# The effect of software updates on the trueness and precision of intraoral scanners

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**Objectives:** The goal of the study was to determine the effects of software updates on the trueness and precision of digital impressions obtained with a variety of intraoral scanner (IOS) systems. **Method and materials:** Seven IOS systems were investigated. Each system was tested using two versions of software, with the second version being the latest at the time of conducting the study. Scans were performed on a custom mandibular typodont model with natural teeth that were either unrestored or restored with amalgam, composite, lithium disilicate, zirconia, and gold. Eight scans were obtained for each software version on any of the tested IOS systems. Experimental IOS scans were compared against an industry-standard master scan of the typodont obtained with an ATOS Capsule scanner proven to have a trueness of 3 µm and a precision of 2 µm. Isolation of each substrate material on the digital experimental and master scans was achieved using the Geomagic metrology software for subsequent analysis of the substrate influence on accuracy. A generalized linear mixed model was used to determine the influence of the software version on the trueness and precision of the impression scan. **Results:** For some IOS systems, scans made with older software versions differ in accuracy compared with those obtained with the most recent software versions. Trueness was improved for most scanners following the software update, although the Element2 IOS performance deteriorated. Software updates had lesser effects on precision and showed variable trends among different systems. Software updates also influence different substrate materials scans' accuracy, although the results show variability among IOS systems. When comparisons were done among IOS systems updated with the latest software version, best performers for complete arch trueness were the Emerald S, Trios 3, and Primescan systems. **Conclusion:** Software updates have a statistically significant effect on the trueness and precision of different IOS systems. These updates can have both positive and negative effects on scan accuracy, although it appears that these variations are within the clinical acceptability levels. *(Quintessence Int 2021;52:2–10; doi: 10.3290/j.qi.b1098315)*

**Key words:** CAD/CAM, digital dentistry, intraoral scanner, software, software update

Digital dentistry is a rapidly growing area that has become an integral part of many office's workflows.[1,2] The key interface between the physical and digital realms is the intraoral scanner (IOS) systems. Clinical use of IOS systems is beneficial to improved patient comfort, enhanced diagnostics, clearer case presentation, rapid transfer of information, improved restoration fabrication, storage efficiency for models, improved esthetic capabilities, and reduced clinical time.[1,3-5]

IOSs, when paired with CAD (computer-aided design) software and chairside milling machines (CAM [computer-aided manufacturing]), are a clinically acceptable alternative to traditional methods of fixed restorations fabrication.[6-10] Digital impressions have been reported to be as accurate as elastomeric impression materials for restorative situations up to 10 fixed units.[11] These systems also are capable of accurately articulating virtual models, thus creating an integrated digital flow for oral rehabilitation.[12,13]

Accuracy of digital impressions can be defined in terms of precision and trueness.[14] An easy-to-understand definition of these terms was mentioned in a previous article: "Precision describes how close repeated measurements are to each other. … Trueness

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describes how far the measurement deviates from the actual dimensions of the measured object. A high trueness delivers a result that is close or equal to the actual dimensions of the measured object."[15] It also is important to define clinically acceptable levels of accuracy; a recent systematic review and meta-analysis found that a marginal gap of 120 µm or less is clinically acceptable for indirect CAD/CAM restorations.[16,17] These results are aligned with findings already published by McLean and von Fraunhofer[18] in 1971 for conventional indirect restorations.

While there are many studies that describe the quality of restorations manufactured with CAD/CAM systems, very few investigated the effects of software version updates on scans' trueness. An early study in 1992 investigated the marginal fit of inlays fabricated using the original and updated CEREC CAD software.[19] It showed significant improvement in the degree of marginal fit with a newer software version compared to the older version. A more recent study had similar findings; however, crown fitting improvements were limited to the region of the spacer, with no improvements in marginal adaptation.[20] The relative impact of the scan and the milling process on the improved trueness could not be evaluated in these studies. Another recent publication that tested the effect of software updates on a single scanner (CEREC Omnicam) reported that the "software version has a significant impact of the accuracy."[21]

Previous studies investigating the accuracy of IOS systems utilized master models manufactured of metal, plastic, or stone that are not an accurate representation of substrates present in the oral cavity.[3,15,22-25] It is known that materials of various reflectivity, refractivity, and translucency impact scan accuracy.[26,27] Master models manufactured of highly reflective materials, such as metal alloys and certain resins, have optical properties that pose a challenge for IOS systems, whereas materials that are less translucent or less reflective, such as plaster stone, create a better scanning environment.[27-29] Therefore, use of different master model materials can result in over- or under-estimation of the scanner's trueness, limiting the study's clinical applicability.

To address this concern, utilization of a custom typodont model with a variety of substrates commonly encountered in the oral cavity was suggested. The described typodont comprises natural teeth that are either unrestored or restored with amalgam, composite, lithium disilicate, zirconia, and gold.[27] This approach has the potential to improve IOS trueness measurement accuracy and better reflect variations dependent on commonly used restorative materials.

The present study utilizes the same typodont used in previous research.[27] It seeks to investigate if intraoral scan accuracy is impacted by software updates in seven different IOS systems. The first null hypothesis postulated that there would be no difference in trueness and precision between scans made with different software versions. The second null hypothesis postulated that there will be no differences among scans generated with different scanners updated with the latest software version.

## Method and materials

A total of seven IOS systems were tested in this study: Emerald (Planmeca), Emerald S (Planmeca), Trios 3 (3Shape), Primescan (Dentsply Sirona), Omnicam (Dentsply Sirona), Medit i500 (Medit), and iTero Element 2 (Align Technologies).

Software versions tested (old version and new version, respectively) were Emerald (5.8, 6.2.1) Emerald S (6.0, 6.2.1), Trios 3 (1.3.4.5, 1.6.9.1), Primescan (5.0.1, 5.1) Omnicam (4.6.1, 5.1), Medit (1.2.0.3, 2.1.2), and iTero Element 2 (1.9.3.3, 1.9.3.7).

Each tooth on the mandibular typodont used in this research project represented different substrates as follows:

- mandibular left second molar (tooth 37): dentin
- mandibular left first molar (tooth 36): blue core composite material (Grandio Core Dual Core, Voco)
- mandibular left second premolar (tooth 35): white core composite material (Grandio Core Dual Core, Voco)
- mandibular left first premolar (tooth 34): unpolished amalgam (Contour, Kerr)
- mandibular left canine (tooth 33): bulk fill composite (Tetric, Ivoclar Vivadent)
- mandibular left lateral incisor (tooth 32): Majesty ES2 – Enamel (Kuraray)
- mandibular left central incisor (tooth 31): Majesty ES2 – Dentin (Kuraray)
- mandibular right central incisor (tooth 41): Empress Direct-Dentin (Ivoclar Vivadent)
- mandibular right lateral incisor (tooth 42): IPS Empress Direct-Enamel (Ivoclar Vivadent)
- mandibular right canine (tooth 43): e.max (Ivoclar Vivadent),
- mandibular right first premolar (tooth 44): polished amalgam (Contour, Kerr)
- mandibular right second premolar (tooth 45): zirconia (Katana Zirconia UTML, Kuraray)
- mandibular right first molar (tooth 46): type 3 gold
- mandibular right second molar (tooth 47): natural enamel.

Previous publications show that "with an effect size of 1.0, $\alpha = .05$, and a power of 0.80, the calculations revealed that eight specimens per group would be needed to detect the postulated

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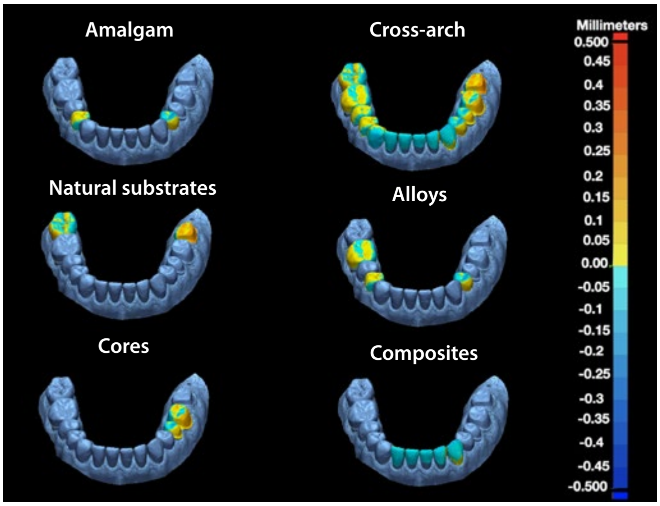


**Fig 1** Selection of specific teeth on the digital model in Geomagic Control X software.



The use of Geomagic metrology software allowed isolation of each substrate on the digital experimental and master scans (Fig 1), and subsequent analysis of the substrate influence on accuracy. Absolute values of deviations between the experimental scans and the master scan in each analyzed area were averaged to represent scans' trueness. The computed standard deviation (SD) of the average represents the scans' precision.

Data are presented as mean ± SD in the figures and in the text. The generalized linear mixed model compared differences in the mean deviation values, with gamma distribution and log-link function using restricted maximum likelihood estimation. Two analyses were performed.

- The influence of software version: In the first model, deviations between experimental scans obtained with different software versions within each substrate group and the master scan were analyzed for each scanner.
- The influence of the hardware: In the second model only deviations between experimental scans obtained with IOS systems updated with the newest software version and the digital master scan were analyzed.

effect size."[30] Therefore, eight scans were made with each IOS system. All scans were performed by the same, experienced clinician following each manufacturer's recommended scanning pattern.

STL files of each experimental scan were exported and compared against a digital master scan, using Geomagic Control X inspection and metrology software (3D Systems). The digital master scan was created with an ATOS Capsule scanner (GOM), proven to have a trueness of 3 μm and a precision of 2 μm.[31]

### *Data analysis*

To simplify the statistical analysis, substrates were combined into categories according to material characteristic properties. Six substrate groups were defined:

- core composite materials with blue and white shades
- restorative composite materials group, which included bulk fill composite, Majesty ES2 - Enamel, Majesty ES2 - Dentin, Empress Direct - Dentin, Empress Direct - Enamel.
- alloys group, which included unpolished amalgam, polished amalgam, and gold.
- all-ceramic crown (ACC) group, which included e.max and zirconia
- natural materials included dentin and enamel
- cross-arch accuracy, which included all materials used in the typodont.

*P* values were adjusted using the sequential Bonferroni method for pairwise comparison with a significance value set at .05. Statistical analyses were done using SPSS (Version 24.0, IBM).

## Results

Descriptive statistics for all groups and scanners are shown in Table 1. It is noted that substrate groups do not have the same number of elements; therefore, the number of scans differs among these. For example, in the "cross-arch" group only scans that were performed for the whole arch were included, ie eight scans. For the "composite" group five different composite substrates each scanned eight times were included, resulting in 40 scans. In each group the number of total scans will always be a multiplication of eight, ie the number of scans performed on each substrate. Statistically significant differences in trueness (mean) and precision (SD) between scans obtained with different software versions are mentioned in Table 1.

### *Effect of software version on trueness*

The mean deviation from the standard is denoted by stars in Fig 2. Following software updates, most scanners showed some improvement of the trueness, at least on some substrates. The exceptions were Primescan and Element 2. For Primescan there was no improvement observed in any substrate; it should be



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**Table 1** Trueness (mean) and precision (SD) (in µm)

| Scanner | Substrate group | Software version: Previous version n | Mean | SD | Updated version n | Mean | SD | Comparison previous vs updated version: Trueness, *P* | Precision, *P* |
|---|---|---|---|---|---|---|---|---|---|
| Element 2 | ACC | 16 | 23 | 3.5 | 16 | 28 | 8.7 | < .05 | |
| | Alloy | 24 | 18 | 4.0 | 24 | 17 | 3.5 | | |
| | Composite | 40 | 21 | 6.2 | 40 | 24 | 7.0 | <.05 | |
| | Core | 16 | 18 | 8.1 | 16 | 16 | 5.5 | | |
| | Natural | 16 | 26 | 13.7 | 16 | 23 | 6.3 | | |
| | Cross-arch | 8 | 22 | 4.3 | 8 | 22 | 2.7 | | < .05 |
| Emerald | ACC | 16 | 42 | 9.5 | 16 | 36 | 6.5 | < .05 | |
| | Alloy | 24 | 43 | 7.4 | 24 | 36 | 10.9 | < .01 | |
| | Composite | 40 | 38 | 6.4 | 40 | 43 | 21.6 | | < .001 |
| | Core | 16 | 59 | 14.4 | 16 | 33 | 19.7 | < .001 | |
| | Natural | 16 | 71 | 16.0 | 16 | 49 | 30.0 | < .01 | |
| | Cross-arch | 8 | 53 | 4.8 | 8 | 42 | 7.9 | < .01 | |
| Emerald S | ACC | 16 | 34 | 7.1 | 16 | 22 | 6.6 | < .001 | |
| | Alloy | 24 | 40 | 11.8 | 24 | 20 | 4.5 | < .001 | |
| | Composite | 40 | 38 | 11.2 | 40 | 20 | 4.1 | < .001 | < .001 |
| | Core | 16 | 36 | 7.7 | 16 | 19 | 5.3 | < .001 | < .05 |
| | Natural | 16 | 39 | 8.2 | 16 | 24 | 11.1 | < .001 | |
| | Cross-arch | 8 | 40 | 2.0 | 8 | 22 | 2.0 | <.001 | |
| Medit i500 | ACC | 16 | 25 | 5.5 | 16 | 21 | 6.9 | < .05 | |
| | Alloy | 24 | 29 | 5.6 | 24 | 31 | 8.5 | | |
| | Composite | 40 | 25 | 7.2 | 40 | 20 | 5.0 | < .001 | |
| | Core | 16 | 25 | 7.5 | 16 | 24 | 18.0 | | < .01 |
| | Natural | 16 | 33 | 8.8 | 16 | 38 | 21.5 | | < .01 |
| | Cross-arch | 8 | 29 | 2.9 | 8 | 29 | 8.6 | | < .05 |
| Omnicam | ACC | 16 | 41 | 15.4 | 16 | 39 | 17.7 | | |
| | Alloy | 24 | 42 | 23.5 | 24 | 35 | 7.9 | | < .001 |
| | Composite | 40 | 55 | 13.3 | 40 | 30 | 17.1 | < .001 | |
| | Core | 16 | 79 | 71.1 | 16 | 36 | 24.7 | < .01 | < .001 |
| | Natural | 16 | 98 | 105.8 | 16 | 47 | 32.8 | < .05 | < .001 |
| | Cross-arch | 8 | 59 | 20.0 | 8 | 36 | 9.7 | < .001 | < .05 |
| Primescan | ACC | 16 | 22 | 4.1 | 16 | 24 | 4.6 | | |
| | Alloy | 24 | 16 | 5.2 | 24 | 18 | 5.2 | | |
| | Composite | 40 | 16 | 5.9 | 40 | 16 | 4.8 | | |
| | Core | 16 | 15 | 8.2 | 16 | 14 | 7.3 | | |
| | Natural | 16 | 21 | 10.4 | 16 | 20 | 8.7 | | |
| | Cross-arch | 8 | 18 | 3.6 | 8 | 19 | 4.5 | | |
| Trios 3 | ACC | 16 | 23 | 10.5 | 16 | 20 | 5.9 | | |
| | Alloy | 24 | 19 | 6.5 | 24 | 18 | 6.0 | | |
| | Composite | 40 | 20 | 7.1 | 40 | 14 | 3.0 | < .001 | < .001 |
| | Core | 16 | 21 | 13.3 | 16 | 19 | 7.1 | | |
| | Natural | 16 | 29 | 20.7 | 16 | 26 | 8.9 | | < .05 |
| | Cross-arch | 8 | 22 | 9.1 | 8 | 20 | 5.2 | | |

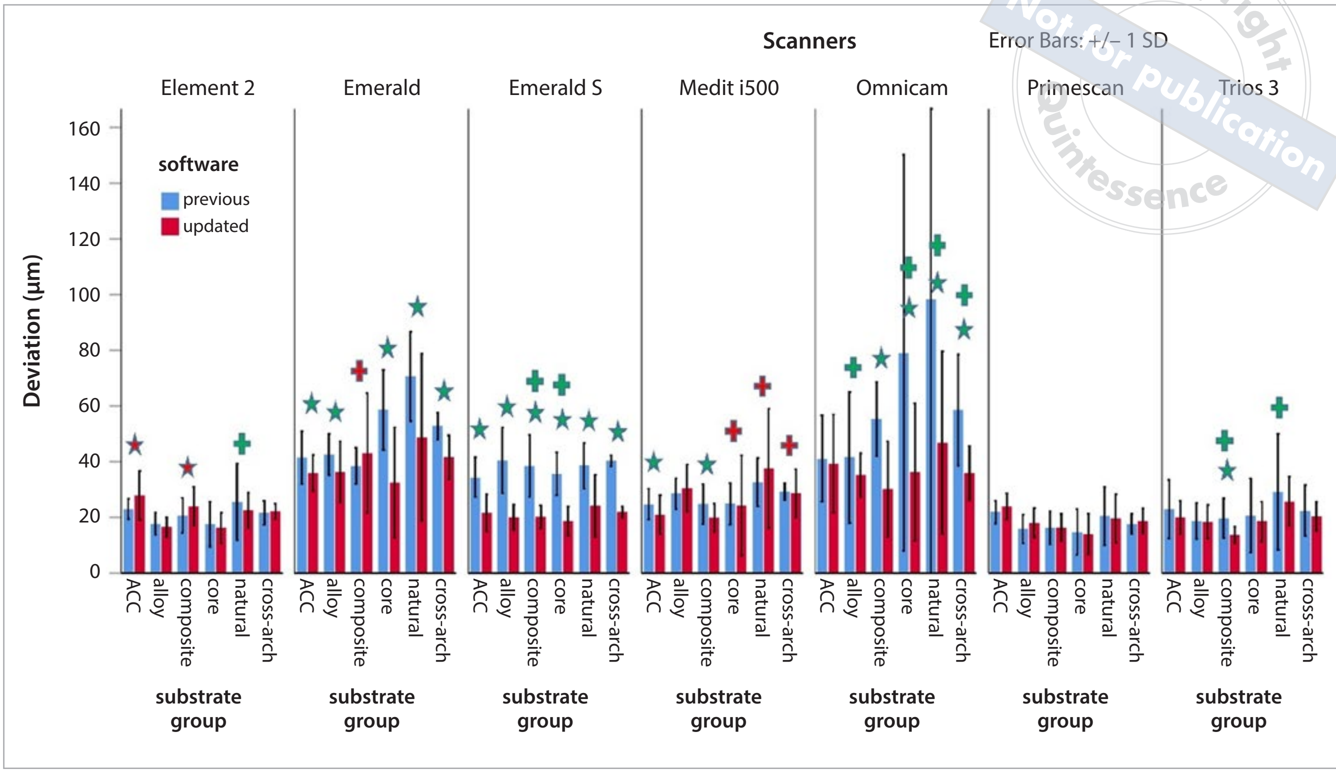



**Fig 2** The mean inaccuracy (trueness, indicated by column height) and the standard deviation (precision, indicated by the error bar, whisker) of scanners for each substrate and software version. Significance at $P < .05$ after Bonferroni adjustment. Stars indicate a significant difference in the mean (trueness) between software versions (green, significant improvement in performance after a software update; red, significant decrease in performance after a software update). Crosses indicate a significant difference in the standard deviation (precision) between software versions (green, significant improvement in performance after a software update; red, significant decrease in performance after a software update).

noted however, that the level of inaccuracy was very low to begin with. In regard to Element 2, the software update caused a statistically significant deterioration in accuracy in the "ACC" ($P = .029$) and "composite" substrates ($P = .040$). Although these inaccuracies were statistically significant, they had a mean of under 30 µm, ie they were at clinically acceptable levels.

Emerald and Emerald S benefited from software updates for most substrates ($P < .001$). The most significant effect of the software update on trueness was observed in the "natural" and "core" substrates scanned with Omnicam. For this scanner, the "core" substrate scans improved from 79 ± 71.1 µm to 36 ± 24.7 µm ($P = .007$), whereas the "natural" substrate scans improved from 98 ± 105.8 µm to 47 ± 32.8 µm ($P = .033$).

## *Effect of software version on precision*

The differences in standard deviation are denoted by crosses in Fig 2. Software updates had lesser effects of precision compared to trueness. While Primescan precision was not influenced by the update, other scanners (Element 2, Emerald S, Omnicam, and Trios 3) showed statistically significant improvements at least for some substrates. It is interesting to note that only Omnicam showed increased precision for the "cross-arch" group that included all substrates ($P = .031$). Two scanners, Emerald and Medit i500, experienced statistically significantly reduced precision for some substrates: for Emerald, the precision for the "composite" group was negatively impacted by the software update ($P < .001$), and for Medit i500 the same effect was observed for the "core" ($P = .002$), "natural" ($P = .003$), and "cross-arch" ($P = .031$) groups.

## *Differences in accuracy between scanners with updated software versions*

Figure 3 shows how each substrate influenced the scan accuracy. For all substrates Emerald and Omnicam were consistently


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ranked 6 or 7 (1 being best and 7 worst – numbers at the bottom of the graph columns in Fig 3), with statistically significantly larger deviations for trueness and precision compared to other scanners ($P < .05$). It should be noted, however, that despite the statistically significant results, the scans for these two scanners were within the clinically acceptable range. Medit i500 was ranked fifth in the groups "alloy," "core," "natural," and "cross-arch." In the "cross-arch" group this scanner only showed a statistically significant difference in precision compared to Emerald S ($P < .05$).

In regard to the best performers, no statistical difference for complete arch trueness was found between the Emerald S, Trios 3, and Primescan. Primescan was the one scanner that showed consistent performance in all substrates, ie no other scanner performed statistically better in any category. Trios 3 and Emerald S had similar results in five out the six substrates considered: Trios 3 scans had statistically less precision in the "natural" group compared to Element 2 ($P < .05$), and in the "composite" substrate Emerald S showed statistically significant less trueness compared Trios 3 ($P < .05$). Element 2 performed well on all substrates with the exception of "composite," where it was significantly less precise than Trios 3 ($P < .05$) and less true than both Trios 3 and Primescan ($P < .05$).

## Discussion

Both null hypotheses must be rejected; scans made with the originally tested software versions differ in accuracy compared with scans made with the most recent software versions for some scanners. Also, some scanners displayed different performance when comparisons were done among hardware updated with the latest software version.

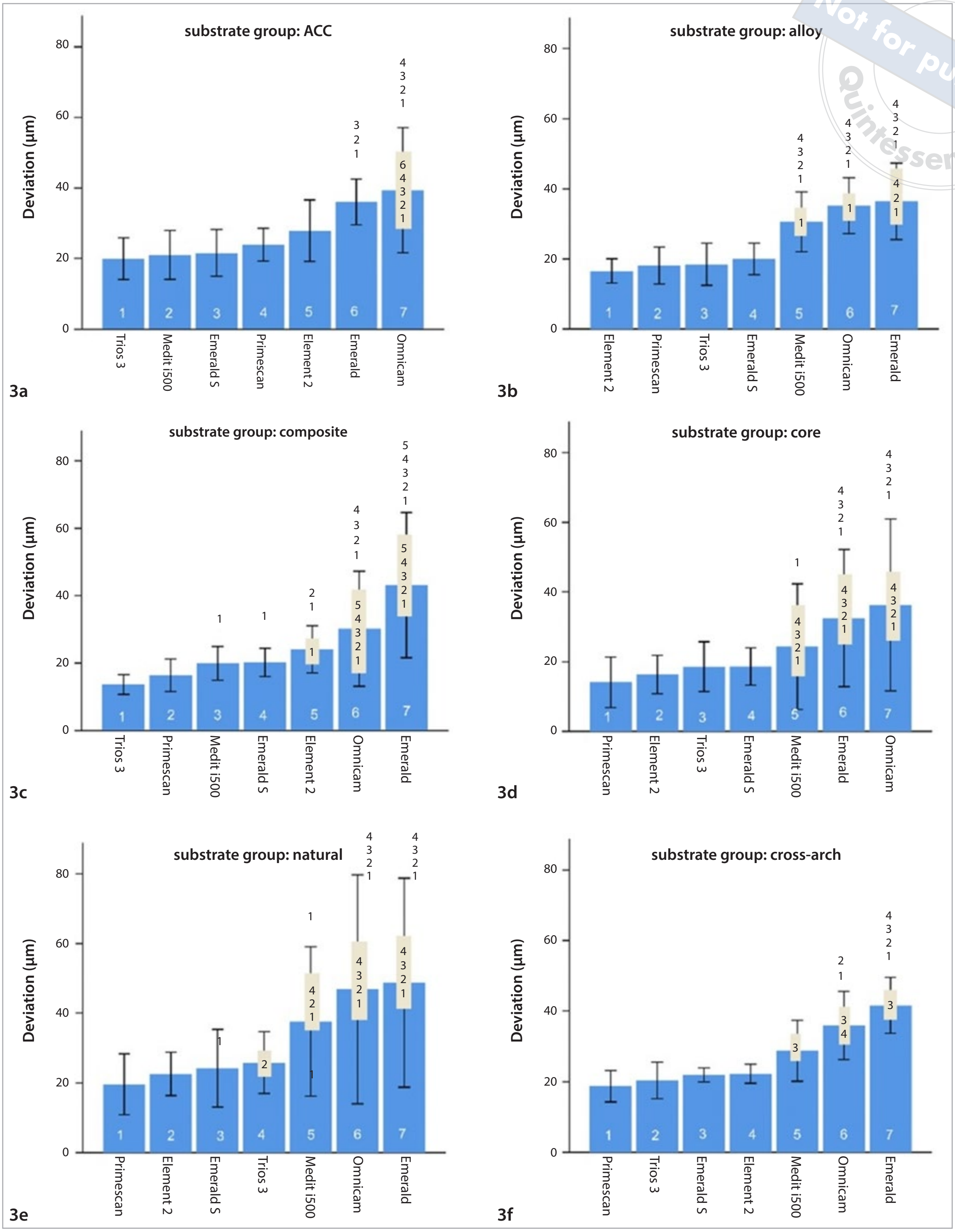
It is apparent that software updates have significant effects on the trueness and precision of IOS systems, even when there are no changes or improvements in hardware (Fig 2). Most scanners showed statistically significant improvements in trueness or precision in at least one substrate group investigated. The only exception to this was Primescan, which did not show statistically significant changes in trueness or precision. Following the software update, some scanners displayed a decrease in precision (Medit i500 and Emerald) or in trueness (Element 2) in certain substrate groups.

The inter-scanner comparisons performed on IOS systems equipped with the most recent software (Fig 3), show that in all substrate categories the Omnicam and Emerald displayed significantly inferior performance in trueness and precision compared to all other scanners. However, inaccuracy values for these two scanners were below the maximum clinically acceptable error level of 120 µm.[16,17] Overall, there were little or no differences in accuracy between the first four best-ranked scanners. These results concur with other publications indicating that Omnicam and Emerald are not the most accurate scanners on the market.[32-34] Prior research also ranks the Trios3 and the Primescan systems as leaders in trueness and precision.[35,36] Interestingly, very little data exist on the Emerald S, which performed remarkably well in the present study, with no statistically significant differences compared with Primescan. The fifth rank was a midway position between the best four and the worst two. This position was shared between Element 2 and Medit i500 depending on the substrate group. These two systems also have shown similar performance in another recent study.[37]

Little research has investigated the effect that software has on the accuracy of IOSs. To the present authors' best knowledge, there is only one study[21] that compared the effect of software upgrade on the accuracy of full-arch scans made by Omnicam; the study mentions that teeth in the model were made from feldspathic ceramic. Omnicam with software version 5.0.0 was found to be better than with version 4.6.1 in a full-arch scan (49.7 µm vs 87.3 µm), similar to the present results (v5.1, 36 µm vs v4.6.1, 59 µm). The accuracy of a scan made on a single model tooth by Omnicam was also improved by a software version upgrade from 4.4.0 to 4.4.4.[21]

In the present study, significant improvements were found in trueness with nothing more than software updates. For example, Emerald S cross-arch global trueness improved from 40 µm with version 6.0 to 22 µm in version 6.2.1, taking it from middle tier to one of the most accurate scanners tested. Likewise, Omnicam saw improvements change from 59 µm to 36 µm. Both these systems are active triangulation systems that rely heavily on software algorithms to combine different images.[38]

As more scanners and software updates emerge in the marketplace, it is critical to monitor the accuracy of these systems. With some scanners showing significant improvements as a result of a software update, perhaps the software version should be considered just as important as the hardware when evaluating these systems. However, it is impossible for the general practitioner to perform these types of analyses after each software update. Furthermore, many manufacturers test their scanners using stone models that do not accurately reflect scanning conditions in the oral cavity.[28] Utilizing a reference typodont model that is more realistic and contains substrates often found in the oral cavity could allow the development of more consistent products for the end-user. It would be ideal if manufactures used a standardized model containing these realistic substrates as an industry-agreed standard.




**Figs 3a to 3f** Comparison of the mean inaccuracy (trueness, indicated by column height) and the standard deviation (precision, indicated by the error bar, whisker) of scanners for each substrate group. Results determined using updated software versions for all scanners. Significance determined at $P < .05$ after Bonferroni adjustment. The order of the scanners on the x-axis represents the actual order of the mean inaccuracy (trueness) values for each scanner in the respective substrate group. This is indicated by a number in white font at the base of each column. The number/s above the error bar indicate/s a significant difference in the mean inaccuracy (trueness) between the scanner of the specific column and scanner column indicated by the number. The number/s with a tan color background in the whiskers indicate/s a significant difference in the standard deviation (precision) between the scanner of the specific column and the scanner indicated by the number.



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During the execution of the present study, issues emerged with data generated for two scanners being investigated. Both the Medit i500 and Planmeca Emerald scanners generated data that were aberrant and significantly less accurate with the updated software than those seen with previous versions. Hardware issues were suspected, and after consulting with manufacturers it was determined that hardware issues were indeed responsible for the data incongruence. Planmeca provided a new unit that produced the numbers shown in the present study. Medit sent multiple different units before numbers that were deemed appropriate based on the previous study data were achieved. The iTero Element 2 update from version 1.9.3.3 to version 1.9.3.7 was a very minimal update. This could be responsible for the relatively few changes in trueness and precision between its previous and updated software versions compared to the other updated scanners that were tested, which seemed to have more robust software changes.

The present study has several limitations. First, lighting conditions, saliva, focal distance, and humidity were not considered. Furthermore, to ensure standardization, only one hardware unit was tested for each scanner, and that unit was considered representative of all scanners of that type. Variations in manufacturing could potentially lead to technical-related inaccuracies. Testing multiple scanners of the same type in future research projects could help control for these potential discrepancies. Scans were performed according to manufacturer specified scanning patterns, but human error and researcher fatigue cannot be completely eliminated from such a study. To address this, future studies could utilize a robotic scanning arm to eliminate variability in scanning pattern and ensure that every scan is performed identically. Additionally, the iterative closest point method of scan alignment used in Geomagic Control X could cause distortion of the values achieved for different substrates. The models were aligned using data from all scanned teeth and as the entire arch is scanned, stitching errors can accumulate.[39-41] The study model utilized in the current project had various substrates within the arch, with some substrates potentially causing higher scanning deviation than others. This in turn may cause an increase in stitching errors. Furthermore, specific regions of the arch may affect scan distortion and, if a specific substrate is always in the same position, an additive effect of the localization and the reflectance may be established.[35,41]

Future methods could align the model using data only from each individual substrate and create multiple, localized alignments that would allow compensation for the cross-arch accumulation of stitching errors.

## Conclusion

Software updates can significantly affect the trueness and precision of different IOS systems. These updates can have both positive and negative effects on scan accuracy, although it appears that these variations are within the clinical acceptability levels.

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