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Original Article

Comparative Analysis of Intra-Oral and Lab Scanner Performance in Full-Arch Dentistry

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ABSTRACT

This research aimed to assess the accuracy—including both trueness and precision—of nine intra-oral digital scanners and four laboratory scanners for full-arch scanning. Although earlier investigations have evaluated certain intra-oral scanners, the rapid evolution of scanning technology warrants an updated analysis to determine the performance of the latest commercially available models. In this in vitro study, nine intra-oral scanners (Omnicam 4.6; Omnicam 5.1; Primescan; CS 3600; Trios 3; Trios 4; Runyes; i500; DL206) and four lab light scanners (Einscan SE; 300e; E2; Ineos X5) were compared. Ten scans from each device were aligned, trimmed, and imported into CloudCompare software. Using a best-fit algorithm, each scan was compared against a master STL model, and deviations were recorded. Standard deviations were calculated, and colorimetric maps highlighted surface deviations. Specific points on the STL mesh were used to quantify accuracy.

Among the intra-oral scanners, Primescan demonstrated the highest overall trueness (17.3 ± 4.9 µm), followed by Trios 4 (20.8 ± 6.2 µm), i500 (25.2 ± 7.3 µm), CS3600 (26.9 ± 15.9 µm), Trios 3 (27.7 ± 6.8 µm), Runyes (47.2 ± 5.4 µm), Omnicam 5.1 (55.1 ± 9.5 µm), Omnicam 4.6 (57.5 ± 3.2 µm), and Launca DL206 (58.5 ± 22.0 µm). For lab scanners, Ineos X5 exhibited the best trueness (0.0 ± 1.9 µm), followed by 3Shape E2 (3.6 ± 2.2 µm), Up3D 300E (12.8 ± 2.7 µm), and Einscan SE (14.9 ± 9.5 µm). The findings indicate that modern intra-oral scanners can reliably generate reproducible full-arch scans in dentate patients. None of the intra-oral devices matched the trueness of the Ineos X5 lab scanner, though Primescan achieved a level of trueness comparable to the 3Shape E2. All devices maintained a mean trueness below 60 µm. While these results apply to dentate arches, scanning fully edentulous arches remains more challenging, and further studies should explore scanner performance in such cases.

Keywords: Intra-oral scanners, Digital dentistry, Trueness, Precision, Lab scanners

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Introduction

The introduction of intra-oral scanners has revolutionized dental workflows, improving patient comfort and allowing clinicians to obtain digital impressions with high predictability and reproducibility, reducing complications associated with conventional tray-based methods [1]. Fully digital workflows became feasible with the first intra-oral scanners in the 1980s, and ongoing technological advances have firmly established these devices as central tools in modern dentistry.

Contemporary scanners enable same-day restorative procedures, minimize the need for traditional impressions, or in some cases replace them entirely. As a result, a growing number of clinicians are adopting intra-oral scanning, with many high-performing devices now available on the market. Compared to conventional methods, intra-oral scanning offers benefits such as speed, patient comfort, efficiency, and enhanced predictive capabilities once the oral environment is digitized. Long-term cost reduction is another advantage of digital workflows [2–4].

An alternative method for digitizing the oral cavity involves capturing impressions or casts using lab scanners, but this study focuses on direct intra-oral scanning and compares it to baseline lab scanner accuracy. While prior studies have assessed some intra-oral scanners, no current literature evaluates the 2020 models examined here [5–9], representing a gap that this study addresses. Full-arch scans have been noted to be more challenging due to the potential for cumulative errors over longer scan distances [10].

The technologies employed by digital scanners vary considerably, which influences their usability, operational efficiency, and measurement accuracy, including both trueness and precision. Each device collects multiple intra-oral measurements and constructs a three-dimensional digital model via computational algorithms. Because intra-oral scanners capture only a limited field of view per frame, individual scans produce partial point clouds rather than full coverage of tooth surfaces. To form a complete arch, the scanner software merges successive frames, producing a unified 3D mesh of the entire dental arch [11]. Different manufacturers implement distinct stitching algorithms, but these processes inherently introduce minor errors, which can accumulate across longer scans, particularly in full-arch procedures [12–14]. Consequently, the final digital model's reliability depends on both the repeatability of scans and the effectiveness of the image-merging process [15, 16].

This investigation evaluated nine contemporary intra-oral scanners and four lab-based light scanners, measuring both trueness and precision, as defined in ISO 5725-1 [17]. Trueness refers to the degree to which a measurement aligns with the actual dimensions of a reference object [18]. In this study, it quantified the deviation of each scan from the master model, with higher trueness indicating closer agreement to the true geometry. Precision indicates the consistency of repeated measurements from the same device, reflecting how reliably a scanner can reproduce identical results. Because accurate and reproducible scans form the foundation for clinical treatment planning, evaluating both trueness and precision allows for a comprehensive assessment of scanner performance. Two lab scanners were included for comparison to provide a baseline standard.

The study tested the primary hypothesis that there would be no significant difference among the scanners in terms of trueness and precision. A secondary hypothesis proposed that intra-oral and lab scanners would not differ in these measures of accuracy.

Materials and Methods

Study model

The International Digital Dental Academy (IDDA) Calibration Model [19] was used as the reference **(Figure 1)**. This model replicates three clinical scenarios in the maxilla:

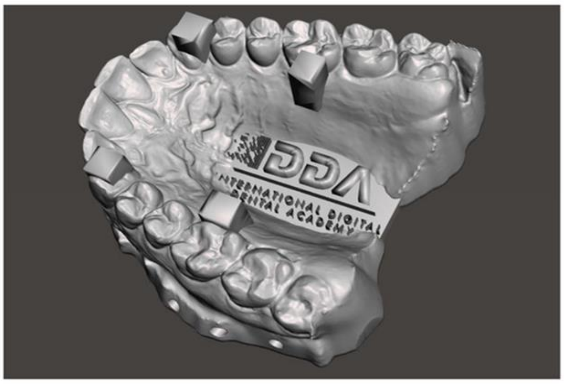

Figure 1. IDDA Calibration Model. The model was printed with an Asiga Max UV printer using NextDent Model Resin, at a 50-micron layer thickness, chosen for its combination of high dimensional fidelity and low reflectivity, optimizing data capture with the scanners under investigation [20].

- A complete dentate arch;
- Four regular columnar structures of known width and spacing;
- A complex surface morphology to challenge scanner performance.

Scanners

All scanners included in this investigation are summarized in **Table 1**.

Table 1. The digital scanners used in this study

Scanner Name	Manufacturer	Scanning Technology	STL File Export	PLY/OBJ Color Export
Omnicam 4.6	Dentsply Sirona, York, PA, USA	Structured Light—Optical Triangulation and Confocal Microscopy	YES	NO

Omnicam 5.1	Dentsply Sirona, York, PA, USA	Structured Light—Optical Triangulation and Confocal Microscopy	YES	NO
Primescan	Dentsply Sirona, York, PA, USA	Structured Light—Confocal Microscopy with Smart Pixel Sensor	YES	NO
CS3600	Carestream Dental, Atlanta, GA, USA	Structured LED Light—Active Speed 3D Video™	YES	YES
Trios 3	3-Shape, Copenhagen, Denmark	Structured Light—Confocal Microscopy and Ultrafast Optical Scanning™	YES	YES
Trios 4	3-Shape, Copenhagen, Denmark	Structured Light—Confocal Microscopy and Ultrafast Optical Scanning™	YES	YES
Runyes	Ningbo Runyes Medical Instrument Co., Shenzhen, China	Structured Light—Active Speed 3D Video™	YES	YES
Launca DL206	Guangdong Launca Medical Device Technology Co., Ltd., Dongguan, China	Structured Light—Active Speed 3D Video™	YES	YES
i500	Medit, Seongbuk-gu, Seoul, Korea	Structured Light—Active Speed 3D Video™	YES	YES
Einscan SE	Shining 3D, Hangzhou, Zhejiang, China	Optical Blue Structured Light	YES	NO
UP3D 300E	Shenzhen UP3D Tech Co., Ltd., Shenzhen, China	Optical Blue Structured Light	YES	NO
E2	3-Shape, Copenhagen, Denmark	Optical Blue Structured Light	YES	NO
Ineos X5	Dentsply Sirona, York, PA, USA	Optical Blue Structured Light	YES	NO

Study design

This in vitro study assessed nine intra-oral scanners (Omnicam 4.6; Omnicam 5.1; Primescan—Dentsply Sirona, York, PA, USA; CS 3600—Carestream Dental, Atlanta, GA, USA; Trios 3 and Trios 4—3Shape, Copenhagen, Denmark; Runyes Quickscan—Ningbo Runyes Medical Instrument Co., China; i500—Medit, Seongbuk-gu, Seoul, Korea; DL206—Guangdong Launca Medical Device Technology Co., Ltd., Dongguan, China) and four lab-based scanners (Einscan SE—Shining 3D, Hangzhou, Zhejiang, China; UP3D 300e—Shenzhen UP3D Tech Co., Ltd., Shenzhen, China; E2—3Shape, Copenhagen, Denmark; Ineos X5—Dentsply Sirona, York, PA, USA).

Each scanner captured ten repeated scans of the calibration model. Trueness and precision were then calculated by comparing scans to the master STL model, enabling a detailed evaluation of scanner accuracy under standardized conditions.

The master model was scanned using each of the listed intra-oral scanners and then compared against the Ineos X5 laboratory scanner, a structured-light device with an ISO 12836-certified accuracy of 2.1 μm [21]. A sample size of 10 scans per device was determined using a calculation based on a 95% confidence level and 5% margin of error, consistent with prior studies demonstrating that this sample size is sufficient for obtaining statistically reliable results [13, 22, 23].

A single experienced operator, trained in digital dentistry and proficient with multiple scanner systems, performed all scans. Each scanner captured ten scans of the master model, with the order of scanning randomized to prevent operator fatigue and reduce potential bias.

Scanning followed the International Digital Dental Academy (IDDA) Scan Training Protocol [19] **(Figure 2)**, beginning at the distal molar of the upper left quadrant, proceeding occlusally across the arch, then moving to the palatal surfaces, and finally returning along the buccal side, maintaining a steady and systematic progression.

Figure 2. IDDA Scan Training Model.

This method allows partial capture of palatal and buccal surfaces during occlusal scanning while maintaining a common reference framework for mesh alignment. Scans were exported in STL format using each manufacturer's recommended workflow. The resulting STL files were imported into Meshlab (ISTI-CNR, Pisa, Italy) [24], an open-source tool for processing and aligning 3D triangular meshes. This procedure was repeated for all intra-oral and lab scanners, resulting in ten aligned and trimmed meshes per scanner for subsequent trueness and precision analyses.

Trueness assessment

Trueness was evaluated by using Ineos X5 scans as the reference standard, compared to the original IDDA calibration STL. Each of the ten aligned scans from every scanner was imported into CloudCompare, where fine alignment ensured optimal registration with the master STL. The mean deviation of each superimposed scan was calculated and recorded alongside the standard deviation, representing the trueness of the scanner.

Deviation mapping

CloudCompare generated a color-coded deviation map illustrating differences between the scanned mesh and the master STL. Deviations toward the interior were shown in blue, outward deviations in red, and areas of minimal deviation in green. The C2M color scale was used uniformly across all scans, ranging from +200 µm (red, outward) to −200 µm (blue, inward).

Precision evaluation

Precision was calculated through all pairwise superimpositions of scans from the same scanner. Statistical analysis involved one-way ANOVA for independent groups with Tukey post hoc tests at α = 0.05, using SPSS v26 (IBM) [25]. Bartlett's test verified variance homogeneity. The mean of the deviations between repeated scans represented the scanner's precision.

Surface feature comparison

To visually assess surface detail, a wireframe capture of the premolar/molar region including the calibration column was generated for each scanner, illustrating its ability to reproduce fine topographic features.

Results and Discussion

The trueness and precision outcomes are presented in **Tables 2 and 3** and visualized in **Figures 3 and 4**. **Table 4** reports the ANOVA significance among scanners.

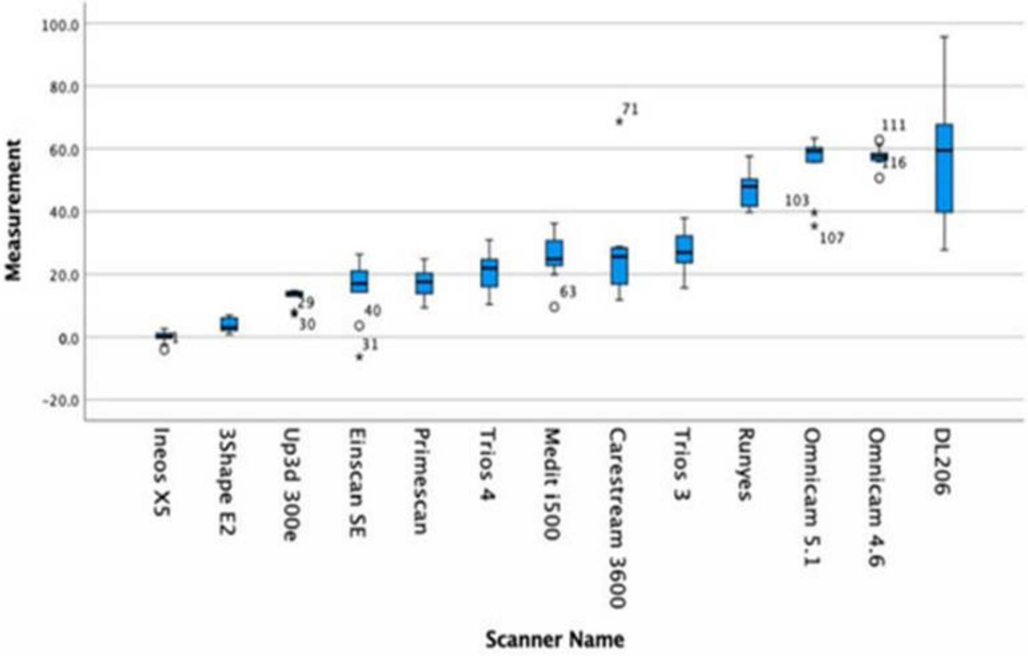

Figure 3. Boxplot illustrating the distribution of datasets for each scanner evaluated. Outliers are indicated with an asterisk (*).

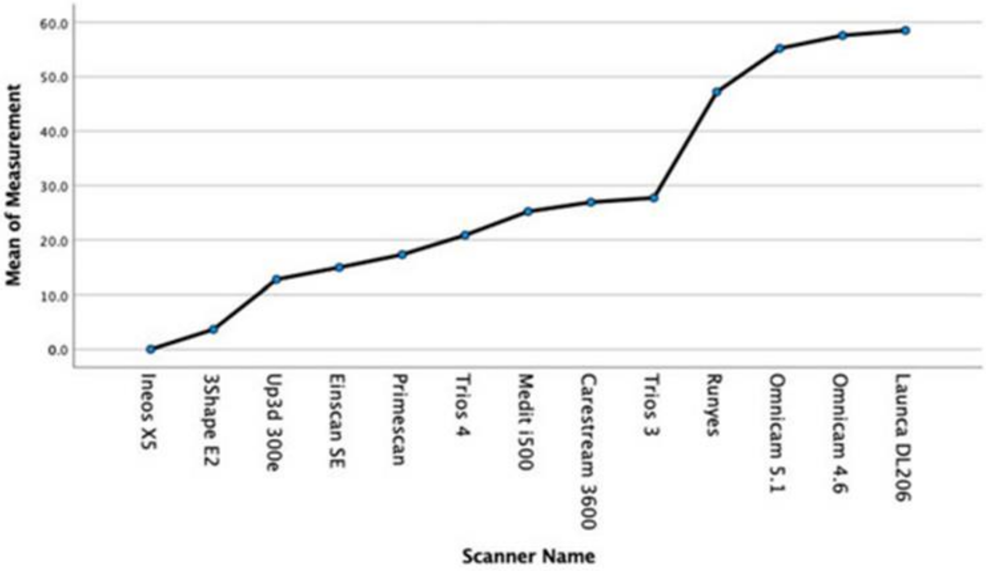

Figure 4. Mean precision measurements for all scanners.

Table 2. Mean ± SD trueness values of each scanner compared to the master scan from the Ineos X5, ranked by increasing deviation, including significance relative to Ineos X5.

Scanner Model	Average Deviation (µm)	Standard Deviation (µm)	p-Value
Ineos X5	0.0	1.9	1.000
3Shape E2	3.6	2.2	0.125
UP3D 300E	12.8	2.7	0.029
Einscan SE	14.9	9.5	0.004
Primescan	17.3	4.9	<0.001
Trios 4	20.8	6.2	<0.001
Medit i500	25.2	7.3	<0.001
CS3600	26.9	15.9	<0.001
Trios 3	27.7	6.8	<0.001
Runyes	47.2	5.4	<0.001
Omnicam 5.1	55.1	9.5	<0.001
Omnicam 4.6	57.5	3.2	<0.001
Launca DL206	58.5	22.0	<0.001

Table 3. Tukey test homogeneous subsets for multiple comparisons (α = 0.05).

Scanner Model	Scan 1 (µm)	Scan 2 (µm)	Scan 3 (µm)	Scan 4 (µm)	Scan 5 (µm)
Ineos X5	0.0				
3Shape E2	3.7	3.7			
UP3D 300E	12.8	12.8	12.8		
Einscan SE		15.0	15.0	15.0	
Primescan		17.3	17.3	17.3	
Trios 4			20.9	20.9	
Medit i500			25.2	25.2	
CS3600			26.9	26.9	

Trios 3				27.7	
Runyes					47.2
Omnicam 5.1					55.2
Omnicam 4.6					57.6
Launca DL206					58.5
p-Value (Significance)	0.125	0.072	0.051	0.123	0.271

Table 4. ANOVA p-values comparing groups.

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic	p-Value
Between Groups	28,324.784639	8	3540.598080	29.235153	0.000
Within Groups	9809.712588	81	121.107563		
Total	38,134.497226	89			

In this investigation, Primescan achieved the highest trueness (17.3 ± 4.9 µm), followed in ascending order by Trios 4 (20.8 ± 6.2 µm), i500 (25.2 ± 7.3 µm), CS3600 (26.9 ± 15.9 µm), Trios 3 (27.7 ± 6.8 µm), Runyes (47.2 ± 5.4 µm), Omnicam 5.1 (55.1 ± 9.5 µm), Omnicam 4.6 (57.5 ± 3.2 µm), and Launca DL206 (58.5 ± 22.0 µm). Confocal-based scanners generally performed with higher trueness compared to others.

Among lab scanners, the Ineos X5 exhibited the best trueness (0.0 ± 1.9 µm), followed by 3Shape E2 (3.6 ± 2.2 µm), UP3D 300E (12.8 ± 2.7 µm), and Einscan SE (14.9 ± 9.5 µm).

Precision results **(Table 3)** show that Ineos X5 was significantly more precise than all intra-oral scanners. Among intra-oral devices, Primescan was the only scanner statistically comparable to lab scanners E2 and 300E in precision. Six intra-oral scanners—Primescan, Trios 4, i500, CS3600, and Trios 3—demonstrated higher precision than Runyes, Omnicam 4.6/5.1, and DL206.

All intra-oral scanners maintained mean full-arch deviations below 60 µm **(Figure 5)**. Notably, five newer-generation scanners (Primescan, Trios 3 & 4, i500, CS3600) achieved mean errors under 30 µm, showing consistent performance and reliability. The older Omnicam model, tested with software versions 4.6 and 5.1, showed improvement with the later version, although deviations remained higher than the other scanners.

The Einscan SE lab scanner achieved high trueness (15.6 ± 9.5 µm) relative to the master STL. However, visual inspection of triangular meshes indicated less detailed surface capture **(Figure 6)**.

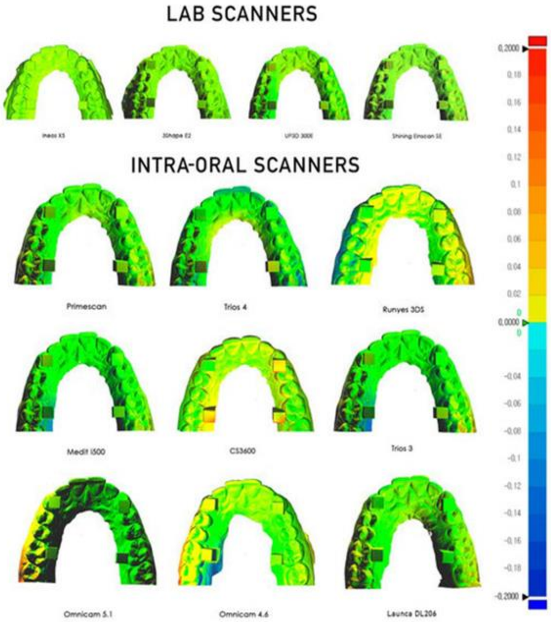

Figure 5. Color-coded deviation map.

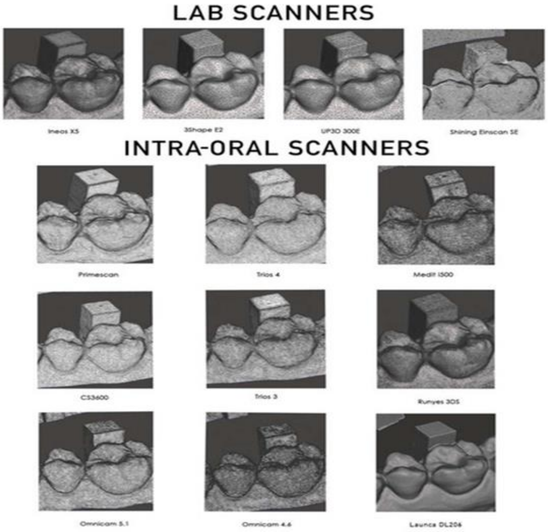

Figure 6. Triangular mesh surface comparison.

The primary null hypothesis was rejected, since measurable differences in trueness and precision were observed among certain intra-oral and lab scanners.

The secondary null hypothesis—that lab and intra-oral scanners show no differences—was partially rejected. While Primescan differed from Ineos X5, it showed comparable performance with other lab scanners, partially supporting the hypothesis.

The progression of intra-oral scanner technology is noteworthy. Despite differences, all scanners achieved overall trueness below 60 µm, demonstrating reliability suitable for clinical use.

Digital intra-oral scanning improves patient comfort and enables the creation of digital impressions more efficiently than conventional tray methods [1]. Its widespread adoption has facilitated same-day dentistry, allowing restorations to be designed and placed within a single visit.

While digital workflows generally yield better marginal fit than conventional impressions, full-arch scanning remains technique-sensitive, and scanner selection strongly affects the accuracy and reproducibility of the final digital model [26–30].

The main objective of this investigation was to evaluate accuracy, trueness, and precision in full-arch digital scans. Seven intra-oral scanners and four laboratory scanners were assessed, making this study the most current evaluation of scanners available as of early 2021. However, the study was performed in vitro, which imposes inherent limitations compared to clinical conditions. In real patients, scans must capture multiple surfaces and materials—including enamel, dentin, soft tissues, and various restorations—and individual variations in arch shape or jaw opening introduce additional complexity. Consequently, while this study provides insights into scanner performance, in vivo trials are essential to fully understand how these factors affect full-arch scanning accuracy for modern scanners.

All scans in this study were performed by a single experienced clinician to maintain consistency. Variation in scanning strategy can significantly influence stitching performance, which directly affects the reliability of the accuracy results [31–33]. The definitions of trueness and precision followed ISO 5725-1 standards, where trueness measures closeness to a reference value and precision reflects repeatability [18]. Lab scanners generally exhibit higher accuracy due to their use of structured light or laser technology, larger fields of view, and fewer scanning limitations (e.g., reflections, moisture, tongue or soft tissue interference) compared to purely optical intra-oral scanners [34]. Consequently, the lab scanners served as benchmarks in this study for evaluating the intra-oral scanner performance.

Previous studies have compared digital intra-oral scanners [22–27], but many focus on older models or generational differences rather than recent software and hardware improvements. For instance, Omnicam version 4.6 was compared with Omnicam version 5.1, showing that enhanced stitching algorithms and upgraded computing hardware substantially improve scanning accuracy [35, 36]. Additionally, proper scanner calibration significantly affects both trueness and precision, and in this study, all devices were calibrated immediately prior to each scanning session [37].

Several limitations of this in vitro work should be noted. Clinical factors such as saliva, blood, and patient movement are not represented and may influence accuracy in real-world settings.

Observational analysis of triangular meshes highlighted noticeable differences between scanners in rendering surface morphology and marginal details. Among lab scanners, increased deviation corresponded with reduced surface detail, whereas intra-oral scanners showed variable performance. Differences were particularly apparent in occlusal anatomy and flatter surfaces, with some scanners struggling to consistently capture these areas. Although total triangle count can indicate detail, each scanner processes point clouds differently when generating CAD meshes. Established brands such as Dentsply Sirona, 3Shape, and Carestream displayed noticeable variation in mesh density, whereas newer devices like Medit, Runyes, and Launca produced more uniform meshes, likely due to optimized algorithms developed over extensive R&D periods.

One of the most striking results was the Launca DL206, launched in early 2021. While its trueness was comparable to Runyes and Omnicam, its triangular mesh exhibited an impressive level of detail. However, because the exact proprietary algorithms converting point clouds into triangular meshes are not publicly disclosed, comparing mesh appearance and triangle count across scanners presents a limitation.

The rapid advancements in modern dentistry, particularly in CAD/CAM, digital impression capture, and chair-side fabrication, are impressive and are expected to play an even larger role in the near future. A core component of contemporary digital dentistry is obtaining accurate, high-fidelity scans of the intra-oral anatomy. Digital intra-oral scanners are now well established, with numerous validated models available commercially. Given the competitive landscape among dental equipment manufacturers, continuous improvements are anticipated. The use of these scanners enhances patient comfort and allows clinicians to capture precise, three-dimensional representations of the oral cavity, supporting same-day restorations and expanding treatment possibilities.

Although there is substantial evidence demonstrating that digital scanners can accurately record dental preparations and produce reliable digital models, comparative data on trueness and precision across different scanner models remains limited. Some reports suggest that scanners can substitute traditional impressions for certain preparations, yet it is unclear whether they can fully replace conventional impressions in all scenarios [20–22, 38–40]. Older studies that reported limited accuracy often focused on a small number of earlier-generation scanners and recommended their use primarily for smaller prosthetic cases [41]. The present study, in contrast, evaluated the latest-generation scanners, showing that most devices with updated software could achieve accuracy within 30 microns.

Conclusion

At the time this study was conducted, very few publications had assessed full-arch accuracy across the newest intra-oral scanners.

This study aimed to compare the full-arch trueness and precision of the leading intra-oral scanners available in 2020, including Dentsply Sirona Primescan and Omnicam (versions 4.6 and 5.1), 3Shape Trios 3 and 4, Carestream 3600, Launca DL206, Runyes, and Medit i500, as well as a lower-cost lab scanner (Shining Einscan SE) and widely used lab scanners (Dentsply Sirona Ineos X5, 3Shape E2, and UP3D 300e).

Each scanner performed ten scans, and all datasets were analyzed using CloudCompare to assess both trueness and precision. The results revealed that Primescan had the lowest overall deviation, yielding the most accurate measurements, statistically comparable to all lab scanners except the Ineos X5. Following Primescan, the Trios 4, Medit i500, CS3600, and Trios 3 produced the next most precise intra-oral scans. No significant differences were observed among these five scanners (Primescan, Trios 3 and 4, i500, CS3600), whereas the older Omnicam, Runyes, and Launca DL206 showed slightly lower performance. However, the updated Omnicam hardware/software did provide improved results, and the deviations of all three remained clinically acceptable.

An additional observational outcome involved examining triangular meshes for anatomical detail. Clear differences were seen in the level of surface detail captured by the Ineos X5 compared to other lab scanners, with a similar pattern observed for Primescan. The scanners varied in their ability to render flat surfaces versus critical anatomical features, concentrating more triangles in areas of functional importance. Notably, the newer Runyes and Launca DL206 scanners displayed exceptional detail, with the Launca DL206 producing a dense, evenly rendered mesh, reflected by a larger STL file size than other scanners.

This study confirms that all current intra-oral scanners are capable of capturing reliable, reproducible full-arch scans in dentate patients. Nonetheless, scanning edentulous arches remains more challenging, warranting further investigation.

Future research should evaluate these scanners in varied clinical settings to validate these findings and establish their utility in real-world practice.

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