Year: 2016

In vivo precision of conventional and digital methods for obtaining quadrant dental impressions

Ender, Andreas; Zimmermann, Moritz; Attin, Thomas; Mehl, Albert

Abstract: OBJECTIVES Quadrant impressions are commonly used as alternative to full-arch impressions. Digital impression systems provide the ability to take these impressions very quickly; however, few studies have investigated the accuracy of the technique in vivo. The aim of this study is to assess the precision of digital quadrant impressions in vivo in comparison to conventional impression techniques. MATERIALS AND METHODS Impressions were obtained via two conventional (metal full-arch tray, CI, and triple tray, T-Tray) and seven digital impression systems (Lava True Definition Scanner, T-Def; Lava Chairside Oral Scanner, COS; Cadent iTero, ITE; 3Shape Trios, TRI; 3Shape Trios Color, TRC; CEREC Bluecam, Software 4.0, BC4.0; CEREC Bluecam, Software 4.2, BC4.2; and CEREC Omnicam, OC). Impressions were taken three times for each of five subjects (n = 15). The impressions were then superimposed within the test groups. Differences from model surfaces were measured using a normal surface distance method. Precision was calculated using the Perc$90_10 value. The values for all test groups were statistically compared. RESULTS The precision ranged from 18.8 (CI) to 58$ $Tray), with the highest precision in the CI, T-Def, BC4.0, TRC, and TRI groups. The deviation pattern varied distinctly dep$ $shot capture exhibited greater deviations at the tooth surface whereas high-frame rate impression systems differed more in$

DOI: https://doi.org/10.1007/s00784-015-1641-y

Originally published at:
Ender, Andreas; Zimmermann, Moritz; Attin, Thomas; Mehl, Albert (2016). In vivo precision of conventional and digital methods for obtaining quadrant dental impressions. Clinical Oral Investigations, 20(7):1495-1504.
DOI: https://doi.org/10.1007/s00784-015-1641-y

In vivo precision of conventional and digital methods for obtaining quadrant dental impressions

Andreas Ender[a], DMD; Moritz Zimmermann[a], Thomas Attin, Prof., DMD[b]; Albert Mehl[c], Prof., DMD

[a]Research Assistant, Clinic for Preventive Dentistry, Periodontology and Cariology; Division for Computerized Restorative Dentistry; Centre of Dental Medicine, University of Zürich

[b]Department Head, Clinic for Preventive Dentistry, Periodontology and Cariology; Centre of Dental Medicine, University of Zürich

[c]Department Head, Clinic for Preventive Dentistry, Periodontology and Cariology; Division for Computerized Restorative Dentistry; Centre of Dental Medicine, University of Zürich

Corresponding author:
Andreas Ender, DMD
Division for Computerized Restorative Dentistry, Center of Dental Medicine, University of Zürich, Plattenstrasse 11
8032 Zürich, Switzerland
E-mail: andreas.ender@zzm.uzh.ch
Phone: 0041 44 634 31 93
Fax: 0041 44 634 31 91

ABSTRACT

Objectives: Quadrant impressions are a commonly used alternative to full-arch impressions. Digital impression systems provide the ability to take these impressions very quickly; however, few studies have investigated the accuracy of the technique in vivo. The aim of this study is to assess the precision of digital quadrant impressions in vivo in comparison to conventional impression techniques
Materials and Methods: Impressions were obtained via two conventional (metal full-arch tray, CI and triple tray, T-Tray) and seven digital impression systems (Lava True Definition Scanner, T-Def; Lava Chairside Oral Scanner, COS; Cadent iTero, ITE; 3Shape Trios, TRI; 3Shape Trios Color, TRC; CEREC Bluecam, Software 4.0, BC4.0; CEREC Bluecam, Software 4.2, BC4.2; and CEREC Omnicam, OC). Impressions were taken three times for each of five subjects (n = 15). The impressions were then superimposed within the test groups. Differences from model surfaces were measured using a normal surface distance method. Precision was calculated using the Perc90_10 value. The values for all test groups were statistically compared.
Results: The precision ranged from 18.8 µm (CI) to 58.5 µm (T-Tray), with the highest precision in the CI, T-Def, BC4.0, TRC, and TRI groups. The deviation pattern varied distinctly depending on the impression method. Impression systems with single-shot capture exhibited greater deviations at the tooth surface whereas high-frame-rate impression systems differed more in gingival areas. Triple tray impressions displayed higher local deviation at the occlusal contact areas of upper and lower jaw.

Conclusions: Digital quadrant impression methods achieve a level of precision, comparable to conventional impression techniques. However there are significant differences in terms of absolute values and deviation pattern.
Clinical Relevance: With all tested digital impression systems, time efficient capturing of quadrant impressions is possible. The clinical precision of digital quadrant impression models is sufficient to cover a broad variety of restorative indications. Yet the precision differs significantly between the digital impression systems.

Keywords
CAD/CAM, digital impression, quadrant impression, precision, accuracy

INTRODUCTION

In dental practice, single unit restorations and small fixed partial dentures (FPDs) are common indications. For these cases, quadrant impression techniques can be used to produce dental casts. The dual-arch quadrant impression technique was introduced in 1971 and its accuracy has been thoroughly demonstrated [1-9].
The basic principle is to capture the preparation site, the neighboring teeth, and the opposing arch in a single impression step. This technique is restricted to posterior regions of the dental arch and requires a well-established interocclusal relationship [10]. This reduces the number of impressions to one and fixes the interocclusal relationship of the upper and lower dental arch in a single impression tray. The conventional dual arch tray technique can produce dental casts with comparable accuracy to full-arch impressions [1, 4, 10, 11].
The digital intraoral impression was introduced for the indication of single unit restorations [12]. The capture of the intraoral situation by means of 3D cameras made the immediate creation of a digital model and on-site production of restoration possible [13, 14].
In recent years, the accuracy of these impression systems has improved to capture larger areas up to full-arch impressions with acceptable accuracy [15-17].
The advantage of digital impression is the time saved, especially when capturing smaller parts of the dental arch. Restricting the impression to quadrants significantly reduces the time needed compared to full-arch impressions [18]. The intraoral capture of the occlusal relationship is highly reproducible [19]. In addition, registration of the interocclusal relationship without placing impression material inside the patient’s mouth reduces the possibility of eccentric movements.
The accuracy of dental impressions is particularly crucial in restorative dentistry [1, 20, 21]. To date, few investigations have addressed the impression accuracy of digital impressions in vivo [22], although several in vitro studies have described the accuracy of digital impression [15, 16, 23, 24]. For accuracy measurements, trueness is difficult to measure in vivo. For trueness measurements, the real dimensions of the test subject must be known (ISO 5725-1) [21, 25]. This is possible for small geometrical parts, which are machined with a high trueness, or for real dental geometry, obtained with high accuracy reference scanners. Inside the patient’s mouth, however, these methods are not applicable. Therefore, in vivo investigations are typically performed as precision measurements from repeated impressions [23, 24, 26]. Precision is the second parameter of accuracy and reflects the reproducibility of different impression methods [24, 27]. However, in combination with in vitro trueness and precision measurements, it is possible to characterize the accuracy of the impression method. In vivo evaluations of accuracy are often performed by measuring the fit of the final

restoration [22, 27-31]. In these studies, digital impression systems show equal or superior fit compared to conventional restorations. This kind of accuracy measurement takes the entire production process of the restoration into account and does not necessarily indicate exclusive impression accuracy.
The accuracy of digital impression systems is best assessed by superimposing the entire model surface [16, 32-34]. In this procedure, deviations between the impressions at each surface point are determined from computed 3D distances [15, 16, 23, 34, 35].
Based on earlier studies, the aim of this study was to evaluate the precision of several impression methods for generating quadrant dental impressions in a clinical in vivo situation. To determine the typical deviation pattern associated with each impression method, the deviations were visually analyzed. The null hypothesis was that there were no significant differences between the precision of the impression methods for quadrant impressions.

MATERIALS AND METHODS

Subject recruitment

Five subjects with full dentition were selected from a voluntary collective. Written informed consent was obtained from all study participants. The ethical commission approved the study. Each impression method was tested in each subject's upper or lower jaw, chosen at random. Three jaw impressions were made for each impression method. Table 1 summarizes the impression methods and associated procedures.

Conventional impressions

Two groups of conventional impression methods were used. First, full-arch metal stock impression trays (ASA Permalock, ASA Dental, Bozzano, Italy) were used with a vinylsiloxanether impression material (Identium, Kettenbach, Eschenburg, Germany) in a heavy body/light body sandwich impression technique (CI). Second, stock triple trays (Triple Tray, Premier Dental Products, Plymouth Meeting, USA) were used to simultaneously capture upper and lower quadrants in maximum intercuspidation with a vinylsiloxanether impression material (Identium) via a sandwich impression technique.
All impressions were disinfected for 10 min (Impresept, 3M ESPE, Seefeld, Germany), stored for 8 hours at ambient room temperature, and then cast with type IV dental stone (Fujirock EP, GC Europe, Leuven, Belgium). Impression trays were removed from the stone model after 40 min. The models were stored at room temperature (23 °C) and ambient humidity for 48 hours and then scanned with an extraoral reference scanner (inEOS X5, Sirona Dental Systems, Bensheim, Germany). The scanned model files were exported in the STL data format.

Digital impressions

The following digital impression systems were evaluated: True Definition Scanner (T-Def; 3M ESPE); Lava COS (LAV; 3M ESPE, Seefeld, Germany); Cadent iTero (ITE; Cadent LTD., Or Yehuda, Israel); 3Shape Trios (TRI; 3Shape, Copenhagen Denmark); 3Shape Trios Color (TRC; 3Shape); CEREC Bluecam with CEREC Software 4.0 (BC 4.0; Sirona Dental Systems); CEREC Bluecam with CEREC Software 4.2 (BC 4.2; Sirona Dental Systems); and

CEREC Omnicam (OC; Sirona Dental Systems).
The impressions were generated according to manufacturer instructions (T-Def, LAV, ITE, TRI, and TRC) or using in-house protocols (CER, OC). The impression methods were applied consecutively for all patients at three separate appointments. The first appointment involved all systems with surface pre-treatment (BC 4.0, BC 4.2, COS, T-Def). The oral surfaces were pre-treated using a matting powder (Sirona OptiSpray, Sirona Dental Systems) in the BC 4.0 and BC 4.2 groups and a dusting powder (Lava COS Powder, 3M ESPE) in the LAV and T-Def group. This was done separately for each scan. The second appointment included all scans for non-powder systems (TRC, TRI, ITE, OC). At the third appointment, conventional impressions were taken for the CI and T-Tray groups. The sequence of patients was random for every test group. In groups BC 4.0 and BC 4.2, all captured images were checked for visibly blurred images. These images were removed and retaken during the impression procedure.
The scan data were directly exported from the acquisition unit (BC 4.0, BC 4.2, OC), exported after being uploaded to a communication portal (TRI and TRC) or exported after being subjected to post-processing (ITE, LAV, T-Def). Finally, all scan data were available as STL data files (Table 1).

Precision measurement

The STL data from each test group were pre-superimposed using CAD software (Geomagic Qualify 12, 3DSYSTEMS, Rock Hill, SC, USA) according to a best-fit algorithm in order to align the orientations of the coordinate systems. The models were trimmed to the dental arch, including the tooth surface and about 1 mm of attached gingiva. The trimmed models were again saved in STL file format.
For deviation measurements, the impression data within each test group were superimposed using special diagnostic software (OraCheck 2.01, Cyfex AG, Zürich, Switzerland), which uses a best-fit algorithm to align two surfaces. The software calculates the distance and direction between the STL vertex point of model 1 and the closest surface point of model 2 using a signed normal surface neighbor method. "Signed" means that the measured distance is negative if the surface of model 2 is inside the surface of model 1 and positive if it is outside. This procedure was repeated for each STL triangle point in model 1. Depending on the STL resolution of the digital models, the software computes between 25,000 and 50,000 distances per superimposition. With three impressions in every test group, three superimpositions were made for each impression method per patient. The distance data were saved as a CSV file and imported into a statistical program (SPSS21, IBM Corp, IL, USA). The 10^{th} and 90^{th} percentiles of the measured distances were calculated as a measure for the deviation between two aligned models. The highest 10% and lowest 10% of values were ignored. The positive and negative limits of the remaining 80% surface distance values were totaled and then divided by 2. After computing the Perc90_10 value of all superimpositions ($n = 15$) for each test group, the means, medians, and standard deviations were calculated (SPSS21, IBM Corp.). In addition, a color difference map of each superimposition was saved as a screenshot for visual analysis of the deviation pattern.

Statistical analysis

Statistical analysis of all Perc90_10 values from every test group was done with SPSS (IBM SPSS Statistics 21, IBM, NY, USA). The normal distribution was determined using the Kolmogorov–Smirnoff test. Levene's test was used to assess the equality of variances for all test groups ($p < 0.05$). The Kruskal–Wallis test was used to assess differences between test groups. Statistical differences between test groups were analyzed via one-way ANOVA with post hoc Dunett's T3 ($p < 0.05$).

RESULTS

The Perc90_10 values were not normally distributed in any group, according to the Kolmogorov–Smirnov test. Leven's test did not indicate any equality of variances ($p < 0.05$). The Kruskal–Wallis test revealed statistical differences between the test groups ($p < 0.05$). Significantly different test groups were identified using post hoc Dunett T3 test. The results of the descriptive analysis are detailed in Table 2, and boxplots of each group are shown in Figure 1.

The precision of all groups is shown in Table 2 and Figure 2. Group CI had a mean precision of 18.8 ± 7.1 µm, the statistically highest precision of all groups, followed by group T-Def (21.7 ± 7.4 µm), TRI (25.7 ± 4.9 µm), TRC (26.1 ± 3.8 µm), and group BC 4.0 (34.2 ± 10.5 µm). Groups BC 4.2 (43.3 ± 19.6 µm), OC (37.4 ± 8.1 µm), COS (47.7 ± 16.1 µm), ITE (49.0 ± 12.4 µm), and T-Tray (58.5 ± 22.8 µm) did not differ significantly. Table 3 shows the statistical differences between the test groups.

Figure 2 shows the typical deviation pattern between repeated quadrant scans within the test groups. Group CI displayed few deviations across the entire model surface. Larger local deviations were caused either by air bubbles in the impression material or the tearing effects of the impression material in the gingival area. Group T-Tray displayed completely different deviation areas. There were large local deviations at the occlusal surface of the teeth. These spots are visible in upper and lower jaw models. Figure 3 shows one impression with the corresponding deviations. This demonstrates that the larger deviations in the models are located in the contact areas with little or no impression material between upper and lower jaw. Group T-Def displayed few deviations at the interproximal parts of the teeth. No deformation of the dental arch itself is visible, with respect to the repeated scans. The same deviation pattern is visible in group COS, yet with more local deviations at the buccal and oral surface of single teeth. Group ITE revealed local spots of larger deviations up to 80 µm, especially at the cusps of the teeth. Group TRI displayed almost no deviations at the tooth surface, but some at the gingival margin. Group TRC displayed the same deviation pattern as group TRI. Group BC 4.0 displayed local deviations at certain surfaces of the teeth, but with magnitudes up to 60 µm. BC 4.0 also had artifacts at the gingival margin, causing irregular surface areas within the 3D model. This includes "spikes" due to the triangulation process with scattered surface points. In group BC 4.2, local higher areas of deviation were visible at certain areas of single teeth, similar to group ITE. Group OC displayed high reproducibility of the tooth surface, but a higher variance in capturing the gingival area and proximal parts of the dental arch. In general, the maximum deviations in all groups did not exceed 100 µm. No deformation of the dental arch was visible, as the deviations were always located in specific parts of the quadrant. These areas were located at the tooth surface for groups COS, ITE, BC 4.0, and BC 4.2. In contrast, groups T-Def, TRI, TRC, and OC displayed deviations at the proximal areas and gingival margins.

DISCUSSION

The aim of this study was to assess the precision of digital quadrant impressions in-vivo in comparison to conventional impression techniques. In conventional impression methods, this is possible with the use of single or double-arch trays [1-3]. However, digital intraoral impression of small parts of the dental arch in cases of individual tooth restoration is a fast procedure compared to conventional impression taking [18, 36]. Combined with a direct digital workflow, immediate restoration production is possible [37].

Based on the results of this study, it can be concluded that the null hypothesis (all impression methods are equally precise) must be rejected. The different impression systems displayed significantly different levels of precision. However, all the digital impression systems reached accuracy levels clinically sufficient for restoration production, and the clinical success of different digital impression systems has been demonstrated in several studies [22, 38, 39].

The conventional impression method with rigid metal trays for a single arch displayed the highest precision. This confirms former in vitro evaluations of this method. Conversely, the quadrant sized impression with triple trays displayed the lowest precision. The locally large deviations are located in the contact areas of upper and lower arch (Fig. 3). In this region, only the separating net of the tray remains as the impression boundary. The flexible net is deformed during the impression itself, when the patient closes into the maximum intercuspidation and during the pouring process, caused by the weight of the casting material. Areas with impression material between upper and lower arch do not show this deformation. Previous studies focused on the measurement of preparations or single target points [1, 4, 6]. As the prepared tooth is covered by impression material in the triple tray, this effect dos not occur in these areas.

In this study, newer systems like the T-Def, TRI, and TRC delivered more precise impressions than older systems like ITE, BC, or COS, although the differences were not always significant. This demonstrates the ongoing development of the CAD/CAM technique in hardware and software.

In a former in vitro study, measurement of conventional and digital impression systems shows that trueness, precision and their standard deviations are equivalent [16]. Therefore it can be assumed that there is no significant systematic error inherent to digital impression systems. Both precision and trueness are statistically distributed around the real value in repeated measurements. In vivo impressions are influenced by many more co-factors than in vitro set-ups. This might lead to less accurate impressions in terms of both trueness and precision. Assuming again precision and trueness deviations have equivalent positive and negative values and there is no systematic error inherent to the impression procedure, the difference between in vitro and in vivo precision gives an approximation of the difference between in vitro and in vivo trueness, provided the same measurement protocol is used. However, this is naturally not proof of a linear correlation between these two variables.

Several studies have evaluated the trueness and precision of digital impressions, focusing on single or FPD preparations [21, 24, 35, 40, 41]. In these smaller areas of the dental arch, digital impressions show high accuracy and are at least on a par with the conventional impression methods. The quality of the digital workflow is based on intraoral digital impression data. Both the preparation itself and the entire dental arch must be accurate. Otherwise, occlusion and fit of the restoration will be incorrect. Syrek et al. showed that both are possible with digital impression systems [22].

The Perc90_10 value was used in this study as the range, and by definition 80% of the model differences were located within it. In general, maximum and minimum values are critical when comparing complex 3D surfaces. This is caused by several factors, such as a) post processing surface data, b) the difference analysis methods, c) the normal vector orientation,

d) the different surface resolutions, and e) artifacts.

- Post processing surface data: The scanned surface data are processed by different software algorithms to extract the final digital model surface. These include algorithms to align the single views, eliminate outlier points, and smooth the surface. In this study, the raw data for groups Tri, TRC, BC 4.0, BC 4.2, and OC were not changed. Conversely, for groups T-Def, COS, and ITE, the data were sent to a central processing facility belonging to the manufacturing company, where the final model was computed and checked. In these cases, it is possible the raw data were modified, e.g., removal of scattered measuring points. In total there might exist different hints of data post processing and resolution so that the difference analysis should be treated carefully.

  In addition, some scanning software fills in non-scanned areas or defects within the model. The distance measurements in those non-captured areas, filled or not, often result in an overestimation of the real surface distances.
- Difference analysis method: The OraCheck difference analysis is based on a difference measurement in normal vector direction from model 2 to model 1. For each STL triangle point from model 2, the distance in the normal direction to the STL triangle surface of model 2 is computed. In contrast, other difference analysis software calculates the distance from an STL triangle point in model 1 to the nearest STL triangle point in model 2. In both methods, distance outlier data can be computed if complex dental tooth surface is slightly displaced. These outlier data do not display the closest distance between the surfaces.
- Normal vector orientation: To define the nearest neighbor, a normal vector from the surface (perpendicular to the model surface) is computed. Especially at the margin of an STL model or at sharp edges, this normal vector can vary due to the orientation of the triangle. Additionally, trimming the digital models to 1mm below the tooth surface does not result in a similar margin in all models, because of the different STL triangle configuration. Therefore, difference analysis in these areas often overestimate the real distance between the two models. Trimming model 1 might cut away surface areas that are closer to model 2 at the specified measurement margin. Therefore, with two trimmed models in these margin areas, larger distances can occur.
- Different surface resolution: The digital model surface is described via STL language. The size of the STL triangle is different between different scanning systems and even multiple scans with the same system. In every scan, due to the manual handling of the intraoral camera, surfaces are captured with different data density. This will lead to different STL triangle resolution at the same surface. Comparing these different STL triangle resolutions can result in false surface displacement values.
- Artifacts: All impression systems can produce artifacts, e.g., air bubbles or tearing effects in the interproximal areas in conventional impressions, outlier surface points from digital image impression, or model defects from registration errors. When assessing the global accuracy of a dental model, it is unclear whether these artifacts have to be taken into account for comparison. Focusing on the overall precision of digital and conventional quadrant impressions in this study, these artifacts were deemed less important. Of course, this can be changed when investigating other aspects of dental impression, e.g., local preparation accuracy.

The handling of these factors were different among the research groups. For some, the raw data was “cleaned” before creating the model surface [42]. Others used the RMS value for model differences, describing 66% of the difference values [23]. The computing of mean positive and mean negative values have also been described [34]. The use of the 10th and 90th percentiles is based on long experience with distance measurement of large surfaces [16, 25, 35, 43].

The results of this study can be compared to the in vitro results of previous studies. Luthard et al. showed a mean deviation (trueness) of 27.9 µm of three teeth with an RMS error computation [23]. Ender et al. reported an in vitro precision of 14.3 µm for BC [35]. The higher deviations in the in vivo study are reflective of patient-relevant factors such as powdering, patient movement, and limited space [42].

In general, near-perfect scanning is necessary for all digital impression systems to attain optimal results [43]. The use of powder has been debated in several studies [23, 44, 45]. In terms of precision, this study revealed no negative effect of powder usage on the accuracy of digital impressions. Group T-Def, which included powder usage, showed the same high accuracy as groups TRI and TRC, where no surface pretreatment was carried out. Groups BC 4.0 and BC 4.2 with surface treatment did not show lower precision than group OC without powdering.

However, in the in vivo environment, the powdered surface is frequently disturbed mechanically by the camera or soft tissue. This can result in scanning artifacts, as seen in group BC 4.0. These artifacts might also be responsible for the very different results in the study published by Patzelt et al., who reported maximum deviations of up to 4.8 mm in group BC [15].

The different deviation patterns of the digital intraoral scanning systems can be attributed to the capturing techniques. Single shot acquisition (ITE, BC 4.0, BC 4.2) requires an image which is kept still for the period of data capture. During that time, the camera must be held in place. This is quite difficult in in vivo situations. Patient or dentist movement, improper support of the camera, and tongue or cheek pressure can lead to displacement of the camera during capture. This movement leads to artifacts and incorrect surface data in the single 3D image, resulting in local deviations at a specific model part. Software can notice such movement to a certain degree, rejecting the 3D image and recapturing the impression. The quality of the software is therefore very important in impression accuracy. Groups BC 4.0 and BC 4.2 showed that different software versions can lead to different results, even with the same hardware.

In contrast, high framerate impression systems like TRI, TRC, or OC display larger displacements in gingival and interproximal areas. This may be because these cameras need an optimal viewing angle to the surface for optimal data capture. Therefore, the interproximal area with small opening angles can only be acquired with reduced data quality compared to the occlusal buccal or oral tooth surface. In other areas, proper camera rotation is limited by patient anatomy. Additionally, intraoral surfaces absorb and reflect the projected light differently. Enamel has different light reflecting properties than gingival tissue. This can be an additional factor, leading to larger surface displacements with non-powder scanning systems. The use of powder, on the other hand, allows for more equal reflection of the projected light. The reflected measurement patterns are of better quality, particularly in areas with high inclinations. Among others, this effect might explain some differences between BC 4.0 and OC in the interproximal areas.

Dental companies expend a lot of effort further improving the quality of digital intraoral

impression. Yet there are specific issues for every scanning system which still need to be solved. Generating the virtual model is always a combination of the hardware of the physical scanning method itself and the software which extracts and processes the relevant data and performs the registration between the individual views. Accordingly, there is no proof or hint whether the different measuring principles are responsible for different kinds of deviation patterns or for specific intrinsic problems. Based on the present results, we guess that the algorithms used for the calculation and further processing of the raw scan data are more crucial to the effects found in this study.
Digital intraoral impression systems continue to undergo rapid development. Patients report greater comfort when digital impression systems are used, and for some indications the time expenditure is lower compared to conventional impression techniques [18]. This shows the potential of digital intraoral impression systems as an equivalent or superior alternative to traditional conventional impression procedures.

CONCLUSION

Within the limitations of this in vivo study, all of the digital impression systems were capable of measuring quadrant impression with clinically satisfying precision. There are differences in precision between different digital impression systems, but while statistically significant, they all fall within a range which allows the successful production of restorations in the digital workflow.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

COMPLIENCE WITH ETHICAL STANDARDS

All authors declare that they have no conflict of interest. All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

REFERENCES

1. Wostmann B, Rehmann P and Balkenhol M (2009) Accuracy of impressions obtained with dual-arch trays. Int J Prosthodont 22:158-160.
2. Small BW (2012) Revisiting impressions using dual-arch trays. Gen Dent 60:379-81.
3. de Lima LM, Borges GA, Junior LH and Spohr AM (2014) In vivo Study of the Accuracy of Dual-arch Impressions. Journal of international oral health : JIOH 6:50-5.
4. Reddy JM, Prashanti E, Kumar GV, Suresh Sajjan MC and Mathew X (2009)

A comparative study of inter-abutment distance of dies made from full arch dual-arch impression trays with those made from full arch stock trays: an in vitro study. Indian journal of dental research: official publication of Indian Society for Dental Research 20:412-7. doi: 10.4103/0970-9290.59437
5. Goldstein JH and Werrin SR (2007) InLab CEREC restorations from a dual-arch impression. Dent Today 26:62, 64.
6. Ceyhan JA, Johnson GH, Lepe X and Phillips KM (2003) A clinical study comparing the three-dimensional accuracy of a working die generated from two dual-arch trays and a complete-arch custom tray. J Prosthet Dent 90:228-34. doi: 10.1016/S0022391303002373
7. Cayouette MJ, Burgess JO, Jones RE, Jr. and Yuan CH (2003) Three-dimensional analysis of dual-arch impression trays. Quintessence Int 34:189-98.
8. Abrams SH (2002) Benefits of the dual-arch impression technique. Accurate impressions and fewer than 1% remakes. Dent Today 21:56-9.
9. Breeding L and Dixon D (2000) Accuracy of casts generated from dual-arch impressions. J Prosthet Dent 84:403-407. doi: 10.1067/mpr.2000.110266
10. Cayouette M, Burgess J, Jones RJ and Yuan C (2003) Three-dimensional analysis of dual-arch impression trays. Quintessence Int 34:189-198.
11. Larson T, Nielsen M and Brackett W (2002) The accuracy of dual-arch impressions: a pilot study. J Prosthet Dent 87:625-627.
12. Mormann W (2006) The evolution of the CEREC system. J Am Dent Assoc 137 Suppl:7S-13S.

13. Reich S, Peltz I, Wichmann M and Estafan D (2005) A comparative study of two CEREC software systems in evaluating manufacturing time and accuracy of restorations. Gen Dent 53:195-198.
14. Mattiola A, Mormann W and Lutz F (1995) The computer-generated occlusion of Cerec-2 inlays and onlays. Schweiz Monatsschr Zahnmed 105:1284-1290.
15. Patzelt SB, Emmanouilidi A, Stampf S, Strub JR and Att W (2014) Accuracy of full-arch scans using intraoral scanners. Clin Oral Investig 18:1687-94. doi: 10.1007/s00784-013-1132-y
16. Ender A and Mehl A (2014) In vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int. doi: 10.3290/j.qi.a32244
17. Ender A and Mehl A (2013) Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent 109:121-8. doi: 10.1016/S0022-3913(13)60028-1
18. Patzelt SB, Lamprinos C, Stampf S and Att W (2014) The time efficiency of intraoral scanners: an in vitro comparative study. J Am Dent Assoc 145:542-51. doi: 10.14219/jada.2014.23
19. Jaschouz S and Mehl A (2014) Reproducibility of habitual intercuspation in vivo. J Dent 42:210-8. doi: 10.1016/j.jdent.2013.09.010
20. Christensen G (2008) Will digital impressions eliminate the current problems with conventional impressions? J Am Dent Assoc 139:761-763.
21. Chandran D, Jagger D, Jagger R and Barbour M (2010) Two- and three-dimensional accuracy of dental impression materials: effects of storage time and moisture contamination. Biomed Mater Eng 20:243-249. doi: 10.3233/

22. Syrek A, Reich G, Ranftl D, Klein C, Cerny B and Brodesser J (2010) Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 38:553-559. doi: 10.1016/j.jdent.2010.03.015
23. Luthardt R, Loos R and Quaas S (2005) Accuracy of intraoral data acquisition in comparison to the conventional impression. Int J Comput Dent 8:283-294.
24. Ziegler M (2009) Digital impression taking with reproducibly high precision. Int J Comput Dent 12:159-63.
25. Ender A and Mehl A (2014) Accuracy in dental medicine, a new way to measure trueness and precision. Journal of visualized experiments : JoVE. doi: 10.3791/51374
26. Flügge TV, Schlager S, Nelson K, Nahles S, Metzger MC (2013) Precision of intraoral dental impression with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop 144:471-478. doi: 10.1016/j.ajodo.2013.04.017
27. Seelbach P, Brueckel C and Wostmann B (2013) Accuracy of digital and conventional impression techniques and workflow. Clin Oral Investig 17:1759-64. doi: 10.1007/s00784-012-0864-4
28. Almeida e Silva JS, Erdelt K, Edelhoff D, Araujo E, Stimmelmayr M, Vieira LC and Guth JF (2014) Marginal and internal fit of four-unit zirconia fixed dental prostheses based on digital and conventional impression techniques. Clin Oral Investig 18:515-23. doi: 10.1007/s00784-013-0987-2
29. Keul C, Stawarczyk B, Erdelt KJ, Beuer F, Edelhoff D and Guth JF (2014) Fit of 4-unit FDPs made of zirconia and CoCr-alloy after chairside and labside digitalization--a laboratory study. Dent Mater 30:400-7. doi: 10.1016/j.dental.2014.01.006
30. Ng J, Ruse D and Wyatt C (2014) A comparison of the marginal fit of crowns fabricated with digital and conventional methods. J Prosthet Dent 112:555-60. doi: 10.1016/j.prosdent.2013.12.002
31. Wettstein F, Sailer I, Roos M and Hammerle C (2008) Clinical study of the internal gaps of zirconia and metal frameworks for fixed partial dentures. Eur J Oral Sci 116:272-279. doi: 10.1111/j.1600-0722.2008.00527.x
32. Brosky M, Pesun I, Lowder P, Delong R and Hodges J (2002) Laser digitization of casts to determine the effect of tray selection and cast formation technique on accuracy. J Prosthet Dent 87:204-209.
33. Delong R, Heinzen M, Hodges J, Ko C and Douglas W (2003) Accuracy of a system for creating 3D computer models of dental arches. J Dent Res 82:438-442.
34. Rudolph H, Luthardt R and Walter M (2007) Computer-aided analysis of the influence of digitizing and surfacing on the accuracy in dental CAD/CAM technology. Comput Biol Med 37:579-587.
35. Mehl A, Ender A, Mormann W and Attin T (2009) Accuracy testing of a new intraoral 3D camera. Int J Comput Dent 12:11-28.
36. Yuzbasioglu E, Kurt H, Turunc R and Bilir H (2014) Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. BMC oral health 14:10. doi: 10.1186/1472-6831-14-10

37. Jedynakiewicz N and Martin N (2001) CEREC: science, research, and clinical application. Compend Contin Educ Dent 22:7-13.
38. Arnetzl G (2006) Different Ceramic Technologies in a clinical long-term comparison. Book title. Quintessenz London
39. Reiss B and Walther W (2000) Clinical long-term results and 10-year Kaplan-Meier analysis of Cerec restorations. Int J Comput Dent 3:9-23.
40. Hoyos A and Soderholm K (2011) Influence of tray rigidity and impression technique on accuracy of polyvinyl siloxane impressions. Int J Prosthodont 24:49-54.
41. Ceyhan J, Johnson G, Lepe X and Phillips K (2003) A clinical study comparing the three-dimensional accuracy of a working die generated from two dual-arch trays and a complete-arch custom tray. J Prosthet Dent 90:228-234. doi: 10.1016/S0022391303002373
42. Rudolph, H, Graf, MR, Kuhn K, Rupf-Kohler S, Eirich A, Edelmann C, Quaas S and Luthardt RG (2015) Performance of dental impression materials: Benchmarking of materials and techniques by three-dimensional analysis. *Dent Mater J*. doi: 10.4012/dmj.2014-197.

43. Ender A and Mehl A (2013) Influence of scanning strategies on the accuracy of digital intraoral scanning systems. Int J Comput Dent 16:11-21.
44. Kim SY, et al (2013) Accuracy of dies captured by an intraoral digital impression system using parallel confocal imaging. Int J Prosthodont 26:161–163.

45. Ting-Shu S, Jian S (2014) Intraoral Digital Impression Technique: A Review. J Prosthodont doi: 10.1111/jopr.12218.

Table 1: Impression procedure for digital impression systems

System	**Surface conditioning**	**Impression procedure**	**STL export**
CI	Select proper standard metal tray	Sandwich impression technique with low and high viscosity material	After pouring and scanning with extraoral scanner
T-Tray	Select proper triple tray	Sandwich impression technique with low and high viscosity material	After pouring and scanning with extraoral scanner
T-Def	Dusting	Scan path: Occlusal, buccal, and oral direction of one quadrant	After post processing

COS	Dusting	Scan path: Occlusal, buccal, and oral direction of one quadrant	After post processing
ITE	None	Guided scanning according to software instructions	After post processing
TRI	None	Scanning according to manufacturer's manual	Direct via 3Shape Communicate Portal
TRC	None	Scanning according to manufacturer's manual	Direct via 3Shape Communicate Portal
BC 4.0 BC 4.2	Powder, Auto Capture set to "Strict" level	Buccal, occlusal, and oral image from every tooth	Direct
OC	None	Scan path: Occlusal, buccal, and oral direction of one quadrant	Direct

Table 2: Precision (Mean, Median, Confidence interval, Standard Deviation, Minimum, Maximum values, µm) of digital quadrant impressions

	Mean	Median	95% Confidence interval Lower Upper	Standard Deviation	Minimum	Maximum
CI	18.8	18.0	14.9 22.7	7.1	8.0	29.5
T-Tray	58.5	62.0	45.9 71.2	22.8	26.9	111.9
T-Def	21.8	20.8	17.7 25.9	7.4	13.2	39.9
COS	47.7	44.1	38.4 57.0	16.1	32.0	94.5
ITE	49.0	46.7	42.1 55.9	12.4	30.8	74.0
TRI	25.7	25.7	23.0 28.4	4.9	18.0	37.6
TRC	26.1	26.7	24.1 28.3	3.8	20.1	34.8

BC 4.0	34.2	33.6	28.4 40.1	10.5	19.0	52.6
BC 4.2	43.3	37.7	32.5 54.2	19.6	17.8	89.2
OC	37.4	35.5	32.9 42.0	8.1	26.9	56.1
	Mean	Median	95% Confidence interval Lower Upper	Standard Deviation	Minimum	Maximum
CI	18.8	18.0	14.9 22.7	7.1	8.0	29.5
T-Tray	58.5	62.0	45.9 71.2	22.8	26.9	111.9
T-Def	21.8	20.8	17.7 25.9	7.4	13.2	39.9
COS	47.7	44.1	38.4 57.0	16.1	32.0	94.5
ITE	49.0	46.7	42.1 55.9	12.4	30.8	74.0
TRI	25.7	25.7	23.0 28.4	4.9	18.0	37.6
TRC	26.1	26.7	24.1 28.3	3.8	20.1	34.8
BC 4.0	34.2	33.6	28.4 40.1	10.5	19.0	52.6
BC 4.2	43.3	37.7	32.5 54.2	19.6	17.8	89.2
OC	37.4	35.5	32.9 42.0	8.1	26.9	56.1

Table 3: Significance levels between test groups according to Kruskal-Wallis with post hoc Dunnet-T3 test. Significant different groups are marked with (x). Significance level was set to $p < 0.05$.

CI						
T-Tray	x					
T-Def		x				
COS	x		x			
ITE	x		x			
TRI		x		x	x	

TRC		x			x	x				
BC 4.0	x	x	x							
BC 4.2	x		x							
OC	x		x			x	x			
	CI	T-Tray	T-Def	COS	ITE	TRI	TRC	BC 4.0	BC4.2	OC

LEGENDS

Figure 1:

Boxplot of precision deviations between all test groups related to quadrant impression. The box represents the range of 50% of the difference measurements. The bar within the box represent the mean precision of the test group using the Perc90_10 value. Circles (°) represent outlier difference measurements (more than 1.5 times away from box width). Asterisks (*) represent extreme values (more than 3 times away from box width.

Figure 2:

Typical deviation pattern between repeated in vivo quadrant impressions in all test groups: a) CI, b) T-Tray, c) T-Def, d) COS, e) ITE, f) TRI, g) TRC, h) BC 4.0, i) BC 4.2, k) OC
The deviation range is color-coded from -50 (purple) to +50 (red) µm. Green surface shows area with no deviation, red (positive) and purple (negative) areas show deviations between repeated scans within the test groups.

Figure 3:

Correlation between material thickness and deformation with triple tray impressions.
The deformation of the final cast is highly correlated to occlusal contact areas, where the impression tray net is not stabilized by the impression material.