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Effect of an auxiliary device on scanning accuracy for multiple implants: an in vitro comparative study

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Abstract

Objectives To determine the influence of a consumable auxiliary device, the O-I buckle, on the accuracy of intraoral scanning among complete arches.

Methods A standard mandibular model with six implants was used as the master model and was scanned by a precise dental laboratory scanner to establish a reference. Three impression techniques were compared: the conventional splinted open-tray impression (CI group), the digital intraoral scanning technique (IOS group), and IOS with the auxiliary device (OI group). For OI group, six prefabricated O-I buckles were attached for each intraoral scan body (ISB) and the definite models were scanned 10 times. The STL datasets were imported into a 3D inspection software to obtain the trueness and precision values for three scanning ranges (BCDE, BCDEF, and ABCDEF). The trueness was the absolute value of the root mean square (RMS) between the reference and test models, while precision referred to the value of the test group subtracted from each other. The data were statistically analyzed using two-way ANOVA and post hoc multiple comparison tests.

Results The impression method ($p<.001$) and scanning range ($p<.001$) significantly influenced the trueness and precision of implant impressions for complete edentulous arches. The IOS with O-I buckle showed higher trueness compared to the IOS group for all implant configurations with most being significantly different ($p=.758$, $= 0.04$, and $=<0.001$ for BCDE, BCDEF, and ABCDEF, respectively) and significantly higher precision was seen in group ABCDEF ($p<.001$). For four and five implants (group BCDE and BCDEF), there was no significant difference comparing IOS with O-I buckle and CI ($p>.05$). As the range expanded, the trueness and precision of IOS and OI decreased ($p<.05$), whereas the accuracy of CI remained stable.

Conclusions The auxiliary O-I buckle fixed to the ISBs significantly improved the multiple-implant intraoral scanning accuracy for digital impressions in complete arches; With CI as a reference, the accuracy of IOS with OI buckles were comparable for four and five implants.

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Clinical relevance The digitization accuracy of intraoral scanning for complete edentulous arches can be improved through IOS with OI buckles. This may lead to improved passive fit of the restoration, improving patient outcomes in a convenient and cheap way.

Keywords Impression accuracy, Intraoral scan, O-I buckle, Complete edentulous arches

Introduction

A passive fit is a major requirement for the long-term success of implant-supported dental restorations as it reduces the incidence of mechanical and biological complications, such as screw loosening, screw/implant fracture, marginal bone loss, peri-implantitis, and implant/prostheses failure [1, 2]. The accuracy of impression for dental implants is considered necessary for ensuring a passive fit of the definitive restoration [3–5].

The intraoral scanner (IOS) captures direct optical impressions, offering an alternative to conventional impression making with benefits, such as fewer clinical steps, greater patient satisfaction, and easier laboratory-professional communication and data storage [6–10]. IOSs have demonstrated acceptable clinical accuracy for single unit [11, 12] and short span impressions [6], making them a viable substitute for traditional methods [3, 11]. However, the accuracy of optical impressions for long span restorations, particularly complete edentulous arches, is lower than that for conventional impressions [13–16]. Paratelli et al. [17] showed that IOSs could not provide optimal outcomes in edentulous mandibles. Scans of complete edentulous arches had errors of 50–250 μm, often surpassing the clinically accepted threshold of < 150 μm [18–21]. Unsatisfactory results in complete edentulous arches could be due to several reasons. For example, multiple images required to reconstruct the virtual model may cause an accumulation of errors. Similarly, a lack of stable anatomical structures for accurate digital impressions of complete edentulous arches may contribute to the reduced accuracy [6, 11, 18, 19, 22–24].

To address the inaccuracies resulting from the lack of anatomic structures and accumulated errors, several devices have been developed for intraoral scanning of full arches [25–32]. These devices consist of composite resin, anatomic frameworks, and geometric components, aiming to minimize the stitching errors and overlapping problems by establishing optical bridges between intraoral scan bodies, and thus improving the trueness of impressions. Cappare et al. [25] and Iturrate et al. [8] demonstrated that the precision of the scanning process can be improved by providing a path using composite resins or geometric aids. Although the results have been promising, these approaches either require photopolymerization or additional scanning, resulting in a higher cost and greater number of clinical steps. A reference-marked rigid splint of known dimensions can also be used to detect and virtually correct the cumulative deviations [33, 34], but requires additional steps and extra materials.

Considering these limitations, the present study developed a convenient and inexpensive O-I buckle that can be easily adjusted to accommodate varying distances between multiple implants and available for different types of intraoral scanners on the market. The objective of this in vitro study was to determine whether the O-I buckle could be utilized to capture the position of multiple implants more accurately. The null hypothesis was that the digital scans acquired with auxiliary device would not influence the impression accuracy of complete arch edentulous patients.

Materials and methods

This study compared complete-arch implant scanning trueness and precision values obtained from IOSs with or without O-I buckles as well as conventional splinted open-tray impression. Statistical software (PASS 15, NCSS LLC) was used to calculate the sample size. The sample size was calculated based on the tests for ANOVA. With $\alpha = 0.05$, mean of the deviation [28] (CI = 19.3, IOS = 88.7, OI = 20.1), a sample size of 10 was necessary, which would have the actual power of 0.9 to detect the difference [28, 35, 36].

The clinical procedure began with the formation of a master model. An edentulous acrylic resin model (IMP5010-L-SP, Nissin Dental Products, Inc.), containing six straight analog implants (Bone-level tapered RC; 3.3 × 10 mm and 4.1 × 10 mm, Institute Straumann AG) and artificial gingiva, was fabricated as the reference model to simulate clinical situations. Straight intermediate abutments (NC 4.6 mm and RC 4.6 mm repositionable analogs for screw-retained abutments; Institute Straumann AG) were screwed over each implant (Fig. 1).

Six ISBs (SB-M, SEGMA Corp.) were fitted and tightened to 10 N.cm using a torque-controlled wrench. Then the master model was scanned for reference using a precise dental laboratory scanner (3Shape D2000 Scanner; 3Shape A/S), and the files were converted to STL format.

The master model was subjected to two different impression methods, depending on the presence or absence of the O-I buckle: the intraoral scan bodies (IOS group, $n = 10$) and the proposed scanning auxiliary device, the O-I buckle, mounted on the ISB (OI group, $n = 10$). The proposed device consisted of two parts, a clamp structure and a connecting rod with an uneven

Fig. 1 The master model

surface. The former was fixed on the scanning rod through a clip (resembling an "O"), and the latter (resembling an "I") allowed scanning and splicing of the vacant part of the two scanning rods (Fig. 2). The scan aids were designed with Mimics software (Materialise, Brussels, Belgium) and printed using the resin printer (DLP, Time to Peak) and acrylates materials (Model Resin, product no. GV-Model 1) according to the diameter parameters of the scan body commonly used in clinical, prefabricated with flexible length bars to accommodate different operation designs. In practice, the prefabricated aids can also be cut easily to accommodate the distance between two adjacent implants and the elasticity of this acrylic material allows the tool to be held in place by clamping force. Six ISBs (SB-M, SEGMA Corp.) were fitted and tightened to 10 N.cm using a torque-controlled wrench. The O-I buckles were manually retained through mechanical retention to the lowermost part of each ISB to avoid obscuring its identification markings, adjusting the extension positions of the connecting rods to attach each component. To simulate different clinical conditions, the six ISBs were labelled A–F from left to right and three groups with different implant combinations (BCDE, BCDEF, and ABCDEF) were created. The model was then scanned using an IOS (3Shape TRIOS Scanner 3; 3Shape A/S) with or without O-I buckle, repeating the process 10 times by an experienced technician to standardize the experimental procedure. The data were exported and converted into STL files (Fig. 3). Scanning initiated from the most distal ISB on the right side, and continued sequentially toward the last ISB on the left side.

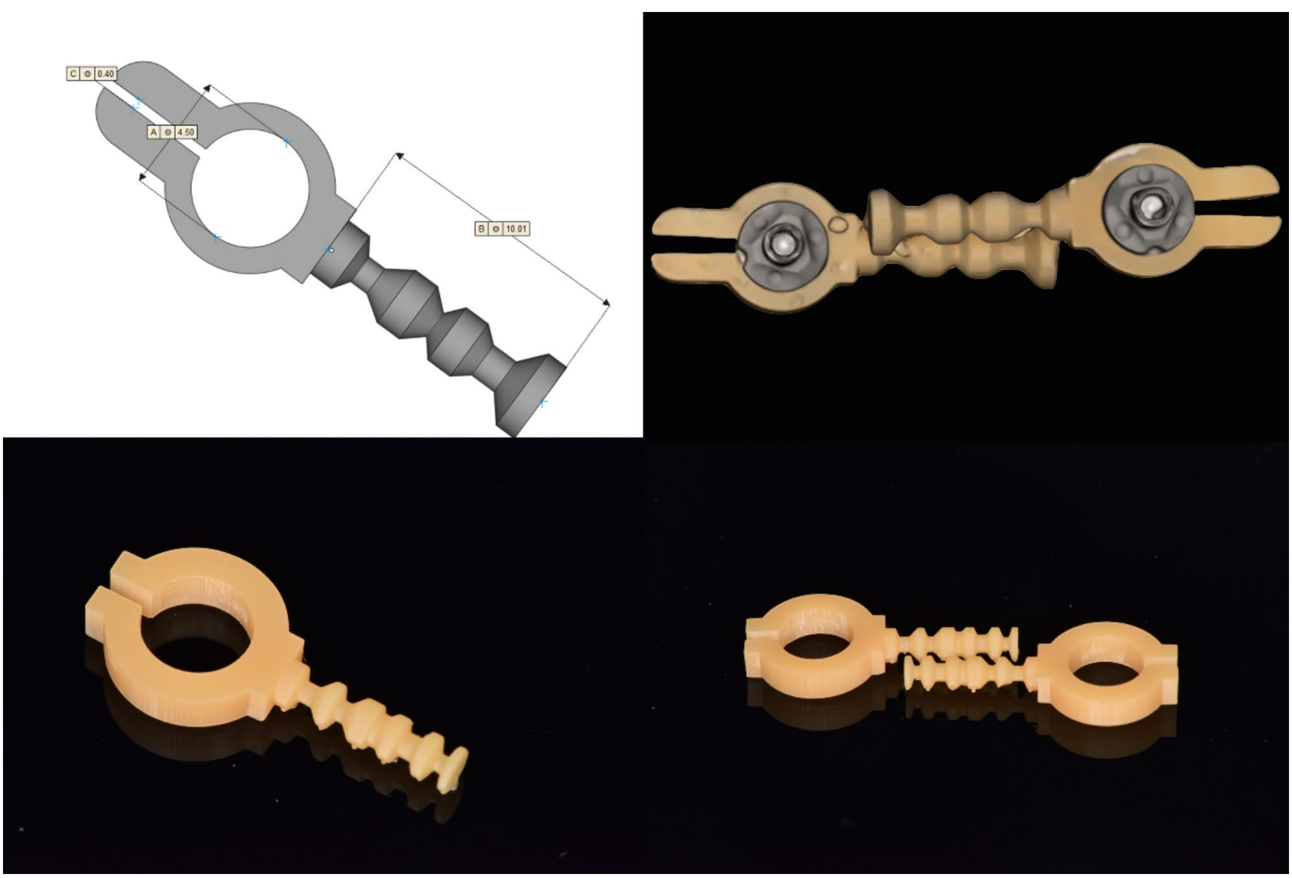

Fig. 2 Presentation of device for intraoral scanning of edentulous arches

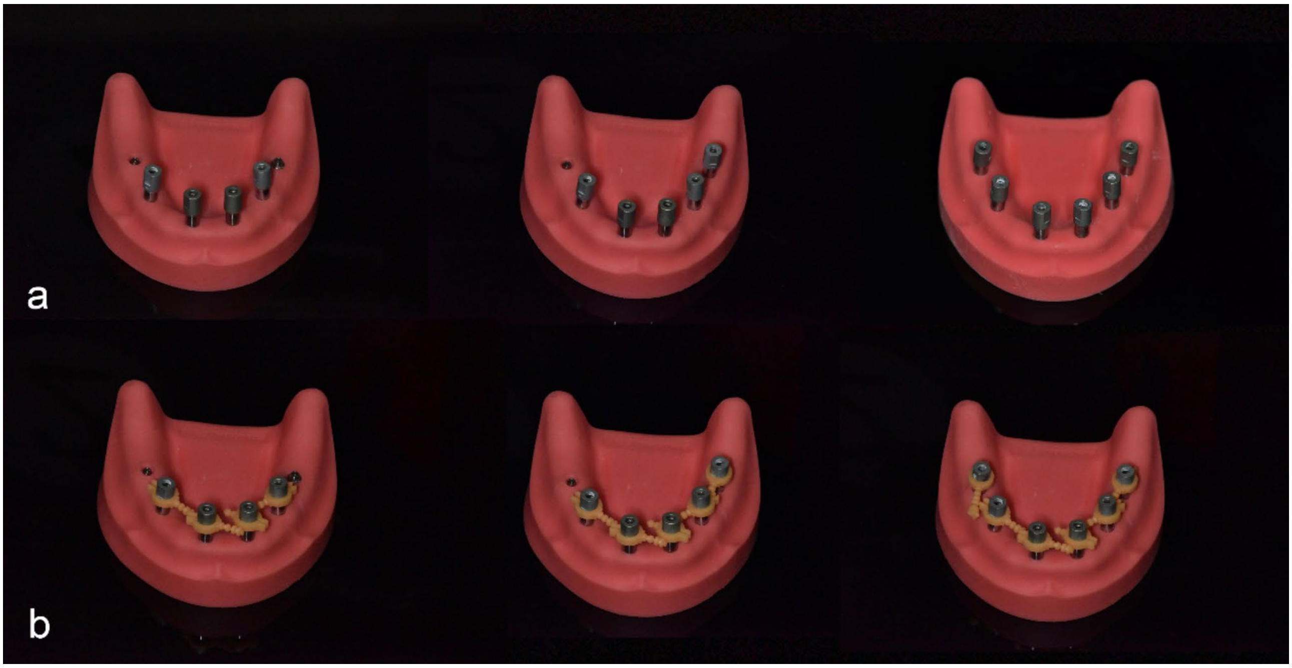

Fig. 3 Three groups of scanning ranges simulating different clinical situations in complete edentulous patients. **a** IOS group: digital impression using ISBs. **b** O-I group: digital impression using ISBs with O-I buckle

After the digital scan was made, six abutment-level open-tray impression posts (RC, 025.0012, Institute Straumann AG) were secured to abutments and splinted with pattern resin (Pattern Resin, GC corp.) incrementally placed on floss scaffold. Then the splinted assemblies were sectioned and reconnected to minimize the polymerization shrinkage. The splinted open-tray impression was conducted at room temperature using a polyvinyl siloxane impression material (Silagum, DMG Chemisch-Pharmazeutische Fabrik GmbH). Multiunit abutment analogs were attached to the copings and poured into type IV dental stones (GC New Fuji Rock, GC Corp.). The final casts with abutments and scan bodies were digitalized by the laboratory scanner (3Shape D2000 Scanner; 3Shape A/S). The whole process was repeated 10 times by one experienced technician and 10 STL data files were generated.

The data were imported into a 3D inspection software program (Geomagic Wrap 2021; 3D Systems). After manually selecting the side surface of the ISB, the axis of the virtual cylinder was obtained, which intersected the upper horizontal plane of the ISB. Using this intersection point and the long axis of the cylinder, a projected standard virtual cylinder (height: 14.5 mm, radius: 7 mm) was obtained to simulate the shape of the ISB.

After setting the tolerance level to 0.001 μm, the STL files from the three groups were aligned and superimposed over the original reference file. Discrepancies were visually displayed using color maps, and root mean square (RMS) values were calculated from the mean of the positive and negative deviations (Fig. 4). The trueness was the absolute value of the root mean square (RMS) between the reference and test models, while precision referred to the value of the test group subtracted from each other.

Statistical analysis was performed using IBM SPSS Statistics (v. 22; IBM Corp.) ($\alpha = 0.05$). Normal distribution and variance homogeneity were indicated by the Shapiro–Wilk and Levene's tests, respectively. A two-way analysis of variance (ANOVA) was initially used to assess the effect of the impression methods and scanning ranges followed by the Tukey honestly significant difference (HSD) test for post hoc multiple comparisons.

Results

The two-way ANOVA showed that both the use of O-I buckle fixed on the ISBs ($p < .001$) and scanning ranges ($p < .05$) had statistically significant effects on the trueness and precision values of the implant location. However, the interaction between the two factors ($p < .001$) had significant effect on trueness and precision, followed by simple effects analyses.

Based on the best-fit algorithm, the trueness and precision values (mean ± SD, μm) of different scanning ranges among three impression methods are listed in Table 1 and the comparison of P values of trueness are listed in Table 2.

In all cross-arch situations, the deviations from the conventional impression were greater than those of the IOS group, and significantly ($p = .002$ for BCDEF, and

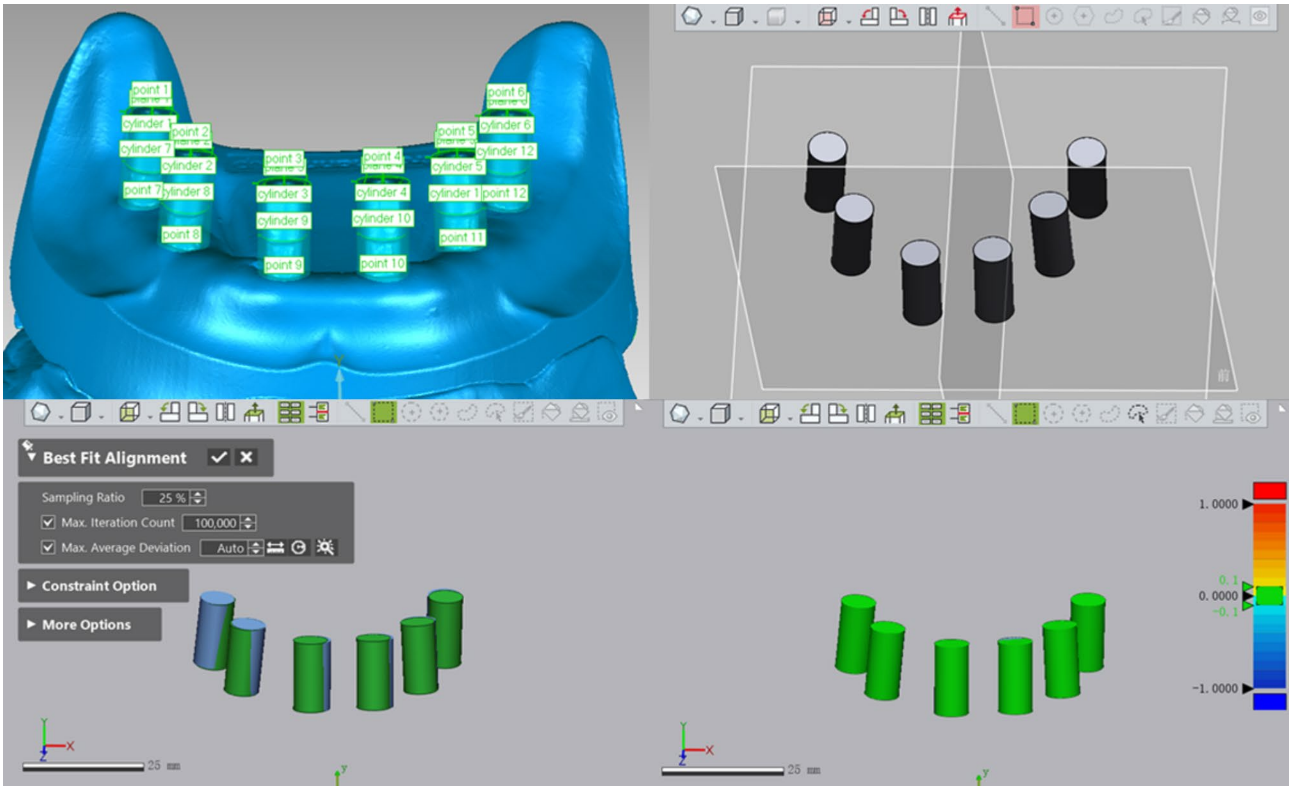

Fig. 4 The outcomes of 3D comparison were presented in the color maps, and the RMS values were automatically calculated

Table 1 Trueness and precision values of conventional impressions and intraoral scanners with or without O-I buckles

	Trueness (mean ± SD, μm)				Precision (mean ± SD, μm)			
	CI	IOS	OI	*P*	CI	IOS	OI	*P*
BCDE	34.00 ± 7.38	37.39 ± 10.10	36.70 ± 8.03	0.758	8.67 ± 5.88	11.66 ± 8.33	9.57 ± 6.18	0.248
BCDEF	37.79 ± 8.31	53.16 ± 11.69	40.20 ± 7.06	0.004*	9.96 ± 6.31	12.69 ± 10.70	8.43 ± 5.41	0.064
ABCDEF	37.17 ± 7.89	72.25 ± 21.23	49.74. ± 7.12	< 0.001*	9.42 ± 6.05	24.88 ± 17.00	8.44 ± 5.57	< 0.001*
	0.700	< 0.001*	0.025*		0.781	< 0.001*	0.773	

CI, Conventional impression; IOS, Intraoral Scan; OI, Intraoral Scan with O-I

SD, standard deviation. **P* <.05

Table 2 Comparison of P values of trueness and precision by best fit algorithm

	Trueness (mean ± SD, μm)			Precision (mean ± SD, μm)		
	CI vs. IOS	CI vs. OI	IOS vs. OI	CI vs. IOS	CI vs. OI	IOS vs. OI
BCDE	0.483	0.576	0.886	0.104	0.623	0.256
BCDEF	0.002*	0.618	0.009*	0.137	0.407	0.021*
ABCDEF	< 0.001*	0.011*	< 0.001*	< 0.001*	0.590	< 0.001*

CI, Conventional impression; IOS, Intraoral Scan; OI, Intraoral Scan with O-I

SD, standard deviation. **P* <.05

< 0.001 for ABCDEF). In most situations of long-span scanning, OI group had higher trueness values than IOS group (p =.009 and < 0.001 for BCDEF and ABCDEF, respectively) with some not being significantly different (p =.886 for BDCE). As the range expanded, the trueness of IOS and OI group decreased (p =.025 and < 0.001 for OI and IOS, respectively), whereas the trueness and precision of CI group remained stable, as did the precision of OI group. And significantly higher precision was seen in group BCDEF and ABCDEF (p =.021 and < 0.001). Meanwhile, CI group had higher trueness values than OI group (p =.011 for ABCDEF), but not all the scores reached statistical significance (p =.576 and 0.618 for BCDE, and BCDEF, respectively) (Fig. 5).

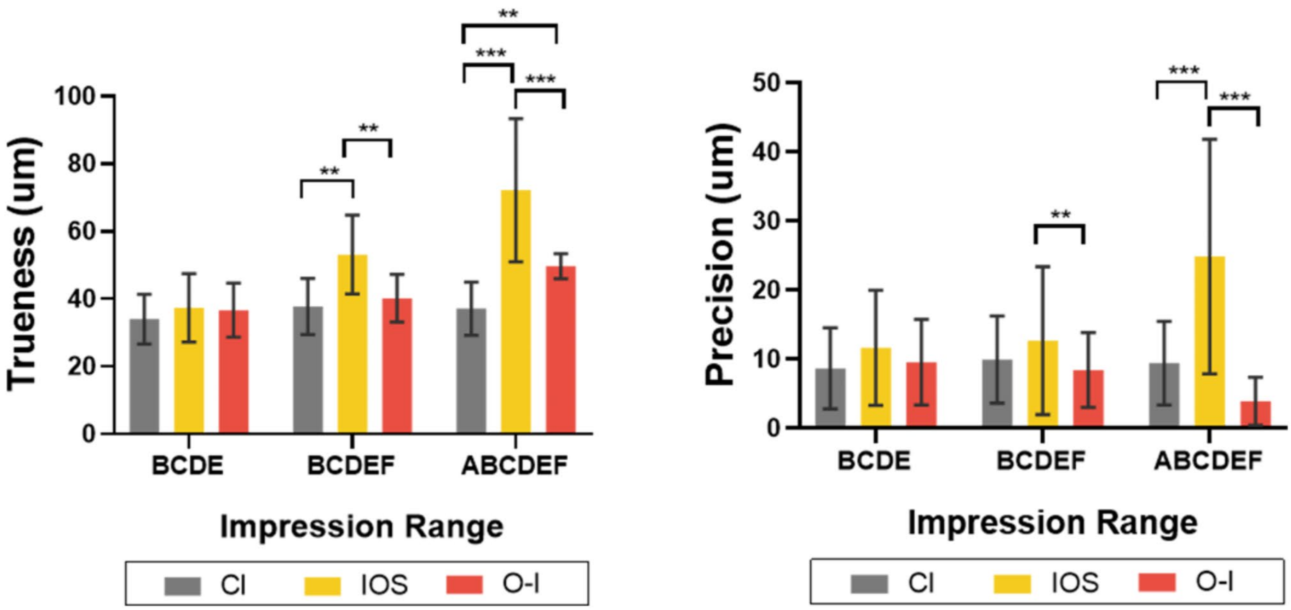

Fig. 5 Trueness and precision of scanners with or without O-I buckles as well as conventional impressions

Discussion

This study analyzed the trueness and precision of intraoral scanning with or without O-I buckle as well as conventional open-tray splinted impression in complete edentulous mandibular arches. The OI group exhibited better results than the IOS group, leading to the rejection of the null hypothesis that there was no significant difference in the trueness and precision of intraoral scans with or without the O-I buckle. Conventional splinted open-tray impressions showed the highest accuracy in the vast majority of cases, followed by digital impressions using O-I buckles, and the digital impressions with original ISBs showed low accuracy relatively.

IOSs have become an essential part of the workflow in digital restorative procedures [37, 38]. Clinicians can obtain a 3D preview of the implant locations and the surrounding structures through direct digital data acquisition, which eliminates material-related inaccuracies and improves patient comfort [8, 39]. Despite these advantages, complete-arch scanning is challenging with IOSs. In edentulous patients, difficulties in identifying markers without the morphological characteristics lead to poor trueness [19, 40, 41]. Conventional splinting open-tray technique is still considered the standard for full-arch impressions, while the accuracy of digital impression remains doubtful [6, 42–44]. In a previous study in 2019, we demonstrated that implant impressions for complete arches obtained using ISBs had lower trueness values compared to conventional impressions [45]. Other studies have also shown that the absence of anatomic structures adversely influences the process of best-fit alignment conducted by IOSs [12, 19, 46]. Furthermore, a greater number of images is required to digitize larger areas, leading to increased connections and cumulative errors.

Several techniques have been developed to reduce the distortions caused by stitching errors and overlapping in complete edentulous arches [8, 36, 46–50], with geometric landmarks based on uneven surface shapes to improve the best-fit alignment. In this study, O-I buckles were used to occupy the space between two scan bodies. Placing and fixing them to the edentulous arches allowed the generation of more accurate digital scans. The trueness values ranged between 36.7 ± 8.03 μm and 49.74 ± 7.12 μm with the O-I buckle, and between 37.39 ± 10.10 μm and 72.25 ± 21.23 μm without it. The precision values ranged between 8.43 ± 5.41 μm and 9.57 ± 6.18 μm with the O-I buckle, and between 11.66 ± 8.33 μm and 24.88 ± 17.00 μm without it. And for four and five implants, the accuracy of IOS with O-I buckle and conventional open-tray splinted impression was comparable. These trueness and precision values represent the mean values and demonstrate the superiority of the O-I buckle. Kim et al. [46] used an auxiliary alumina artificial device to simulate a denture, providing more information about anatomic irregularities, which improved the trueness values for the tested IOS. Iturrate et al. [51] also reported the use of a polymeric device to provide an irregular shape adjacent to the surface structures, improving the accuracy of digital scanning. An in vitro study by Huang et al. demonstrated that CAD/CAM-formed titanium alloy scan bodies with extensional structures could provide more characteristic points on the ISB surface, which was found to be beneficial for the stitching procedure [52]. However, all these approaches increase the cost, scanning time, and production steps, which adversely influence the satisfaction level of patients. The devices must be prefabricated and require adequate fixation intraorally. In contrast, the projected joining auxiliary device used in this study offers advantages, such as disassembly, easy adjustment, simple sterilization, and low cost. As a prefabricated device suitable for direct clinical use, it eliminates the need for multiple scans for customization. Furthermore, the length of the connecting rods can be easily adjusted to meet the clinical needs before or after the O-I buckles are printed.

Additionally, scanning discrepancies observed in IOS groups increased as the scanning range expanded. This trend was also evident in the OI group with the application of the O-I buckle, while the conventional impression remained unaffected. As the digital scanning span expanded, more reference points needed to be matched, leading to more image stitching and a higher likelihood of accumulation errors [19, 53–55]. It is noteworthy that the impression accuracy of OI group with six implants was not as well as that of the CI group. It may due to the fact the implants that are at the edge and scanned at the endpoints have lower accuracy. Larger discrepancies were observed at the endpoints of the scanned model, particularly at positions A and F, in line with previous studies suggesting potential errors in complete arches, particularly in the posterior area [35, 56]. Mizumoto et al. also reported that the implant location had a significant effect on the deviation, not because of the anterior or posterior ISB positions, but because of cross-arch positions. They reported higher deviations in the first scanned ISB compared to other ISBs, which may be related to the study design or the scan path [56, 57]. These findings suggest that, in the digital scanning group, position A and F—the first and final scanned ISB—may have influenced the deviation to some extent.

In this study, files were superimposed using the best-fit algorithm, which is based on the iterative closest point algorithm for aligning STL files. The algorithm minimizes the error between the distance of each corresponding point, being not affected by the operators. The main limitation is that systematic errors inevitably occur during the superimposition process, which can be avoided by using the root-mean-square error to measure 3D deviations [52].

There were some limitations in this study that must be acknowledged. The in vitro design may not accurately simulate the clinical situations. Factors such as blood, saliva, metallic restorations, and tongue or frenulum movement may interfere in the clinical scanning process [23, 53, 58]. In order to minimize the impact of movable tissues, scanning areas were limited to the regions on the model corresponding to the soft tissues with minimal or no movement, such as the attached gingiva. The proposed device also requires improvement, as mobility within the connecting parts between the two rods may make scanning more challenging, particularly in patients with limited mouth opening. This device is fixed by a clamp, and multiple use will cause a decrease in clamping force. So it is recommended to use it as a disposable device.

Conclusions

The present study compared the performance of IOSs with or without the auxiliary device for the acquisition of implant positions in completely edentulous arches. Considering the limitations of this in vitro study, the following conclusions can be drawn:

1. The auxiliary intraoral scanning aid, the O-I buckle, is a disposable and inexpensive device that can significantly improve the trueness of IOS for full arch intraoral scanning. It can also be customized for different types of scan bodies.
2. For four and five implants, the accuracy of IOS with O-I buckle and conventional splinted open-tray impression was comparable; for six implants, IOS with O-I buckle was slightly less accurate than conventional splinted open-tray impression.
3. The scanning method and range affects the accuracy of impressions for multiple implants in completely edentulous arches.

Further in vivo studies are needed to verify the accuracy of intraoral scanning using the O-I buckle.

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Author contributions

All authors contributed to the study conception and design. Material preparation and data collection were performed by Mingyue Lyu, Dingyi Xu, Yizhou Li and Heling Zhao. Analysis and investigation were performed by Dingyi Xu and Yizhou Li. The first draft of the manuscript was written by Mingyue Lyu and Dingyi Xu. Quan Yuan and Shiwen Zhang commented on previous versions of the manuscript and supervised the work. All authors read and approved the final manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethical approval

Ethics approval was not required for this in vitro study.

Competing interests

The authors declare no competing interests.

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