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Clinical study on the accuracy of wireless intraoral scanners for digital full arch impressions of dentate arches

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ABSTRACT

Objective: The aim of this clinical study was to update the literature on the scan accuracy (trueness and precision) of four modern wireless intraoral scanners (IOS) and to compare their performance with wired IOS and conventional impressions (CVI). A metallic reference aid was employed as the reference dataset.
Methods: Digital impressions were obtained from four wireless IOS (Dexis IS 3800 W, Medit i700, Primescan 2, and Trios 5), one wired IOS (Primescan AC), and one CVI in thirty patients. Scan data were analysed using 3D software, and CVI dental stone casts were evaluated using a coordinate measuring machine. Scan accuracy between the reference aid and the various impression systems was compared. Statistical analysis was performed using mixed-effects ANOVA models, with significance set at $p < 0.05$.
Results: Statistically significant differences in trueness and precision were observed between the impression systems ($p < 0.05$). A significant interaction between impression system and linear distance ($p < 0.05$) indicated that performance varied depending on the length of scan path. The Dexis IS 3800 W and Medit i700 exhibited the greatest deviations, whereas the cloud-native Primescan 2 demonstrated comparable or superior accuracy to other impression systems.
Conclusions: Within the limitations of this clinical study, the overall accuracy of CVI remained high. Accuracy was influenced by both the impression system and the length of the scan path, with smaller deviations observed over short distances and increased inaccuracies over longer distances, particularly in diagonal and intermolar regions.
Clinical significance: Wireless IOS demonstrated statistically significant differences in certain cases, highlighting the importance of carefully evaluating the performance of each system individually.

1. Introduction

The concept of wireless intraoral scanners (IOS) gained increasing attention in recent years, with growing adoption in clinical practice due to their ergonomic and workflow benefits. Since the introduction of the first wireless IOS, various manufacturers developed systems offering enhanced manoeuvrability, flexibility, and hygiene. However, early devices demonstrated reduced accuracy, particularly in full-arch scans. Additionally, the shift to wireless technology introduced challenges such as limited battery life and reliance on stable connections [1–4]. In 2024, Dentsply Sirona launched the first cloud-native IOS, shifting data processing from the device to remote servers, thereby requiring only a wireless handpiece and display device. This innovation reduced hardware requirements but raised concerns regarding data speed, latency, and accuracy, especially in regions with limited internet infrastructure [3,5].

Although numerous in vitro studies evaluated the accuracy of IOS, few examined these systems under clinical conditions using a reference structure [6–8]. This was largely due to the lack of an intraoral reference structure that allows reliable in vivo comparisons, as well as the inherent logistical challenges of conducting clinical trials. As summarized in the comprehensive review by Mehl et al. [9], only two reference methods have been considered reliable for assessing full-arch scan accuracy in vivo: the bar method and the sphere method, the latter enabling measurement of multiple intra-arch distances beyond the intermolar region.

To the best of the author's knowledge, no data regarding the full-arch accuracy of wireless IOS, including the latest cloud-based solution, had been reported in the literature to date. Therefore, the aim of this clinical

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study was to evaluate the scan accuracy of digital full-arch impressions obtained using five different wireless intraoral scanners: Dexis IS 3800 W (EH Germany, Herzogenrath, Germany), i700w (Medit, Seoul, South Korea), Primescan 2 (Dentsply Sirona, Bensheim, Germany), and Trios 5 (3Shape, Copenhagen, Denmark), as well as one wired intraoral scanner, Primescan AC (Dentsply Sirona), according to ISO 5725–1 (mean values to describe trueness and standard deviation (SD) to describe precision) [10]. Furthermore, the results were compared to those from a conventional monophase polyether impression followed by casting of a dental stone cast.

The following null hypotheses was tested: there are no significant differences in scan accuracy between the impression systems.

2. Participants, materials and methods

2.1. Study design and ethical approval

This clinical study was designed to compare the accuracy (trueness and precision) of full-arch mandibular impressions obtained using three wireless on-premises IOS (Dexis IS 3800 W, Medit i700w, and Trios 5), one wireless cloud-based IOS (Primescan 2), one wired IOS (Primescan AC), and a conventional polyether impression (Impregum) with subsequent dental stone casting. A reference aid with four spheres was employed for measurement.

A total of thirty patients were recruited for this study, consistent with the sample sizes reported in previous studies on this topic [11,12].

The inclusion criteria for this study required participants to possess a complete mandibular dentition without restorations extending over the cusps, and a dental arch that permitting stable placement of the measuring spheres on the occlusal surfaces. Additionally, participants were required to demonstrate good oral hygiene. Exclusion criteria encompassed individuals with severe systemic illnesses, such as epilepsy, and those with known allergies to the materials utilised in the study.

The study was conducted at the Department of Prosthodontics of the Justus Liebig University (JLU), between June and September 2024, in accordance with ethical principles including the Declaration of Helsinki. Ethical approval was granted by the local Ethics Committee of the JLU (Ref. no. 163/15) and the study was recorded in the German Clinical Trial Register (DRKS00027135). To ensure consistency, all impressions and measurements were carried out by a single experienced dentist (L. C.).

2.2. Reference aid

Four bearing steel spheres (1.3505 100Cr6 DIN5401; TIS, Gauting, Germany), each with a diameter of 5 mm, were reversibly fixed to the occlusal surfaces of the mandibular arch using a flowable composite (Grandio Flow, Voco, Cuxhaven, Germany). A metallic reference aid (Bretthauer GmbH, Dillenburg, Germany) was employed to ensure precise and reproducible positioning of the spheres. Lip and cheek retraction was facilitated using a cheek retractor (Optragate, Ivoclar Vivadent, Schaan, Lichtenstein) to provide optimal access to the teeth. The design and clinical application of the reference aid have been described in detail by Kuhr et al. [6] in detail. Fig. 1 depicts the reference aid and its clinical positioning.

2.3. Experimental procedure

Five different intraoral scanners (IOS) were used to obtain full-arch digital impressions of the mandibular arch from each participant:

- Dexis IS 3800 W wireless (‘3800-wl’, EH Germany, Herzogenrath, Germany; version 1.0.0.16)
- Medit i700w wireless (‘i700-wl’, Medit, Seoul, South Korea; version 1.11.1)
- Primescan AC wired (‘PRI1-w’, Dentsply Sirona, Bensheim, Germany; version 5.2.4)
- Primescan 2 wireless (‘PRI2-wl’, Dentsply Sirona; version 1.1.1)
- Trios 5 wireless (‘TRI5-wl’, 3Shape, Copenhagen, Denmark; version 22.1.1)

Each digital impression was obtained by initiating the scan on the occlusal surface, followed by the oral surface, and concluding with the buccal surface [7,12–17]. The scan origin was consistently set at the fourth quadrant. To ensure standardised conditions, each intraoral scanner was calibrated prior to use, if a corresponding procedure was provided by the respective manufacturer. The resulting scan datasets were directly exported as Standard Tessellation Language (STL) files.

After removal of the cheek retractor, a conventional impression (CVI) was taken using a medium-body polyether impression material (Impregum Penta Soft Quick, 3 M Espe, Minneapolis, MN, USA) in a prefabricated metallic impression tray (Ehricke stainless steel, Orbis Dental, Münster, Germany). The polyether impression was stored for a minimum of two hours to allow for elastic recovery before being cast with type IV dental stone (Fujirock EP, GC Corporation, Tokyo, Japan). The resulting dental stone casts were stored under controlled laboratory conditions ($23\,^{\circ}C \pm 1\,^{\circ}C$, 50 % $\pm$ 10 % humidity) for a period of no less than five and no more than ten days prior to measurement [18].

2.4. Measurement and analysis

A coordinate measurement machine (CMM; Thome Präzision, Messel, Germany), equipped with the Metrologic X4 software package (X4 V10 GA x64, Metrologic Group, Meylan, France), was used for precise measurements of the reference aid and dental stone casts. The reference aid with spheres was measured ten times, and the mean value for each sphere position was calculated. This digital reference model was than saved as a dataset in Initial Graphics Exchange Specification (IGES) format.

For the digital impressions, the STL files were imported into a 3D analysis software (GOM Inspect 2019, Gom, Braunschweig, Germany). Linear measurements between the centres of the four spheres (1–4) were performed by aligning the scanned sphere positions to their CAD

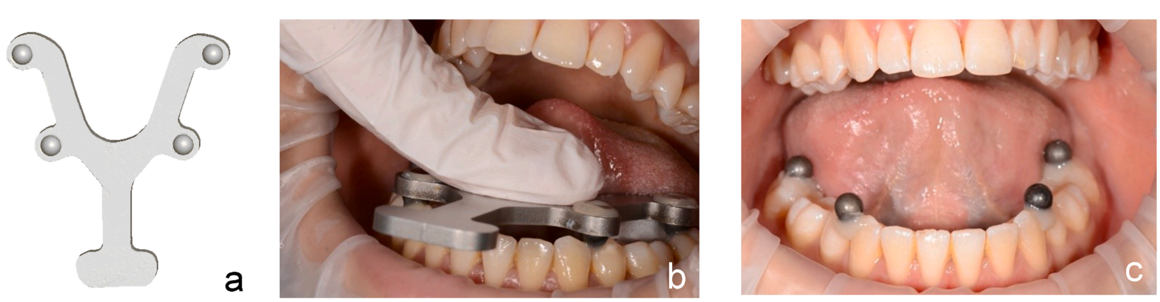

Fig. 1. Example of the reference aid with four spheres: (a) the reference aid, (b) intraoral application, (c) final position of the spheres fixed on the occlusal surface.

reference model. Deviations between the measured distances in the digital impressions and the reference model were calculated ((D1_2, D1_3, D1_4, D2_3, D2_4, D3_4, Fig. 2). Surface superimposition was carried out using a best fit algorithm to ensure accurate alignment and visualisation of 3D deviations.

2.5. Statistical analysis

Statistical analysis was performed using SPSS software (version 26, IBM, Armonk, NY, USA). For the analysis of trueness, data were transformed using a square root transformation. A two-factor analysis of variance (ANOVA) was conducted with impression and distance as factors. To account for the repeated measures within each patient, a variance component model with patient as a random factor was applied using the MIXED procedure in SPSS. As variance heterogeneity was present, a model was selected that estimated variances separately for each combination of factor levels, thereby appropriately modelling the heterogeneity. Pairwise comparisons were derived from the estimated marginal means and adjusted for multiple testing using the Sidak correction. For visual representation, data were displayed using box plots. For the analysis of precision, robust Levene's tests were based on medians (Brown-Forsythe test) were used to compare impression systems within and across groups for each measured distance. To account for the dependency of repeated measurements, the tests were performed on model residuals. Differences were considered statistically significant at $p < 0.05$.

3. Results

Deviations in the pooled linear distances (D1_2, D1_3, D1_4, D2_3, D2_4, D3_4) between the reference dataset and the six impression systems are shown in Table 1 and Fig. 3. With regard to trueness, statistically significant differences were found only for the 3800-wl and i700-wl system in comparison to the other impression systems ($p < 0.001$). Regarding precision, no significant differences were found between the following pairs: 3800-wl and i700-wl, PRI1-w and PRI2-wl, TRI5-wl and PRI2-wl, and CVI and PRI1-w ($p > 0.05$). A detailed statistical analysis of trueness and precision, including p-values for the pooled linear distances, is presented in Table 2.

The detailed analysis of the individual linear distances revealed partially significant differences between the six impression systems in terms of trueness and precision. The corresponding deviations are shown in Table 3 and Fig. 4. The 3800-wl and i700-wl systems consistently demonstrated the largest deviations across most distances when compared to the other impression systems.

Table 1
Deviations (mean ± standard deviation (SD) [µm] of the pooled data of linear distances (D1_2, D1_3, D1_4, D2_3, D2_4, D3_4) of the six impression systems (3800-wl = Dexis 3800 wireless, i700-wl = Medit i700 wireless, PRI1-*w* = Primescan AC wired, PRI2-wl = Primescan 2 wireless, TRI5-wl = Trios 5 wireless, CVI = conventional polyether impression/dental stone cast).

Impression System	Mean (Trueness) ± SD (Precision) [µm]
3800-wl	115.3 ± 104.1
i700-wl	88.0 ± 100.9
PRI1-w	44.8 ± 42.1
PRI2-wl	46.3 ± 47.7
TRI5-wl	51.0 ± 55.8
CVI	40.9 ± 44.0

The analysis of trueness for the individual linear distances revealed several statistically significant differences between the impression systems (see Table 4 for exact p-values). For the short linear distance near the scan origin (D1_2), the 3800-wl system demonstrated significantly greater deviations than all other impression systems, whereas the PRI2-wl system exhibited significantly smaller deviation in comparison to CVI. Regarding the intermolar distance (D1_4), the PRI2-wl system exhibited significantly smaller deviations than the i700-wl, while the 3800-wl showed significantly greater deviations compared to PRI1-w, PRI2-wl, TRI5-wl, and CVI. Additionally, PRI2-wl and TRI5-wl demonstrated significantly greater deviations than CVI. For the first diagonal distance (D1_3), the 3800-wl system exhibited significantly greater deviations than PRI1-w, PRI2-wl, TRI5-wl, and CVI, while the i700-wl also showed significantly greater deviations than PRI1-w and PRI2-wl. In the second diagonal distance (D2_4), both the 3800-wl and the i700-wl systems demonstrated significantly greater deviations than CVI. Finally, for the anterior distance (D2_3), the 3800-wl system once again exhibited significantly greater deviations than PRI1-w, PRI2-wl, TRI5-wl, and CVI.

The analysis of precision also revealed several statistically significant differences between the impression systems across all measured linear distances (see Table 4 for detailed p-values). For the short distance near the scan origin (D1_2), the 3800-wl system showed significantly greater deviations than all other impression systems. In contrast, PRI2-wl demonstrated significantly smaller deviation compared to all other impression systems. For the other short distance (D3_4), the CVI exhibited the greatest deviation compared to all other impression systems. Additionally, the 3800-wl system demonstrated significantly higher deviations than all other IOS. With regard to the intermolar distance (D1_4), the 3800-wl system showed significantly greater deviations than all other impression systems except for the i700-wl.

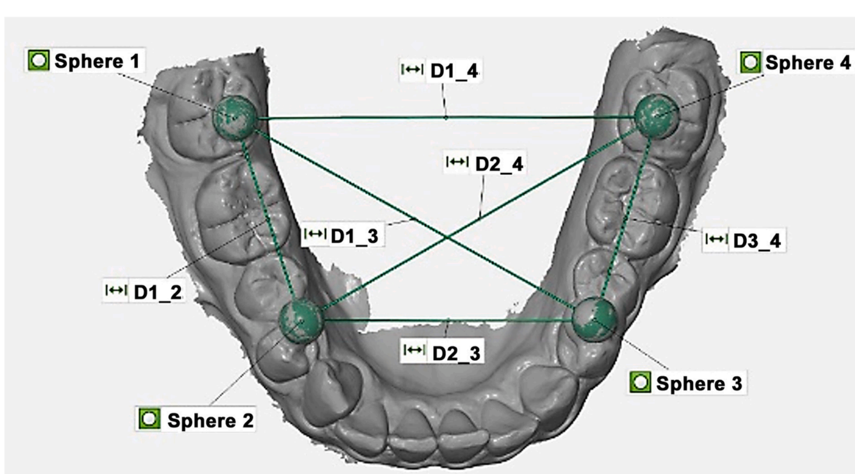

Fig. 2.. Example of the measurement of the linear distances ($D1_2$, $D1_3$, $D1_4$, $D2_3$, $D2_4$, $D3_4$) between the four spheres in the three-dimensional analysis software GOM Inspect.

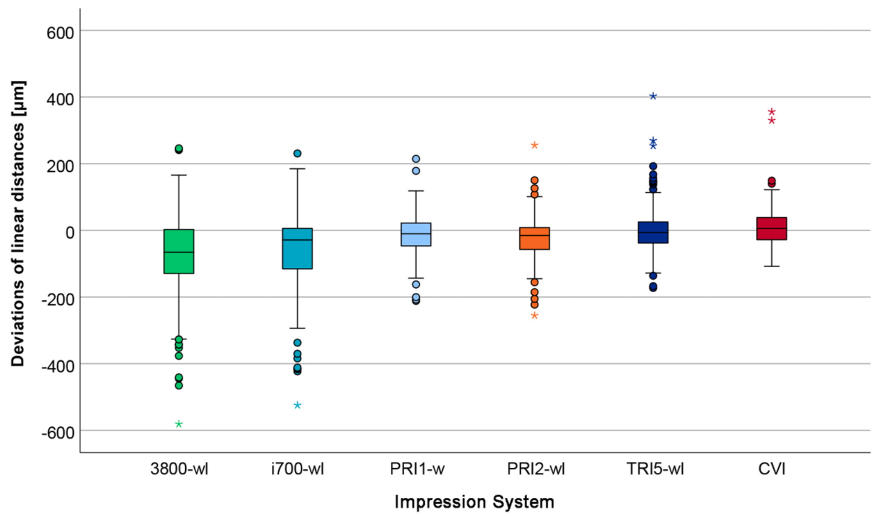

Fig. 3.. Boxplot diagram displaying the positive and negative deviations (mean ± standard deviation (SD) [µm] of the pooled data of linear distances ($D1_2$, $D1_3$, $D1_4$, $D2_3$, $D2_4$, $D3_4$) of the six impression systems (3800-wl = Dexis 3800 wireless, i700-wl = Medit i700 wireless, PRI1-w = Primescan AC wired, PRI2-wl = Primescan 2 wireless, TRI5-wl = Trios 5 wireless, CVI = conventional polyether impression/dental stone cast) for all groups; outliers (o), extreme values (*).

Table 2
Statistically analysis for trueness (upper right part) and precision (lower left part, presented in italic letter in grey boxes) of the pooled data of linear distances (D1_2, D1_3, D1_4, D2_3, D2_4, D3_4) of the six impression systems (3800-wl = Dexis 3800 wireless, i700-wl = Medit i700 wireless, PRI1-*w* = Primescan AC wired, PRI2-wl = Primescan 2 wireless, TRI5-wl = Trios 5 wireless, CVI = conventional polyether impression/dental stone cast) according to ISO 5725[10].

Impression System	3800-wl	i700-wl	PRI1-w	PRI2-wl	TRI5-wl	CVI
3800-wl	-	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
i700-wl	*0.889*	-	< 0.001	< 0.001	< 0.001	< 0.001
PRI1-w	*< 0.001*	*< 0.001*	-	1.000	1.000	0.989
PRI2-wl	*< 0.001*	*< 0.001*	*0.094*	-	1.000	0.997
TRI5-wl	*< 0.001*	*< 0.001*	*0.006*	*0.227*	-	0.742
CVI	*< 0.001*	*< 0.001*	*0.515*	*0.029*	*0.002*	-

Similarly, the i700-wl demonstrated significantly greater deviation than all systems except for the 3800-wl. Furthermore, CVI showed significantly smaller deviation than PRI2-wl and TRI5-wl. For the diagonal distance (D1_3), both the 3800-wl and the i700-wl systems exhibited significantly greater deviations than all other impression systems. This pattern was consistent for the second diagonal distance (D2_4), where the 3800-wl and the i700-wl also showed significantly greater deviations, with the exception of TRI5-wl when compared to 3800-wl. In this context, CVI was significantly more precise than the 3800-wl, i700-wl, and TRI5-wl systems. Finally, for the anterior distance (D2_3), the i700-wl exhibited significantly greater deviations than PRI1-w, PRI2-wl, and Trios 5.

4. Discussion

The null hypothesis, that there were no significant differences between the scan accuracy of the impression systems had to be partially rejected.

Several factors are known to influence the accuracy of an intraoral scan [19]. To minimise variability and ensure consistency, all controllable parameters were standardised in this in vivo study. All scans and measurements were carried out by the same dentist (L.C.) [20]. A consistent scan path, well described in the literature, was followed [21], and each IOS was operated using the latest available software version, as previous studies have shown that software updates can significantly affect scan accuracy [22–24]. Furthermore, each IOS handpiece was calibrated prior to use in accordance with the manufacturer's instructions to ensure optimal performance [25]. All scans were conducted in the same clinical environment to eliminate potential variability related to external factors such as wireless or internet connectivity, an aspect particularly relevant to cloud-based IOS systems.

Although numerous studies have analysed the accuracy of full-arch scans, comparing their results remained challenging due to the predominant use of in vitro setups employing reference models [26–28]. Such in vitro setups facilitated the matching process for scanner software, as they lacked confounding clinical factors such as soft tissues, saliva, and patient movement, which can interfere with alignment. Consequently, these controlled conditions were likely to overestimate the accuracy and precision of intraoral scans when compared to actual clinical scenarios.

Table 3
Deviations (mean ± standard deviation (SD) [μm] of linear distances (D1_2, D1_3, D1_4, D2_3, D2_4, D3_4) of the six impression systems (3800-wl = Dexis 3800 wireless, i700-wl = Medit i700 wireless, PRI1-*w* = Primescan AC wired, PRI2-wl = Primescan 2 wireless, TRI5-wl = Trios 5 wireless, CVI = conventional polyether impression/dental stone cast).

Distance	Impression System	Mean (Trueness) ± SD (Precision) [μm]
D1_2	3800-wl	71.3 ± 35.7
	i700-wl	17.4 ± 16.1
	PRI1-w	19.4 ± 15.8
	PRI2-wl	12.7 ± 8.8
	TRI5-wl	18.1 ± 16.3
	CVI	30.0 ± 26.0
D1_3	3800-wl	177.5 ± 128.8
	i700-wl	105.9 ± 77.0
	PRI1-w	46.6 ± 42.8
	PRI2-wl	48.3 ± 36.5
	TRI5-wl	58.4 ± 43.6
	CVI	53.3 ± 64.3
D1_4	3800-wl	202.7 ± 135.5
	i700-wl	188.7 ± 150.5
	PRI1-w	65.9 ± 57.3
	PRI2-wl	99.4 ± 71.8
	TRI5-wl	105.6 ± 86.2
	CVI	48.5 ± 41.2
D2_3	3800-wl	87.2 ± 57.2
	i700-wl	72.3 ± 53.4
	PRI1-w	44.7 ± 29.6
	PRI2-wl	39.5 ± 28.6
	TRI5-wl	44.0 ± 31.4
	CVI	42.7 ± 59.2
D2_4	3800-wl	96.5 ± 79.8
	i700-wl	118.2 ± 98.2
	PRI1-w	66.0 ± 48.8
	PRI2-wl	58.6 ± 36.7
	TRI5-wl	58.9 ± 54.9
	CVI	39.1 ± 28.8
D3_4	3800-wl	56.2 ± 47.1
	i700-wl	25.4 ± 16.6
	PRI1-w	26.3 ± 18.4
	PRI2-wl	19.1 ± 16.3
	TRI5-wl	21.2 ± 17.4
	CVI	32.1 ± 26.4

Many other studies – both in vitro and in vivo – that analysed the accuracy of full-arch scans compared the dimensional data obtained from an IOS with a dataset derived from a conventional impression and the resulting dental stone cast. However, this approach allowed only a comparison between the IOS scan and the conventional model, as the true intraoral geometry of the patient is not accessible. While this method may have been adequate for smaller scan areas, such as single quadrants, its validity becomes questionable in full-arch assessments [9].

However, as the size of the scanned area increased, matching errors in digital scans inevitably accumulated, and distortions in conventional impressions became more prevalent. Therefore, in accordance with ISO 5725–1 [8,10,29], a reference structure with known dimensions was required to address these limitations. In this study, such a reference was employed to evaluate not only the precision but also the trueness of the scans and impressions. This approach enables accurate measurement of individual linear distances and potential deviations across the entire arch. Moreover, the non-translucent surface of the reference spheres ensures high scanability and accuracy [30], and this method has proven reliable in previous studies [6,7,31].

As anticipated, superior results were obtained for shorter, more anterior, and particular quadrant-bound distances. The fact that scan accuracy depends on the length of the scan path emphasises the cumulative nature of digital errors during full-arch scanning. While these deviations may be acceptable for simpler appliances, such as occlusal splints, they can impact the fit and long-term success of more complex restorations, such as fixed full-arch prostheses.

The present study demonstrated notable differences in both trueness and precision among the tested impression systems. Trueness reflects the closeness of the measured values to the true dimensions of the object. A low trueness indicates systematic deviations, resulting in scans that consistently misrepresent the actual geometry. This was evident especially in the 3800-wl system, which showed significantly greater deviations compared to other scanners across multiple measured distances. Such systematic inaccuracies can compromise clinical outcomes, for example, by producing not fitting restorations. In contrast, precision pertains to the reproducibility of repeated measurements under identical conditions. A low precision implies high variability between scans, even if the average measurement may be close to the true value. This inconsistency was also observed in the 3800-wl system as well as the

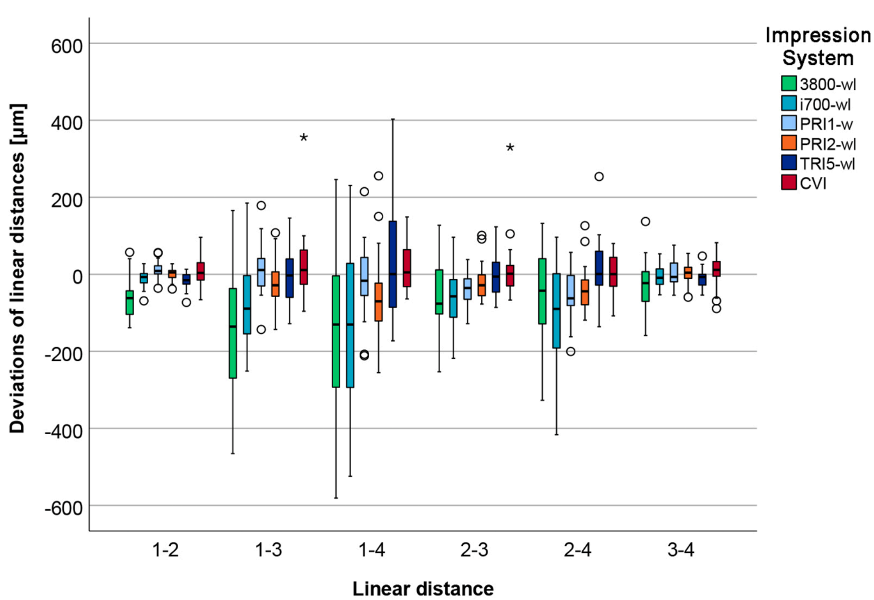

Fig. 4.. Boxplot diagram displaying the positive and negative deviations (mean ± standard deviation (SD) [μm] of the linear distances ($D1_2$, $D1_3$, $D1_4$, $D2_3$, $D2_4$, $D3_4$) of the six impression systems (3800-wl = Dexis 3800 wireless, i700-wl = Medit i700 wireless, PRI1-w = Primescan AC wired, PRI2-wl = Primescan 2 wireless, TRI5-wl = Trios 5 wireless, CVI = conventional polyether impression/dental stone cast) for all groups; outliers (o), extreme values (*).

Table 4
Statistically analysis for trueness (upper right part) and precision (lower left part, presented in italic letter in grey boxes) of linear distances (D1_2, D1_3, D1_4, D2_3, D2_4, D3_4) of the six impression systems (3800-wl = Dexis 3800 wireless, i700-wl = Medit i700 wireless, PRI1-*w* = Primescan AC wired, PRI2-wl = Primescan 2 wireless, TRI5-wl = Trios 5 wireless, CVI = conventional polyether impression/dental stone cast) according to ISO 5725[10].

Distance	Impression System	3800-wl	i700-wl	PRI1-w	PRI2-wl	TRI5-wl	CVI
D1_2	3800-wl	-	> 0.001	> 0.001	> 0.001	> 0.001	> 0.001
	i700-wl	*> 0.001*	-	1.000	0.999	1.000	0.387
	PRI1-w	*> 0.001*	*0.904*	-	0.832	1.000	0.768
	PRI2-wl	*> 0.001*	*0.009*	*0.003*	-	0.980	0.030
	TRI5-wl	*> 0.001*	*0.840*	*0.746*	*0.029*	-	0.578
	CVI	*0.020*	*0.071*	*0.078*	*> 0.001*	*0.058*	-
D1_3	3800-wl	-	0.243	> 0.001	> 0.001	> 0.001	> 0.001
	i700-wl	*0.002*	-	0.014	0.023	0.183	0.052
	PRI1-w	*> 0.001*	*0.001*	-	1.000	0.997	1.000
	PRI2-wl	*> 0.001*	*> 0.001*	*0.724*	-	1.000	1.000
	TRI5-wl	*> 0.001*	*0.002*	*0.424*	*0.186*	-	1.000
	CVI	*> 0.001*	*0.025*	*0.647*	*0.481*	*0.973*	-
D1_4	3800-wl	-	1.000	> 0.001	0.010	0.022	> 0.001
	i700-wl	*0.360*	-	1.000	0.002	0.169	0.263
	PRI1-w	*> 0.001*	*> 0.001*	-	0.535	0.550	0.876

i700-wl system, which exhibited the largest deviations and variability across most distances. Reduced precision undermines the reliability of intraoral scans, limiting their utility in fabricating consistently accurate prosthetic restorations. Therefore, both high trueness and precision are essential for the overall accuracy and clinical applicability of digital impression systems. While some systems demonstrated acceptable trueness but variable precision, others consistently deviated from the true dimensions. These findings highlight the necessity to consider both parameters when evaluating and selecting intraoral scanners for clinical practice.

The consistently greater deviations observed with the 3800-wl and i700-wl systems may be attributed to specific hardware limitations and differences in data acquisition or processing algorithms, which warrant further investigation. As the manufacturers do not disclose their software algorithms, any explanation regarding their influence on the observed differences in trueness and precision remains speculative. However, it is reasonable to assume that variations in image stitching, data compression, and error correction protocols may contribute to the performance disparities identified among the IOS systems.

The findings of the present study aligned with those of previous studies [6,7,19,31]. Notably, when focusing on a single quadrant, the trueness and precision of most IOS were comparable to those of the CVI.

With respect to sole cloud-based IOS included in this study, although not investigated in further detail, it should be noted that a fully functional high-speed internet connection, capable of uploading data at speeds exceeding 50 Mbps, was available, as stipulated in the manufacturer's system requirements at the time of the study. Under these conditions, the results obtained with the new PRI2-wl cloud-based IOS did not differ significantly from those of the local PRI1-w system. However, for routine clinical dentistry, it was essential to understand the influence of internet connection speed on the system's usability and its potential adverse effects on accuracy and precision. Further data were required in this regard, as the setup of the present study did not permit controlled reduction internet connection speed for testing purposes.

It could, however, be assumed that even today, such a fast internet connection, ensuring a stable and continuous data flow with an upload speed exceeding 50 Mbps, is not standard in dental practices. This was particularly critical for cloud-based IOS systems, which required consistent, high upload speeds to function effectively.

From a technical perspective, most commercial internet connections prioritised download speeds over upload speeds, as the latter are primarily required by content providers and held less relevance for the average internet user. In Europe, only five countries reported an average broadband upload speed of 50 Mbps or higher as of October 2023 [32], while 19 European countries recorded upload speeds below 40 Mbps. Symmetrical high upload and download speeds in commercial internet connections were almost exclusively associated with fiber-optic connections [32].

A survey of dental practices in Hesse (Germany) revealed that the majority of respondents reported download speed of less than 50 Mbps in their practices [33]. Furthermore, it was hypothesised that data security concerns were more significant in cloud-native systems than in on-premises systems, as all data acquired by the IOS, whether relevant to the computation or not, had to be transferred to a third party. In contrast, with on-premises IOS, the primary computation of the dataset remained internal, and only the dataset representing the finalised model was transmitted to the dental laboratory.

To the best of the authors' knowledge, the only study to date that has evaluated the cloud-based PRI2-wl system was that conducted by Dönmez et al. [3] Although comparable results were reported for both the PRI-1 w and PRI2-wl systems, which aligned with the findings of the present study, the in vitro study design used to assess the accuracy of implant impression systems across different models did not permit direct comparison with the in vivo conditions of the present investigation.

This study has several limitations that should be taken into account when interpreting the findings. Firstly, the analysis was limited to the mandibular arch due to methodological constraints, notably the risk of accidental ingestion of the reversibly attached reference spheres in the maxilla. Consequently, the results are not generalisable to the maxillary arch, as anatomical and functional differences, such as tooth mobility and the floor of the mouth, may influence scan accuracy. Future research should seek to overcome this limitation to facilitate a more comprehensive evaluation encompassing the maxillary arch.

Secondly, the study population consisted solely of young individuals without dental restorations or complex prosthetic treatments, such as implants. This narrow demographic limited the applicability of the results to more diverse clinical populations, particularly older patients with varied dental conditions. Although prior research by Schlenz et al.

[31] indicates minimal effects of age and gap configurations on scan accuracy, further studies are needed to validate these findings across broader patient cohorts.

Thirdly, being a single-centre study, the results may be affected by site-specific factors including operator expertise, equipment calibration, and environmental variables, which could impact scan quality and reproducibility. These factors may limit the external validity of the findings. Therefore, multi-centre studies with standardised protocols are essential to confirm and extend these results.

The results indicate that clinicians should carefully consider the type and extent of the intended prosthetic restoration, as this directly determines the required level of scan accuracy. For smaller restorations, removable prostheses, or occlusal splints, extremely high precision may be less critical, and most available IOS systems are likely to be adequate. In contrast, fixed restorations involving longer spans, particularly full-arch rehabilitations, require closer scrutiny of IOS performance. Notably, the cloud-based PRI2-wl demonstrated comparable accuracy to on-premises systems under ideal internet conditions. However, variability in clinical environments may influence its performance, highlighting the need for further investigation under real-world conditions.

5. Conclusion

The following conclusions can be drawn within the limitations of this clinical study:

1. Statistically significant differences in trueness and precision were identified among the six impression systems. The 3800-wl and i700-wl systems showed the greatest deviation for most measured distances and were therefore the least accurate. Notably, the PRI2-wl, as the first cloud-native IOS, demonstrated comparable or superior accuracy relative to the other impression systems.
2. The scan accuracy depended on the impression system used and the distance being measured. The smallest deviations were observed at shorter distances, whereas higher inaccuracies occurred at longer distances, particularly for diagonal and intermolar measurements.

Research data

The research data will be made available from the corresponding author upon reasonable request.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Maximiliane Amelie Schlenz: Writing – original draft, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Luca Chillemi:** Writing – review & editing, Software, Investigation. **Bernd Wöstmann:** Writing – original draft, Validation, Resources, Methodology.

Declaration of competing interest

The authors declare that they have no conflict of interest regarding the publication of this article.

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References

[1] 3Shape, 3Shape presents TRIOS 3 Wireless. https://www.3shape.com/de/news/2017/3shape-launches-trios-3-wireless, 2025 (accessed 15 March 2025).
[2] S. Sombun, C. Ongthiemsak, In vitro study of the accuracy and efficiency of wireless intraoral scanners at various battery levels, J. Dent. 138 (2023) 104686. https://10.1016/j.jdent.2023.104686.
[3] M.B. Dönmez, G. Cakmak, M. Schimmel, M. Bayadse, B. Yilmaz, S. Abou-Ayash, Scan accuracy of recently introduced wireless intraoral scanners in different fixed partial denture situations, J. Dent. 153 (2025) 105558. https://10.1016/j.jdent.2025.105558.
[4] B. Koo, K. Son, J.M. Lee, S.Y. Kim, M.U. Jin, K.B. Lee, Prediction of learning curves of wired and wireless intraoral scanners, Sci. Rep. 13 (2023) 21661. https://10.1038/s41598-023-48855-2.
[5] Dentsply Sirona, Dentsply Sirona presents Primescan® 2 powered by DS Core: the first cloud-native intraoral scanning solution. https://investor.dentsplysirona.com/news-releases/news-release-details/dentsply-sirona-presents-primescanr-2-powered-ds-core-first/, 2025 (accessed 15 March 2025).
[6] F. Kuhr, A. Schmidt, P. Rehmann, B. Wöstmann, A new method for assessing the accuracy of full arch impressions in patients, J. Dent. 55 (2016) 68–74. https://10.1016/j.jdent.2016.10.002.
[7] A. Schmidt, L. Klussmann, B. Wöstmann, M.A. Schlenz, Accuracy of digital and conventional full-arch impressions in patients: an update, J. Clin. Med. 9 (2020) 688. https://10.3390/jcm9030688.
[8] C. Keul, J.F. Güth, Accuracy of full-arch digital impressions: an in vitro and in vivo comparison, Clin. Oral Investig. 24 (2020) 735–745. https://10.1007/s00784-019-02965-2.
[9] A. Mehl, S. Reich, F. Beuer, J.F. Güth, Accuracy, trueness, and precision - a guideline for the evaluation of these basic values in digital dentistry, Int. J. Comput. Dent. 24 (2021) 341–352.
[10] ISO, ISO 5725-1:1994(en), accuracy (trueness and precision) of measurement methods and results — Part 1: general principles and definitions, 2003.
[11] N.C. Bock, K. Klaus, M.M. Liebel, S. Ruf, B. Wöstmann, M.A. Schlenz, What to prefer in patients with multibracket appliances? Digital vs. Conventional full-arch impressions-A reference aid-based In Vivo study, J. Clin. Med. 12 (2023) 3071. https://10.3390/jcm12093071.
[12] M.A. Schlenz, J.M. Stillersfeld, B. Wöstmann, A. Schmidt, Update on the accuracy of conventional and digital full-arch impressions of partially edentulous and fully dentate jaws in young and elderly subjects: a clinical trial, J. Clin. Med. 11 (2022) 3723. https://10.3390/jcm11133723.
[13] 3Shape, Importance of scan strategy: avoiding common quality issues. https://support.3shape.com/products-trios-and-accessories-trios-3-how-to/correct-full-trios-scan-scanning-strategy, 2025 (accessed 6 September 2025).
[14] Medit, A. Proper scan strategy for scanning a full arch. https://www.medit.com/a-proper-scan-strategy-for-scanning-a-full-arch/, 2025 (accessed 6 September 2025).
[15] Dexis, Dexis ScanFlow Software. https://dexis.com/en-us/dexis-is-scanflow, 2025 (accessed 6 September 2025).
[16] M.A. Schlenz, V. Schubert, A. Schmidt, B. Wöstmann, S. Ruf, K. Klaus, Digital versus conventional impression taking focusing on interdental areas: a clinical trial, Int. J. Environ. Res. Public Health 17 (2020) 4725. https://10.3390/ijerph17134725.
[17] P. Kontis, J.F. Güth, C. Keul, Accuracy of full-arch digitalization for partially edentulous jaws - a laboratory study on basis of coordinate-based data analysis, Clin. Oral Investig. 26 (2022) 3651–3662. https://10.1007/s00784-021-04335-3.
[18] R.G. Luthardt, P. Kuhmstedt, M.H. Walter, A new method for the computer-aided evaluation of three-dimensional changes in gypsum materials, Dent. Mater. 19 (2003) 19–24. https://10.1016/s0109-5641(02)00013-1.
[19] J. Abduo, M. Elseyoufi, Accuracy of intraoral scanners: a systematic review of influencing factors, Eur. J. Prosthodont. Restor. Dent. 26 (2018) 101–121. https://10.1922/EJPRD_01752Abduo21.
[20] C.C.D. Resende, T.A.Q. Barbosa, G.F. Moura, L.D.N. Tavares, F.A.P. Rizzante, F. M. George, F.D.D. Neves, G. Mendonca, Influence of operator experience, scanner type, and scan size on 3D scans, J. Prosthet. Dent. 125 (2021) 294–299. https://10.1016/j.prosdent.2019.12.011.
[21] P. Müller, A. Ender, T. Joda, J. Katsoulis, Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner, Quintessence Int. 47 (2016) 343–349. https://10.3290/j.qi.a35524.
[22] A. Schmidt, M.A. Schlenz, H. Liu, H.S. Kämpe, B. Wöstmann, The influence of hard- and software improvement of intraoral scanners on the implant transfer accuracy from 2012 to 2021: an In vitro study, Appl. Sci. 11 (2021) 7166.
[23] S. Logozzo, E.M. Zanetti, G. Franceschini, A. Kilpelä, A. Mäkynen, Recent advances in dental optics – Part I: 3D intraoral scanners for restorative dentistry, Opt. Lasers. Eng. 54 (2014) 203–221. https://10.1016/j.optlaseng.2013.07.017.
[24] A. Schmidt, C.R. Benedickt, M.A. Schlenz, P. Rehmann, B. Wöstmann, Torsion and linear accuracy in intraoral scans obtained with different scanning principles, J. Prosthodont. Res. 64 (2020) 167–174. https://10.1016/j.jpor.2019.06.006.
[25] P. Rehmann, V. Sichwardt, B. Wöstmann, Intraoral Scanning systems: need for maintenance, Int. J. Prosthodont. 30 (2017) 27–29. https://10.11607/ijp.4976.

[26] I. Baresel, J. Baresel, Full arch accuracy of intraoral scanners with different acquisition technologies: an in vitro study, J. Dent. 156 (2025) 105703. https://10.1016/j.jdent.2025.105703.

[27] K. Schlogl, J.F. Güth, T. Graf, C. Keul, Accuracy of full arch scans performed with nine different scanning patterns- an in vitro study, Clin. Oral Investig. 29 (2025) 92. https://10.1007/s00784-025-06154-2.

[28] H.M.M. Aung, T.Y. Linn, W.F. Lee, J.C. Chao, N.C. Teng, T.Y. Renn, W.J. Chang, Accuracy of intraoral scanners in maxillary multiple restorations: an in vitro study, J. Dent. Sci. 19 (Suppl 2) (2024) S116–S121. https://10.1016/j.jds.2024.07.016.

[29] J.F. Güth, D. Edelhoff, J. Schweiger, C. Keul, A new method for the evaluation of the accuracy of full-arch digital impressions in vitro, Clin. Oral Investig. 20 (2016) 1487–1494. https://10.1007/s00784-015-1626-x.

[30] A. Ender, A. Mehl, In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions, Quintessence Int. 46 (2015) 9–17. https://10.3290/j.qi.a32244.

[31] M.A. Schlenz, J.M. Stillersfeld, B. Wöstmann, A. Schmidt, Update on the accuracy of conventional and digital full-arch impressions of partially edentulous and fully dentate jaws in young and elderly subjects: a clinical trial, J. Clin. Med. 11 (2022) 3723. https://10.3390/jcm11133723.

[32] A. Popov, European markets show significant disparity in broadband user experience. https://www.opensignal.com/2023/10/12/european-markets-show-significant-disparity-in-broadband-user-experience, 2023 (accessed 01 May 2025).

[33] M.A. Schlenz, N. Schulz-Weidner, M. Olbrich, D. Buchmann, B. Wöstmann, Insights into the digitalization of dental practices: a cross-sectional pilot study in Hesse, Int. J. Comput. Dent. 28 (2025) 9–19. https://10.3290/j.ijcd.b4494409.