Comparison of Accuracy Between a Conventional and Two Digital Intraoral Impression Techniques

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Purpose: To compare the accuracy (ie, precision and trueness) of full-arch impressions fabricated using either a conventional polyvinyl siloxane (PVS) material or one of two intraoral optical scanners. Materials and Methods: Full-arch impressions of a reference model were obtained using addition silicone impression material (Aquasil Ultra; Dentsply Caulk) and two optical scanners (Trios, 3Shape, and CEREC Omnicam, Sirona). Surface matching software (Geomagic Control, 3D Systems) was used to superimpose the scans within groups to determine the mean deviations in precision and trueness (μm) between the scans, which were calculated for each group and compared statistically using one-way analysis of variance with post hoc Bonferroni (trueness) and Games-Howell (precision) tests (IBM SPSS ver 24, IBM UK). Qualitative analysis was also carried out from three-dimensional maps of differences between scans. Results: Means and standard deviations (SD) of deviations in precision for conventional, Trios, and Omnicam groups were 21.7 (± 5.4), 49.9 (± 18.3), and 36.5 (± 11.12) μm, respectively. Means and SDs for deviations in trueness were 24.3 (± 5.7), 87.1 (± 7.9), and 80.3 (± 12.1) μm, respectively. The conventional impression showed statistically significantly improved mean precision ($P < .006$) and mean trueness ($P < .001$) compared to both digital impression procedures. There were no statistically significant differences in precision ($P = .153$) or trueness ($P = .757$) between the digital impressions. The qualitative analysis revealed local deviations along the palatal surfaces of the molars and incisal edges of the anterior teeth of < 100 μm. Conclusion: Conventional full-arch PVS impressions exhibited improved mean accuracy compared to two direct optical scanners. No significant differences were found between the two digital impression methods. Int J Prosthodont 2018;31:107–113. doi: 10.11607/ijp.5643

A dental impression is a negative likeness or copy in reverse of the surface of dental soft or hard tissue used either for diagnostic purposes or for the fabrication of prosthodontic restorations.³ The accuracy of the final impression sent to the lab technician will subsequently determine the degree of marginal adaptation and internal gaps present within the final restoration.² Recently, with the advent of computer-aided design/
conventional impressions. However, studies have also shown that for more extensive restorations, conventional impressions followed by extraoral scanning are preferable and more accurate.

Various new intraoral scanners are being introduced by commercial companies at a rapid rate. As a result, research is constantly becoming outdated, as more studies use versions of digital impression systems that have already been upgraded or replaced and new systems offer significant improvements. Two popular intraoral scanning systems are produced by 3Shape and Sirona. The latest versions of these scanners (Trios 3, 3Shape, and CEREC Omnicam, Sirona) have not been adequately independently tested for accuracy, although the manufacturers claim significant improvements compared to previous versions.

The aim of the present study was to compare the accuracy (ie, precision and trueness) of full-arch conventional impressions to that of full-arch digital impressions produced from two different digital intraoral impression systems. The null hypothesis was that there would be no statistically significant differences in mean precision or mean trueness between impressions taken using conventional or digital impression methods.

Materials and Methods

Preparation of the Reference Model

A model of a maxillary arch form was fabricated on a silver plating machine. The model consisted of seven teeth surrounding five reference points (two in each posterior sextant and one in the anterior sextant) (Fig 1). The surface of the model was glass beaded with a grain size of 40 to 70 mm to reduce optical reflections, which could lead to potential scanning artifacts.

Calibration and Reference Scanning

The protocol followed to achieve the required calibration of the reference scanner was similar to the protocol adopted by Ender and Mehl. The reference model was scanned five separate times using a contacting laboratory scanner (Incise, Renishaw PLC). The model was removed and repositioned between scans. Each scan was carried out using a step-over distance of 50 μm. Individual points in the x, y, and z axes were digitally recorded by the contacting stylus probe and were exported in a surface tessellation language (STL) format via the scanner software (Tracecut, Renishaw PLC).
To measure precision, the five scans were imported into surface-matching software (Geomagic Control 2014, 3D Systems). Each scan (1, 2, 3, 4, or 5) was superimposed against each of the other scans (10 superimpositions in total) using the software’s best fit matching algorithm tool. The software initially selected 50,000 random data points from the images and continued to align them by finding matching regions to align both scans in the same coordinates in space. Once this was completed, a more accurate superimposition was carried out using 100,000 data points to further minimize the distance between sets. For practical reasons, four areas were selected from each scan for comparison: the palatal and incisal areas of the anterior teeth and the occlusal third of the second molars. Following alignment, any areas outside the field of comparison were removed digitally (Fig 2). To calculate the precision, 3D differences between each data point in each of the scans were quantitatively calculated, and mean absolute deviations were reported in microns. Differences were also assessed qualitatively through color-coded mapping of superimposed images. Both quantitative and qualitative evaluations were used to validate the manufacturer’s data of the reference scanner within the recommended tolerance levels.

Conventional Impressions

Five conventional impressions of the silver-plated reference model were taken with a two-consistency, one-step technique using a polyvinyl siloxane (PVS) impression material (Aquasil Ultra; Dentsply Caulk) with custom trays that provided a uniform space of 3 mm between the tray and tooth surface. Adhesive was applied to the trays with five brush strokes (approximately 0.2 mL per tray). All impressions were taken under standard laboratory conditions (23°C) by a single operator (J.M.) following the manufacturer’s recommendations. Following material polymerization, the impression trays were removed from the reference model and inspected for defects. Casts were then poured with a pre-weighed amount of type IV dental stone (Silky-Rock; Whipmix) per the manufacturer’s instructions. The casts were allowed to set for 24 hours prior to removal from the impression. Each of the five casts was scanned using the reference scanner (Renishaw Incise) using the same methods as described above, converted into an STL file format, and imported into Geomagic Control (3D Systems). To determine the precision of conventional impressions, the five scans were superimposed with each of the other scans (10 superimpositions in total) using the same method as described above, and the mean deviations were calculated (V_Prec 1–10) and averaged across the scans. To assess trueness, the same five scans were superimposed with one scan of the reference model (Ref_1), leading to five mean deviation values, which were averaged and compared.

Digital Impressions

Two intraoral scanners were used to obtain digital impressions of the reference model. A single operator (J.M.) trained and calibrated in the use of the scanners made five digital impressions of the reference model with the Trios 3 scanner (3Shape) and five digital impressions with the CEREC Omnicam scanner (Sirona). The model was removed and repositioned in between each scan, but the scanning coordinates were kept the same. The resulting digital files were converted to an STL file format and imported into Geomagic Control for comparisons. The precision and trueness values were determined in the same manner as described above, by repeated superimpositions of each of the five scans and comparison with the reference scan, respectively.

Once scans for all groups had been completed, a final scan of the reference model was taken with the reference scanner to ensure that there was model stability during the entire scanning process. To avoid potential residue from contaminating the reference model with PVS impression material, the following order was employed: reference scanner (n = 5); Trios 3Shape (n = 5); Cerec Omnicam (n = 5); Aquasil Ultra (n = 5); final reference scan (n = 1).

Statistical Analyses

Power calculations and sample size estimation were carried out based on previously published data. Normality of variance and distribution was carried out using Levene and Shapiro-Wilk tests (P < .05). Comparison of means between groups was performed using one-way analysis of variance (ANOVA) with post hoc Bonferroni (trueness) and Games-Howell (precision) tests. P < .05 was considered statistically significant. IBM SPSS software version 24 (IBM UK Ltd) was used to analyze the results.

Results

The stability of the reference model was confirmed at the end of experimentation by superimposing an image of the reference model following its use in all groups (Ref_Final) with an image of the original reference scan 5 (Ref_5). This gave a mean deviation of 6.2 μm, which was within the measurement error from the methods used in this study.
Table 1 shows the mean deviation measurements of precision for the three groups of impression procedures and for the reference scanner, derived from repeated superimpositions using Geomagic Control software. The reference scanner had a mean deviation in precision of 4.8 μm (± 0.7 μm). Among the test groups, the lowest mean deviation in precision (indicating greater accuracy) was noted for the conventional impression group (21.7 μm), followed by CEREC Omnicam (36.5 μm) and 3Shape Trios 3 (49.9 μm).

One-way ANOVA and post hoc Games-Howell tests showed that there were statistically significant differences in mean deviations between groups, with statistically significantly higher precision exhibited for the conventional vs the digital impression procedures ($P < .006$). There was no statistically significant difference in precision between the two intraoral scanners ($P = .153$).

**Trueness**

The results of the trueness measurements are depicted in Table 2. One-way ANOVA and post hoc Bonferroni tests showed that there were statistically significant differences in mean trueness between the groups ($P < .001$). Conventional impressions yielded significantly better trueness compared to both digital impression techniques ($P < .001$), whereas there were no statistically significant differences in trueness between the two intraoral scanners ($P = .757$).

**Qualitative Analysis**

3D comparisons between superimposed scans were carried out using Geomagic Control. Figures 3 to 5 show the typical deviation patterns seen with the different test groups. Conventional impressions using PVS impression material showed no significant distortions between scans; however, some isolated point-positive deviations of > 300 μm, confined to the molar fissures, were noted. Upon closer examination, it was determined that these deviations were the result of small air blows present in the impression, which were cast as positive nodules.
CEREC Omnicam showed more generalized distortions between scans of ∼90 μm. Local positive deviations were typically present along the palatal surfaces of the molars and incisal edges of the anterior teeth. Negative deviations were also present along some incisal edges, suggesting a wave-like distortion throughout the whole scan.

The 3Shape Trios scans generally showed distortions in the molar regions. Deviations were typically negative in the palatal area of these molars (<100 μm) and became positive as they approached the occlusal surfaces (60 μm).

Discussion

The purpose of this in vitro study was to assess and compare the accuracy of single-arch conventional and digital impressions. The importance of accuracy within prosthodontics is paramount for the production of adequately fitting restorations that conform harmoniously with the patients’ occlusion.35 For digital impression systems to achieve these results, it is necessary for them to perform at least as well as their conventional counterparts.7,33

On the basis of the findings of this in vitro study, the null hypothesis that there would be no difference in mean accuracy between conventional and digital impression procedures could be rejected. Conventional impressions demonstrated statistically significantly higher accuracy, whereas no significant difference existed between the two intraoral scanners tested. The higher accuracy exhibited by conventional full-arch impressions, as well as the mean values in precision and trueness, are in agreement with previous studies.18,19,31,36,37 Despite the statistical significance of the differences observed in this study, it is important to note that for all tested impression techniques, the mean and maximum values of deviations in both precision and trueness were below 100 μm. Although there is no clinically acceptable threshold for accuracy, the values would probably be clinically acceptable for most scenarios of short-span or segmented prostheses, but would warrant caution in cases of extended one-piece prostheses, where such inaccuracies would be compounded. Indeed, a number of studies25–26 have demonstrated that intraoral scanning can lead to fabrication of short-span prostheses with equal or even improved marginal and internal fit compared to conventional impressions. Therefore, the results of this study are in agreement with previous studies27–31 in suggesting that, in cases of more extensive restorations or need for maximum accuracy across the arch, conventional impressions are still the gold standard. Another important point is that optical scanners seem to perform better in an in vitro environment, such as in this study, and their accuracy seems to be reduced in vivo.30,36

The qualitative analysis of deviations revealed significant local deviations for the conventional impressions (>300 μm) present largely in the molar fissure patterns; however, these were a result of minor impression defects in those areas. The protocol of this study did not include the removal of positive stone nodules with a scalpel, as would be the case when examining working casts, as it was felt important to leave these areas unaltered to assess their influence on the final accuracy. If these defects had been corrected prior to scanning, the qualitative accuracy analysis of the conventional impression procedure would have been better. Similar high deviations (500 μm) have previously been reported by other authors33 using an alginate impression material. Both optical impression techniques demonstrated deviations of <100 μm, typically present along the palatal surfaces of the molars and incisal edges of the anterior teeth. The pattern of deviations was similar to that reported in other studies.18,31,36 Such deviations present in the areas of curvatures might be a result of the curvature and sinuosity of the surfaces being scanned, limiting accuracy in these areas of complex morphology.38 The CEREC Omnicam was used in this study without the use of powder, as recommended by the manufacturer; it is interesting that the results were similar to a recent study31 that used the same scanner with powder to overcome the high reflectivity of the polished metal specimens.

The study methodology was similar to that used in previous studies.19,31,34 The use of a contacting surface scanner has been reported as a very accurate and repeatable method of capturing surface characteristics in many studies.39,40 The precision of the contacting profilometer was confirmed in this study with a mean deviation value of 4.8 μm; this allowed its use as a reference scanner. However, one drawback of its use was the inability to engage any undercuts in either the reference or conventional models. As a result, data were restricted to areas above the maximum bulkosity of the teeth being profiled. Conclusions could thus only be drawn from the occlusal aspects of the teeth, and any distortions or deviations at the gingival aspect were not investigated. The use of a noncontact laser scanner could have allowed the capturing of any tooth undercuts present in the models.30 However, the use of such scanners can lead to the production of artefacts through the absorption or reflection of light sources.41 The silver-plated model used during this study was glass beaded using a similar protocol as adopted by Seelbach et al24 to give the cast a similar roughness to that found on natural teeth, such that optical reflections could approximate the clinical...
situation. Metal-plated reference models have been used in previous studies comparing accuracy of digital and conventional impressions. The advantages include the ability to resist abrasion and distortion and the ability to include intricate details through the use of silver plating. The stability of the reference model was confirmed at the end of experimentation.

Conclusions

Within the limitations of this in vitro study, conventional full-arch PVS impressions exhibited higher accuracy compared to two direct optical scanners. However, all deviations were less than 100 μm.

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References

Osseointegration mechanisms are still not entirely understood. The present pilot study aimed to demonstrate the involvement of the immune system in the process of osseointegration around titanium implants by comparing bone healing in the presence and absence of a titanium implant. A total of 15 New Zealand White rabbits had one osteotomy performed at each of the distal femurs: On one side, no implant was placed (sham), and on the other side, a titanium implant was introduced. Subjects were sacrificed at 10 and 28 days for gene expression analysis (three subjects at each time point) and for decalcified qualitative histology (six subjects at each time point); at 10 days, the three subjects for gene expression analysis were part of the six subjects for histology. For gene expression analysis, at 10 days, ARG1 was significantly upregulated around titanium, indicating an activation of M2 macrophages. At 28 days, CD11b, ARG1, NCF-1, and C5aR1 were significantly upregulated, indicating activation of the innate immune system (respectively: M1 macrophages, M2 macrophages and group 2 innate lymphoid cells, neutrophils, and the complement system); on the other hand, the bone resorption markers RANKL, OPG, cathepsin K, and TRAP were significantly downregulated around titanium. At 10 days, new bone formation was seen around both sham and titanium sites, separating bone marrow from the osteotomy/implant site. At 28 days, no bone trabeculae was seen on the sham site (which was healing at the original cortical level), whereas around titanium implants, bone continued into organization of more mature cortical-like bone, forming a layer between the implant and bone marrow. The authors concluded that presence of a titanium implant during bone healing activates the immune system and displays type 2 inflammation, which is likely to guide the host-biomaterial relationship. At the same time, the bone resorption suppressed around titanium sites compared to sham sites after 4 weeks of implantation suggests a shift to a more pronounced bone-forming environment. This suggests two important steps in osseointegration: identification of the titanium foreign body by the immune system and the development of a bone-forming environment, which at tissue level translates into bone build-up on the titanium surface and can be perceived as an attempt to isolate the foreign body from the bone marrow space.