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Research article

Comparison of the measurement error of optical impressions obtained with four intraoral and one extra-oral dental scanners of post and core preparations

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ABSTRACT

Statement of problem: Innovations in intraoral scanner (IOS) technology are opening up ever more indications for computer-aided design and manufacturing (CAD-CAM). The manufacturers claim that the latest generations of scanners allow the digitizing of root canal preparations. However, there is a lack of studies evaluating the quality of the optical impressions made for this type of treatment.
Purpose: The purpose of this study was to evaluate the measurement error of 4 IOSs and a laboratory scanner used for the digitizing of root canal preparations and to highlight the effect of the presence or absence of adjacent teeth on the quality of the digital model.
Material and methods: Two models: one presenting adjacent teeth, one without adjacent teeth, both presenting a 10 mm deep nominal conical pit mimicking a root canal preparation were fabricated. Each model was scanned 10 times with a laboratory scanner (E3) and 4 intraoral scanners (Primescan, Omnicam, TRIOS 4, and Medit i700). The digital models were then exported as standard tessellation language (STL) files and analyzed to evaluate the mean measurement error of the digitizing of the root preparation at three different depths: 0–3 mm, 3–6 mm, and 6–9 mm. Significant differences were assessed with a 1-way ANOVA test and the pairwise comparison between scanners was done by Tukey's multiple comparison test.
Results: Statistical differences were found between scanners ($P < 0.05$). The mean measurement error ranged from 9.8 ± 0.5 μm with the Medit i700 to 28.2 ± 10 μm with the E3. The E3 and Omnicam scanners were in some cases incapable of digitizing the conical preparation in its entirety. The group Primescan, TRIOS 4, and Medit i700 showed minimally significant differences. The presence of adjacent teeth had a negative effect on the model quality for some scanners, mainly because of the obstruction of the IOS's head.
Conclusions: Significant differences were found among the dental scanners used for digitizing root canal preparations. Optical impressions with modern intraoral scanners seem to be an adapted

Abbreviations: IOS, intraoral scanner; CAD-CAM, Computer aided design - Computer aided manufacturing.

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method of registration of root canal preparation for post-and-copings of post-and-cores fabrication.

1. Introduction

The advances in adhesive dentistry have reduced the need for posts in endodontically treated teeth [1]. However, post-and-core are still an essential type of prosthetic restorations for a tooth with heavily damaged coronal structure and for preparations with sub-gingival finish lines as these situations do not allow a satisfactory impermeability of the dental dam [2,3]. As for most prosthetic treatments, the clinical success of root anchoring restorations relies on an accurate registration of root canal preparations [4,5,6], allowing for the fabrication of a post that is finely fitted to its resting surface. Intraoral scanners (IOS) haven't traditionally been used for these indications mainly since digitizing root canal preparations was thought to be too challenging for dental optical scanners. However, recent advances in IOSs technology seem to allow the use of optical impressions in root canal preparations [7,8,9,10,11]. In addition to the usual advantages offered by computer-aided design and manufacturing (CAD-CAM): patient comfort, immediate control of preparation quality, or dematerialization of the workflow [12,13,14]. The use of digital models and CAD-CAM offers, in these cases, specific advantages: (1) Elimination of the risk of impression material deformation during tray disinsertion. (2) The use of specific milled blocks reinforcement with fibers. (3) Elimination of the complex step of spacer varnish application.

The purpose of this study was to evaluate the measurement error of four intraoral and one extra-oral scanners for digitizing root canal preparations, to assess whether or not the use of optical impressions was adapted to the fabrication of post-and-core or post-and-coping restorations. The influence of the presence or absence of adjacent teeth to the prepared tooth was evaluated, as this influence had already been demonstrated [15].

The null hypothesis was that no significant difference would be found among the scanners in terms of measurement error and that the presence of adjacent teeth wouldn't significantly affect measurement quality.

2. Material and methods

Four IOSs and a laboratory tabletop scanner were included in this study (Table 1): the Primescan and Omnicam IOSs (Dentsply Sirona), the Medit i700 IOS (Medit Corp), the TRIOS 4 IOS, and the E3 tabletop scanner (3Shape A/S).

A nominal post-and-core root canal preparation for a mandibular premolar tooth was designed with CAD software (Fig. 1A), (Catia V5, Dassault Systems). The design consisted of an oval sectioned volume with a completely flat upper face, this face features a nominal 10 mm deep conical hole, 3 mm wide at the entrance, with a conicity of 4°. Using CAD software Meshmixer (Autodesk Inc.), gingival and dental elements were added to the nominal element to mimic the preparation environment and help with stitching during digitizing. In order to evaluate the influence of the presence/absence of adjacent teeth during the scan, two different models presenting the same nominal element were designed. One with an adjacent molar and premolar (Fig. 1B), and one without (Fig. 1C). The two objects were fabricated using a stereolithography 3D printer with the Model V2 resin (Formlabs 3B, Formlabs) with a 25 μm layer thickness (Fig. 1D). This method appears to be an adapted method to fabricate dental metrological artifacts [16,17].

It has been found that the use of a micro-CT tomographic scanner for the obtention of a reference model seems suitable in dental metrology [18,19]. A Quantum FX micro CT tomographic scanner (Perkinelmer) with the settings of 90 kV, 160 mA, and 20 μm voxels was used to obtain a reference DICOM file for the two objects, these DICOMs were transformed into two reference STLs, one for each object.

A graphical summary of the study's methodology is presented in Fig. 2. Twenty scans were performed with each scanner, 10 of the model presenting adjacent teeth (PAT) and 10 of the one without adjacent teeth (WAT). Each scan was performed by the same operator (L.D.). Scans were performed using different angulations to maximize the portion of the root canal preparation that was digitized. To mimic clinical situations, angulations that would be impossible to achieve in the mouth were avoided as much as possible. The quality of the scans was checked visually before the STL exportation. Some scanners required a specific digitizing protocol: The E3 tabletop scanner uses automated angulations, after an initial scan, the software allows to add images recordings of manually selected unsatisfactorily digitized areas. This function was used 3 consecutive times on the root preparation area for each scan; The Medit i700 was used with the maximal "23 mm depth of field" setting, and with the specific "model digitizing" filter; the "zoom function" of the TRIOS 4 was used to improve digitizing of the root preparation area. The STL files were exported from each IOS software for metrological analysis. The GOM inspect software (Zeiss) was used for metrological analysis, the methodology used on GOM inspect software is presented in Fig. 3. The reference CAD STLs of the PAT and WAT models were imported into the software as a base for different

Table 1
Dental scanners included in the study.

Scanner	Company	Technology	Software version	Serial Number
Primescan	Dentsply Sirona	Confocal	5.2.2	111119
Omnicam	Dentsply Sirona	Triangulation	5.2.2	148359
Medit i700	Medit Corp	Triangulation	2.6.2	AZ2108106573
TRIOS 4	3Shape A/S	Confocal	21.4	05902729752862
E3 (Tabletop scanner)	3Shape A/S	Triangulation	2.1.6.1	1CD2051005B

alignments, this allowed positioning every scan with the axis of the conical pit parallel to the Z-axis as they are designed in the CAD models. The reference STL file from the micro-CT was aligned to the CAD model using a best-fit algorithm. A nominal cone was constructed as the smallest circumscribed cone of this reference STL (the smallest possible cone containing all the points of the STL). The scanners' STLs were then imported, the root canal preparation of the digitized nominal element was isolated and aligned on the CAD model with the same best-fit algorithm. The points of the scanned model corresponding to the root canal preparation area from the entrance of the pit to a depth of 9 mm were isolated, and the mean absolute distance between each of these points and the nominal reference cone from the micro-CT STL using the cone surface's normal vectors was calculated. The results were exported and analyzed on a spreadsheet. As studies already proved significant differences with respect to the digitizing depth [7,8,10], the analysis of the results was made for three different preparation portions: 0–3 mm, 3–6 mm, and 6–9 mm. This was made possible by the correspondence between the Z axis and the pit axis. This threshold of 3 mm portions was used as a satisfactory compromise between richness and ease of interpretation of results.

After validation of the normal distribution of results for each scanner with the Shapiro-Wilk test ($\alpha = 0.05$), a 1-way ANOVA test was performed to evaluate the rejection or not of the null hypothesis. A pairwise comparison was then performed with Tukey's multiple comparisons test.

3. Results

The results of the mean measurement error test for the 3 depth ranges: 0–3 mm, 3–6 mm, and 6–9 mm with mean values and 95% confidence interval are presented in Table 2. A graphical representation of the test results is presented in Fig. 4. For some cases (Omnicam WAT, E3 WAT, and E3 PAT), the registration of the entire preparation was impossible, the scanning software automatically closed the model without having the total depth digitized. In these cases, the results are presented as "non exploitable" (NE) as it would be impossible to reliably produce a post that would anchor beyond that depth.

The mean measurement error ranges between 10 μm and 30 μm. For most cases, the high repeatability of the protocol results in narrow confidence intervals. The best results for the model PAT are obtained with the Primescan with 13.7 ± 0.4 μm from 0 to 3 mm, 12.7 ± 0.5 from 3 to 6 mm, and 19.5 ± 2 from 6 to 9 mm, the worst are obtained with the Omnicam that only managed to digitize the first third of the root preparation with a 24.3 ± 0.5 μm mean measurement error. The best results for the model WAT (and overall) are obtained with the Medit i700 with 12.4 ± 0.7 μm from 0 to 3 mm, 9.8 ± 0.5 μm from 3 to 6 mm, and 16.4 ± 1.2 μm from 6 to 9 mm, the worst are obtained with the E3 tabletop scanner that only managed to digitize the first two thirds of the root preparation with the lowest repeatability, presenting a mean measurement error of 21.7 ± 3.2 μm from 0 to 3 mm and 24.0 ± 5.9 μm from 3 to 6 mm.

The absence of adjacent teeth seems to have a positive effect on the quality of the model for the Omnicam, the Medit i700, and the TRIOS 4, and little to no influence for the Primescan and the E3.

When the entire root canal preparation was digitized correctly, the quality of the model does not seem to decrease importantly with depth. The overall mean measurement error between all scanners (PAT and WAT) is 20 μm from 0 to 3 mm, 18 μm from 3 to 6 mm, and 20 μm from 6 to 9 mm.

The results of the pairwise statistical analysis by using Tukey's multiple comparisons tests are presented in Table 3. The pairs are

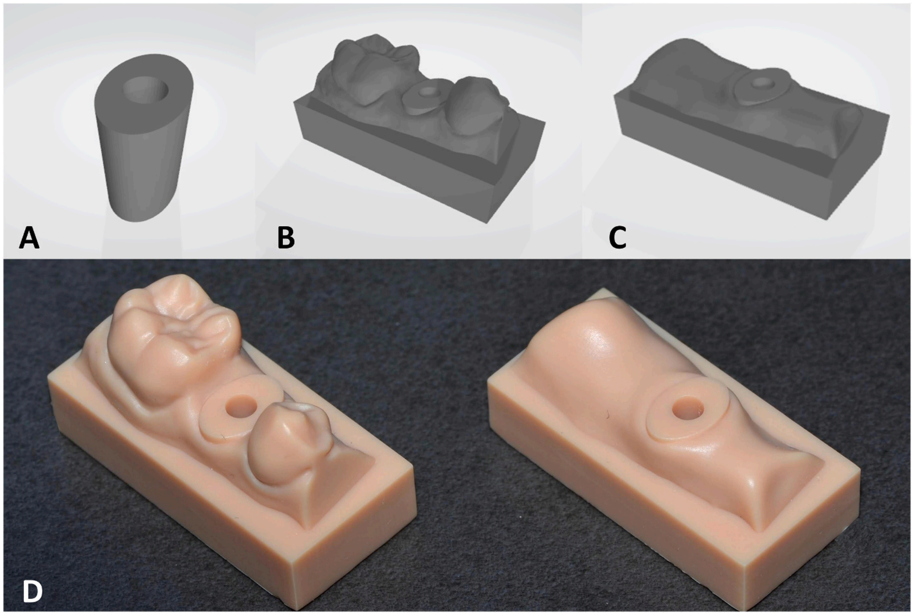

Fig. 1. A, Nominal root canal preparation CAD model. B, CAD model presenting adjacent teeth (PAT). C, CAD model without adjacent teeth (WAT). D, 3D printed reference models.

separated into three groups:

- Pairs of different scanners for the model presenting adjacent teeth (PAT).
- Pairs of different scanners for the model without adjacent teeth (WAT).
- Pairs of the same scanner for the two different models (PAT and WAT).

The null hypothesis that the scanners were equivalent was rejected for the 3 different depths. (F = 74.41, DF = 2.142, $p < 0.001$) for 0–3 mm, (F = 318.8, DF = 4.547, $p < 0.001$) for 3–6 mm, (F = 64.57, DF = 9.245, $p < 0.001$) for 6–9 mm.

Concerning the results with the model presenting adjacent teeth (PAT). The Primescan shows significantly better results than all other scanners at 0–3 mm depth. And better results than the Omnicam and the E3 at 3–6 mm and 6–9 mm depths, the TRIOS 4 and Medit i700 don't show significant differences. The Omnicam and E3 not being able to digitize the entire root preparation. They show significantly worse results at 3–6 mm and 6–9 mm depths.

Concerning the results with the model without adjacent teeth (WAT). The group consisting of the Primescan, the Omnicam, the Medit i700, and the TRIOS 4 shows few significant differences (only marginal differences at 0–3 mm depth). The E3 tabletop scanner however shows significantly worse results at 0–3 mm depth compared with the Omnicam and TRIOS 4, and at all depths compared with the Primescan and Medit i700.

Concerning the same-scanner pairs comparing models PAT and WAT. PAT groups never show significantly better results than WAT groups. WAT groups show significantly better results for all scanners at the 0–3 mm depth. The Omnicam WAT shows significantly better results than the Omnicam PAT at all depths. The Medit i700 WAT shows significantly better results than the Medit i700 PAT at 0–3 mm and 3–6 mm depths.

4. Discussion

This study's purpose was to evaluate the quality of optical impressions for root canal preparations. To this end, the methodology used in this study gave consistent and relevant results. Naturally, the use of standardized root canal preparations with a calibrated drill in combination with optical scan transfers would alleviates the problem of scanning these preparations, but anatomical post-and-cores still allow for a large number of situations to be treated more conservatively.

One of the main limitations of this study comes from the unique geometry of the root canal preparation, situations with narrower or less conical preparations are not that uncommon and experimentation could be performed with different geometries, or with the registration of multiple preparations on a single optical impression. The manufacturing method of the reference objects must also be criticized. Although the dimensional verification of the cone by micro-CT was performed, the limited quality of the stereolithography printing may have increased the measurement error results. It is also necessary to note that the scanning was done outside the mouth which greatly facilitated the registration by using various angulations. It seems that the multiplication of angulations was particularly

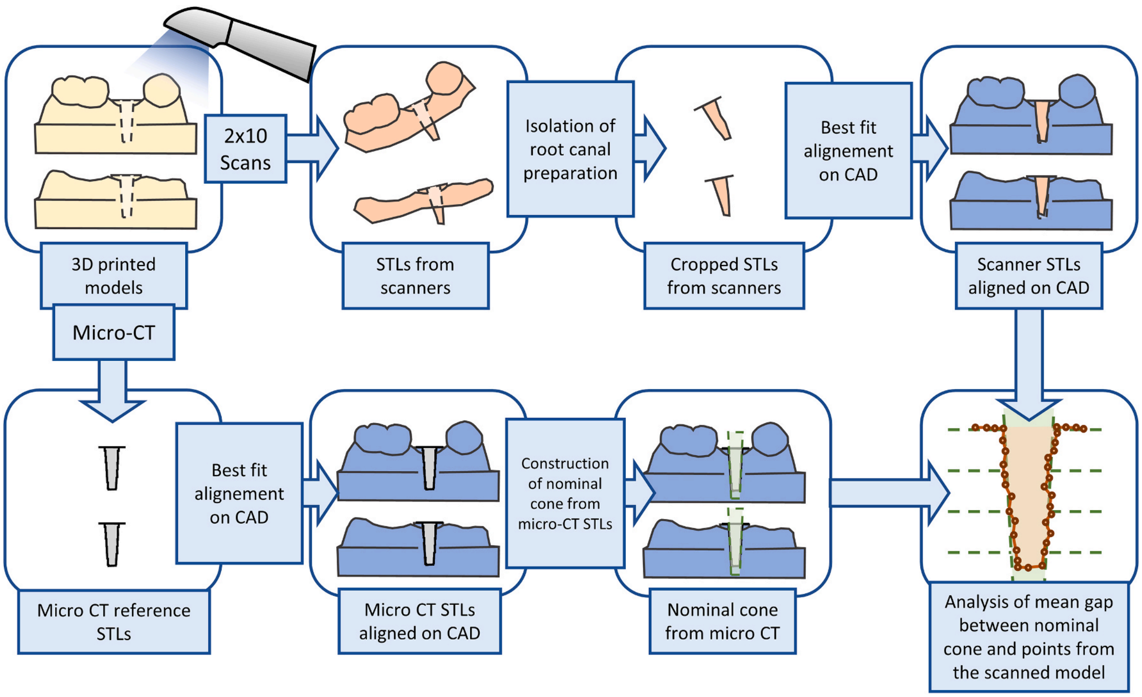

Fig. 2. Graphical summary of the study's methodology.

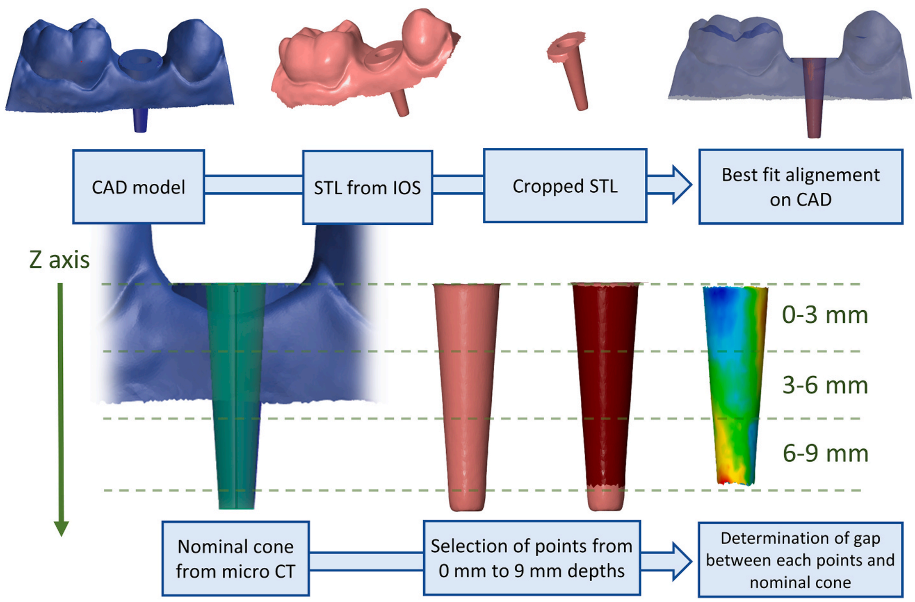

Fig. 3. Graphical summary of the methodology used in the metrological software (Gom inspect). The model was cropped using planes perpendicular to the Z axis at 0 mm and 9 mm depths.

Table 2
Test results for mean measurement error (μm), at the three different depths, for the models presenting adjacent teeth (PAT) and without adjacent teeth (WAT), with 95% confidence interval. NE stands for non-exploitable scan at the specified depth.

Scanners	0–3 mm	3–6 mm	6–9 mm
Primescan PAT	13.7 ± 0.4	12.7 ± 0.5	19.5 ± 2
Primescan WAT	13.7 ± 0.4	12.7 ± 0.5	19.5 ± 2
Omnicam PAT	24.3 ± 0.5	NE	NE
Omnicam WAT	14.6 ± 0.5	15.4 ± 0.8	19.2 ± 3.2
TRIOS 4 PAT	26.4 ± 1.3	20.3 ± 2.1	25.7 ± 2.0
TRIOS 4 WAT	18.4 ± 0.6	17.1 ± 0.8	15.9 ± 1.3
Medit i700 PAT	24.0 ± 1.9	19.5 ± 0.7	22.3 ± 0.8
Medit i700 WAT	12.4 ± 0.7	9.8 ± 0.5	16.4 ± 1.2
3Shape PAT	27.6 ± 0.6	28.2 ± 10	NE
3Shape WAT	21.7 ± 3.2	24.0 ± 5.9	NE

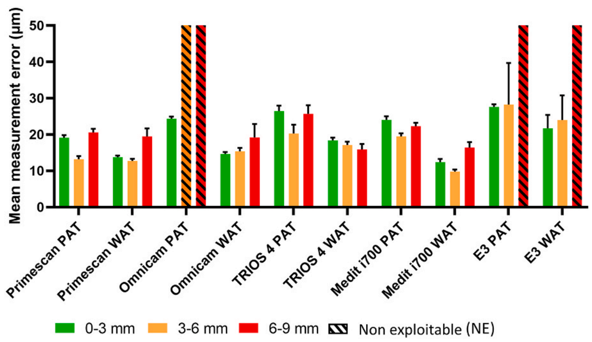

Fig. 4. Graphical representation of mean measurement error results (μm) at 3 different depths: 0–3 mm (green), 3–6 mm (orange), and 6–9 mm (red). Cross-hatched bars indicate non exploitable (NE) scans at specified depth. Vertical bars represent 95% confidence interval for each mean. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

important for the scanners using triangulation technology, and although angulations that were impossible to achieve in the mouth were avoided, it is obvious that the digitization conditions were easier than in a clinical setting. Despite all these concerns, it seems that for newer IOSs, the measurement error results appear to be largely satisfactory for the fabrication of post-and-copings or post-and-cores

Table 3
Significant differences between scanner pairs using Tukey's multiple comparisons test.

Tukey's multiple comparisons tests	Superior scanner	Summary	*P* Value	Superior scanner	Summary	*P* Value	Superior scanner	Summary	*P* Value
Presenting adjacent teeth comparison (PAT)									
Depth	0–3 mm			3–6 mm			6–9 mm		
Primescan vs. Omnicam	Primescan	****	<0.001	Primescan	****	<0.001	Primescan	****	<0.001
Primescan vs. TRIOS 4	Primescan	****	<0.001		ns	0.330		ns	>0.999
Primescan vs. Medit i700	Primescan	****	<0.001		ns	0.496		ns	>0.999
Primescan vs. E3	Primescan	****	<0.001	Primescan	****	<0.001	Primescan	****	<0.001
Omnicam vs. TRIOS 4		ns	0.352	TRIOS 4	****	<0.001	TRIOS 4	****	<0.001
Omnicam vs. Medit i700		ns	>0.999	Medit i700	****	<0.001	Medit i700	****	<0.001
Omnicam vs. E3	Omnicam	*	0.013	E3	****	<0.001	Omnicam	*	0.010
TRIOS 4 vs. Medit i700		ns	0.192		ns	>0.999		ns	>0.999
TRIOS 4 vs. E3		ns	0.946		ns	0.176	TRIOS 4	****	<0.001
Medit i700 vs. E3	Medit i700	**	0.005		ns	0.096	Medit i700	****	<0.001
Without adjacent teeth comparison (WAT)									
Depth	0–3 mm			3–6 mm			6–9 mm		
Primescan vs. Omnicam		ns	0.990		ns	0.996		ns	>0.999
Primescan vs. TRIOS 4	Primescan	****	<0.001		ns	0.891		ns	>0.999
Primescan vs. Medit i700		ns	0.892		ns	0.991		ns	>0.999
Primescan vs. E3	Primescan	****	<0.001	Primescan	**	0.008	Primescan	****	<0.001
Omnicam vs. TRIOS 4	Omnicam	**	0.002		ns	0.999		ns	>0.999
Omnicam vs. Medit i700		ns	0.277		ns	0.659		ns	>0.999
Omnicam vs. E3	Omnicam	****	<0.001		ns	0.108	Omnicam	****	<0.001
TRIOS 4 vs. Medit i700	Medit i700	****	<0.001		ns	0.279		ns	>0.999
TRIOS 4 vs. E3	TRIOS 4	*	0.013		ns	0.365	TRIOS 4	****	<0.001
Medit i700 vs. E3	Medit i700	****	<0.001	Medit i700	***	<0.001	Medit i700	****	<0.001
Same scanner with or without adjacent teeth (PAT vs WAT)									
Depth	0–3 mm			3–6 mm			6–9 mm		
Primescan PAT vs. WAT	WAT	****	<0.001		ns	>0.999		ns	>0.999
Omnicam PAT vs. WAT	WAT	****	<0.001	WAT	****	<0.001	WAT	****	<0.001
TRIOS 4 PAT vs. WAT	WAT	****	<0.001		ns	0.986		ns	0.999
Medit i700 PAT vs. WAT	WAT	****	<0.001	WAT	*	0.040		ns	>0.999
E3 PAT vs. WAT	WAT	****	<0.001		ns	0.906		ns	>0.999

restorations.

Concerning the influence of adjacent teeth, the main effect of their presence was that they prevented the scanner head from being brought as close as possible to the entrance of the pit. This influence, therefore, depended on the depth of field of the scanner used. If this depth was sufficient, as with the Primescan, TRIOS 4, or Medit i700, the effect was negligible. On the other hand, with the Omnicam, which has a shallower depth of field, the presence of adjacent teeth largely deteriorated the quality of the scan. It is assumable that this effect would be found with other entry-level triangulation IOSs. This didn't influence the tabletop scanner for which the root canal preparations were always at the same distance from the receptor with or without adjacent teeth.

In conclusion, if a concrete more subjective guideline were to be provided for clinicians, it was noted that if the entire root canal preparation could be scanned quickly and without problems, the quality of the impression seemed satisfactory. On the other hand, a laborious scan, presenting holes in the model of an incomplete digitizing of the root canal preparation resulted in unsatisfactory model quality.

5. Conclusions

Based on the findings of this in vitro study, and within this study limitations, the following conclusions were drawn:

1. Differences between dental scanners were identified for the digitizing of root canal preparation.
2. Optical impressions with modern IOSs seem to be an adapted method of registration of root canal preparation for post-and-copings of post-and-cores fabrication.
3. The presence of adjacent teeth can negatively affect the quality of root canal preparation digitized with IOSs.
4. Tabletop scanner do not seem to be an adapted tool for the digitizing of root canal preparation.

Author contribution statement

Lucien Dupagne, DDS, PhD: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bernardin Mawussi, PhD; Laurent Tapie, PhD; Nicolas Lebon, PhD: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

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.

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