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ASSESSMENT OF ACCURACY OF SCANNABILITY AND THE EFFECT OF SURFACE ROUGHNESS ON POLYMETHYLMETHACRYLATE INTRA-ORAL SCAN BODY: IN VITRO STUDY

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ABSTRACT

BACKGROUND: This study aims to create a cost-effective, custom-made intraoral scan body using digital dentistry techniques and to compare its scannability with that of a manufacturer-provided scan body. It also investigates the impact of surface roughness on scannability.

METHODS: An epoxy mandibular model with four dummy implants was utilized in this study, placed in canine-molar region. A total of ten manufacturer intraoral scan bodies (ISBs) were tightened and scanned with a bench scanner to (reference scan). Ten ISBs were 3D printed and another ten were milled. All groups underwent scanning with an intraoral scanner (MEDIT I 700), and the resulting scans were superimposed for comparison. The evaluation of 3D deviation and angular deviation was performed using Geomagic software. In a separate treatment group, specimens received sandblasting with 250 µm Al_2O_3 at a pressure of 0.3 MPa for 30 seconds from a distance of 5 mm.

RESULTS: The study found a significant difference in accuracy (trueness and precision) between the control group (manufacturer's ISBs) and the test groups (3D printed and milled), with a p-value of less than 0.05. The 3D-printed ISBs demonstrated superior accuracy compared to the milled ISBs. Additionally, significant differences were observed when comparing the mixed group (3D printed/milled) to the control group ($p < 0.05$). However, surface roughness did not significantly affect trueness and precision in either test group.

CONCLUSIONS: The control group demonstrated superior accuracy compared to the two test groups. However, 3D printing yielded better results for trueness and precision than the milled group.

RUNNING TITTLE: Scannability and surface roughness on polymethylmethacrylate ISBs

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BACKGROUND

An accurately fitting implant-supported prosthesis relies on the precise transfer of the implant's position and angle from the patient's mouth to the dental lab through a highly accurate impression. The emergence of intraoral scanning and digital technologies has transformed the design and production of implant-supported prostheses, altering workflows across many clinical procedures (1, 2).

An intraoral scan body (ISB) is an advanced implant transfer tool that attaches to the implant and captures a digital impression of the patient’s mouth. ISBs come in various shapes, sizes, and designs, making them especially useful in complex cases, such as angled implants or restricted inter-arch space. However, they can be costly, with some priced similarly to the implants themselves (3, 4).

A manufacturer-specific scan body tailored to a particular implant system is typically used when a digital impression of a single implant is required. ISBs are usually made from materials like PMMA, PEEK, titanium alloys, or other polymers (5).

This study aimed to evaluate a custom, cost-effective ISB using digital technology (3D printing and milling) and compare it to manufacturer-provided ISBs regarding accuracy (trueness and precision). The null hypothesis suggested that there was no significant difference in accuracy among the manufacturer's, 3D-printed, and milled ISBs, while also assessing the impact of surface roughness on scannability.

METHODS

1- Sample size estimation

Sample size was calculated assuming 5% alpha error and 80% study power. The mean ± SD marginal gap was 82.21 ± 15.26 µm for 3D printed resin (6), 106.75 ± 12.76 µm for milled PMMA (6) and 33.99 ± 8.81 µm for PEEK (7). The highest sample size was based on the difference between 3D printed resin and milled PMMA. Based on the difference between independent means using highest SD= 15.26 to ensure enough study power, a sample of 8 samples per group is required, yielding an effect size of 1.608. This was increased to 10 samples to make up processing errors. Total sample = Number per group x Number of groups = 10 x 4 = 40 samples. Sample size was based on Rosner's method (8) calculated by G*Power 3.1.9.7

Model Fabrication and Implant Installation:

An edentulous mandibular model constructed from epoxy resin and coated with a 3-mm thick layer of flexible polyurethane to mimic mucosa (Epoxy mandibular model; Ramses Medical Products Factory) was utilized. Four straight dummy implants measuring Ø4.1 × 10-mm (IS Dummy Implant; Vitronex) were inserted into the model. Two implants were placed in the canine regions on the right and left sides, while the other two were positioned in the first molar areas on the right and left sides. (Figure 1)

Ten scan bodies were produced using a DLP 3D printer (NextDent 5100; NextDent B.V.) with Savoy C&B resin (Savoy Digital System) (Figure 2A). The specimens were printed at a wavelength of 405 nm, achieving a resolution of 50 µm and a build speed of 30 mm/h, in accordance with the manufacturer's specifications. Following printing, the specimens were cleaned in ethanol for 5 minutes, finished, polished (LD2746; Komet, SC), and post-cured using the LC-3DPrint Box (NextDent Co.) (9), adhering to the manufacturer's guidelines (10). Additionally, ten scan bodies were milled from PMMA resin blanks (Yamahachi; Aichi Co.) using a milling machine (DWX-52D Plus; Roland DG Corp.) following the manufacturer's instructions. (9) (Figure 2B).

The digital design of the scan bodies were created through reverse engineering, followed by 3D printing or milling using CAD software (G-CAD, MeshMixer, Autodesk) (11) (Figure 3).

Scanning Protocol

The first group (control group) consisted of ten PEEK ISBs provided by the manufacturer, tightened to 15 Ncm torque on four dummy straight implants (SPI/MPI implant; VitroNex Elite implant) (Figure 4). The reference group was scanned using a benchtop scanner (Medit Corp.) and an intraoral scanner (MEDIT I 700; MEDIT Corp). The test groups were scanned as follows: The second group included ten 3D-printed ISBs, torqued to 15 Ncm on four dummy straight implants, and the third group included ten milled ISBs, also torqued to 15 Ncm on four dummy straight implants (SPI/MPI implant; VitroNex Elite implant).

The STL files were transferred to Geomagic (Geomagic U.S., Research Triangle Park) for superimposing the test scans onto the control group. The 3D analysis involved aligning the CAD reference model (CRM) with the CAD test models (CTMs) before performing a 3D comparison (13-15).

For the trueness analysis, 3D deviation and angular deviation were assessed by superimposition each test scan body onto the reference model. The precision analysis examined the variance in both angular and 3D deviations within each test group..

The software's "pre-alignment" tool initially positioned the STL files, followed by the "local best fit" tool. The optimal alignment was achieved using the iterative closest point (ICP) method to minimize point cloud differences (15). After alignment, 3D and angular deviations were assessed (16-18). Angular deviation was determined by measuring the angle between the lines aligned with the manufacturer's scan body in the CRM and the test scan body (3D printed and milled) in the CTM to assess vertical position deviation (Figure 5).

Surface Roughness Effect

Both test groups (3D-printed and milled ISBs) underwent air abrasion treatment using 250 µm Al2O3 (Korox 250, Bego GmbH, Bremen, Germany) at 0.3 MPa for 30 seconds from a 5 mm distance (P-G 400, Harnisch-Rieth GmbH & Co., Winterbach). The surface roughness of two sides of each ISB was assessed using a surface profilometer (Marsurf PS10, Mahr), then digital scans were taken using intra-oral scanner (Medit I700). STL files were then imported into Geomagic (Geomagic U.S., Research Triangle Park) to compare the scannability of air-abraded ISBs with that of smooth-surfaced ISBs. Surface texture was further examined under a stereomicroscope at 80x and 110x magnification.

Statistical analysis

Normality of data was checked using Shapiro Wilk test and normal distribution was confirmed for all variables. Data were mainly presented using mean and standard deviation (SD) in addition to median, minimum and maximum values. Trueness and precision were analyzed using *Two Way Analysis of variance (ANOVA)* to assess the effect of ISBs material and surface roughness. All tests were two tailed and the significance level was set at p value<0.05. Data were analyzed using IBM SPSS version 25, Armonk.

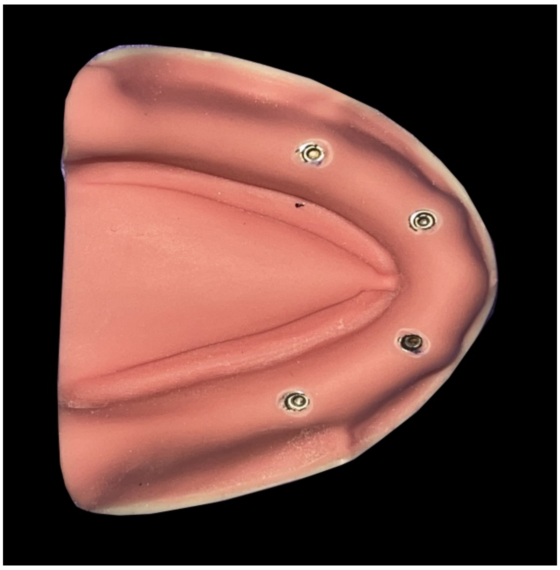

Figure 1: Ramsis mandibular edentulous modelwith 4 implants placed

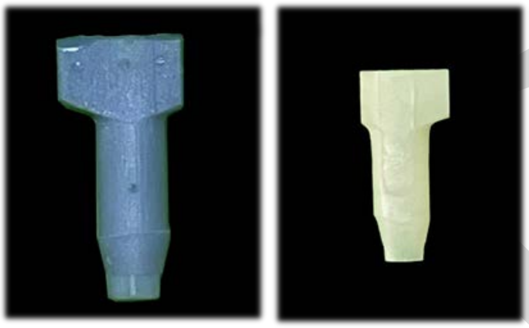

Figure 2: Investigated scanbodies, (A) 3D printed ISB, (B) milled ISB

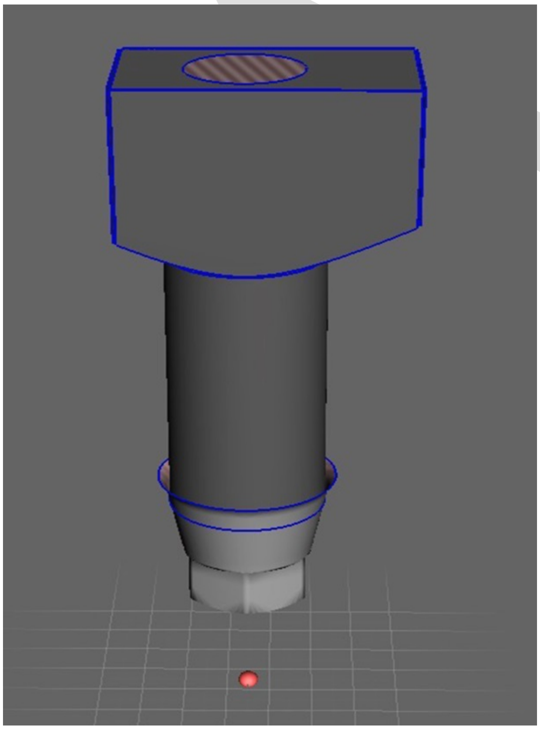

Figure 3: Scanbody digital designing through Meshmixer program

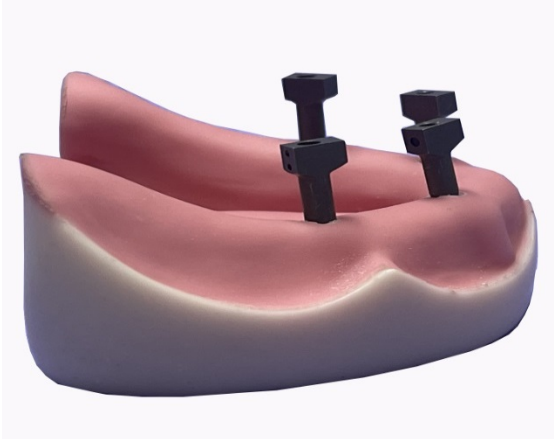

Figure 4: ISBs attached on implants

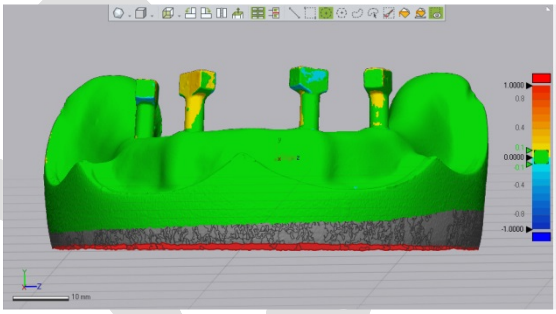

Figure 5: Data analysis and superimposition through Geomagic program

RESULTS

Accuracy (Trueness and Precision)

The study results show significant differences in trueness and precision between 3D-printed and milled ISBs, which are influenced by material type and surface roughness. According to Table 1, 3D-printed ISBs demonstrated better trueness on smooth surfaces (Mean ± SD: 0.005 ± 0.002) compared to milled ISBs (0.036 ± 0.012), while trueness on rough surfaces was similar for both materials. Precision was notably lower for milled ISBs, especially on smooth surfaces (0.465 ± 0.036), compared to 3D-printed ISBs (0.040 ± 0.017). A Two-Way ANOVA (Table 2) confirmed that both material ($p < 0.001$, $\eta P^2 = 0.517$ for trueness; $p < 0.001$, $\eta P^2 = 0.939$ for precision) and surface roughness ($p = 0.044$, $\eta P^2 = 0.108$ for trueness; $p < 0.001$, $\eta P^2 = 0.509$ for precision) significantly influenced the outcomes, along with their interaction ($p < 0.001$, $\eta P^2 = 0.501$ for trueness; $p < 0.001$, $\eta P^2 = 0.941$ for precision). Estimated marginal means (Table 3) showed that milled ISBs generally had lower precision (Mean: 0.331) compared to 3D-printed ISBs (0.120), with notable differences in trueness and precision across surface types, highlighting the importance of material and surface treatment for ISB performance.

The findings revealed significant differences in angular deviation between the study groups, influenced by both surface roughness and material type. 3D-printed ISBs exhibited lower mean angular deviations compared to milled ISBs, with smoother surfaces displaying notably less deviation. Specifically, for the 3D-printed ISBs, the smooth surface group had a mean ± SD of 0.63 ± 0.09, while the rough surface group showed a higher mean of 1.51 ± 0.23. In contrast, milled ISBs had greater deviations, with the smooth surface group averaging 1.66 ± 0.31 and the rough surface group at 1.78 ± 0.01. Two-way ANOVA results demonstrated that both material type and surface roughness had statistically significant effects on angular deviation, with a significant interaction between these factors ($p < 0.001$). The partial eta squared values indicated a large effect size for material ($\eta^2 = 0.753$), roughness ($\eta^2 = 0.648$), and their interaction ($\eta^2 = 0.508$). Estimated marginal means further supported these results, showing that 3D-printed ISBs (mean = 1.07) had significantly lower deviations than milled ISBs (mean = 1.72), while smooth surfaces (mean = 1.14) showed lower deviations compared to rough surfaces (mean = 1.65).

Table 1: Comparison of trueness and precision between study groups according to surface roughness

		3D printed ISB		Milled ISB	
		Smooth (n=10)	Rough (n=10)	Smooth (n=10)	Rough (n=10)
Trueness	Mean ±SD	0.005 ±0.002	0.026 ±0.005	0.036 ±0.012	0.026 ±0.008
	Median	0.006	0.026	0.033	0.028
	Min - Max	0.002 – 0.009	0.019 – 0.035	0.020 – 0.060	0.015 – 0.040
Precision	Mean ±SD	0.040 ±0.017	0.199 ±0.031	0.465 ±0.036	0.196 ±0.026
	Median	0.038	0.195	0.465	0.193
	Min - Max	0.015 – 0.065	0.150 – 0.250	0.400 – 0.520	0.168 – 0.250

Table 2: Two Way ANOVA assessing the effect of material and surface roughness on trueness and precision

	Trueness			Precision		
	Material	Roughness	Interaction	Material	Roughness	Interaction
df	1	1	1	1	1	1
Mean square	0.002	0.002	0.002	0.446	0.030	0.461
F test	38.51	4.372	36.10	552.87	37.26	572.43
p value	<0.001*	0.044*	<0.001*	<0.001*	<0.001*	<0.001*
η_P^2	0.517	0.108	0.501	0.939	0.509	0.941

Table 3: Estimated marginal means of trueness and precision

		Mean	95% CI	Mean diff
Trueness	3D printed ISB	0.016	0.012, 0.019	0.016
	Milled ISB	0.031	0.028, 0.035	
	Smooth	0.021	0.017, 0.025	0.005
	Rough	0.026	0.022, 0.030	
Precision	3D printed ISB	0.120	0.107, 0.132	0.211
	Milled ISB	0.331	0.318, 0.343	
	Smooth	0.252	0.240, 0.265	0.055
	Rough	0.198	0.185, 0.211	

CI: Confidence Interval

DISCUSSION

In this study, we aimed to develop a custom, cost-effective scan body for routine optical scanning of implant positions using digital technology, particularly when prefabricated scan bodies are not available. Trueness was defined as how closely the fabricated implant scan bodies (ISBs) matched the intended dimensions, while precision referred to the consistency of measurements across multiple fabrications or scans, even if those measurements weren't perfectly aligned with the intended dimensions. We compared the accuracy (trueness and precision) and marginal gap between two groups of polymeric ISBs: one produced using 3D printing and the other using milling. We also examined how altering the surface roughness of each group affected trueness and precision.

Our results indicated that the two 3D-printed groups (smooth and rough) performed better in terms of trueness and precision compared to the milled groups (smooth and rough). This might be because the accuracy of models produced depends on the size of the burs used in milling machines. This finding aligns with previous research showing that 3D printing technologies can achieve better details, including better undercuts and anatomical features (19,20).

A two-way ANOVA was conducted to evaluate the effects of material and surface roughness on trueness and precision. The analysis revealed that material had a more significant impact on trueness. These results suggest that changing the surface texture has a minor effect on trueness and precision compared to the impact of the material. Additionally, increasing the roughness of the ISB surface negatively affects scannability. This finding supports Marta Revilla-León's research, which highlighted that intraoral scanners capture multiple images or data points to create a 3D model. Surface roughness can interfere with this process by causing data misinterpretation or shadowing effects, leading to inaccuracies in the final model (21-25).

CONCLUSION

3D printing technology for manufacturing ISBs demonstrated superior trueness and precision compared to the subtractive milling method. While 3D printing results were not as good as those of the control group, this study provides strong evidence that advancements in additive manufacturing could make 3D printing a highly effective and cost-efficient alternative to traditional manufacturing methods.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interests.

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