete digital workflow is based only on digital data, both the preparation itself and the entire dental arch must be accurate. Otherwise, the occlusion and articulation of the digital casts will be incorrect, decreasing precision in the restorations. Few studies have investigated complete dental arch casts fabricated from digital impressions.[39,43,45]

A previous study showed high accuracy of a new reference scanner for replicating the complete-arch geometry.[43] This reference scanner enables a direct comparison of conventional and digital impressions. Although the conventional impression results in highly precise casts, the quality of the definitive restoration may differ because of the continued mechanical manipulation of the stone cast.[24]

The results of the present study can be compared with the in vitro results of a previous study.[34] Unlike the previously described extraoral cast, the present study shows the behavior of the impression materials and systems inside the oral cavity. Therefore, patient-specific factors, such as anatomic restrictions, movement, saliva, and soft tissue, can be included in the evaluation of the impression accuracy. Highly precise conventional impression systems such as VSE perform nearly identically in vitro and in vivo. In contrast, the precision decreased in all of the digital systems when they were applied in vivo. The low precision of the irreversible hydrocolloid material may be caused by internal tearing in the material as there was no visible fracture of the material in the impression tray. This material may require additional study to determine whether this observation reflects the general properties of the material or is limited to the specific brand. Studies have also shown inconsistent results for irreversible hydrocolloid impressions.[46,47]

Another patient-specific factor sometimes discussed is the deformation of the mandible during jaw opening. In this in vivo study, no difference was visible between the precision of maxillary and mandibular impressions in both the conventional and digital impression groups. The participants were not forced to open the jaw to an extreme degree during the impression procedure. The greatest opening of the jaw happens during the insertion and the removal of a conventional impression tray. During the setting time of the impression material, the patient relaxes the mandibula and is not keeping the maximum opening distance. In the digital impression groups, the highest jaw opening occurs when scanning the distal teeth. Scanning the anterior region of the complete arch was also performed in a relaxed opening position of the jaws.

The comparison between the VSES and VSES-dig groups revealed the influence of extraoral digitization on conventional impression making. The precision of the VSES-dig group was primarily affected by the extraoral scanner.

In general, near-perfect scanning is necessary in all of the digital impression systems to attain optimal results.[39] In this study, 2 experienced dentists who were trained in the optimal scanning technique for each scanning system before scanning the participants performed all the digital impressions. Deviations ≥100 µm across the complete arch may lead to inaccurate fitting of the definitive restoration in the maxillary and mandibular jaws, which can be particularly problematic in cases of large rehabilitations. Single-unit restorations up to 4-unit FPDs can be fabricated from digital impression data. The clinical success of these restorations has been confirmed in several studies.[2,25,48,49]

Digital intraoral impression systems continue to develop rapidly. The precision of older scanning systems (LAV, CER, ITE) is lower compared with newer systems (T-Def, OC, TRI, and TRC). The precision of complete-arch scans approaches or exceeds that of some conventional impression materials (POE, ALG). Patients report greater comfort when digital impression systems are used, and for some indications, the time expenditure is lower than for conventional impression techniques.[50] This shows the potential of digital intraoral impression systems as an equivalent or better alternative to traditional conventional impression procedures. In this study, only fully dentured complete jaws were scanned. The influence of larger edentulous parts of the jaw cannot be determined from this study design. Yet, these parts with little geometric information might lead to larger deformation of the scan and further investigation is needed. To our knowledge, in vivo studies evaluating the impression accuracy of partly or fully edentulous jaws have not yet been published.

CONCLUSION

Within the limitations of this in vivo study, all of the digital impression systems were capable of measuring complete dental arches. However, different conventional impression materials and digital impression systems differ significantly according to the complete-arch precision.

Highly accurate conventional impression materials provide significantly higher precision than current digital impression systems. The digital impression systems did not differ significantly in terms of complete-arch scan precision. Impressions made with irreversible hydrocolloid material are significantly less precise than digital impressions. No advantage in accuracy is gained by digitizing a conventional impression directly compared with using the conventional pouring procedure.

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TABLES

Table 1. Impression procedure for conventional impression material

Material	Setting time	Storage time	Tray adhesive	Impression method
POE	10 min	8 hours	yes	monophasic
VSE	10 min	8 hours	yes	2 viscosities
VSES	10 min	8 hours	yes	monophasic
VSES-D	10 min	8 hours	Yes	monophasic, digitization with extraoral impression scanner
ALG	5 min	10 min	no	monophasic

Table 2. Impression procedure for digital impression systems

System	Surface conditioning	Scanning principle	Scan procedure	STL-Export
CER	Powder	Active Triangulation, Single image shot	Buccal, occlusal and oral image from every tooth, camera flip at midline	Direct via CEREC-Connect portal
OC	None	Active Triangulation, continuous images	scan path: Occlusal, buccal and oral direction of one quadrant, adding of second quadrant with same procedure	Direct via CEREC Connect portal
ITE	None	Confocal laser, single image shot	Guided scanning according to software instructions	After uploading to Cadent Center and central postprocessing
LAV	Dusting	Wavefront sampling, continuous images	scan path: Occlusal, buccal and oral direction of one quadrant, adding second quadrant with same procedure	After uploading to 3M Connection Center and central postprocessing

T-Def	Dusting	Wavefront sampling, continuous images		After uploading to 3M Connection Center and central postprocessing
TRI	None	Confocal Laser, continuous images	Scanning according to manufacturer's manual for complete-arch impression	Direct via 3Shape Communicate Portal
TRC	None	Confocal Laser, continuous images	Scanning according to manufacturer's manual for complete-arch impression	Direct via 3Shape Communicate Portal

Table 3. Precision (Mean, Standard Deviation, Median, Confidence interval, Minimum, Maximum values) of conventional and digital impression (µm)

	Mean (SD)	Median	95% Confidence interval	Minimum	Maximum
VSE	17.7 (5.1)	17.5	(14.6,20.2)	10.0	28.0
VSES	18.3 (8.8)	18.0	(16.1,20.5)	19.0	23.0
VSES-dig	36.7 (3.8)	35.5	(34.0,39.4)	32.0	42.5
POE	34.9 (8.8)	35.0	(29.6,40.2)	19.0	54.0
ALG	162.2 (71.3)	146.5	(122.7,201.7)	84.0	337.1
CER	56.4 (15.4)	53.5	(47.9,64.9)	35.7	86.4
OC	48.6 (11.6)	45.5	(42.2,55.0)	34.3	72.0
LAV	82.8 (39.3)	76.5	(61.0,104.6)	37.0	170.5
T-Def	59.7 (29.4)	52.4	(43.4,76.0)	24.9	120.1
ITE	68.1 (18.9)	65.9	(57.6,78.6)	39.2	103.9
TRI	47.5 (21.4)	41.9	(35.7,59.4)	25.5	89.3
TRC	42.9 (20.4)	41.1	(31.6,54.2)	25.2	105.7

LEGENDS

Fig. 1. Statistical significance between test groups according to 1-way Anova with post hoc Bonferroni (α=.05).

	VSE	VSES	VSES-dig	POE	ALG	CER	OC	LAV	T-Def	ITE	TRI	TRC
SE		o	o	o	XXX	X	o	XXX	XX	XXX	o	o
SES	o		o	o	XXX	o	o	XXX	X	XX	o	o
SES-dig	o	o		o	XXX	o	o	XX	o	o	o	o
OE	o	o	o		XXX	o	o	XX	o	o	o	o
LG	XXX	XXX	XXX	XXX		XXX	XXX	XXX	XXX	XXX	XXX	XXX
ER	X	o	o	o	XXX		o	o	o	o	o	o
C	o	o	o	o	XXX	o		o	o	o	o	o
AV	XXX	XXX	XX	XX	XXX	o	o		o	o	o	X
-Def	XX	X	o	o	XXX	o	o	o		o	o	o
E	XXX	XX	o	o	XXX	o	o	o	o		o	o
RI	o	o	o	o	XXX	o	o	o	o	o		o
RC	o	o	o	o	XXX	o	o	X	o	o	o	

O= No statistical difference

X= statistical difference *P*<.05

XX= statistical difference *P*<.01

XXX= statistical difference *P*<.001

Fig. 2. Precision of conventional and digital complete arch impression in vivo (μm).

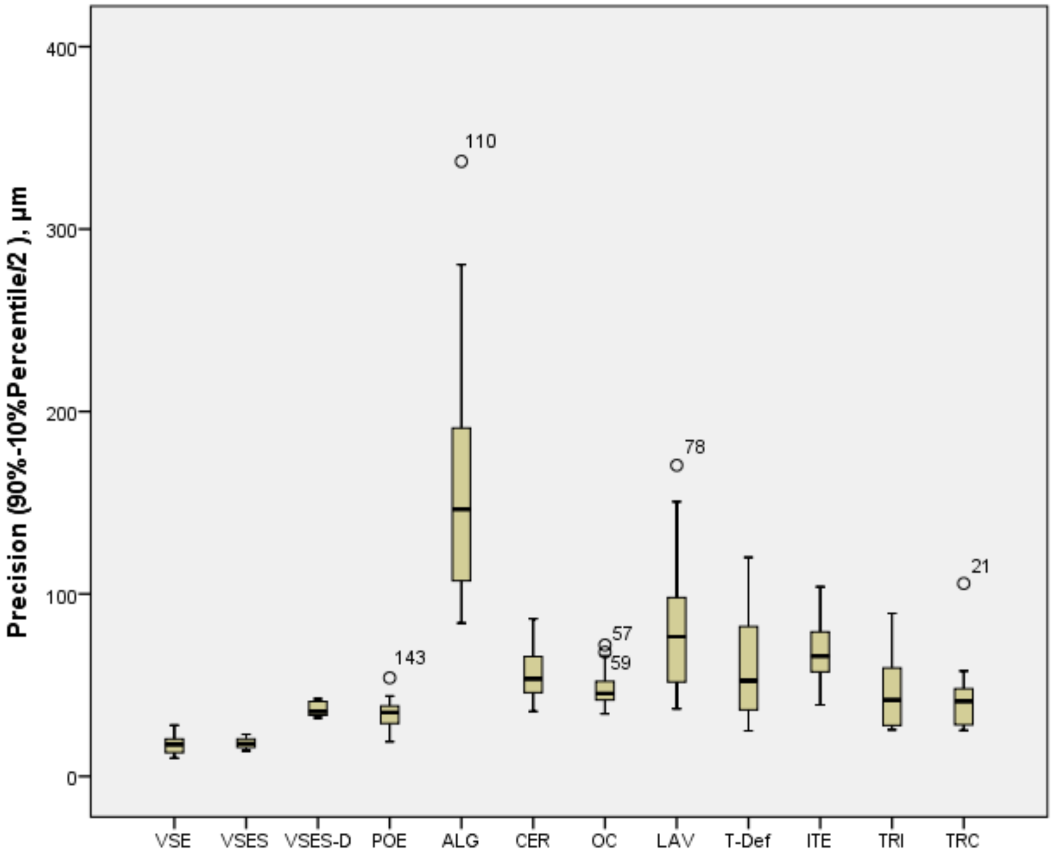
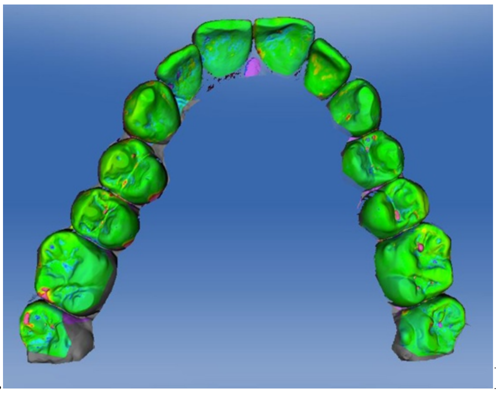
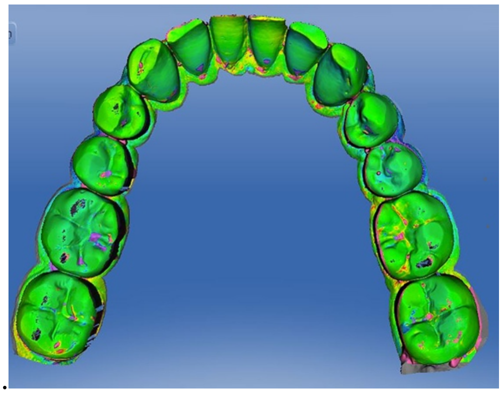
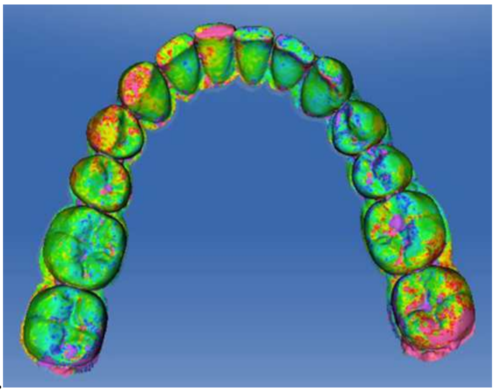
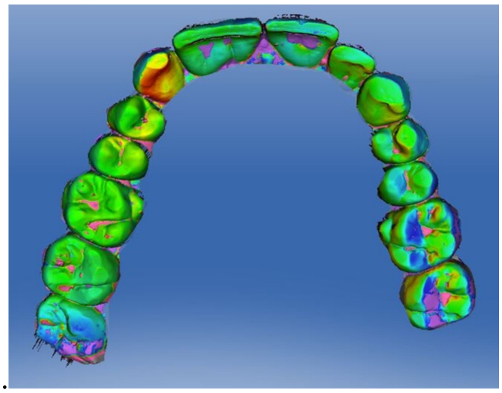


Fig. 3Difference pattern between repeated impression (precision); color graded from -100µm (purple) to +100µm (red). A, VSE. B, VSES. C, VSES-D. D, POE. E, ALG. F, CER. G, OC. H, LAV. I, T-Def. K, ITE. L, TRI. M, TRC. .

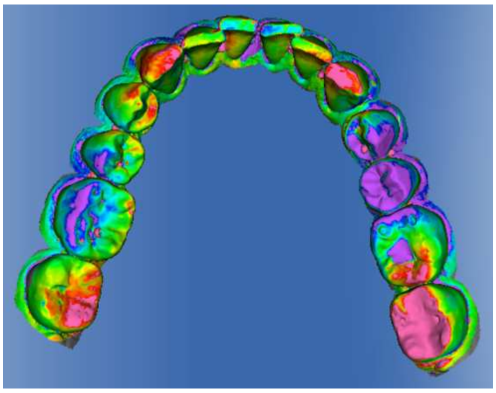
A. 

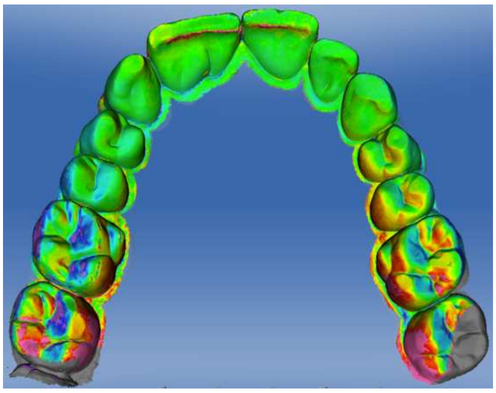
B. 

C. 

D. 

E.



F. 

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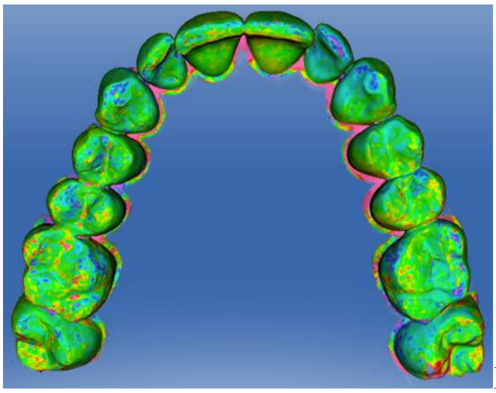
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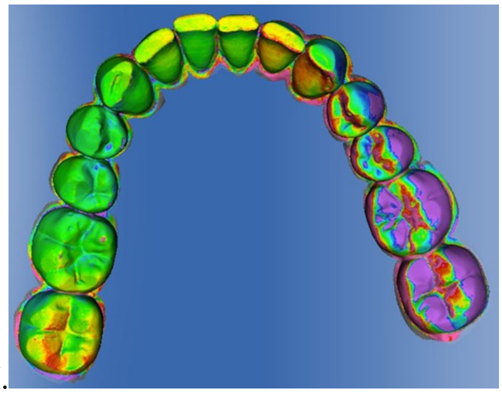
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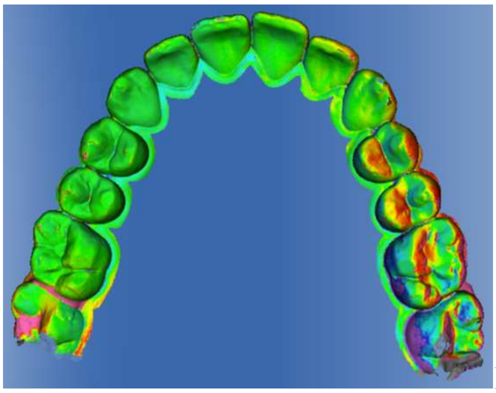
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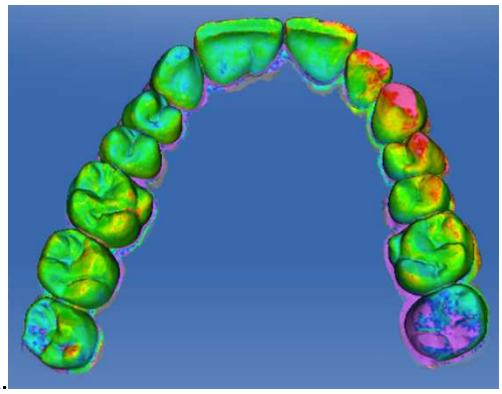
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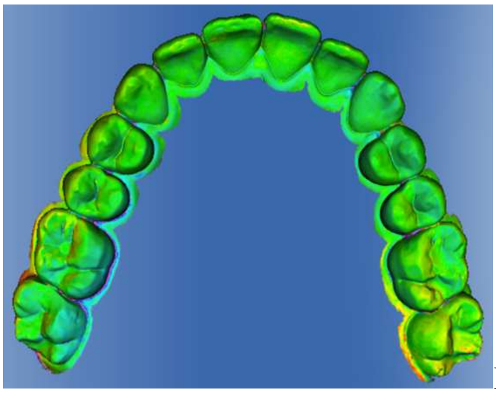
M.