Title: Comparison of accuracy between a conventional and 2 digital intraoral impression techniques

Short title: Accuracy of 2 intraoral scanners

Malik JS[a] , Rodriguez JM[a], Weisbloom M[a], and Petridis H[a]

[a] Prosthodontic Unit, Department of Restorative Dentistry, UCL Eastman Dental Institute, University College London, London, UK

Correspondence:

Dr Haralampos Petridis, Prosthodontic Unit, Department of Restorative Dentistry, UCL Eastman Dental Institute, University College London, 256 Gray's Inn Rd, London WC1X 8LD, UK Tel: +44 (0)20 3456 1250; E-mail: c.petridis@ucl.ac.uk

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

Abstract

Aims: The objective of this study was to compare the precision and trueness of full-arch impressions using either a conventional polyvinylsiloxane (PVS) material or 2 intraoral optical scanners.

Methods: Full arch impressions were obtained of a reference model using addition silicone impression material (Aquasil Ultra; Dentsply Caulk, Delaware, USA) and two optical scanners (Trios, 3Shape, Copenhagen, Denmark and CEREC Omnicam, Sirona, Wals, Austria). Surface matching software (Geomagic® Control™, 3D Systems©, Rock Hill, SC, USA) was used to superimpose the scans within groups in order to determine the mean deviations (μm) between the scans. The overall mean precision and trueness for each group was calculated 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 Ltd, Portsmouth, England). Qualitative analysis was also carried out from three-dimensional maps of differences between scans.

Results: Mean and standard deviations (SD) of precision for conventional, Trios and Omnicam groups were 21.7 (±5.4), 49.9 (±18.3), and 36.5 (±11.12), respectively. Mean and standard deviations (SD) for trueness were 24.3 (±5.7), 87.1 (±7.9), and 80.3 (±12.1) respectively. The conventional impression showed statistically significant improved mean precision ($P<.006$) and mean trueness ($P<.001$) compared to both digital impression procedures. There were no statistically significant differences in precision ($P=0.153$) or trueness ($P=0.757$) between the digital impressions. The qualitative analysis revealed local deviations along the palatal surfaces of the molars and incisal edges of the anterior teeth in the order of <100μm.

Conclusion: Conventional full-arch PVS impressions exhibited improved mean accuracy compared to 2 direct optical scanners. No significant differences were found between the two digital impression methods.

Key words: Precision, Trueness, Accuracy, Intraoral scanner, digital impression

1. Introduction

A dental impression is a negative likeness or copy in reverse of the surface of a dental soft or hard tissue used either for diagnostic purposes or for the fabrication of prosthodontic restorations.[1] 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/computer-aided manufacturing (CAD/CAM), digital techniques have been developed to achieve the same goal. This involves the use of digital scanners which act as a data collection tool in order to produce a three dimensional image of the object being scanned.[3-6]

Although the gold standard for dental impressions is still considered to be the use of elastomeric impression materials[7,8], intra-oral scanning seems to have a number of advantages, including increased patient and operator satisfaction[9-11], reduced time[9,10,12-14], as well as the ability to digitally store and retrieve information.[3,6,15] Interestingly, a recent randomized study showed that these potential advantages are not universal for all scanner types.[16] Of course, one of the most important aspects of a digital impression is the degree of accuracy compared to the conventional technique. Accuracy is defined by using the terms precision and trueness.[17,18] Precision describes the degree of reproducibility between repeated measurements and trueness describes the closeness of agreement to the object being measured.[19] A number of studies[20-26] 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. However, studies[27-31] have also shown that for more extensive restorations, conventional impressions, followed by extra-oral 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.[3,23,32,33]

Two popular intraoral scanning systems are produced by 3Shape and Sirona. The latest versions of these scanners (Trios 3, 3Shape, Copenhagen, Denmark, and CEREC Omnicam, Sirona, Wals, Austria) 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 (precision and trueness) of full arch conventional impressions and 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 and mean trueness of impressions taken using conventional and digital impression methods.

2. Materials and methods

2.1. 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 (2 in each posterior sextant and one in the anterior sextant (Figure 1). The surface of the model was glass beaded with a grain size of 40-70μm to reduce optical reflections which could lead to potential scanning artefacts.[12]

2.2. Calibration and reference scanning

The protocol followed to achieve the required calibration of the reference scanner was similar to the protocol adopted by Ender & Mehl[19]. The reference model was scanned five separate times using a contacting laboratory scanner (Incise™, Renishaw® PLC, Gloucestershire, UK). The model was removed and repositioned between scans. Each scan was carried out using a step-over distance of 50μm. 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, Gloucestershire, UK).

The five scans were imported into surface-matching software (Geomagic® Control™ 2014, 3D Systems©, Rock Hill, SC, USA) for measurement of precision. Each scan (1, 2, 3, 4 or 5) was superimposed against each other of the 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 with a more accurate superimposition was carried out using 100,000 data points to further minimise the distance between sets. For practical reasons 4 areas were selected from each scan for comparison. These were the palatal and incisal areas of the anterior teeth and the occlusal third of the 2nd molars. Following alignment, any areas outside the field of comparison were removed digitally (Figure 2).[31] To calculate precision, three-dimensional 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 colour 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.[14]

2.3. Conventional impressions

Five conventional impressions of the silver-plated reference model were taken with a two consistency one–step technique using a polyvinylsiloxane (PVS) impression material (Aquasil Ultra; Dentsply Caulk, Delaware, USA) with custom trays providing a uniform space of 3mm between the tray and tooth surface. Adhesive was applied to the trays with 5 brush strokes (approximately 0.2mL per tray).[8] All impressions were taken under standard laboratory conditions (23°C) by a single operator (J.M.) following the manufacturers recommendations. Following material polymerization the impression trays were removed from the reference model and were inspected for defects. Following that, casts were poured with a pre-weighed amount of Type IV dental stone (Silky-Rock; Whipmix®, Louisville, USA) as 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 were 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©, Rock Hill, SC, USA). To determine the precision of conventional impressions, the five scans were superimposed to each other (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. In order to assess trueness the same 5 scans were superimposed with one scan of the reference model (Ref_1) leading to 5 mean deviation values which were averaged and compared.

2.4. Digital impressions

Two intraoral scanners were used to obtain digital impressions of the reference model. Five digital impressions of the reference model were made with the Trios 3 scanner (3Shape, Copenhagen, Denmark) and five digital impressions were made with the CEREC Omnicam scanner (Sirona, Wals, Austria) by a single operator (J.M). The operator was trained and calibrated in the use of the scanners before they were carried out.[12] 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 were imported into Geomagic® Control™ (3D Systems©, Rock Hill, SC, USA) 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 [12]. To avoid potential residue from contaminating the reference model from polyvinylsiloxane impression material, the following impression/scanning protocol was employed:

a) Reference scanner (n=5)

b) Trios 3Shape (n=5)

c) Cerec Omincam (n=5)

d) Aquasil Ultra (n=5)

e) Reference scan final (n=1)

2.5. Statistical Analyses

Power calculations and sample size estimation were carried out based on previously published data.[33,34] Normality of variance and distribution was carried out using Levene's and Shapiro-Wilk tests (*P*<0.05). Comparison of means between groups was performed using one-way analysis of variance (ANOVA) with post-hoc Bonferroni (trueness) and Games-Howell (precision) tests. Statistical significance was inferred where *P*<0.05. IBM© SPSS® software version 24 (IBM UK Ltd, Portsmouth, England) was used to analyze the results.

3. 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 6.2μm which was within the measurement error from the methods used in this study.

3.1. Precision

Table 1 shows the precision mean deviation measurements for the three groups of impression procedures and the reference scanner derived from repeated superimpositions using Geomagic® Control™ software. The reference scanner had a mean precision of 4.8μm (±0.7μm). Amongst the test groups, the lowest mean precision deviation, indicating greater accuracy, was noted for the conventional impression group (21.7μm), followed by CEREC Omnicam (36.5 μm) and 3Shape Trios 3 (49.9μm).

One-way ANOVA and post hoc Games-Howell tests showed that there were statistically significant differences in mean deviations between groups with statistically significant higher precision exhibited for conventional versus digital impression procedures (*P*<.006). There was no statistically significant difference in precision between the 2 intraoral scanners (*P*=0.153).

3.2. 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 deviations between the 2 intraoral scanners ($P=.757$).

3.3. Qualitative analysis

Three-dimensional comparisons between superimposed scans were carried out using Geomagic® Control™. Figures 3-5 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 >300μm were noted, confined to the molar fissures. Upon closer examination it was determined that these deviations were a result of small air blows present in the impression which were cast as positive nodules.

CEREC Omnicam showed more generalised distortions between scans in the range of 90μm. 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 in the order of <100μm and became positive as they approached the occlusal surfaces (~60μm).

4. Discussion

The purpose of this in vitro study was to assess and compare the accuracy, via precision and trueness, of single arch conventional and digital impressions. The importance of accuracy within prosthodontics is paramount for the production of adequately fitting restorations which conform harmoniously with the patients' occlusion.[35] In order for digital impression systems to achieve these results, it is necessary for them to perform at least as well as their conventional counterparts.[33,36]

On the basis of the findings of this in vitro study, the null hypothesis that there would be no difference in mean accuracy (precision and trueness) between conventional and digital impression procedures could be rejected. Conventional impressions demonstrated statistically significant higher accuracy, whereas no significant difference existed between the 2 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.[18,19,31,37,38] 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 both precision and trueness were below 100μm. 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 studies[20-26] 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 studies[27-31] 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 that optical scanners seem to perform better in an in vitro environment, such as this study, and their accuracy seems to be reduced in vivo.[30,37]

The qualitative analysis of deviations revealed significant local deviations for the conventional impressions (>300μm), 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 and assess the 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 authors[33] using an alginate impression material. Both optical impression techniques demonstrated deviations in the order of <100μm, 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.[18,31,37] 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.[39] 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 study[31] which 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.[40,41] The precision of the contacting profilometer was confirmed in this study with a mean value of 4.8µm; this allowed its use as a reference scanner. However, one drawback of its use was the inability to engage any undercuts in both the reference and conventional models. As a result, data was restricted to areas above the maximum bulbosity 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 non-contact laser scanner could have allowed the capturing of any tooth undercuts present in the models.[41] However, the use of such scanners can lead to the production of artefacts through the absorption or reflection of light sources.[42] The silver plated model used during this study was glass beaded using a similar protocol adopted by Seelbach et al[24], in order 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.[18,19,24] The advantages include the ability to resist abrasion, distortion and the ability to include intricate details through the use of silver plating.[43] The stability of the reference model was confirmed at the end of experimentation.

5. Conclusion

Within the limitations of this in vitro study, conventional full-arch PVS impressions exhibited higher accuracy compared to 2 direct optical scanners. However, all deviations were less than 100μm.

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Table 1. Precision of conventional and digital impressions (μm)

	Mean	Std. Deviation	Minimum	Maximum
Reference	4.8	0.7	3.9	5.6
Conventional	21.7	5.4	15.8	30.2
Trios	49.9	18.3	21.5	83.3
Omnicam	36.5	11.2	23.9	53.4

Table 2. Trueness of conventional and digital impressions (µm)

	Mean	Std. Deviation	Minimum	Maximum
Conventional	24.3	5.7	19.0	32.8
Trios	87.1	7.9	74.9	94.5
Omnicam	80.3	12.1	63.3	94.9

FIGURE LEGENDS

Figure 1. Silver plated reference model

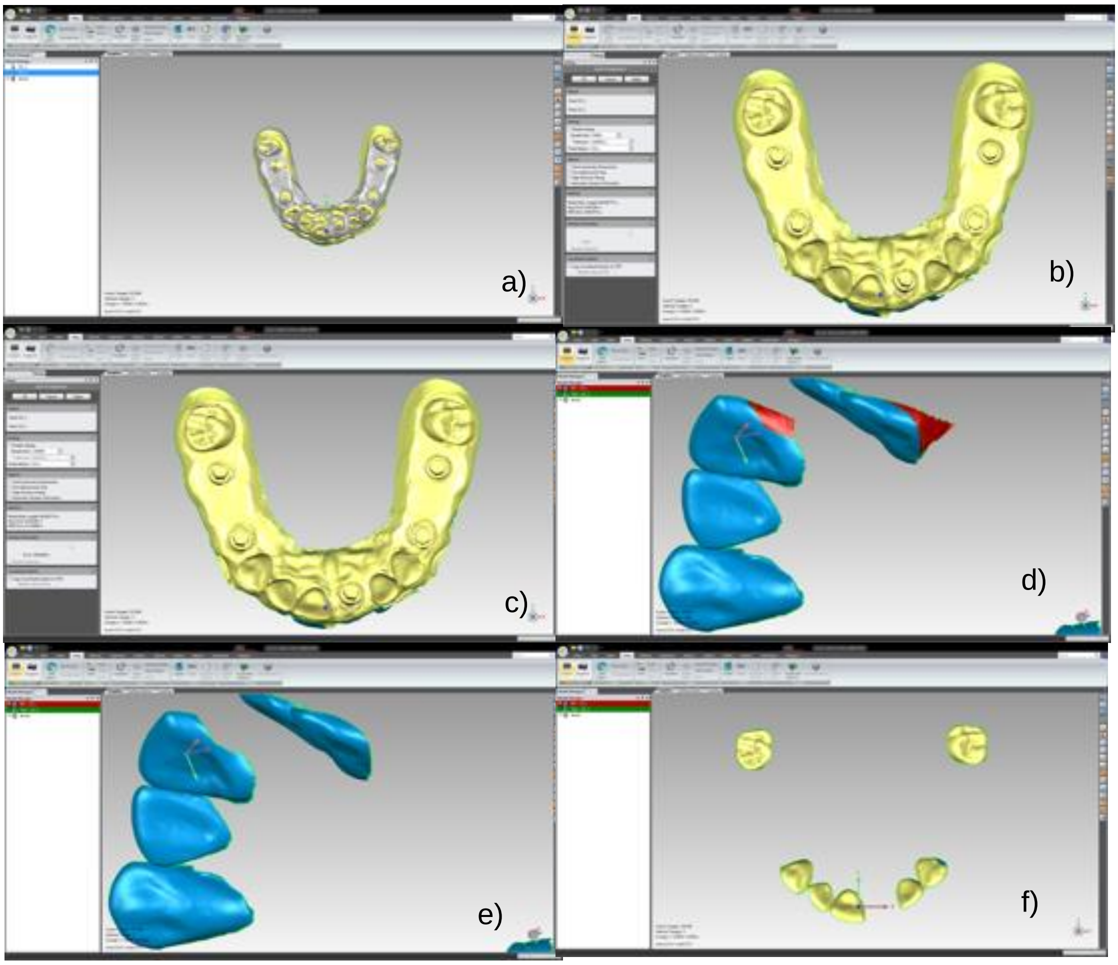
Figure 2. Process of superimposition. a) paired scans prior to superimposition b) initial superimposition with 50,000 surface points c) high precision superimposition with 100,000 surface points d) and e) careful trimming of unwanted data points f) final trimmed model

Figure 3. Color-coded three-dimensional superimpositions showing typical deviations patterns in the conventional impression group

Figure 4. Color-coded three-dimensional superimpositions showing typical deviations patterns in the Cerec Omnicam group.

Figure 5. Color-coded three-dimensional superimpositions showing typical deviations patterns in the Trios group.

Figure 1. Silver plated reference model



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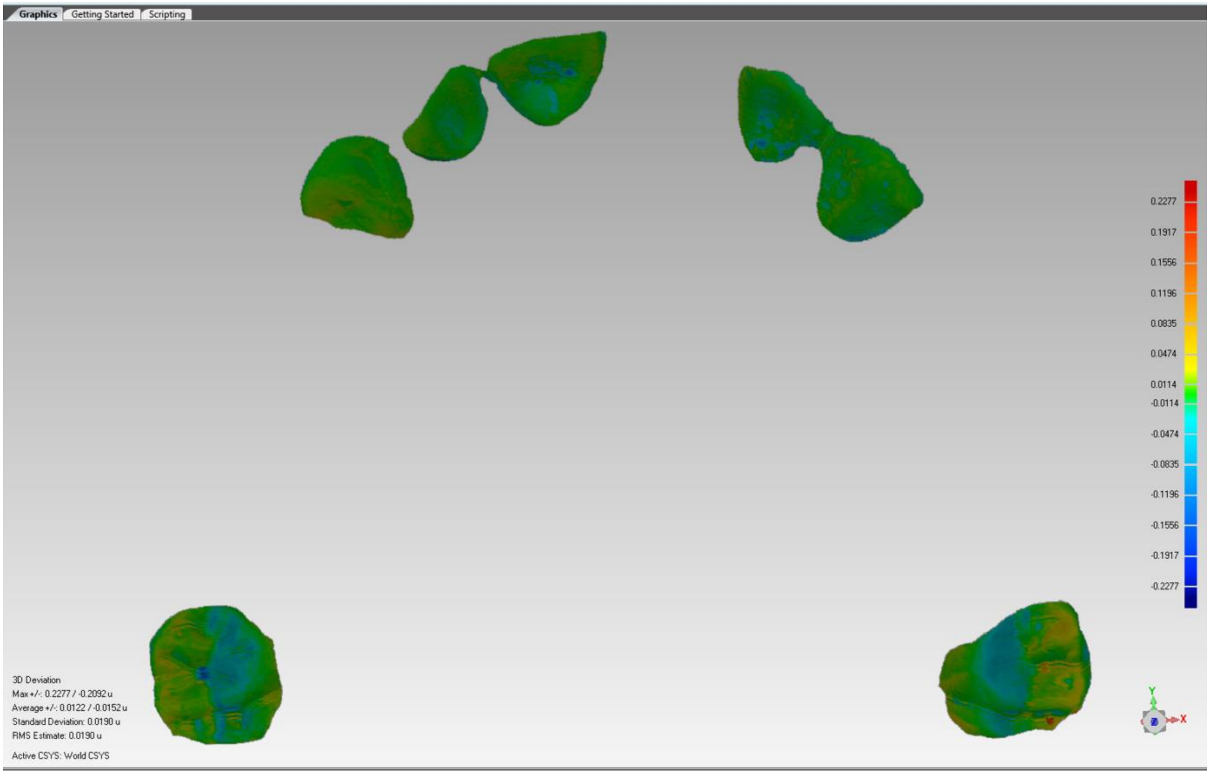

Figure 3. Color-coded three-dimensional superimpositions showing typical deviations patterns in the conventional impression group

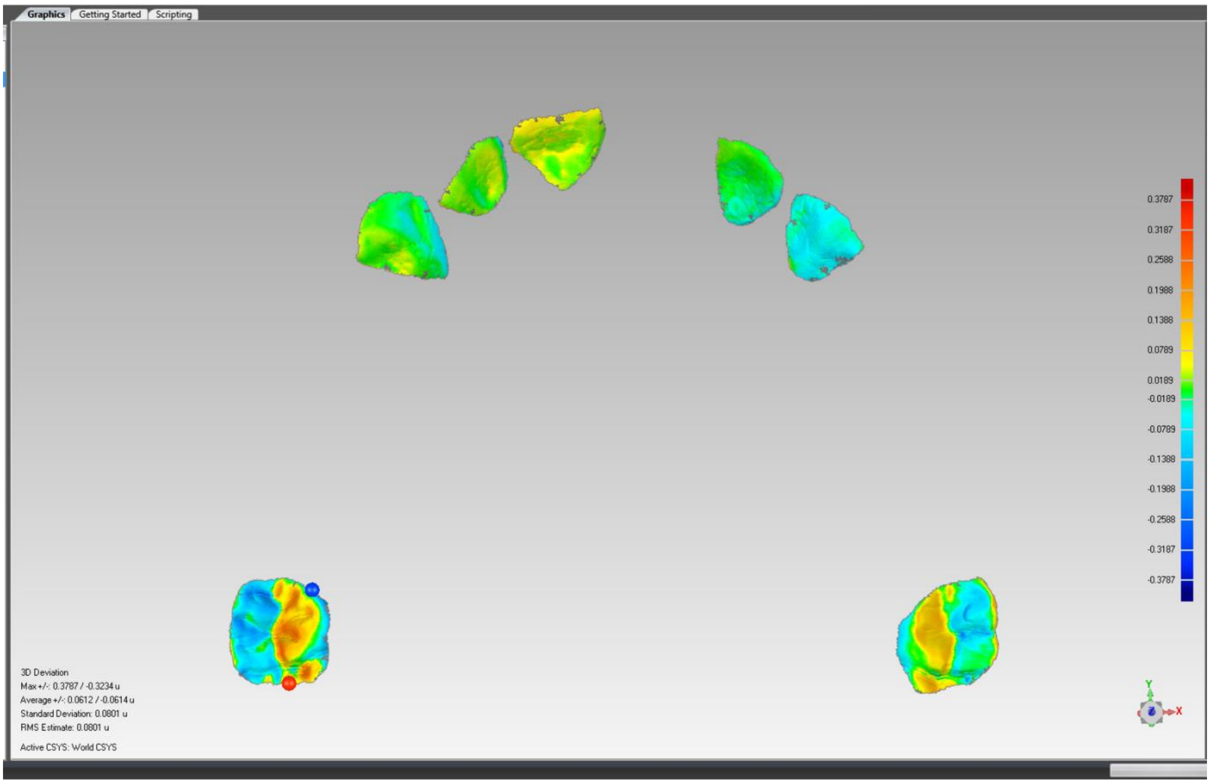

Figure 4. Color-coded three-dimensional superimpositions showing typical deviations patterns in the Cerec Omnicam group.

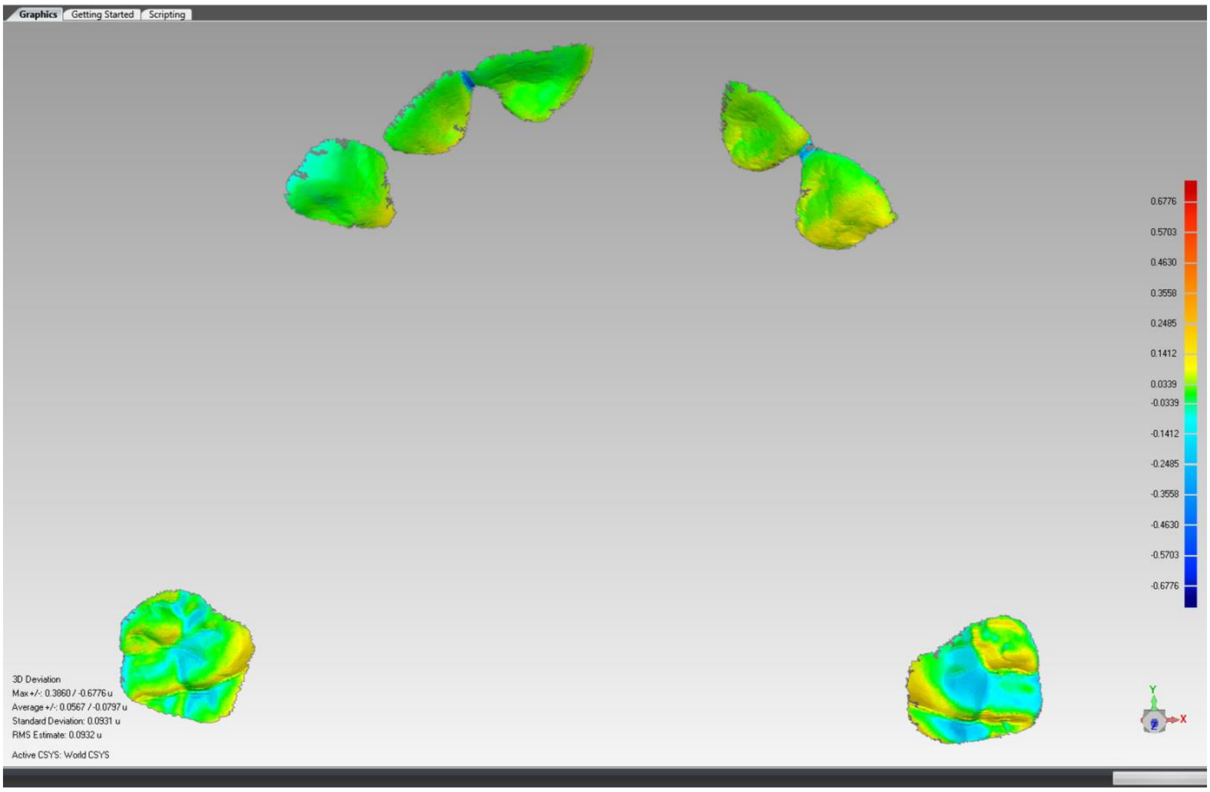

Figure 5. Color-coded three-dimensional superimpositions showing typical deviations patterns in the Trios group.