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Accuracy, Time, and Comfort of Different Intraoral Scanners: An In Vivo Comparison Study

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Abstract: Background: The purpose of this study was to compare the accuracy of three different intraoral scanners (IOSs) and to evaluate the patients' experience. Methods: Thirty subjects were scanned with three different IOSs (TRIOS Color®, iTero Element 5D®, and iTero Lumina®): a sample of 90 maxillary casts was collected. The inclusion criteria were permanent dentition, absence of defects during the dental impression, and complete record of the palatal vault. After the scanning procedure, patients were asked to answer a questionnaire (10 answers, scale from 1 to 10) to compare their experiences with iTero Element and iTero Lumina in the scanning procedure. Results: Differences were recorded in the upper central incisor region (f-ratio of 4.186 for Mesiodistal 1.1 and f-ratio of 4.222 for Mesiodistal 2.1, $p < 0.05$), while intercanine width Upper 13–23 showed the smallest f-ratio (0.226) when compared to the other results, followed by Mesiodistal 1.4 (0.433). Patients reported more comfort, less pain, decreased duration, and a better technology visualization of the impression with iTero Lumina. No significant differences concerning dryness of the mouth and gag reflex were found. Conclusions: The examined IOSs offer comparable accuracy in capturing dental arch dimensions. The interviewed patients expressed an overall preference for digital impressions performed with iTero Lumina, linked to increased comfort, painless practice, and a better technology visualization of the impression.

Keywords: digital dentistry; digital cast analysis; clinical practice; digital impressions

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1. Introduction

A dental impression is a crucial procedure that reproduces the patient's oral cavity for diagnosis, treatment planning, and the fabrication of dental appliances. To ensure a model that is as close to reality as possible, it is essential to accurately capture the dental anatomy, the correct position of the teeth, and the morphology of surrounding tissues [1,2].

Traditionally, the accuracy of the impressions depended on the materials used, the types of impression trays, and the specific techniques employed. Each step in the process introduced potential human and material errors [3]. Additionally, conventional impressions were often uncomfortable for patients, leading to poor tolerance and complicating the procedure [4,5].

The advent of intraoral scanners (IOSs) and digital dentistry offers an innovative solution in modern dental practice. Unlike conventional methods, IOSs produce dental impressions by stitching together multiple three-dimensional images to create a complete 3D model [6]. The concept of digital impressions emerged in the late 1980s. The early scanners were bulky and expensive, which restricted their use to a limited number of pioneering dental practices. It was not until the early 2000s that this technology became more widespread [5,6].

Intraoral scanners capture dental impressions through optical acquisitions. This involves detecting numerous individual images, which are then processed collectively, along with the continuous streaming of optical data [7].

Optical impressions created with IOSs offer numerous advantages, making their adoption in clinical practice increasingly essential. These benefits include a reduced gag reflex, shorter working time, elimination of distortion from impression materials or gypsum, improved communication with patients and dental laboratories, and easy reproducibility [6,7].

In orthodontics, the adoption of digital workflows and impressions has become prevalent. This is partly due to the high incidence of orthodontic treatments among children, who are generally less cooperative than adults, and partly because certain orthodontic devices, such as aligners, are fabricated from digital impressions, allowing dentists to save time and reduce costs. For many patients, traditional impression-taking is one of the most stressful aspects of dental treatment, making digital impressions a more appealing option [8].

A recent review compared traditional and digital impressions, revealing that nearly all studies reported a patient preference for digital technology over conventional methods. This preference is largely attributed to the greater efficiency of the intraoral scanning procedure, particularly regarding the time required to capture the impression [9].

Several studies [10–12] have evaluated the performance of IOSs both in vivo and in vitro, concluding that intraoral scanners can accurately reproduce 3D dental models. Their accuracy is clinically adequate compared to traditional impression techniques, as assessed through two-dimensional linear measurements [13,14].

Therefore, the present study aims to compare the accuracy of three different intraoral scanners (IOSs) and to evaluate patients' experiences with digital impression techniques.

2. Materials and Methods

This in vivo study followed the principles of the World Medical Assembly in the Declaration of Helsinki on medical protocols and ethics and received a positive response from the Ethics Committee of the Hospital of Rome Tor Vergata (protocol number: 48/23). Patients were informed that they were participating in the study, and their informed consent was obtained before their digital impressions were taken.

A sample of 30 subjects (15 males, 15 females, mean age 24.5 $\pm$ 4.3 years) was collected and digital impressions with three different intraoral scanners were made for a total of 90 maxillary digital dental casts to test the accuracy of the different dental impression techniques.

2.1. Inclusion and Exclusion Criteria

Patients were selected according to these inclusion criteria: Caucasian ancestry and complete permanent dentition (except for third molars). The exclusion criteria applied were the presence of caries and/or periodontal diseases, supernumerary teeth or agenesis, defects during the digital impression, and incomplete records of the palatal vault.

2.2. Intraoral Scanner Specifications

The 3 tested IOSs were TRIOS Color® (T), iTero Element 5D® (E), and iTero Lumina® (L) (Figure 1).

The intraoral scanner TRIOS Color® (3Shape, Copenhagen, Denmark) provides ultrafast colored imaging based on confocal microscopy principles: it captures single pictures, stitched together into a three-dimensional network. This scanner does not require any powder application and has a scanning depth of 17 mm [15].

The iTero Element 5D® (Align Technology, Santa Clara, CA, USA) is a powder-free intraoral scanner that utilizes parallel confocal imaging technology and point-and-stitch reconstruction to make accurate digital imprints. The scanning depth is about 15 mm [16].

The iTero Lumina® (Align Technology, Santa Clara, CA, USA) uses an innovative technology called "multi-direct capture" rather than using confocal imaging. The scanning depth has been increased from 15 mm to 25 mm. It also does not require powder application [17].

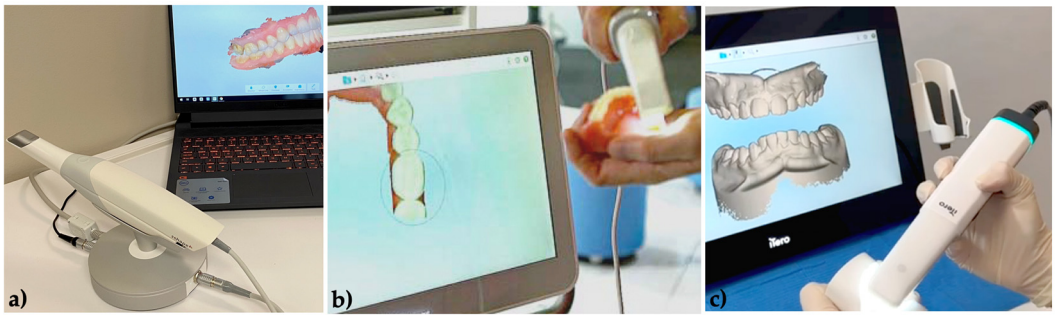

Figure 1. Intraoral scanners used in this study: (**a**) TRIOS Color® (3Shape, Copenhagen, Denmark); (**b**) iTero Element 5D® (Align Technology, Santa Clara, CA, USA); (**c**) iTero Lumina® (Align Technology, Santa Clara, CA, USA).

2.3. Intraoral Scanning Protocol

The digital impressions were taken with each intraoral scanner. Each scanner was calibrated accurately before the scanning procedure.

The intraoral scanning impressions were repeated by an experienced and trained examiner with five years of experience in orthodontics and a subspecialization in digital dentistry. The examiner performed each scan once with TRIOS (T), once with iTero 5D Element (E), and once with iTero Lumina (L).

A standard protocol was created to make the scanning procedure repeatable: the digital scanning impression started from the occlusal surfaces of the second left upper permanent molars, then the occlusal areas and the incisal margin of the upper arch. The scanner was then positioned into the palatal surfaces from the left second molars to the other part and then was shifted into the buccal surfaces. The palatal vault was completely recorded during the digital scanning. Each virtual cast was accepted only if all tooth surfaces were completely evident and no alterations were found. The scanning procedure was repeated if any crack line or any variation appeared or if the palatal vault was not fully recorded.

A sample of 90 digital casts was collected (30 digital casts made by TRIOS Color, 30 digital casts scanned by iTero Element, and 30 digital casts made by iTero Lumina).

2.4. Measurements Protocol

For standardization and subsequent digital processing, datasets from each scan were exported in stereolithography file format (.STL) and the software Viewbox 4.0 (dHAL Software, Kifissia, Greece) was used for the digital cast analysis. Each model was cut and trimmed to remove unnecessary parts. A total number of 38 points were digitized to perform a digital analysis. Figures 2 and 3 show the linear dental measurements performed on upper digital and stone dental casts, as reported below:

- Second molar diameter (Upper 17–27): distance between right second molar fossa and left second molar fossa;
- First molar diameter (Upper 16–26): distance between right first molar fossa and left first molar fossa;
- Second premolar diameter (Upper 15–25): distance between right second premolar vestibular cusp and left premolar vestibular cusp;
- First premolar diameter (14–24): distance between right first premolar vestibular cusp and left first premolar vestibular cusp;
- Intercanine diameter (13–23): distance between right first canine cusp and left canine cusp;
- Mesiodistal x7: linear measurement between distal interproximal point and mesial interproximal point of the second molar;
- Mesiodistal x6: linear measurement between distal interproximal point and mesial interproximal point of the first molar;

- Mesiodistal x5: linear measurement between distal interproximal point and mesial interproximal point of the second premolar;
- Mesiodistal x4: linear measurement between distal interproximal point and mesial interproximal point of the first premolar;
- Mesiodistal x3: linear measurement between distal interproximal point and mesial interproximal point of canine;
- Mesiodistal x2: linear measurement between distal interproximal point and mesial interproximal point of lateral incisor;
- Mesiodistal x1: linear measurement between distal interproximal point and mesial interproximal point of the central incisor.

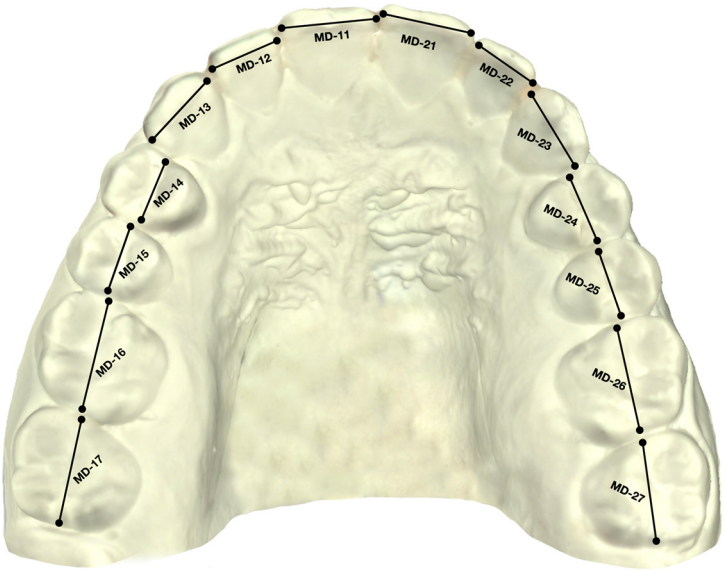

Figure 2. Graphic representation of the mesiodistal dental measurements performed in this study. MD: mesiodistal.

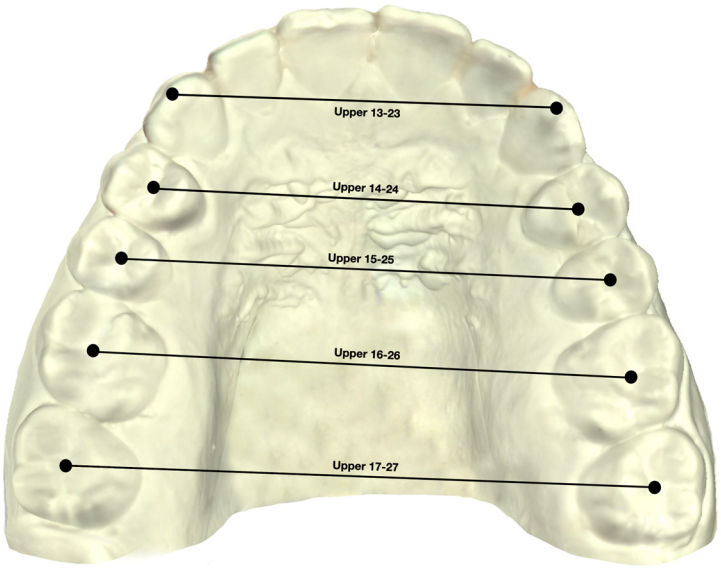

Figure 3. Graphic representation of the dental width measurements performed in this study.

2.5. Patients' Questionnaire Submission

A satisfaction survey form was designed using an online software (Google LLC., 1600 Amphitheatre Parkway, Mountain View, CA, USA) and proposed to each patient. After the scanning procedure, patients were asked to answer this questionnaire in the Italian

language. The questionnaire was composed of 10 questions for iTero Element and for iTero Lumina, respectively, to compare patients' experience with these two different scanners used in the procedure. To guarantee anonymity, the satisfaction survey was designed and administered online using Google Forms. Answers were collected with a Likert-type scale ranging from 1 to 10 [18], in which numbers 1 to 10 represented the grade of patients' satisfaction (1: Extremely unsatisfied, 2: Mildly unsatisfied, 3: Slightly unsatisfied, 4: Unsatisfied, 5: Neutral, 6: Slightly satisfied, 7: Mildly satisfied, 8: Satisfied, 9: Very satisfied, 10: Extremely satisfied). One questionnaire was returned without responses and was excluded from the statistical analysis. The complete question list is shown in Table 1.

Table 1. Satisfaction survey question list.

Q1 "Comfort": How would you rate the comfort during intraoral scanning?
Q2 "Stress": How would you rate your stress during intraoral scanning?
Q3 "Pain": How would you rate pain during intraoral scanning?
Q4 "Mouth dryness": How would you rate your mouth dryness during intraoral scanning?
Q5 "Gag reflex": How would you rate the gag reflex during the intraoral scanning?
Q6 "Experience": How would you rate the experience with the intraoral scanning?
Q7 "Duration": How would you rate the duration of the intraoral scanning procedure?
Q8 "Technology": How would you rate the technology of the intraoral scanning procedure?
Q9 "Communication": How would you rate the communication of the intraoral scanning procedure?
Q10 "General satisfaction": How would you rate the general satisfaction of the intraoral scanning procedure?

Q: question.

2.6. Statistical Analysis

To determine the reliability of the method, all cast measurements were repeated by another examiner after approximately two weeks to evaluate any method error in the measurements. The second examiner also had five years of experience in orthodontics and a subspecialization in digital dentistry.

To assess the inter-rater reliability of the measurements obtained from the three different scanners, a two-way Intraclass Correlation Coefficient (ICC) was calculated.

The magnitude of the random error was calculated by using Dahlberg's formula. Exploratory statistics revealed that all variables were normally distributed with equality of variances. Mean differences in measurements between the three groups (TRIOS dental casts, iTero Element dental casts, and iTero Lumina dental casts) were contrasted utilizing the analysis of variance (ANOVA) with Tukey's post hoc tests (SigmaStat 3.5, Systat Software, Point Richmond, Richmond, CA, USA). In a previous pilot study, 10 patients were used to calculate the reproducibility and the sample size, which indicated the need for approximately 74 patients to estimate the upper intercanine width (Upper 13–23) with a 95% confidence interval (CI), a minimum difference of 28 mm, and a standard deviation (SD) of 1 mm with a power of 80%. All statistical computations were performed with specific software (SigmaStat 3.5, Systat Software, Point Richmond, Richmond, CA, USA). To analyze the differences between iTero Element and iTero Lumina as reported in the patients' satisfaction surveys, a paired t-test was used (PRISM 10.3—Graph Pad software, Boston, MA, USA).

3. Results

No systematic error was found between the repeated measurements. The method errors and reliability coefficients for the linear measurements ranged from 0.999 for the upper first intermolar width to 0.478 for the upper inter canine width, respectively. Descriptive statistics for linear measurements and the results of statistical analysis are shown in Table 2.

Table 2. Descriptive statistics and statistical analysis for upper dental casts.

Upper Dental Cast	Trios Cast (T)		Element Cast (E)		Lumina Cast (L)		F	*p*	T vs. E	T vs. L	E vs. L
	M	SD	M	SD	M	SD			*p*	*p*	*p*
Upper 17–27	51.2	1.6	48.4	1.3	47.6	1.4	3.748	NS	NS	NS	NS
Upper 16–26	42.6	1.5	40.6	2.3	41.4	1.7	1.462	NS	NS	NS	NS
Upper 15–25	36.8	1.6	35.6	1.1	35.4	0.9	1.792	NS	NS	NS	NS
Upper 14–24	32.8	1.3	31.8	1.3	31	1.5	2.068	NS	NS	NS	NS
Upper 13–23	30.4	1.3	29.6	2.9	29.2	2.6	0.226	NS	NS	NS	NS
Mesiodistal 11	9.2	1.3	7.4	0.9	7.8	0.8	4.186	*	*	*	NS
Mesiodistal 12	6.0	0.8	5.3	1.4	4.7	1.7	1.007	NS	NS	NS	NS
Mesiodistal 13	7.2	0.8	6.0	0.7	6.6	1.0	2.700	NS	NS	NS	NS
Mesiodistal 14	7.4	1.5	7.2	0.8	7.2	1.3	0.433	NS	NS	NS	NS
Mesiodistal 15	7.5	0.8	7.8	2.0	6.8	1.6	1.330	NS	NS	NS	NS
Mesiodistal 16	10.6	0.5	9.6	0.8	9.1	0.8	1.882	NS	NS	NS	NS
Mesiodistal 17	9.8	0.8	8.6	1.1	8.8	1.3	1.675	NS	NS	NS	NS
Mesiodistal 21	7.7	0.8	6.4	0.9	6.8	0.8	4.222	*	*	*	NS
Mesiodistal 22	5.7	0.5	5.2	0.7	5.4	1.1	3.111	NS	NS	NS	NS
Mesiodistal 23	7.8	0.7	6.6	1.2	6.6	1.0	2.182	NS	NS	NS	NS
Mesiodistal 24	7.2	1.2	6.7	0.7	6.4	1.4	1.152	NS	NS	NS	NS
Mesiodistal 25	7.8	0.8	6.4	0.5	6.2	0.3	1.441	NS	NS	NS	NS
Mesiodistal 26	10.4	0.5	9.6	0.9	9.2	0.8	3.111	NS	NS	NS	NS
Mesiodistal 27	9.6	1.0	8.8	0.8	8.4	0.9	1.697	NS	NS	NS	NS

M: media, SD: standard deviation, F: f-ratio, *p*: *p*-value, * <0.5, NS: not significant.

The statistical comparison between digital casts made with the three IOSs revealed few significant differences between the three analyzed impression techniques. The region in which the most significant differences were appreciable was the upper central incisor region (f-ratio of 4.186 for Mesiodistal 1.1 and f-ratio of 4.222 for mesiodistal 2.1, p-value < 0.05), while intercanine width Upper 13–23 showed the smallest f-ratio (0.226) when compared to the other results, followed by Mesiodistal 14 (f-ratio of 0.433).

Table 3 shows the results of the satisfaction survey carried out to analyze the experience with the iTero Element and iTero Lumina IOSs and the different perceptions in terms of duration and comfort. According to the questionnaire, patients had a more comfortable experience with iTero Lumina when compared to iTero Element.

Table 3. Satisfaction survey responses for iTero Element and iTero Lumina.

	iTero Element		iTero Lumina		*p*	Difference	95% Confidence	
	M	SD	M	SD			Lower	Upper
Q1: “Comfort”	5.1	0.9	7.3	1.3	**	−2.2	−3.2	−1.2
Q2: “Stress”	2.5	1.1	2.3	1.2	NS	0.2	−0.9	1.3
Q3: “Pain”	4.1	1.0	2.6	0.9	**	1.5	0.6	2.4
Q4: “Mouth dryness”	4.6	1.1	4.3	1.0	NS	0.3	−0.7	1.3
Q5: “Gag reflex”	4.5	2.8	3.8	2.6	NS	0.7	−19	3.3
Q6: “Experience”	7.2	0.9	8.4	1.2	*	−1.2	−2.2	0.2
Q7: “Duration”	6.1	0.8	8.1	0.7	***	−2.0	−2.8	−1.2
Q8: “Technology”	6.0	1.1	7.9	0.8	**	−1.9	−2.8	−0.9
Q9: “Communication”	6.1	0.7	7.0	1.1	*	−0.9	−1.8	−0.1
Q10: “General satisfaction”	8.1	0.7	8.9	0.4	*	−0.8	−1.5	−0.1

M: media, SD: standard deviation, *p*: *p*-value, * <0.5, ** <0.01 *** <0.001, NS: not significant.

The most significant differences between iTero Lumina and iTero Element reported by patients were more comfort ($p < 0.01$), less pain ($p < 0.01$), decreased duration ($p < 0.001$), and a better technology visualization of the impression ($p < 0.01$).

Another aspect that patients appreciated was the immediate and realistic visualization of their upper and lower dental impression on the scanner screen, showing a general

increased satisfaction with iTero Lumina compared to Element ($p < 0.5$). No significant differences were detected between the two IOSs in terms of dryness of the mouth and gag reflex.

4. Discussion

This study evaluated and compared the accuracy and patient satisfaction associated with digital impressions obtained using three different intraoral scanners (IOSs) in a sample of orthodontic patients. Specifically, this study was the first to include the newly introduced iTero Lumina alongside other popular IOSs, such as the widely used iTero models and the TRIOS, which have been extensively examined in previous clinical studies. The results provide valuable insights into the performance of these IOSs and found differences in their accuracy and patient satisfaction, which can guide clinicians in selecting the most appropriate scanner for their practice.

The results of this investigation reported that all three examined IOSs successfully generated the reproducible surface topography of anatomical dental structures with no statistical differences. The intraoral scanners examined in this study showed good performance and comparable trueness. Our results were similar to other studies [19] that evaluated the accuracy of six IOSs for single crown preparations. The authors found that the accuracy of iTero and Trios was similar when four different scan strategies, guided by the various manufacturers' instructions, were used and concluded that both the examined digital devices provided sufficient flexibility for the acquisition of 3D images without affecting the accuracy of the impression.

There were some statistical differences between TRIOS, iTero Element, and Lumina, as reported in the central incisors' region. The discrepancy found in the results may come from the intraoral conditions of the patients and the anatomical accessibility during the scanning phase [20]. Other characteristics such as the scanner's size and diameter are important for an improved scanning workflow. Also, the software updates strongly influenced the examined parameters of the IOSs (summary chart, scanning time, continuity, and accuracy) [21]. Furthermore, it has been reported in the literature that the clinically acceptable discrepancy with digital techniques impressions is at least 50 µm as the minimum required for trueness and 10 µm for precision [22].

The satisfaction survey conducted in this investigation revealed an overall preference for digital impressions performed with iTero Lumina, linked to increased comfort and painless practice of the IOS, which also offered a better technology visualization of the impression.

There were no significant differences between the two IOSs in terms of dryness of mouth and gag reflex. This result shows also a great standard deviation, suggesting that these variables depend on the individual patient and their personal experience. However, an overall appreciation of the IOSs was found, suggesting that a general reduction in dry mouth and gag reflex during scanning contributed to the patients' general satisfaction may ultimately improve treatment adherence and outcomes, as reported in other studies [10–14,18–21]. The differences found between the two IOSs may come from the reduced size and diameter of iTero Lumina's handpiece.

Furthermore, the preference for iTero Lumina over iTero Element among patients was also recorded in duration perception. Patients perceived the duration time to be shorter with iTero Lumina. Clinicians involved in this study also reported that the procedure with Lumina required a reduction in time when compared to iTero Element.

This investigation underscores the importance of technological advancements and ergonomic design in digital impression systems. Overall, its findings emphasize the growing importance of digital technology in orthodontic practice. Further research is needed to explore digital innovation in scanning techniques to enhance patient care and improve treatment outcomes. As digital technology continues to evolve and improve, it is likely to become the standard of care in orthodontics, offering benefits not only in terms

of clinical accuracy but also in patient satisfaction and preference, ensuring that digital impression systems provide maximum benefit to both clinicians and patients.

The limitations of this study are the small size of the sample and its cross-sectional nature. Future studies should include a larger sample to validate the findings and ensure they are generalizable.

5. Conclusions

The evaluated intraoral scanners (IOSs) demonstrated similar accuracy in capturing dental arch dimensions, indicating that they perform comparably.

However, the patients interviewed showed a distinct preference for digital impressions taken with the iTero Lumina, citing increased comfort, a painless experience, and enhanced visualization of the impression as key reasons for their preference.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflict of interest.

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