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Effect of Different Intraoral Scanners on the Accuracy of Bite Registration in Edentulous Maxillary and Mandibular Arches

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ABSTRACT

Objectives: The objective of this study was to use in vitro models to examine the bite registration accuracy of four different intraoral scanners (IOS) for edentulous maxillary and mandibular arches. The objective was to assess the trueness and precision of the IOS and determine if there were significant differences between them.
Methods: An Asiga Max UV 3D printer was used to print maxillary and mandibular edentulous models based on the shape of Frasaco models (artificial dental arch models). Four dental implants were placed symmetrically in both models using Straumann BLT RC implants. Digital impressions were taken with Primescan, Trios 3, Trios 4, and Medit i500 intraoral scanners (n = 10 for each IOS). Digital bite registrations were made, and scanning data was exported in STL format. The accuracy of the interarch distance (the distance between the metrological spheres attached to the mandibular and maxillary models) was estimated for each IOS.
Results: The results showed significant differences in trueness and precision between different IOS ($p < .05$), except Medit i500 and Trios 3 ($p > .05$). Primescan provided the most accurate results, followed by Medit i500, Trios 3, and Trios 4, respectively.
Conclusions: within the limitations of this study, the IOS type affects the accuracy of interocclusal bite registration in in vitro design. Only Primescan achieved clinically acceptable accuracy for the interocclusal recording of edentulous arches.
Clinical Relevance: The comparison of the accuracy of bite registration between different intraoral scanners will help increase the efficiency of the clinical application of digitalized interarch registration.

1. Introduction

Bite registration is a crucial part of treating edentulous patients with implant-supported fixed prostheses. Indirect methods utilizing different imprint materials have been used in conventional laboratory procedures and accompanying prosthodontic treatments for a long time [1]. Conventional techniques require at least two visits for the patient and a wax rim or other type of appliance for a dentist to capture interarch relations, with a notable risk for errors at any stage of the procedure, including getting the interocclusal records and transferring models to an articulator [2]. Moreover, this analog workflow is time-consuming, and errors cannot be eliminated due to the inherent properties of the materials used [2].

Technologies like intraoral scanning and digital design and production offer solutions that are universally applicable, affordable, repeatable, and friendly to patients [3]· Due to recent advancements in digital dentistry, clinicians may now quickly and more correctly establish the interocclusal relationship than they could with traditional approaches

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[4]. Digital scanning offers several benefits, such as ease of use, fewer treatment sessions required, and increased patient comfort, including the elimination of gag reflex, possible allergies to the impression materials utilized, the capacity to take impressions without squeezing delicate tissue, and the removal of issues related to material qualities, including deformation, shrinkage, and expansion [5–8].

Acquiring an accurate vertical dimension can be achieved using acrylic resins, gypsum, wax, zinc oxide, eugenol, and elastomeric materials [9]. However, there is a tendency towards elastomeric materials due to their impression accuracy, ease of handling, and dimensional stability [10]. Therefore, using an elastomeric material as a bite rim made on the spot became one of the more popular techniques to guide future bite vertical dimensions [11]. Even with the advantageous properties of the elastomeric materials, there are still vertical disparities. Better dimensional stability was achieved using scannable recording materials, but the vertical differences were not eliminated [12].

There is limited scientific evidence regarding bite registration of the edentulous arch. According to a recent study by Nuytens et al. [13], the digital bite workflow was 60% faster, and the overall virtual bite registration deviation was around 1 mm using their proposed strategy.

Accuracy in scanning is characterized by precision and trueness. While precision is the scanner's capacity to produce consistent results when many measurements of the same object are made, trueness is the measurement's capacity to match the actual value [14]. Although advances in digital technologies provide better alternatives to conventional techniques, many different intraoral scanning manufacturers and their differences in performance and indications make it challenging to choose a proper intraoral scanner (IOS). Information about the accuracy of these types of procedures with various scanners is scarce in the literature. Therefore, this study aimed to compare the bite registration accuracy of four different IOS between edentulous maxillary and mandibular arches in vitro models. The null hypothesis was that there was no significant difference in bite registration accuracy between different IOS.

2. Materials and Methods

2.1. Fabrication of the initial model with implant and scan bodies for reference scan

Asiga Max UV (Asiga; version 1.2.11) 3D printer was used to produce one maxillary and one mandibular edentulous model by the Frasaco model (Frasaco GmbH, Germany) design. In both models, four Straumann BLT RC 4.1 mm diameter (Straumann, Basel, Switzerland) dental implants were placed in the second incisor (straight) and second premolar regions (tilted 5° distally). Locations for implants were selected according to standard clinical practice when restoring total arch cases. 5° tilt was also introduced to simulate *in vivo*-like environment. Scanbodies (CARES RC Mono scan body, Straumann, Basel, Switzerland) were attached to the implants with a 15 Ncm torque using a cordless electric screwdriver (NSK iSD900, Tokyo, Japan). Five metrological spheres were attached to the base of each model so as not to interfere with the bite registration procedure. Models were articulated into Kavo Protar evo 7 (Kavo Dental, Biberach, Germany) where future prostheses would be manufactured. Reference scans were obtained using a Nikon Altera 10.7.6 (Nikon Metrology, Shinagawa, Tokyo, Japan).

2.2. Creation of digital impressions and bite registration

Scanning was performed over a period of 10 days in a room with controlled temperature and relative humidity through a recuperating system. One operator performed scanning with 6 years of intraoral scanning experience (the operator had at least six months of experience using all scanners). According to the study on the aging of 3D-printed model dimensional changes over time, statistically significant dimensional changes occur in models after three weeks [15]. Scanning was done one scanner at a time, scanning maxillary and mandibular models and then scanning interocclusal distance. The scanners used were Trios 3, Primescan, Medit i500 and Trios 4. No randomization was done because scanning was done in a short period of time. Digital impressions were taken with Primescan (Dentsply Sirona, Charlotte, USA, v. 5.0.1), Trios 3 (3Shape, Copenhagen, Denmark, v. 1.18.2.10), Trios 4 (3Shape, Copenhagen, Denmark, v. 19.2.2) and Medit i500 (Medit, Seoul, South Korea, v. 2.0.3) intraoral scanners, ten times each (n = 10) model. For the registration of digital bite records, the interarch index was made using silicone putty (Variotime Easy Putty, Kulzer GmbH, Germany), and the index was then cut through the crest of the alveolar ridge area, unveiling the buccal part of the edentulous jaw and scan body's buccal surfaces. (Fig. 1A-F) To increase the success rate of automated bite registration completion, the left posterior region to right posterior region scanning technique was used for the bite registration scanning. Five kilograms of weight were placed on top of the articulator during each bite scan. Without scanning the emergence profile, the scanning sequences were implemented according to manufacturer instructions.

2.3. Preparation of acquired images for accuracy comparison

Scanning data were exported in standard tessellation language (STL) format for further analysis. Metrology software Geomagic Control X (3D Systems, USA) was used for the maxillomandibular relation estimation by measuring distances between the centers of corresponding metrological spheres in the mandible and maxilla, as illustrated in Fig. 2. Sphere centers were estimated using a software tool to highlight model regions resembling spheres, which then estimated the centers of the "best fitted" spheres. Differences between reference distances obtained by a metrological scanner and those from the rest of the digital impressions were analyzed to evaluate trueness. Precision was evaluated in a piecewise manner by assessing the distance difference between each pair of group elements in a non-repeating fashion, examining all possible unique pairs disregarding their order in the established pair. A total number of comparisons per group $n=(10-1)*10/2=45$. The mean distances between the five pairs of spheres were also calculated. Trueness and precision for each IOS device were estimated using unsigned values representing the deviations between the scans.

2.4. Statistical evaluation of the acquired data

The sample size G*Power software (v. 3.1.9.2, Dusseldorf University) served to calculate the power of statistical analysis.

Statistical analyses were completed using a statistical software program (IBM SPSS Statistics 29.0, IBM Corp., Armonk, NY, USA). Statistical analysis of all data pairs across scanner groups was conducted. The normality of the data was evaluated using the Shapiro-Wilk test, for testing the homogeneity of variance between groups, Levene's test was used. Statistics for normality and homogeneity are presented in Table 5. The distribution of samples was analyzed using the Kruskal-Wallis test, and the pairwise comparisons between the groups were conducted using the Conover-Iman test with the Holm method in regards to both trueness and precision values. The significance level $\alpha = 0.05$ was chosen for all used statistical tests.

3. Results

According to the mean trueness values of all five distances, Trios 4 presented the highest mean trueness values (513.06 µm), followed by Trios 3 (210.86 µm), Medit i500 (162.18 µm), and Primescan (74.74 µm), respectively, with a significant difference between the groups ($p < .05$) (Table 1). The pair-wise comparisons presented an important difference between all groups ($p < .05$) except Medit i500 and Trios 3 ($p > .05$) (Table 2, Fig. 3).

In terms of total mean precision values of all five distances, Trios 4 presented the highest mean values (562.82 µm), followed by Trios 3

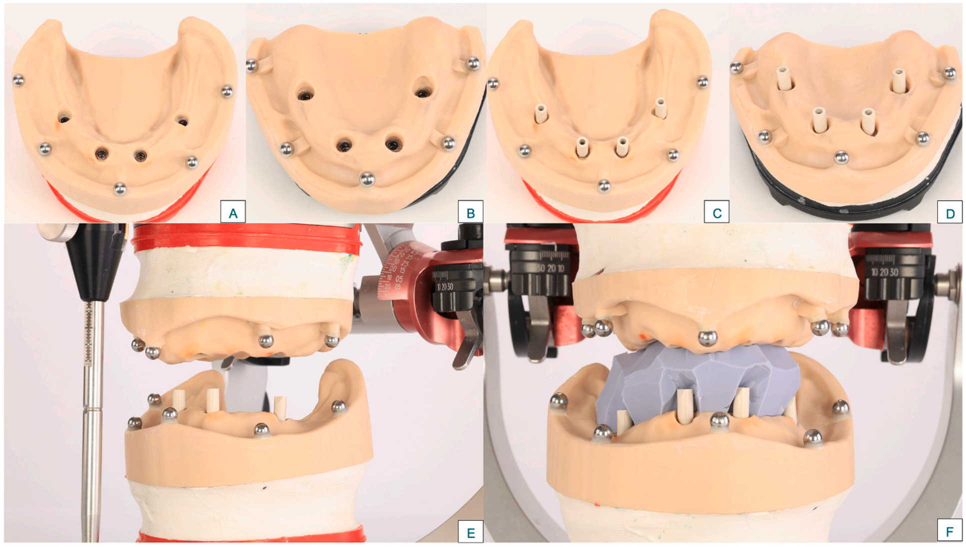

Fig. 1. The representative image of models with implants, scan bodies, and suggested bite registration technique. A-B: Mandibular and maxillary models with present implants. C-D: Scan bodies placed on their respective implants in the model jaws. E: Record of bite registration with the models in the articulator at maximum intercuspation. F: The putty bite registration rim impression cut through the crest of the alveolar ridge area, unveiling the buccal part of the edentulous jaw and scan body's buccal surfaces.

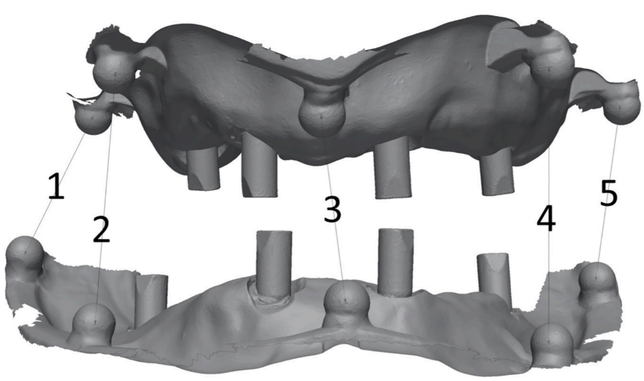

Fig. 2. The representative measurement of distances between the scanned metrological spheres.

(240 µm), Medit i500 (192.26 µm), and Primescan (90.16 µm), respectively, with a significant difference among the groups (p <.05) (Table 3). Pairwise comparisons presented significant differences between the groups (p <.05) except for Medit i500 and Trios 3 (p >.05) (Table 4; Fig. 4).

4. Discussion

Different elements can impact the accuracy of digital scanning, which might be responsible for the variations observed among the research articles. The accuracy of intraoral scanning may be influenced by device-related factors such as the scanning protocol [14], intraoral scanner [16], calibration [17], environmental light required for the scanner [18], intraoral factors including scan body adjustment [19], surface characteristics [20], and presence of saliva [21], and operator-related factors such as experience [22] and the learning curve [23] of the operator.

In this in vitro study, the accuracy of four different IOS was compared regarding trueness and precision in the edentulous maxillary and mandibular arches. All intraoral scanners differed significantly, and therefore the null hypothesis was rejected. According to the results of this study, in terms of trueness and precision, Primescan provided significantly the most accurate results, followed by Medit i500, Trios 3, and Trios 4, respectively. Trueness and precision assessment presented significant differences between all devices except the difference between Medit i500 and Trios 3, which were similar in comparison. The study's results reveal a substantial variation in the accuracy of IOS in the mandibular and maxillary arches, rejecting the null hypothesis. With 100 µm being accepted as the clinically acceptable threshold for

Table 1
Mean and standard deviation of trueness with the summary of Kruskal-Wallis results for group comparison (α=.05).

	Distance (µm)						Statistics
	1	2	3	4	5	Mean distance	
Trios4	760.7 (344.6)	705.0 (498.4)	463.1 (117.8)	358.8 (237.6)	277.7 (246.1)	513.06	$\chi^2(3)=71$, p=<.05
Medit	214.1 (125.2)	116.3 (72.8)	94.9 (92.0)	181.3 (97.9)	204.3 (109.4)	162.18	
Primescan	184.7 (121.8)	77.0 (53.4)	27.2 (23.7)	45.9 (31.9)	38.9 (32.3)	74.74	
Trios3	248.6 (238.7)	92.5 (56.3)	197.1 (290.8)	246.0 (289.9)	270.1 (278.8)	210.86	

Table 2
Multiple comparisons of trueness between groups using a post-hoc Conover test.

Pair	A B	CS 3600 Medit	CS 3600 Primescan	CS 3600 Trios3	Medit Primescan	Medit Trios3	Primescan Trios3
p-values		$1.50*(10^{-7})$	$8.23*(10^{-20})$	$1.50*(10^{-7})$	$1.51*(10^{-5})$	**0.98**	$1.51*(10^{-5})$

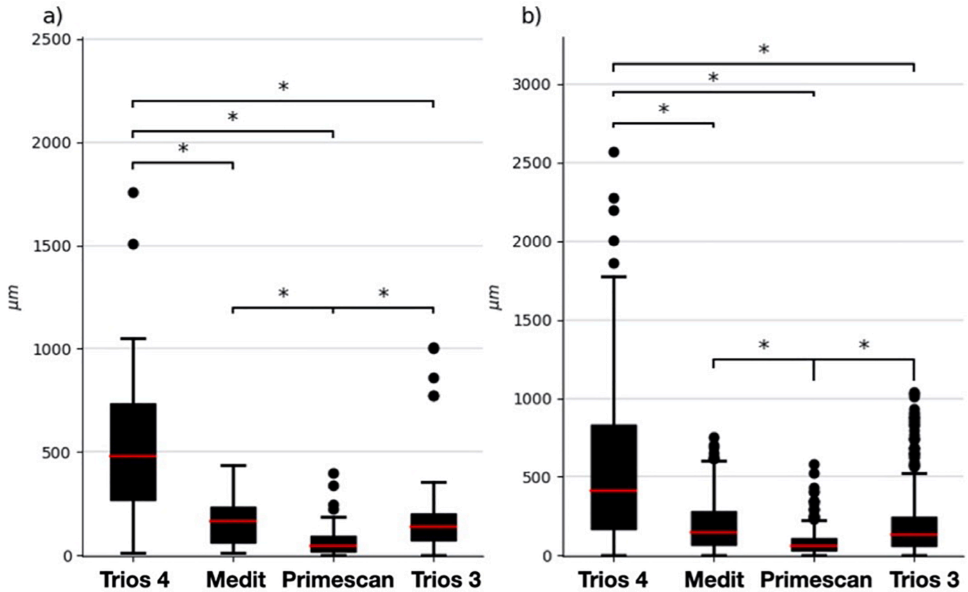

Fig. 3. Trueness (a) and precision (b) data. Asterixis and lines connecting the data imply a significant difference (p<0.05) between them.

Table 3
Mean and standard deviation of precision with the summary of Kruskal-Wallis results for group comparison.

STL files	Distance (μm)						Statistics
	1	2	3	4	5	Mean distance	
Trios 4	916.9 (616.5)	790.4 (574.6)	434.6 (412.6)	312.5 (232.8)	374.7 (237.1)	565.82	$\chi^2(3)=123$, p=<.05
Medit	304.2 (195.4)	86.5 (55.9)	151.9 (110.4)	138.1 (97.1)	280.6 (193.4)	192.26	
Primescan	200.4 (133.7)	93.2 (58.6)	40.1 (27.0)	55.6 (41.8)	61.5 (40.9)	90.16	
Trios3	242.3 (235.9)	121.7 (78.4)	269.4 (332.9)	270.5 (308.1)	296.1 (260.3)	240	

Table 4
Multiple comparisons of precision between groups using a post-hoc Conover test.

Pair	A B	Trios 4 Medit	Trios 4 Primescan	Trios 4 Trios3	Medit Primescan	Medit Trios3	Primescan Trios3
p-values		$1.01*(10^{-18})$	$2.72*(10^{-54})$	$6.13*(10^{-18})$	$2.3*(10^{-18})$	**0.80**	$5.92*(10^{-14})$

Table 5
Shapiro-Wilk and Leven's test results (p-values) for trueness and precision data.

	Shapiro test results				Leven test
	Trios4	Medit	Primescan	Trios3	
Trueness	$2*10^{-3}$	$1.4*10^{-2}$	$3*10^{-7}$	$5*10^{-7}$	$1*10^{-16}$
Precision	$2*10^{-12}$	$5*10^{-12}$	$1*10^{-17}$	$1*10^{-17}$	$1*10^{-48}$

deviations in digital impressions [24], only Primescan provided clinically acceptable accuracy. However, this threshold is considered to be much lower than 100 μm for occlusal contacts. Therefore, all tested IOS were not able to meet such requirements.

While scanning a fully edentulous arch, the most significant challenge is the lack of substantial landmarks and smooth and mobile mucosa covered with saliva, which will hinder accurate image-stitching with IOS. [25]. The design of the IOS tip may obstruct the IOS from going around the maxilla's tuberosity to capture the vestibule area's accurate depth [26]. Moreover, the accuracy of the digital impression may further deteriorate because of soft tissue movements during the scanning process; hence, the compromised stitching process of the digital images leads to distortion of the final digital implant impression [27]. Although lacking in number, several studies presented advantageous solutions for using artificial landmarks to increase the accuracy of digital impressions in edentulous arches [28,29]. It is documented that even for dentate patients, clinicians can expect different occlusal record results depending on how hard the patient bites, as shown in a study by Okamoto et. al. [30] An even more significant differences may be expected for edentulous patients when dentures or auxiliary bite registration devices rest on soft tissues.

The presented clinical challenges of digital scanning of edentulous arches also represent one of the most significant drawbacks of the current study's in vitro study design. When scanning edentulous patients, soft tissue geometry plays an important role in stitching information. It is commonly recognized that, due to the tissue elasticity and humidity of the surface, scanning soft tissues is less precise than scanning teeth. Gingival imitation in the present study has been composed of plastic, which has a matt texture that is rigid, immovable, and dry. Therefore, the results of this study in clinical conditions may differ.

A systematic review reported discrepancies in full-arch digital implant impressions and deemed the clinical use of intraoral scanners for full-arch digital implant impressions insufficient in accuracy. Interimplant distance, scan body type, intraoral scanner type, and operator experience were reported to impact the accuracy of impressions significantly [31]. The result of the present study concurs with the systematic review, revealing a significant impact of different IOS with great discrepancies in comparison to each other on the accuracy of the digital

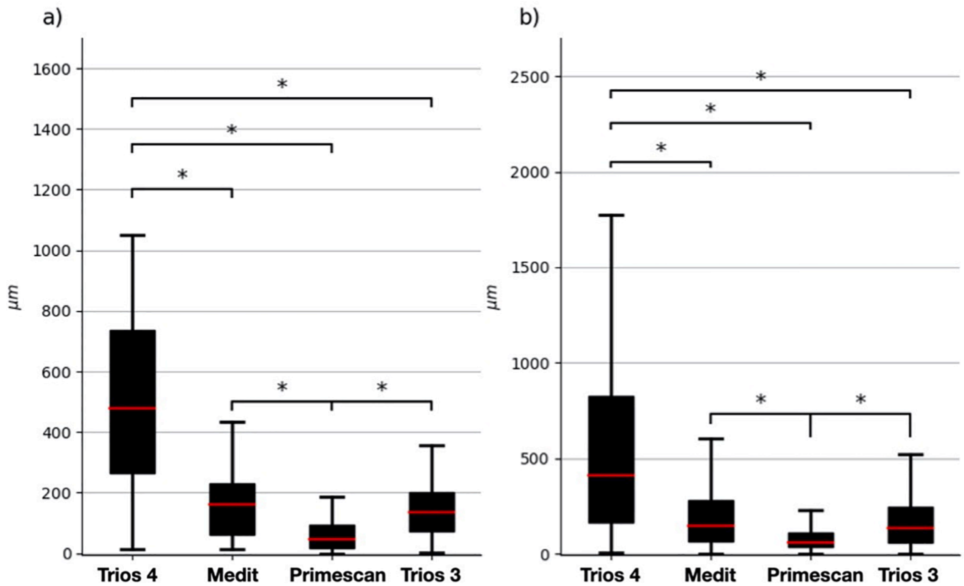

Fig. 4. Trueness (a) and precision (b) data without outliers. Asterixis and lines connecting the data imply a significant difference ($p<0.05$) between them.

impressions. Mangano et al. reported an important difference between different IOS regarding trueness and precision in full edentulous arches. At the same time, there was a significant difference only in trueness in partially edentulous arches [32]. Imburgia also compared four different IOS and found higher trueness and precision in partially edentulous arches than in fully edentulous arches, further emphasizing possible discrepancies of digital scanning procedures in fully edentulous arches [33].

On the other hand, in a systematic review, Srivastava et al. suggested using the IOS as clinically acceptable, with a reservation of a place for more improvement in the scanning process of mobile tissues and suggestions for better described and assessed clinical techniques and their implications. They emphasized the importance of the scanning process being completed in one shot rather than a re-scanning process to capture the missing parts [27]. According to a recent study by Nuytens et al. [13], the overall virtual bite registration deviation was around 1 mm using their proposed strategy. All our tested systems showed less than 1mm of deviations with few outlier exceptions utilizing this silicone bite registration technique.

The clinical challenges described above also present another drawback of the in vitro study design. In vitro, settings cannot replicate anatomical barriers that must be overcome in routine clinical practice when digitally scanning edentulous arches. Another limitation is the use of printed models for the reference and IOS scans. Even though model shrinkage was considered (timespan of model scanning was as short as possible, measurements were done using metrological spheres), 3D-printed models are subject to shrinkage over time, and often these contractions are entirely unpredictable. Although the models are blocked in the articulator in a particular position to avoid any discrepancies, the use of printed models still stands as an essential limitation of this study at the expense of acquiring homogenous models. In conjunction with 3D printed nuances, some other related limitations need to be mentioned: The environment in which scanning was done was controlled to some extent only (operator temperature and humidity were controlled by a standard recuperating system).)

Different digital bite registration techniques were suggested for edentulous arches with or without the presence of implant applications. [1,4,12,34]. Digitalized interocclusal recording has been discussed previously, and different techniques have been suggested [1,34–36]. The digitalized interocclusal recording reduces chairside time and appointment numbers and is thus an essential aspect of digitalized impression [35,36].

The presence of scan bodies during digitalized interocclusal recording is required to establish better digital interarch relations [6, 13]. However, such inclusion of scan bodies requires special adjustments to the bite registration material. In a previous study, dual-function scan bodies were suggested to decrease chairside time and increase efficiency [13]. Unfortunately, the technique requires the presence of dentition in the opposite arch, leaving the digital interocclusal registration of the edentulous maxillary and mandibular arches as a clinical challenge.

In the current study, the recommended and applied method involved making an edentulous ridge impression using a silicone putty, cutting it through the alveolar ridge area's crest to reveal the buccal portion of the edentulous jaw, and scanning the body's buccal surface. While the method worked well to accommodate the mandibular implant scan bodies, it is necessary to look for more effective strategies for digital interocclusal recording in both maxillary and mandibular edentulous arches. There was a significant difference in the accuracy results of all IOS, and the exclusion of maxillary scan bodies because of spatial inefficiency in the interocclusal putty was a critical loss of data. Techniques involving implant-supported temporary fixed restorations for bite registrations, different scanning strategies, and more clinical studies, should be evaluated and compared in future studies.

Other limitations not mentioned above: scanning was performed by one operator with six years of intraoral scanning experience. However, with some scanning systems, the experience is more limited than others (the operator had at least six months of experience using all scanners). No randomization in the scanning sequence was done while scanning with all systems.

5. Conclusions

Under the limitations of this in vitro study, digital bite registration accuracy in the case of 4 implants in each edentulous arch was significantly different, whereas only Primescan provided results within acceptable limits of 100µm. Due to the limitations of adopting an in vitro comparison technique, further studies are needed to evaluate and compare different digital bite registration techniques for edentulous cases that could provide clinically acceptable results.

CRediT authorship contribution statement

Vygandas Rutkūnas: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Darius Jegelevičius:** Writing – original draft, Validation, Methodology, Investigation, Data curation. **Agnė Gedrimienė:** Writing – original draft, Validation, Methodology, Investigation, Data curation. **Liudas Auškalnis:** Writing – original draft, Visualization, Methodology, Investigation, Data curation. **Tan Fırat Eyüboğlu:** Writing – review & editing, Writing – original draft, Validation. **Mutlu Özcan:** Writing – review & editing, Writing – original draft, Validation. **Nadin Al-Haj Husain:** Writing – original draft, Validation. **Mykolas Akulauskas:** Writing – original draft, Validation, Investigation, Formal analysis, Conceptualization. **Justinas Pletkus:** Writing – original draft, Validation, Methodology, Investigation, Data curation.

Declaration of competing interest

The authors had no commercial interest in any materials used in this study.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jdent.2024.105050.

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