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Influence of Prefabricated Auxiliary Device Design and Intraoral Scanner Type on the 3D Trueness of Intraoral Scans

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Abstract

BACKGROUND/AIMS: It was aimed to compare the trueness of digital impressions acquired using prefabricated auxiliary devices (PADs) in 2 different forms, in combination with 2 intraoral scanners (IOSs).

MATERIALS AND METHODS: A master cast of a partially edentulous maxilla with two multi-unit analogues was initially scanned in a laboratory setting, with the resulting data saved as a reference standard tessellation language (STL) file. Subsequently, experimental STL files were generated, by using two different IOSs, the Omnicam and iTero, following three distinct scanning routes: without a PAD, with an indented PAD, and with a plain PAD. Each experimental STL file was superimposed onto the reference STL file; the scan bodies were transformed into virtual hollow cylinders, and the Cartesian coordinates of the centre lines passing through these cylinders were recorded, enabling the calculation of angular deviation (AD) and linear deviations (LD). Statistical analysis was performed using two-way analysis of variance with Tukey's post-hoc test ($\alpha=0.05$).

RESULTS: PAD design, IOS type, and their interaction terms significantly influenced the deviation values ($p<0.05$), except for the PAD design effect on AD values in location #13 and the IOS type effect on LD values in location #13 ($p>0.05$). In both AD and LD data, the Omnicam + no-PAD and iTero + indented PAD, groups exhibited the highest and the lowest values across all locations, respectively. The LD values in all locations and the AD values in location #13 were below the acceptability thresholds (<100 µm and <0.5°). However, the AD values of Omnicam + no-PAD, iTero + no-PAD, and Omnicam + plain-PAD groups were clinically unacceptable (>0.5°) in location #17.

CONCLUSION: The iTero + indented PAD group outperformed the other groups in terms of trueness.

Keywords: Intraoral-scan, prefabricated-auxiliary-device, scan-aid, superimposition, trueness

INTRODUCTION

Intraoral scanners (IOSs) have gained prominence in dental practice as an effective and practical alternative to traditional impression-making.[1] IOSs offer patient comfort and streamline workflow by eliminating stages such as tray selection, dispensing, and setting of impression materials, and the production of stone casts. Additionally, IOSs offer accessible storage on electronic databases and significantly improve communication among dental professionals, patients, and technicians, as captured digital images can be used for visual explanations.[2,3] However, IOSs capture consecutive 2D images via a limited-range sensor, which are subsequently combined into a single 3D image by running the iterative closest point algorithm.[2] This process, known as image stitching, is supported by solid anatomical landmarks available

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along the scan path.[1,2] In instances of the loss of several contiguous teeth, image stitching presents challenges due to the extended distance of the edentulous region between scan bodies.[3,4] The lack of anatomical landmarks can lead to cumulative errors during the stitching process, resulting in distortion. Therefore, previous studies recommend using IOSs as an alternative to conventional techniques for single-unit and short-span fixed partial restorations, where anatomical references are more readily available.[5-8] Without anatomical landmarks, IOSs may inaccurately stitch images or misunderstand scan segments as superfluous data.[1,9-12] To address this drawback, artificial landmarks must be created to maintain continuity between scan bodies, allowing for accurate tracking of the scanning route.[13-15] Using fiducial markers, applying pressure-indicating paste, splinting scan bodies with different materials, utilising scan bodies with flags, and positioning prefabricated auxiliary devices (PADs) on the scan bodies are the proposed approaches to installing artificial landmarks.[16-21] However, data supporting the effectiveness of these approaches are scarce. Therefore, this study aimed to compare the trueness, (refers to the closeness of the experimental object to the reference object) of digital implant impressions acquired by using 2 different PADs in combination with 2 different IOSs. The null hypothesis posited that the utilization of a PAD would not affect trueness, that there would be no disparity in trueness among different PADs, and that there would be no disparity in trueness among IOSs.

MATERIALS AND METHODS

A partially edentulous maxillary cast was created by pouring a self-curing acrylic resin (Meliodent Rapid Repair Denture Acrylic; Kulzer GmbH) into a dentulous silicone mould (AG-3 G Silicone Index; Frasaco). Two multiunit analogues (T0 32202; NucleOSS) were then positioned within the cast, designating it the master cast. To enable scanning, scan bodies (T0 32033; NucleOSS) were fastened to the multiunit analogues, and the cast was scanned using a benchtop laboratory scanner (inEOS X5; Dentsply Sirona). The resulting data were saved in standard tessellation language format, establishing a reference dataset for further comparison. Experimental scan datasets were obtained with 2 different IOS devices (CEREC Omnicam and iTero Element 5D Plus) across 3 separate routes: 1) with no PAD, 2) with indented PAD, and 3) with plain PAD (Figure 1). Using a software tool (G*power, v.3.1.9.7, Heinrich-Heine-University), the minimum required sample size was calculated to be 18 with 85% power, an effect size of 0.40, and a significance level of 0.05. Indented and plain PADs were first virtually designed, by using a software program (SolidWorks; Dassault Systèmes Corp.) and then 3D printed with the aid of a fused deposition modelling device (Prusa i3 MK3S; Prusa Research AS, Czech Republic) with polylactic acid plus filament. The print nozzle temperature was set at 210 °C, and the print bed temperature was set at 60 °C. Eighteen consecutive scans were performed for each group by an experienced calibrated operator. All datasets were transferred into a metrology software application (Geomagic Control; 3D Systems). Each experimental scan dataset was superimposed over the reference scan dataset, and best-fit alignment was subsequently applied. For the evaluation of angular deviation (AD) and linear distortion (LD), the feature creation tab was utilised to generate the best-fit plane (plane 1) on the occlusal surface of the scan body. An offset plane (plane 2) was then created 10 mm away from plane 1, corresponding to the height of the scan body. Hollow virtual cylinders were designed along the line passing through the centres of both planes, matching the scan body's diameter. The Cartesian coordinates of these centre lines were recorded. AD and LD were calculated as described in a previous study.[2]

Statistical Analysis

Data were processed in a software program (SPSS Statistics 25.0; SPSS Inc.). The assumption of normal distribution was verified by using the Shapiro-Wilk test. Statistical analysis was performed by using two-way analysis of variance (ANOVA) with Tukey's post-hoc test (α=0.05).

RESULTS

The mean AD and LD values ± standard deviations with pairwise comparisons are presented in Table 1. The results of 2-way ANOVA proved that the PAD design, IOS type, and their interaction terms significantly influenced the deviation values ($p<0.05$), except for the PAD design effect on AD values in location #13 and the IOS type effect on LD values in location #13 ($p>0.05$). In both AD and LD data, the Omnicam + no-PAD and iTero + indented PAD groups exhibited the highest and the lowest values across all locations, respectively. The LD values in all locations and the AD values in location #13 were below the acceptability thresholds (<100 μm for LD and <0.5° for AD). However, the AD values of Omnicam + no-PAD, iTero +no-PAD, and Omnicam + plain-PAD groups were clinically unacceptable (>0.5°) in location #17.

DISCUSSION

In a scenario of a partially edentulous case, this study compared the trueness of digital impressions acquired by using PADs in 2 different forms, in combination with 2 IOSs, all null hypotheses were rejected because the PAD design, IOS type, and their interaction terms significantly influenced the AD and LD values. According to the results, Omnicam had higher AD and LD values in all locations. This is consistent with a previous study[22] and can be attributed to several reasons. First, Omnicam gathers data via unpolarised white light through active triangulation technology.[9,22] Omnicam may have encountered confusion while scanning the white PAD. Second, white substrates reflect light diffusely, diminishing the contrast between the substrate and the light emitted by the scanner. White surfaces tend to scatter light in multiple directions, as reflective materials do.[8] This scattering phenomenon diminishes the quantity of structured light reflected to the scanner's sensors, complicating accurate surface mapping. Third, white might overwhelm

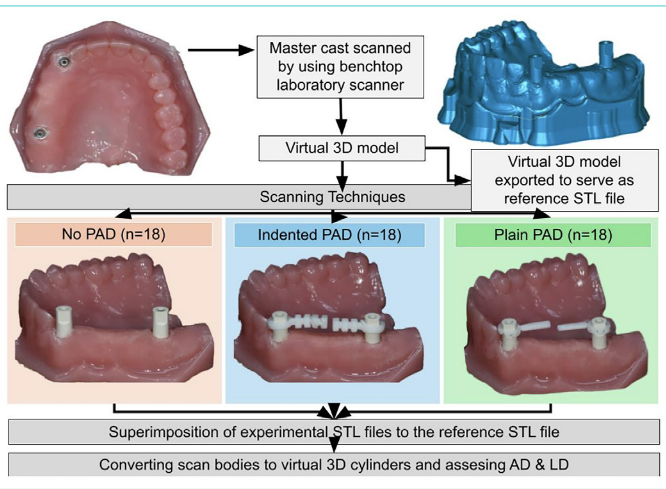

Figure 1. Workflow of study.

PAD: Prefabricated auxiliary device, STL: Standard tessellation language, AD: Angular distortion, LD: Linear distortion.

Table 1. Mean angular and linear deviation values ± standard deviations with Tukey post-hoc comparisons

	Angular deviation (degrees)			Linear deviation (µm)		
Routes	Omnicam	iTero	Total	Omnicam	iTero	Total
Data for location #13						
Without PAD	$0.21\pm0.04^{A,a}$	$0.15\pm0.03^{B,b}$	0.18 ± 0.04^{a}	$4.40\pm052^{A,ab}$	$3.10\pm0.88^{A,a}$	3.75 ± 0.97^{a}
With indented PAD	$0.19\pm0.03^{A,a}$	$0.12\pm0.05^{B,a}$	0.16 ± 0.05^{a}	$4.10\pm1.20^{A,a}$	$3.20\pm1.32^{A,a}$	3.65 ± 1.31^{a}
With plain PAD	$0.19\pm0.05^{A,a}$	$0.13\pm0.03^{B,ab}$	0.16 ± 0.05^{a}	$5.60\pm2.12^{A,b}$	$5.90\pm3.18^{A,b}$	5.75 ± 2.63^{b}
Total	0.19 ± 0.04^{A}	0.14 ± 0.04^{B}	0.16 ± 0.05	4.70 ± 1.53^{A}	4.06 ± 2.38^{A}	4.38 ± 2.10
Data for location #17						
Without PAD	$1.26\pm0.15^{A,c}$	$1.10\pm0.063^{B,c}$	1.18 ± 0.14^{c}	$22.00\pm2.58^{A,c}$	$19.30\pm1.16^{B,c}$	20.65 ± 2.39^{c}
With indented PAD	$0.43\pm0.04^{A,a}$	$0.34\pm0.03^{B,a}$	0.39 ± 0.06^{a}	$7.60\pm0.52^{A,a}$	$6.10\pm0.74^{B,a}$	6.85 ± 0.99^{a}
With plain PAD	$0.53\pm0.03^{A,b}$	$0.47\pm0.02^{B,b}$	0.50 ± 0.04^{b}	$9.60\pm0.84^{A,b}$	$8.50\pm0.53^{A,b}$	9.05 ± 0.89^{b}
Total	0.74 ± 0.39^{A}	0.64 ± 0.34^{B}	0.69 ± 0.36	13.06 ± 6.66^{A}	11.30 ± 5.90^{B}	12.18 ± 6.30

PAD: Prefabricated auxiliary device. Different superscript lowercase letters indicate significant differences in the same column; different superscript uppercase letters indicate significant differences in the same row.

the sensor due to its high light reflectivity, resulting in overexposure and erroneous scanning data. Fourth, the compact scanner head of Omnicam (in comparison to iTero) necessitates stitching together more 2D images or videos, which may compromise trueness. On the other hand, iTero functions with parallel confocal imaging technology. This technology lies in focusing light at a certain depth and detecting only the light that reflects at the same angle.[9,22] This method reduces the influence of scattered light, which often occurs when surfaces are reflective or white.[9,22,23] Following the results of this study, iTero better handles diffuse-reflecting materials, such as white substrates, since it filters out the light, which is not in focus, hence reducing noise and improving the clarity of the scan. Comprehensive and stable anatomical landmarks available on the scan path help to achieve accurate imagestitching.[1,2,8,13] Consistently, in the groups where scan bodies were supported with PADs, including artificial landmarks, lower AD and LD values were detected. Both PADs were prepared to extend deliberately toward the edentulous area, serving as an optical bridge with enhanced surface morphology to facilitate stitching. Strikingly, the indented PAD exhibited significantly better performance than the plain PAD. This is due to the irregular surface topography of the indented PAD, which presents more abundant artificial landmarks and will allow for better stitching.[2,17,18] Moreover, when evaluating the locations, it was found that both AD and LD values increased from location #13 to location #17. This can be attributed to the accumulation of stitching errors.

Study Limitations

This study has several limitations. The PADs with a lateral extension were used. Different PAD designs may present different results. The responsiveness to the scanned substrate with defined optical features can vary widely for different IOSs due to their different data acquisition systems, although only two IOSs were preferred. Neither inter-implant distance nor angulation was included as a variable. Moreover, the presence of saliva and variations in ambient lighting conditions were not evaluated, which can all alter the results.

CONCLUSION

Based on the limitations of this study, the subsequent conclusions can be drawn: 1) the utilisation of PAD improved the trueness values; 2) IOS type affected the trueness, and iTero outperformed Omnicam; 3) the group in which iTero was coupled with indentation PAD exhibited superior trueness compared to the others.

MAIN POINTS

- Intraoral scanners (IOSs) have transformed dental practice by providing a more comfortable and efficient workflow, eliminating traditional impression-making stages, and improving communication among dental professionals, patients, and technicians.
- The study highlights the importance of creating artificial landmarks, such as using prefabricated auxiliary devices (PADs), to enhance the accuracy of digital impressions in the absence of natural anatomical landmarks.
- The study found that PAD design, IOS type, and their interaction significantly influenced the trueness of digital impressions, with the iTero scanner performing better overall. Indented PADs provided more accurate image stitching due to their irregular surface topography, which offered more abundant artificial landmarks, thereby reducing distortion.
- The findings seek to address the challenges of image stitching in extended edentulous regions and to improve the reliability of IOSs in dental practice.

ETHICS

Ethics Committee Approval: Not available.

Informed Consent: Not available.

Footnotes

Authorship Contributions

Concept: S.K.Y., Design: S.K.Y., Data Collection and/or Processing: S.Ç., Analysis and/or Interpretation: Ö.Ö., Literature Search: S.Ç., Writing: Ö.Ö., S.Ç.

DISCLOSURES

Conflict of Interest: No conflict of interest was declared by the authors.

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