

Comparison among intraoral scanning, grammetry, and photogrammetry used for full- arch implant prosthesis impressions regarding accuracy of fit and marginal adaptation: An in-vitro study

Islam Mohamed Heiba

British University in Egypt

Basma Refaat Fayad

British University in Egypt

maha nagy mohamed kamal

maha.kamal@bue.edu.eg

British University in Egypt

Eman Gamal Abdelghaffar

British University in Egypt

Research Article

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Abstract

Background. The accuracy of digital impressions is critical for passive fit of full-arch implant prostheses. Comparative evidence on intraoral scanning, grammetry, and photogrammetry remains limited. This in vitro study compared the accuracy of fit and marginal adaptation of milled maxillary jigs fabricated using different scanning protocols (intraoral scanning, grammetry, and photogrammetry).

Materials and Methods. An edentulous maxillary model with four parallel implant analogues was fabricated using three-dimensional printing. Three groups were created depending on the scanning protocol used to capture full-arch implant scans (n = 10 each). Group I: conventional intraoral scanning with vertical scan bodies (VS). Group II: grammetry using MEDIT TruScan ioConnect horizontal scan bodies (GR), and Group III: extraoral photogrammetry using T-Marker system with iPad Pro (PG). In each group, the corresponding scan bodies were placed on the implant abutment analogs of the reference cast, and thirty digital impressions were recorded. Titanium jigs were digitally designed and milled for each scan. Accuracy of fit was evaluated using surface matching software, calculating root mean square (RMS) deviation, while marginal adaptation was assessed at 240 points per group using digital optical microscopy at 50× magnification. One-way ANOVA analysis of variance with Tukey post-hoc test and Pearson correlation were used ($\alpha = 0.05$).

Results. Group III (Photogrammetry scanning protocol) demonstrated the lowest mean RMS deviation ($21.6 \pm 5.2 \mu\text{m}$) and smallest marginal gaps ($22.75 \pm 1.92 \mu\text{m}$), followed by **group II** (grammetry scanning protocol) ($31.4 \pm 9.1 \mu\text{m}$; $30.83 \pm 2.07 \mu\text{m}$) while the highest mean RMS deviation and the largest marginal gaps were found at **group III** (conventional intraoral scanning protocol) ($34.6 \pm 8.4 \mu\text{m}$; $33.28 \pm 3.54 \mu\text{m}$). Significant differences were found among groups for both outcomes ($p < 0.05$). Post-hoc analysis revealed that group III (photogrammetry scanning protocol) had significantly better accuracy than conventional intraoral scanning ($p < 0.05$) and significantly smaller marginal gaps than both grammetry and conventional intraoral scanning ($p < 0.001$). No significant differences were observed between grammetry and conventional scanning for either outcome ($p > 0.05$). A moderate positive correlation was found between RMS deviation and marginal gap ($r = 0.468$, $p = 0.009$).

Conclusions Photogrammetry using the T-Marker system provided superior accuracy of fit and marginal adaptation compared to conventional intraoral scanning for full-arch implant impressions. Grammetry showed intermediate but statistically comparable results to conventional scanning under in vitro conditions. The significant correlation between digital accuracy metrics and marginal adaptation supports the clinical relevance of RMS deviation as a predictor of prosthetic fit.

Background

The success of full-arch implant prostheses begins mainly with the precise transfer of intraoral conditions and anatomy to achieve passive fit [1]. Conventional impression techniques, such as the open-tray method, present several limitations, including dimensional instability of the impression material, splinting material, and the resulting stone model [2]. These dimensional changes adversely

affect passive fit, which is directly associated with long-term clinical success and patient satisfaction. Furthermore, conventional impressions are highly technique-sensitive and time-consuming, particularly for full-arch implant prostheses [3].

Digital technology can overcome many of these problems [4]. The evolution of scanning technologies has enabled the use of intraoral scanners to capture the oral cavity [4, 5]. These scanners employ optical technologies such as active triangulation with structured light and confocal laser or ultrafast optical sectioning [4–6]. However, early intraoral scanning faced difficulties in completely edentulous patients due to image stitching problems that propagate errors [7, 8]. Although implant-specific scan bodies allowed successful capture of implant positions, capturing multiple implants for a full arch remained challenging because of the lack of anatomical landmarks, leading to incorrect stitching [9].

To address stitching problems, hybrid approaches such as grammetry have been evolved. Grammetry uses prefabricated auxiliary devices (e.g., scan flags) that integrate directly into the intraoral scanning workflow, creating artificial landmarks that eliminate stitching issues [9–11]. Regarding geometric design, shorter and simplified scan bodies enhance trueness, whereas greater height and complexity introduce deviations [12]. More enhancements were done to the customized auxiliary devices, such as modified scan bodies with additional geometric features, to improve scanner recognition and positional trueness, particularly in edentulous arches [13, 14].

An alternative to scan body-based intraoral scanning is photogrammetry, which uses triangulation image capture rather than sequential image stitching via extraoral cameras (e.g., mobile or iPad camera) and coded markers. This technique eliminates image stitching and reduces propagation of errors that cause distortion [15].

Passive fit is essential for the durability of implant-supported prostheses, as misfit can lead to mechanical and biological complications including screw loosening, crestal bone loss, tissue inflammation, food stagnation, and pocket formation [16, 17]. Passive fit is achieved when static and / or dynamic stresses were absent at the implant-prosthesis interface upon complete seating [18]. The accepted threshold for misfit is below 100 μm linear deviation [17, 18]. However, achieving such precise adaptation is challenging in full-arch prostheses due to cumulative propagation of errors during impression taking, laboratory procedures, and framework fabrication [19]. Therefore, evaluating the accuracy of fit and the marginal fit of full-arch implant prostheses constructed from different digital impression techniques is essential [20].

Two primary methods are used to assess the accuracy of fit. Surface matching software (e.g., Geomagic Control X) provides a comprehensive three-dimensional analysis of the entire fitting surface, calculating overall deviations such as root mean square (RMS) values. RMS quantifies the average magnitude of discrepancies between corresponding points on two surfaces, providing a single numerical value that reflects overall three-dimensional accuracy. Measurements are reported in micrometers (μm), with a clinically acceptable threshold below 100 μm . Deviations are visually represented using color maps,

where green indicates optimal fit (within tolerance), while red and blue indicate positive and negative deviations, respectively [21–25].

The other method for accuracy assessment is using digital optical microscopy (DOM) that has emerged as a reliable, cost-effective, and time-efficient method for evaluating marginal adaptation. DOM uses high-resolution digital microscopes with motorized stages, automated image stitching, and advanced software to analyze the prosthesis-abutment interface at magnifications of 50× to 500× [21]. Validation studies show that DOM produces comparable results to scanning electron microscopy (SEM), with a reported bias of only 0.86 μm ($p > 0.05$), indicating no statistically significant difference. DOM offers practical advantages: no sputter coating, lower equipment costs, and approximately 40% less analysis time (59 ± 6 vs. 100 ± 11 minutes per specimen) [24].

To enhance chairside workflows, recent innovations have focused on refining scan body designs, adding horizontally extended scan body geometric shapes, and modifying the scanning techniques for potential improvements in 3D imaging accuracy. However, strong supporting evidence for these designs remains scarce; therefore, this in-vitro study aimed to compare intraoral scanning (with vertical scan bodies), grammetry (MEDIT TruScan system with ioConnect scan bodies), and photogrammetry (T-marker system) for full-arch implant prosthesis impressions regarding accuracy of fit (evaluated with Geomagic software) and marginal fit (evaluated with digital optical microscopy) of digitally milled full-arch implant jigs. The null hypothesis was that there would be no statistically significant difference in the accuracy of fit or marginal adaptation among the three techniques, and no significant correlation between accuracy of fit and marginal adaptation.

Materials and methods

The study was approved by the Ethical Committee of the British University in Egypt (BUE) “in accordance with the Declaration of Helsinki”. with research approval number 26–030.

Sample size calculation

Using G*Power software for Windows version 3.1.9.4 based on the previous study [10], the minimum sample size required to detect a significant difference between the three groups was 6 specimens. However, the sample size was increased to 10 scans per group (total $n = 30$) to account for potential technical failures and to align with similar in vitro studies. This was calculated to have 80% power, $\alpha = 0.05$, $1-\beta = 0.8$.

Model fabrication

An educational maxillary edentulous arch model was scanned using a benchtop scanner (E2; 3Shape A/S, Denmark), the STL file was utilized for planning and positioning of four parallel implants (diameter $\varnothing 4.2 \times 10$ mm; Vitronex Elite; Flotecn SRL, Italy) at the canine and first molar areas. A soft tissue replica

containing four multi-unit abutment replicas was performed using CAD software (Exocad GmbH, Germany), simulating a maxillary edentulous model with four multi-unit abutments.

A three-dimensional (3D) printed cast was made from a liquid model resin (V3; Formlabs Inc, USA) using a 3D printer (4B; 3Shape A/S, Denmark). The artificial gingiva was printed (Flexible 80A; Formlabs Inc, USA), and the digital implant analogs of the multi-unit abutment (Vitonex Elite; Flotecnico SRL, Italy) were integrated into the printed cast (Fig. 1).

Scan techniques grouping

The digital impressions were divided into three groups according to the scanning protocol: Group I (intraoral scanning with vertical scan bodies, VS), Group II (intraoral scanning with grammetry horizontal scan bodies, GR), and Group III (extraoral photogrammetry using a stereo camera with photogrammetry scan bodies, PG). All scanning procedures were performed by a single experienced operator under standardized environmental conditions.

Scanning procedures

For Group I (VS), vertical scan bodies (Vitronex, Italy) were hand-tightened on the implant analogues (Fig. 2a). The model was scanned using a Medit i700 intraoral scanner (Medit Corp., Korea) following the manufacturer's recommended scanning protocol. The scanner head was positioned 2–3 mm away from the scan bodies, and the scan was completed within 35 seconds to decrease potential distortion from extended scanning as per manufacturer instructions.

For Group II (GR), ioConnect horizontal scan bodies (Medit TruScan system, Medit Corp., Korea) were inserted into the four implant analogues (Fig. 3a). To minimize scanning errors and achieve optimal accuracy, the flags were positioned toward the center of the palate to reduce the data capture area. A brief central scan of approximately 7 seconds was then performed, as per manufacturer instructions.

For Group III (PG), the T-Markers (TruAbutment, CA, USA) were tightened onto the implant analogues, all T-markers were facing forward as recommended by the manufacturer for ease of detection (Fig. 4a). The T-Marker application was downloaded from the App Store and opened on the iPad Pro (Apple Inc, CA, USA). The tablet was paired with the T-Marker application then marker numbers were selected on the application. The markers were captured by the iPad camera at a detection distance of 7–12 cm, as per manufacturer instructions. After capturing the four analogues, a “Done” message was displayed by the application possessing the positional data of the optical markers. The application converted the data to correspond a digital library, then the software created a 3D mesh demonstrating the location of the implant analogues.

A total of 30 scans were recorded, 10 of each group, and all scans were exported as standard tessellation language (STL) files. (Fig. 2a&b).

Following placement of the HS Cap small (Medit TruScan system, Medit Corp., Korea) over the four implant analogues to serve as soft tissue reference points, a gingival extension scan was conducted for both the GR and PG groups. The same intraoral scanner was used as in the previous steps. This scan was subsequently superimposed with the corresponding implant analogue scans per group protocol. The soft tissue scan and the implant position scan were aligned to produce the working cast, which was exported as an STL file to Exocad DentalCAD (Exocad GmbH, Germany) for maxillary jig designing.

A maxillary metallic jig was digitally designed for each scan of the three groups using CAD software (Exocad DentalCAD; Exocad GmbH, Germany). First, the scanned STL files were imported, and the implant analogues were identified as reference points for the jig. Each jig was designed to connect the four analogues via a rigid bar that included cylindrical screw channels to allow passive seating of the fixation screws. To differentiate jigs across groups, horizontal attachments were added to the palatal side of the bar: one attachment for VS group, two attachments for the GR group, and three attachments for the PG group. (Fig. 3a,b,c,d).

The completed jig designs STL files were imported into a 5-axis milling machine (VHF, Germany) for milling of titanium blanks (Lodden titanium plate; Guangdong, P.R. China) using a 2.0 mm carbide bur at a speed of 30,000–45,000 rpm with a feed rate of 600–800 mm/min. Continuous coolant application prevented overheating. Each jig was then removed from the blank by detaching the supporting arms, followed by finishing using a 1.0 mm round bur. Polishing was carried out with silicon carbide abrasive papers under continuous irrigation (Fig. 5b). Finally, all finished jigs were scanned using the same benchtop scanner and the STL files were obtained.

Data analysis

The accuracy of the jig fit was evaluated using surface matching analysis software through superimposition of the reference model to the scanned jig. All STL files were imported into Geomagic surface matching software program (Geomagic Control X, version 2018; 3D Systems, USA) for accuracy of fit evaluation. The scanned models were imported separately as reference data; each scanned jig was imported as measured data. Pre-alignment was made then best fit alignment was applied (Fig. 4a,b,c,&d). Root mean square (RMS) deviation was automatically calculated by the software; the results were displayed as 3D color map and numerical values (Fig. 5a,b,c,d).

Marginal adaptation of the maxillary jigs was evaluated using digital optical microscopy (DOM; U500x Digital Microscope; Guangdong, China). At 50× magnification, the mean marginal gap was assessed at the mesial, mid-mesial, and distal areas on both the buccal and palatal sides of each implant analogue site (Fig. 6a,b,c,d). Six measurements were obtained per region, yielding 24 measurements per jig. With ten jigs per group, the total number of measurements was 240 per group. All measurements were recorded in an Excel spreadsheet for subsequent statistical analysis.

Statistical Analysis

Statistical analysis was performed with IBM (IBM Corporation, NY, USA) SPSS (SPSS, Inc., an IBM Company) Statistics Version 20 for Windows.

- Data normality was evaluated using the Shapiro-Wilk test.
- ANOVA test was used for comparison between the three groups.
- Tukey test was used as a post-hoc test. The significant level was set at $P \leq 0.05$.

Results

The Shapiro–Wilk test confirmed that the data for all three groups were normally distributed.

Descriptive statistics for the accuracy of fit and marginal gap are presented in Table 1. For accuracy of fit (expressed as mean deviation in micrometres, μm), the PG group showed the lowest mean deviation ($21.6 \pm 5.2 \mu\text{m}$), indicating the highest accuracy, followed by the GR group ($31.4 \pm 9.1 \mu\text{m}$) and then the VS group which showed the highest mean deviation and least accuracy ($34.6 \pm 8.4 \mu\text{m}$). A one-way analysis of variance (ANOVA) revealed a statistically significant difference in accuracy of fit among the three groups ($p < 0.05$).

Table 1
Mean $\pm$ standard deviation of RMS values in μm of the maxillary jig accuracy of fit & marginal adaptation in μm for the three scanning techniques using A one-way analysis of variance (ANOVA)

Scanning technique	VS	GR	PG	p-value
Accuracy of fit	34.6 ± 8.4^a	31.4 ± 9.1^a	21.6 ± 5.2^b	< 0.01
Marginal adaptation	33.28 ± 3.54^A	30.83 ± 2.07^A	22.75 ± 1.92^B	< 0.01

Different superscripts in each row indicate statistically significant differences $p < 0.01$

Post-hoc pairwise comparisons using Tukey's honestly significant difference (HSD) test (Table 2) indicated that the PG group had significantly better accuracy of fit than the scan bodies group ($p < 0.05$). However, no statistically significant differences were observed between the PG and GR groups, nor between the GR and VS groups ($p > 0.05$ for both).

Table 2
Tukey HSD pairwise comparison for RMS values of accuracy of fit & marginal gap values

Accuracy of fit	Comparison	Mean difference (μm)	95% CI	P-value
	PG vs. GR	-9.8	-19.8 to -0.2	0.057 ^a
	PG vs. VS	-13	-23.0 to -3.0	0.008 ^b
	GR vs. VS	-3.2	-13.2 to 6.8	0.713 ^{ns}
Marginal gap	PG vs. GR	-8.08	-10.53 to -5.63	< 0.001 ^A
	PG vs. VS	-10.53	-12.98 to -8.08	< 0.001 ^B
	GR vs. VS	-2.45	-4.90 to 0.00	0.051 ^{ns}

Different superscripts indicate statistically significant differences $p < 0.05$, ns: non-significant

The marginal gap results are also summarized in Table 1. The PG group exhibited the smallest marginal gaps ($22.75 \pm 1.92 \mu\text{m}$), indicating the best marginal adaptation, followed by the GR group ($30.83 \pm 2.07 \mu\text{m}$) and the VS group ($33.28 \pm 3.54 \mu\text{m}$). A one-way ANOVA showed a statistically significant difference in marginal gap among the three groups ($p < 0.001$). Tukey's HSD post-hoc comparisons demonstrated that the PG group had significantly smaller marginal gaps than both the GR group ($p < 0.001$) and the VS group ($p < 0.001$) as shown in Table 2. The difference between the GR and VS groups was not statistically significant ($p = 0.051$).

A Pearson correlation test was conducted to assess the relationship between accuracy of fit (root mean square [RMS] deviation) and marginal gap. The results revealed a statistically significant moderate positive correlation between the two variables ($r = 0.468$, $r^2 = 0.219$, $p = 0.009$). This indicates that specimens with higher RMS deviation (poorer accuracy of fit) tended to have larger marginal gaps (poorer marginal adaptation), whereas specimens with lower RMS deviation (better accuracy of fit) tended to have smaller marginal gaps (better marginal adaptation).

Discussion

This in vitro study evaluated the accuracy of fit and marginal adaptation of maxillary jigs fabricated using three digital impression techniques: photogrammetry (T-Markers), grammetry (ioConnect), and conventional intraoral scan bodies, rehabilitating edentulous patients following the All-on-4 protocol. The null hypothesis, that no significant differences would exist among the three techniques, was partially rejected. Photogrammetry demonstrated superior accuracy of fit and marginal adaptation compared to conventional scan bodies, but no statistically significant difference was observed between

photogrammetry and grammetry for accuracy of fit, nor between grammetry and conventional scan bodies for either outcome. These findings are partially consistent with the growing body of evidence comparing photogrammetry and intraoral scanning for full-arch implant impressions [10, 26].

The finding that the T-Markers photogrammetry system achieved the lowest RMS deviation ($21.6 \pm 5.2 \mu\text{m}$) and smallest marginal gaps ($22.75 \pm 1.92 \mu\text{m}$) aligns with previous systematic reviews and meta-analyses [11, 16, 20]. A recent meta-analysis of several studies reported that photogrammetry systems provide significantly better trueness than intraoral scanners in both distance deviation ($p = 0.001$) and angular deviation ($p = 0.02$), with precision also favoring photogrammetry ($p = 0.01$ for distance; $p < 0.001$ for angular deviation) [15]. Another meta-analysis comparing stereophotogrammetry and intraoral scanning for complete-arch implant impressions found surface deviation mean ranges of $5.18\text{--}48.74 \mu\text{m}$ for photogrammetry versus $14.8\text{--}67.72 \mu\text{m}$ for intraoral scanning [20]. The present study extends these findings by demonstrating that the T-Marker™ system, using an iPad Pro®, achieves accuracy comparable to established photogrammetry systems, and that the MEDIT TruScan ioConnect grammetry system offers intermediate accuracy between photogrammetry and conventional intraoral scanning.

The superior accuracy and marginal adaptation observed with photogrammetry are likely attributable to its operating principle, which relies on triangulation algorithms and optical markers rather than sequential image stitching. This approach reduces cumulative error propagation, a well-documented limitation of conventional intraoral scanning, particularly in full-arch or edentulous cases where anatomical landmarks are sparse [10, 11, 27]. Photogrammetry is also less influenced by variables such as scanning pattern, scanning speed, and ambient light conditions [10, 28, 29].

In contrast, both conventional intraoral scanning and grammetry depend on sequential image stitching, which inherently introduces cumulative errors [26, 30]. Grammetry employs a horizontal scan body design intended to provide continuous geometric references across the arch, thereby reducing stitching errors compared to conventional vertical scan bodies. However, the present study found no statistically significant difference between the ioConnect group and the conventional intraoral scan bodies group for either the accuracy of fit or the marginal gap, with lower mean deviation values obtained from group II. This divergence from previous reports describing significant improvements with grammetry may be explained by several factors. First, the larger and more reflective surface area of the splinted ioConnect framework may have introduced optical recognition challenges, partially offsetting the theoretical benefits of continuous geometric references. Second, the operator's experience with conventional intraoral scanning may have enabled near-optimal performance, narrowing the performance gap. Third, the controlled laboratory environment (standardized lighting, fixed scanning sequence, absence of patient movement) likely minimized the stitching errors that grammetry is specifically designed to address [10, 31–35].

A notable finding of the present study is the moderate positive correlation between RMS deviation and marginal gap ($r = 0.468$, $r^2 = 0.219$, $p = 0.009$). This relationship indicates that specimens with higher RMS deviation (poorer accuracy of fit) tended to have larger marginal gaps (poorer marginal adaptation),

while those with lower RMS deviation (better accuracy of fit) tended to have smaller marginal gaps. To the best of our knowledge, this quantitative correlation has been infrequently reported in the literature. The finding supports the clinical relevance of using RMS deviation as a surrogate endpoint for prosthetic fit in future in vitro and clinical studies, as improvements in digital impression accuracy appear to translate directly into better marginal adaptation.

Implications for Digital Workflows in Implant Dentistry

The findings of this study suggest that the photogrammetry scanning protocol is promising for enhancing chairside workflows in implant dentistry, particularly for fully edentulous cases treated with the All-on-4 protocol, while reserving intraoral scanning and grammetry scanning techniques for short-span or partially dentate arches. Furthermore, the enhanced accuracy observed with the photogrammetry protocol highlights its potential as a reliable alternative to traditional intraoral scanning systems and conventional impression techniques, potentially reducing clinical chair time and laboratory costs. This study is pioneering in investigating the accuracy of extraoral photogrammetry by defining which scan body design and shape can produce better results in terms of accuracy and marginal fit of the resultant prostheses.

Limitations of this in vitro study.

- Providing standardized conditions cannot fully replicate the clinical environment. Factors such as saliva, bleeding, tongue movements, limited mouth opening, bruxism, and variations in mucosal texture and lighting were not simulated.
- Implant analogues were placed in parallel with no angulations; different results may be obtained with angulated implants or variable implant depths.
- This study used a maxillary model with four implants; findings may differ for mandibular models or maxillary models with six implants, as intraoral scanning has been shown to demonstrate inferior precision in the mandible compared to the maxilla due to the difference in anatomy and the presence of the tongue.
- Assessment was limited to marginal gap and RMS deviation, without evaluation of other clinically relevant parameters such as internal fit, screw loosening, or long-term prosthetic complications.

Conclusions

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. Photogrammetry using the T-Marker™ system with an iPad Pro® demonstrated the highest accuracy of fit (lowest RMS deviation) and best marginal adaptation among the three techniques evaluated.
2. Grammetry using the MEDIT TruScan ioConnect horizontal scan bodies provided intermediate accuracy of fit and marginal adaptation. However, no statistically significant differences were

observed between the grammetry and conventional scan body groups for either outcome or grammetry remained inferior to photogrammetry in absolute terms.

3. A statistically significant moderate positive correlation was observed between RMS deviation (accuracy of fit) and marginal gap ($r = 0.468$, $p = 0.009$), confirming that digital accuracy metrics can serve as valid predictors of physical prosthetic fit.

Abbreviations

RMS

root mean square

DOM

digital optical microscope

CAD

Computer-aided design

VS

vertical scan bodies

GR

grammetry

PG

Photogrammetry

STL

Standard Tessellation Language

CAD

Computer-aided design

Declarations

Ethics approval & Consent to participate

The study was approved by the Ethical Committee of the British University in Egypt (BUE) “in accordance with the Declaration of Helsinki”. With research approval number 26-030.

Consent to participate: “Not applicable.” This study didn’t involve the use of any animal or human data or tissue.

- **Clinical trial number**
- “Not applicable.”

Consent for publication

“Not applicable.”

Availability of data and materials

NO data availability; there is no data underlying the manuscript; all data were presented by figures and tables in the current study.

Competing interest

The author declares that there is no competing interest.

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Authors' contributions

IMH and BRF conceptualized and designed the study and drafted the paper. EGAA designed the practical models and collected the data. MNMK analyzed the results and interpreted the data. All authors read and approved the final manuscript.

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Figures



Figure 1

Three-dimensional printed maxillary edentulous cast with integrated multi-unit abutment analogs.

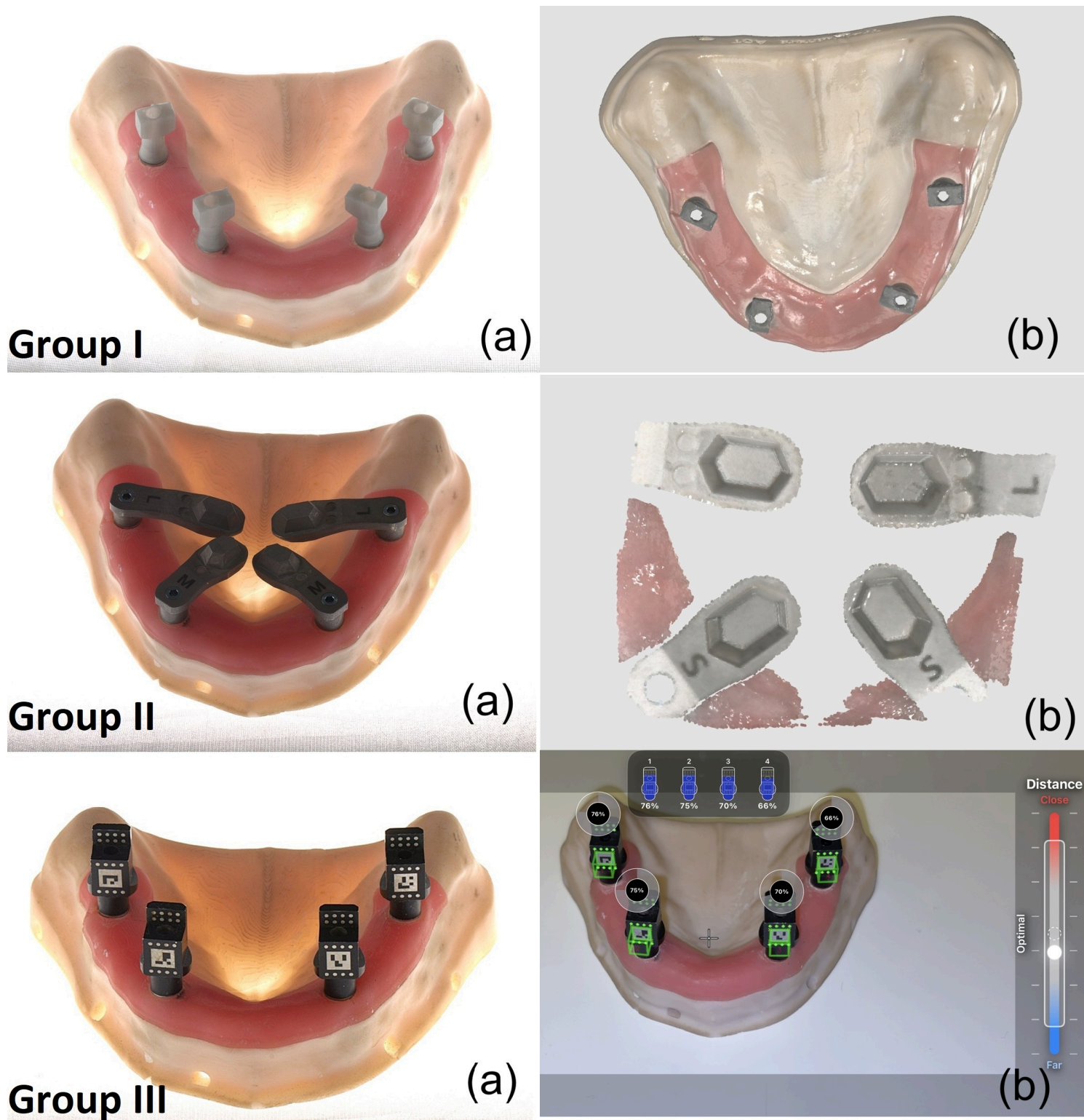


Figure 2

a&b. (a) Scan bodies of different groups mounted on the multi-unit abutments. (b) Scan images of different groups.

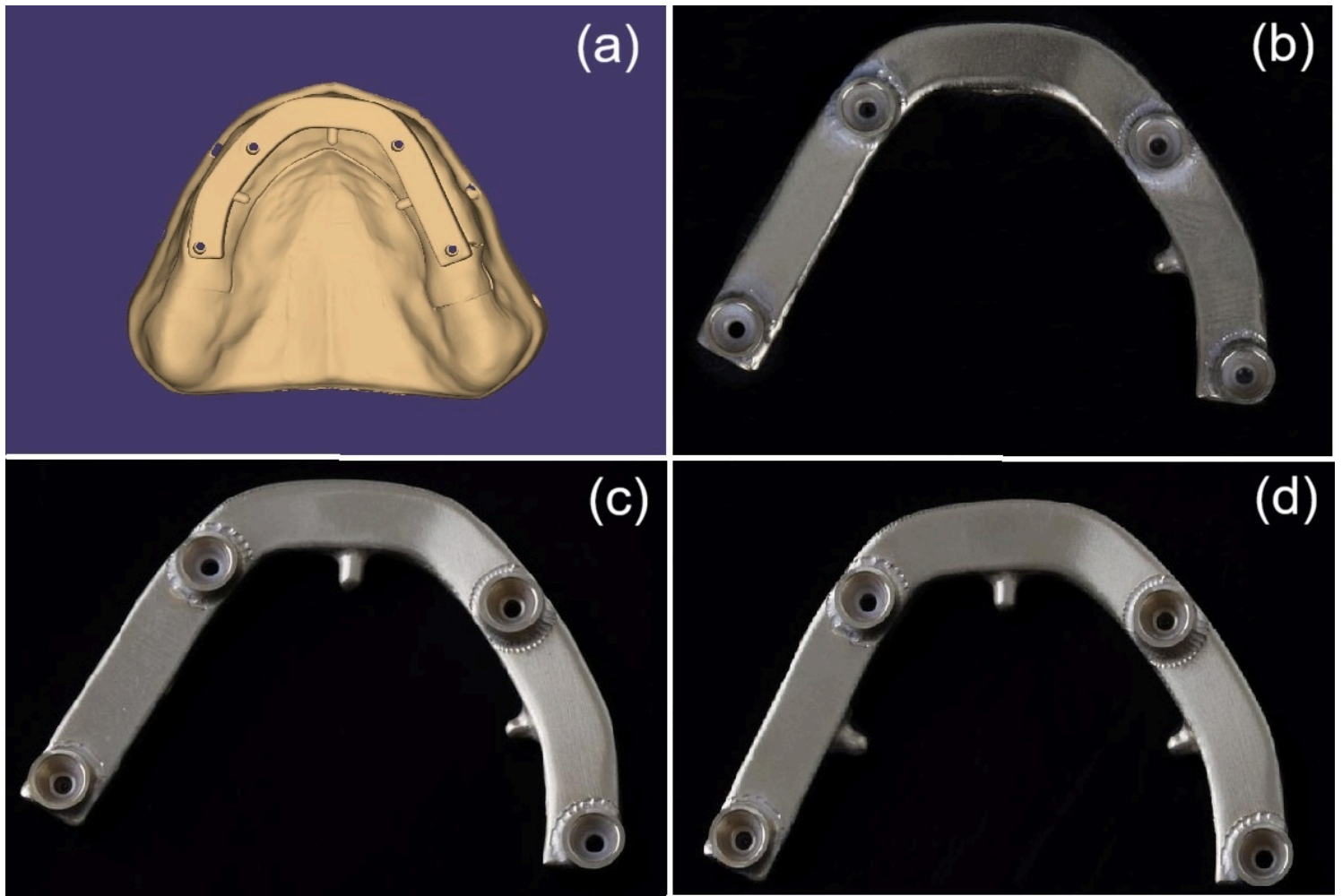


Figure 3

a,b,c,d. (a) Digital jig design connecting the four implant analogs. (b) Milled jig for group I. (c) Milled jig for group II. (d) Milled jig for group III.

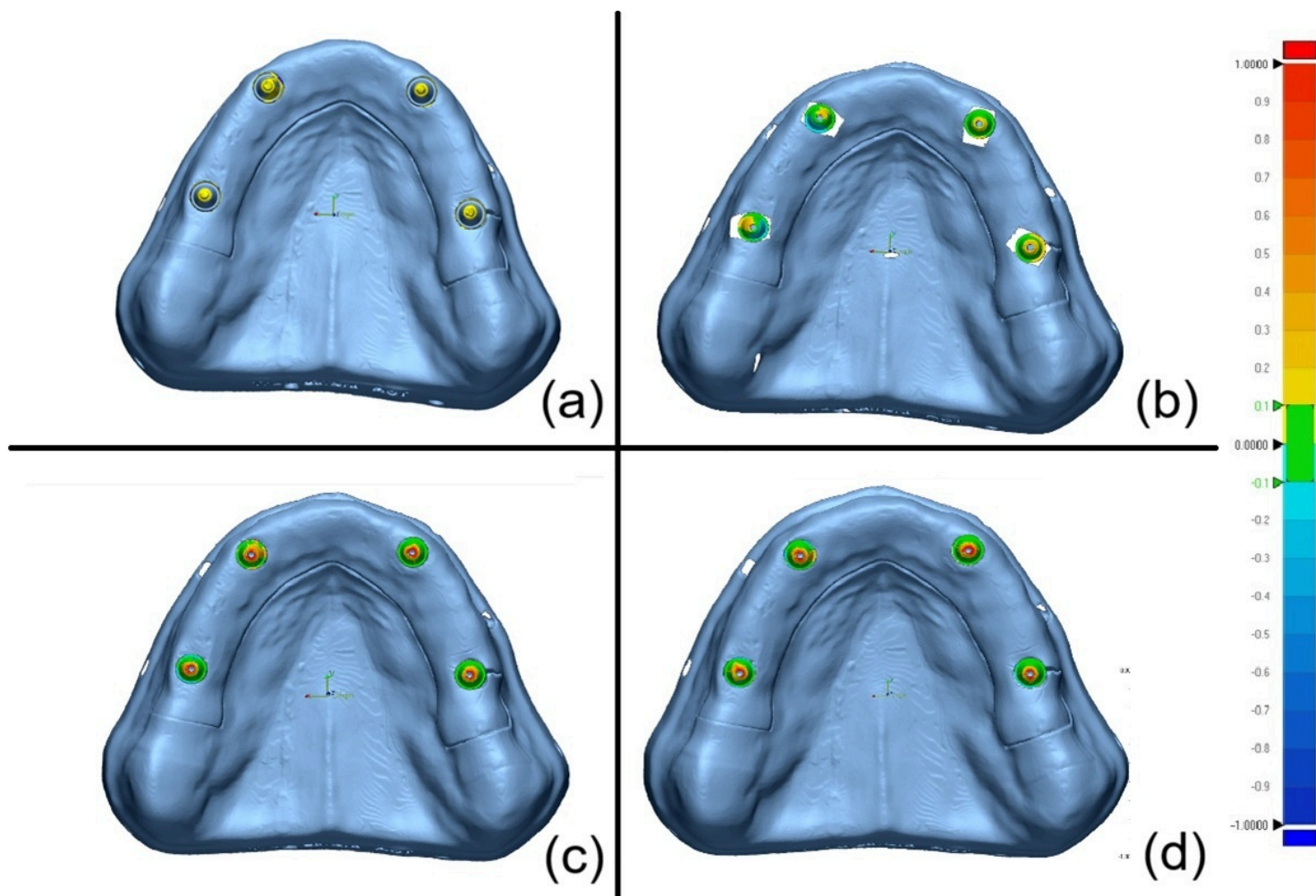


Figure 4

a,b,c,d. (a)pre-alignment of the jig to the reference model. (b) Best-fit alignment for group I (c) Best-fit alignment for group II (d) Best-fit alignment for group III.

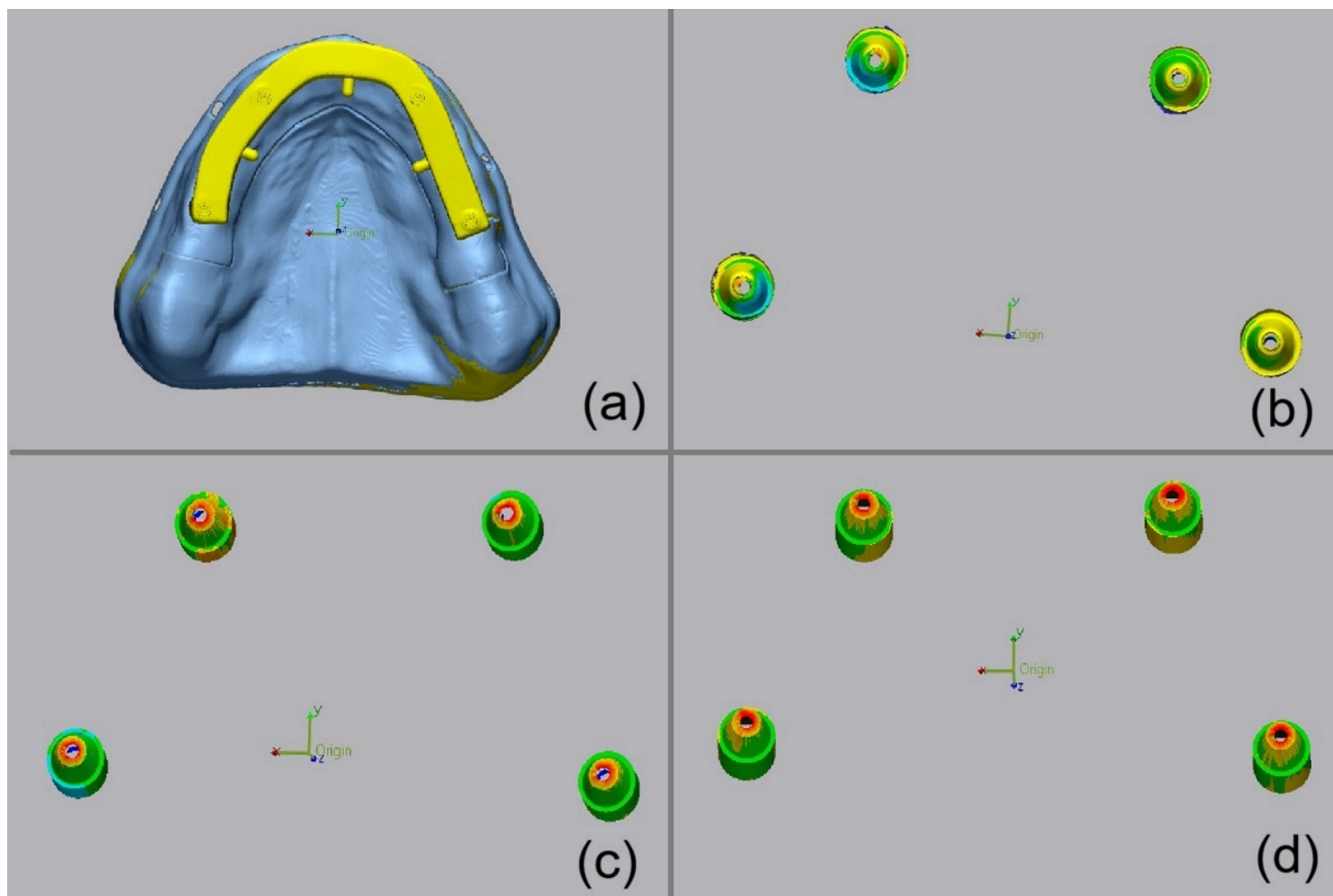


Figure 5

a,b,c, d. 3D color map deviation analysis. (a) Best-fit alignment to reference model. (b) group I analysis. (c) group II analysis. (d) group III analysis.

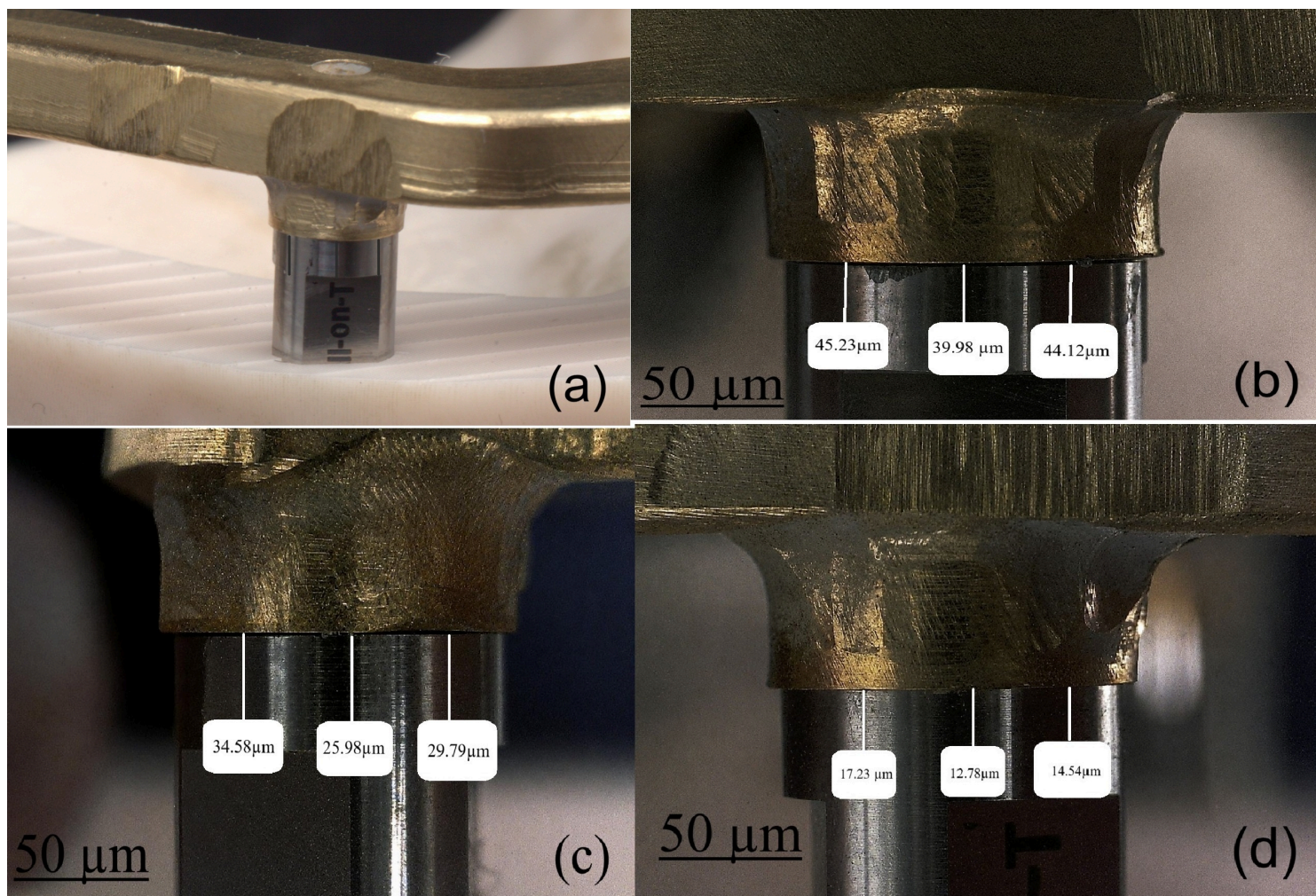


Figure 6

a,b,c,d. (a) Marginal gap assessment sites using digital optical microscopy. (b) group I sample, (c) group II sample, (d) group III sample.