

Model-free digital-correction workflow for multi-implant restorations: A clinical proof-of-concept study

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Abstract

Purpose: This clinical proof-of-concept study evaluates the feasibility and accuracy of a digital workflow for fabricating and correcting implant-supported restorations of multiple dental implants in an edentulous maxilla using intraoral scanning and reverse-scan bodies.

Methods: An intraoral scan (IOS) was performed using vertical scan bodies in one patient with four implants in the edentulous maxilla. Ten verification bars (VB) were fabricated and clinically assessed. Nonpassive VBs were sectioned and reconnected intraorally (splinted verification bars, SVBs) and then scanned using reverse-scan bodies and a laboratory scanner. New verification bars (NVB) were fabricated based on these data. The linear and angular deviations between the implants were analyzed across the IOS, VBs, SVBs, and NVBs. Statistical analysis included Welch's ANOVA and post hoc testing ($\alpha = 0.05$).

Results: None of the VBs achieved a clinically passive fit. IOS-VB comparisons showed mean linear deviations of 14–77 μm , with four measurements $>100 \mu\text{m}$. Mean deviations between VBs and SVBs ranged from 35 to 173 μm , with 20 measurements $>100 \mu\text{m}$. In contrast, SVB-NVB mean deviations ranged from 4 to 27 μm , with only one $>100 \mu\text{m}$. All NVBs demonstrated a clinically passive fit and no significant differences were observed between the SVBs and NVBs ($P > 0.05$).

Conclusions: Under the specific conditions of this proof-of-concept study, a combined digital-correction workflow using reverse-scan bodies and integrated titanium base abutments achieved clinically acceptable outcomes. However, multiple variables were modified simultaneously; therefore, the contribution of each step to the final passive fit could not be isolated.

Keywords: Digital workflow, Intraoral scanner, Oral implants, Passive fit, Reverse-scan bodies

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1. Introduction

Achieving a passive fit for restorations on multiple oral implants is critical for the long-term success of implant-supported fixed dental prostheses or bar splints[1–4]. A passive fit can prevent biological and mechanical complications, including screw loosening, the fracture of prosthetic components, and the transmission of unfavorable stresses to the bone-implant interface, potentially leading to peri-implant bone loss[3–5]. Several factors influence the attainment of a passive fit, such as the number and position of implants, parallelism, the manufacturing technique, and the restoration material[6–8]. Moreover, the impression technique is a critical determinant of final accuracy[9,10]. According to ISO 5725-1, accuracy encompasses true-

ness, the closeness of a measurement to the actual implant position, and precision, which describes the consistency of repeated measurements under the same conditions[11].

WHAT IS ALREADY KNOWN ABOUT THE TOPIC?

» Implant-supported suprastructures must be adequately fit to prevent complications. In edentulous jaws, complete-arch intraoral scanning may be inaccurate because of stitching errors and limited anatomical landmarks. Reverse-scan body workflows have mainly been described for existing interim prostheses, with limited prospective clinical evidence.

WHAT THIS STUDY ADDS?

» In a single-patient proof-of-concept setting, reverse-scan bodies enable a digital-correction workflow after intraoral sectioning and the splinting of nonpassive bars. This approach avoids conventional impressions and physical models and demonstrates the feasibility of obtaining clinically passive suprastructures.

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Implant-supported dental prostheses are traditionally fabricated using elastomeric impressions and plaster models as the standard technique. However, recent progress in digital workflows has led to the implementation of computer-aided design and manufacturing (CAD-CAM) systems for designing and producing both fixed and removable implant-supported restorations[12]. In the most commonly used approach, plaster models fabricated from elastomeric impressions of oral implants are subsequently digitized using optical laboratory scanners to facilitate a digital workflow[13]. In recent years, intraoral scanning has emerged as an alternative to conventional impression techniques, offering shorter treatment times, improved patient comfort owing to its noncontact nature, and enabling a fully digital workflow[14]. Typically, scan bodies are attached intraorally to implants and scanned using an intraoral scanner (IOS) to create a digital model. However, accurately capturing implant positions in the edentulous jaw remains a significant challenge[15]. Unlike dentate patients, the lack of anatomical landmarks in edentulous jaws provides fewer intraoral reference points. This can compromise the stitching of the acquired digital images; in other words, the joining of the images into a complete scan[16]. Consequently, the resulting virtual model may be inaccurate, which may adversely affect the passive fit of the final restoration.

In vitro studies investigating the accuracy of digital intraoral impressions for multiple implants have shown inconsistent results, leaving the clinical applicability of this approach a topic of ongoing debate[17]. Protocols employing splinted scan bodies with auxiliary features have been developed to enhance the accuracy of implant scans in fully edentulous jaws[18,19]. However, even with these modifications, persistent variability in accuracy has been reported[20]. *In vivo* research examining digital impressions of oral implants using IOS and evaluating the fit of the resulting restorations is limited[21,22].

When an implant-supported restoration does not exhibit a passive fit, it can be sectioned and reconnected intraorally. To maintain a digital workflow, reverse-scan bodies mounted on titanium base abutments (Ti bases) in the restoration can be attached and digitized using extraoral scanning. Subsequently, a new restoration can be fabricated based on the acquired implant positions[23]. This approach for digitizing reverse-scan bodies has already been described for the initial fabrication of definitive implant-supported restorations when a passively fitting interim prosthesis is available[24,25]. It originates from a semidigital laboratory protocol in which conventional implant impressions are scanned to capture implant positions, thereby eliminating the need to fabricate a physical implant master model. This technique using reverse-scan bodies has been described in the literature; however, no prospective clinical studies have evaluated its accuracy in the edentulous maxilla using a digital workflow that includes reverse-scan bodies for the correction of restorations[26,27].

Therefore, the aim of this study is to evaluate the feasibility and accuracy of a digital workflow for the fabrication of implant-supported restorations in the edentulous maxilla using four implants. Specifically, the study investigated the use of intraoral scanning for initial data acquisition and the application of reverse-scan bodies to capture implant positions in cases of nonpassive fit. Repeated measurements were intended to characterize within-case technical variability rather than interpatient biological variability.

2. Materials and Methods

2.1. Study participant

A 53-year-old patient with an edentulous maxilla was enrolled in this study at the Department of Reconstructive Dentistry, University Center for Dental Medicine, Basel, Switzerland. Written informed consent was obtained before her participation. Implant positions were planned for implant-supported removable dental prostheses retained on a bar. Guided implant placement was performed by virtual planning using the coDiagnostiX software (Dental Wings GmbH, Chemnitz, Germany). Following this plan, four implants were inserted in the maxilla (Straumann® SLActive® Tissue Level implants: 3.3×10 mm in regions 12 and 22 according to FDI notation; 4.1×10 mm in region 26; 4.1×8 mm in region 15; Institut Straumann AG, Basel, Switzerland). The study protocol was approved by the Ethics Committee of Northwest and Central Switzerland (EKNZ) (EKNZ-ID 2021-00249), and was conducted in compliance with the Declaration of Helsinki and all relevant national laws and regulatory guidelines.

2.2. Digital workflow

The scan bodies were intraorally attached to the implants and remained in place until 10 intraoral scans were completed using a TRIOS4 intraoral scanner (3Shape, Copenhagen, Denmark; version 21.2.0). The scanning procedure was performed by an experienced operator (A. K.-G.) under consistent ambient lighting conditions according to the manufacturer's instructions ($n = 10$ per jaw; IOS group; **Fig. 1a**). Ten titanium verification bars (VBs) were fabricated based on each intraoral scan using CAD-CAM (Exocad Dental CAD 3.1 Rijeka 8349, exocad GmbH, Darmstadt, Germany; Power Mill 2016 R2, Autodesk, San Francisco, USA; **Fig. 1b**), and Ti bases (Straumann® Variobase® RN for bridge/bar cylindrical, 5×3.5 mm, Institut Straumann AG, Basel, Switzerland) were subsequently cemented (Multilink Hybrid abutment, Ivoclar Vivadent, Schaan, Liechtenstein) without the use of a physical model (**Fig. 2 a, b**). The passive fit of each VB was assessed clinically through visual and tactile examinations and Sheffield tests[1–3]. Nonpassive VBs were separated and re-splinted intraorally using a light-curing acrylic resin (Primopattern LC Gel, Primotec, Bad Homburg, Germany) (**Fig. 1c**). The original VBs and re-splinted verification bars (SVBs) were provided with attached reverse-scan bodies (RevEx, RN, Institut Straumann AG, Basel, Switzerland) and digitized using an optical laboratory scanner (inEos X5, Dentsply Sirona, Bensheim, Germany; software inLab 22.1.1.276516) for further analysis. Finally, new verification bars (NVBs) with integrated Ti bases were milled, and their passive fit was examined clinically (**Fig. 1d**). For further analysis, the NVBs (with attached reverse-scan bodies) were digitized using a laboratory scanner.

2.3. Data analysis

The scans from the IOS, VB, SVB, and NVB groups were all available in a standard tessellation language format and imported into the metrology software Geomagic Control X (Version 2018.1.2, 3D Systems, Rock Hill, SC, USA). The vertical axis and upper plane of the scan bodies were constructed as described in a previous publication[10]. Using these reference geometries, the distances and angles between the individual scan bodies were calculated for each scan, resulting in six linear and angular measurements per scan (**Fig. 3**). The distances between the scan bodies were determined by identifying the intersection points between the upper plane and vertical axis,

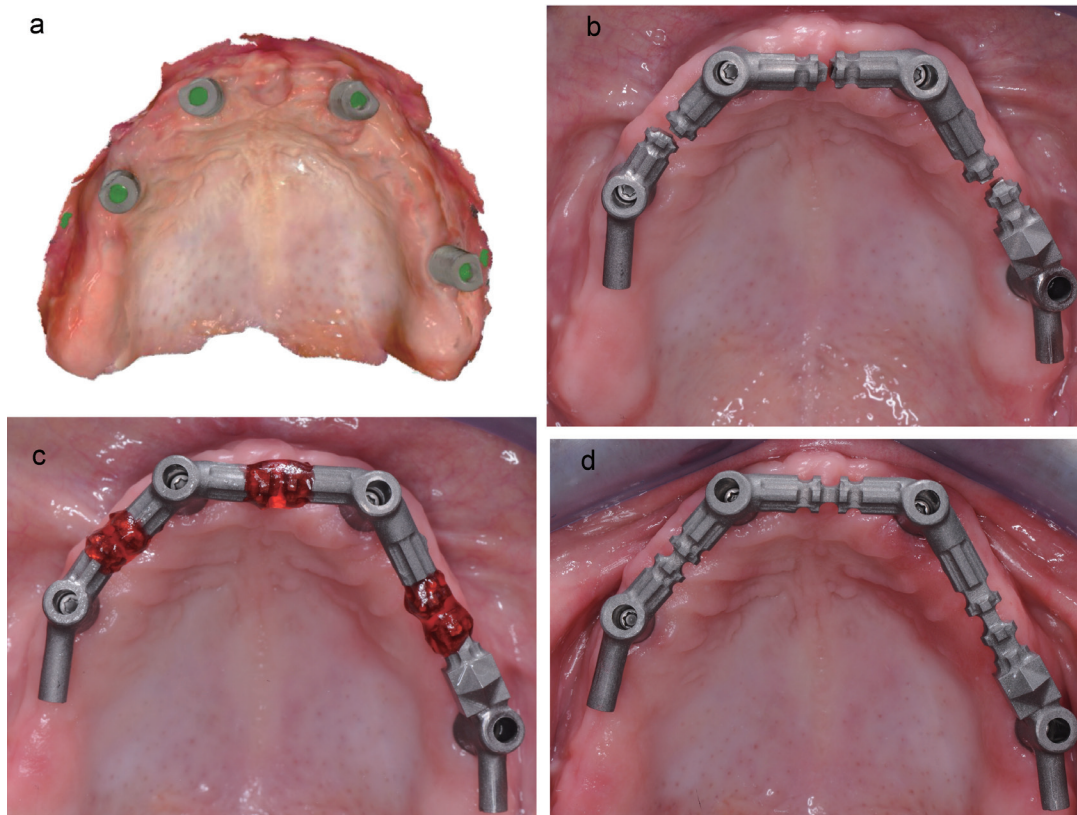


Fig. 1. a) Intraoral scan of the edentulous maxilla with scan bodies attached to four implants, b) clinical examination and separation of a nonpassive titanium verification bar with model-free cemented titanium bases, c) re-splinted verification bar after separation and reconnection, d) newly fabricated verification bar with integrated titanium base abutments.

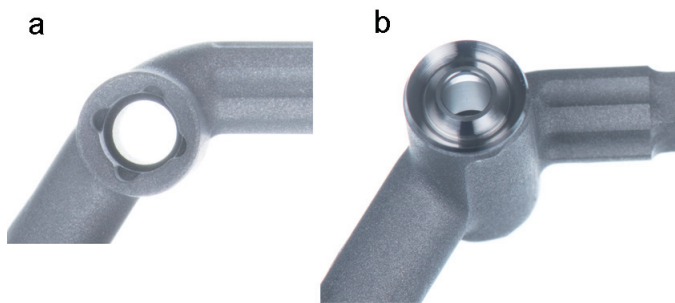


Fig. 2. Detailed visualization of the implant region of the verification bar. a) after manufacturing and b) after model-free cementation of titanium base abutments.

whereas the angles between the two scan bodies were measured based on their respective vertical axes.

2.4. Statistical analysis

The sample size was determined based on previous studies using similar methodologies[28,29] and was calculated using G*Power software (version 3.1.9.7, Universität Kiel, Kiel, Germany). The analysis showed that a sample size of 10 would be adequate, assuming a significance level of $\alpha = 0.05$, a statistical power of 80%, and an effect size of 1.4. Statistical analysis was conducted using Python 3.12

(Python Software Foundation, Python, Wilmington, DE, USA). The Shapiro–Wilk test was conducted to evaluate the normality of the data distributions, and Levene’s test was used to assess the homogeneity of variances across the datasets. Both the angle and distance measurement groups (IOS, VB, SVB, and NVB) for each scan body pair were compared using Welch’s ANOVA, followed by the Games–Howell post hoc test. The Holm–Bonferroni correction method was applied to adjust the p -values to account for multiple comparisons. Twelve comparisons, each analyzed separately, were conducted: six for angle measurements and six for distance measurements. The significance level was set at $\alpha = 0.05$.

3. Results

3.1. Clinical examination

All VBs were clinically examined, and their passive fit was evaluated using visual and tactile methods, as well as the Sheffield test. In this evaluation, none of the 10 VBs with cemented Ti bases showed a passive fit (**Fig. 4**); therefore, they were separated and reconnected intraorally (SVB). The SVBs were digitized using reverse-scan bodies and new verification bars (NVBs) with integrated Ti bases were fabricated based on this. All 10 NVBs demonstrated a passive fit on the implants during clinical examination, including the Sheffield test (**Figs. 5a and b**).

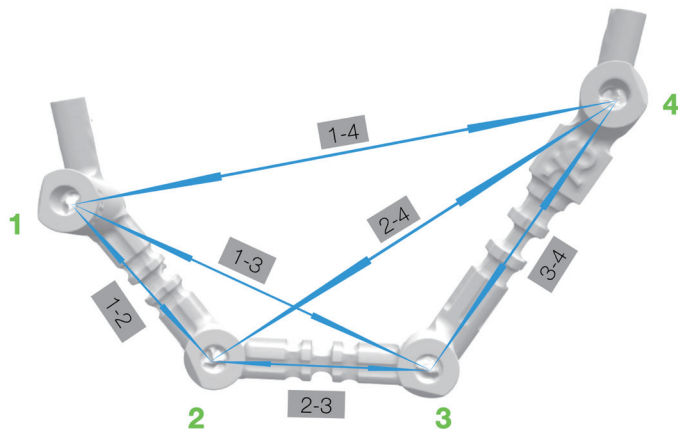


Fig. 3. Representation of the evaluated distances and angles between implants 1, 2, 3, and 4

3.2. Linear/angular deviation

3.2.1. Linear deviations

The linear deviations between the implants across different datasets (IOS, VB, SVB, and NVB) are presented in **Table 1**. A comparison between IOS and VB shows that the smallest mean deviation was observed between implants 1 and 2 (14 μm), whereas the largest mean deviation occurred between implants 1 and 4 (77 μm). Statistically significant differences were observed between implants 1–3, 1–4, 2–3, and 2–4 ($P < 0.05$). In the IOS-VB comparison, four distances of separate measurements exhibited deviations greater than 100 μm . A comparison of interimplant distances between the VB and SVB indicated that all distances showed significant deviations ($P < 0.05$; **Table 1**), except for distance 3–4. The lowest mean deviation was observed for distance 3–4 (35 μm), and the highest was recorded for the cross-arch distance 1–4 (173 μm). The mean deviations between SVB and VB increased across all distances compared with the IOS-VB comparison, except for distance 1–3. Overall, 20 measurements of the distance deviation between VB and SVB exceeded 100 μm . Notably, for distance 1–4, 8 out of 10 measured values were greater than 100

μm . No significant differences were observed between SVB and NVB ($P > 0.05$). The mean deviations ranged from 4 μm (distance 1–3) to 27 μm (distance 3–4), indicating smaller deviations between the examined distances compared with previous comparisons. Among all 60 measured values of the distance deviation between SVB and NVB (10 verification bars $\times$ 6 distances = 60 values), only one exceeded 100 μm . This outlier was observed at the cross-arch distance 1–3 and measured 137 μm .

3.2.2. Angular deviations

The angular deviations between the implants across the different datasets (IOS, VB, SVB, and NVB) are shown in **Table 2**. The lowest mean angular deviation in the IOS-VB comparison was observed between implants 1 and 2 (0.06°), and the highest was observed between implants 2 and 4 (0.53°). The differences between IOS and VB were not statistically significant for any of the mean angles, except between implants 2 and 3 ($P = 0.01$) and 2 and 4 ($P = 0.03$). Of the 60 measured interimplant angles, 25 exceeded 0.4°. In the VB-SVB comparison, the lowest mean angular deviations were again observed between implants 1 and 2 (0.02°), whereas the highest were between implants 1 and 3 (0.66°). Significant differences in the mean angles of the SVB were observed compared to the VB for the interimplant angles between implants 1 and 3 ($P = 0.03$) and 1 and 4 ($P = 0.01$). In the VB-SVB comparison of separate measurements, only 22 of the 60 measured interimplant angles did not exceed 0.4°. The lowest mean angular deviation in the SVB-NVB comparison was observed between implants 1 and 4 (0.02°), whereas the highest was observed between implants 3 and 4 (0.59°). No significant differences were observed comparing NVB to the IOS, VB, and SVB datasets ($P > 0.05$). The greatest interimplant angle deviations in the SVB-NVB comparison of separate measurements exceeding 0.4° were observed between implants 1 and 3, 1 and 4, and 2 and 3.

4. Discussion

This prospective clinical proof-of-concept study evaluated the feasibility and accuracy of a digital workflow, including an IOS and the use of reverse-scan bodies, for the fabrication and correction of restorations supported by four implants in an edentulous maxilla. The study demonstrated that, following IOS and a model-free fixation

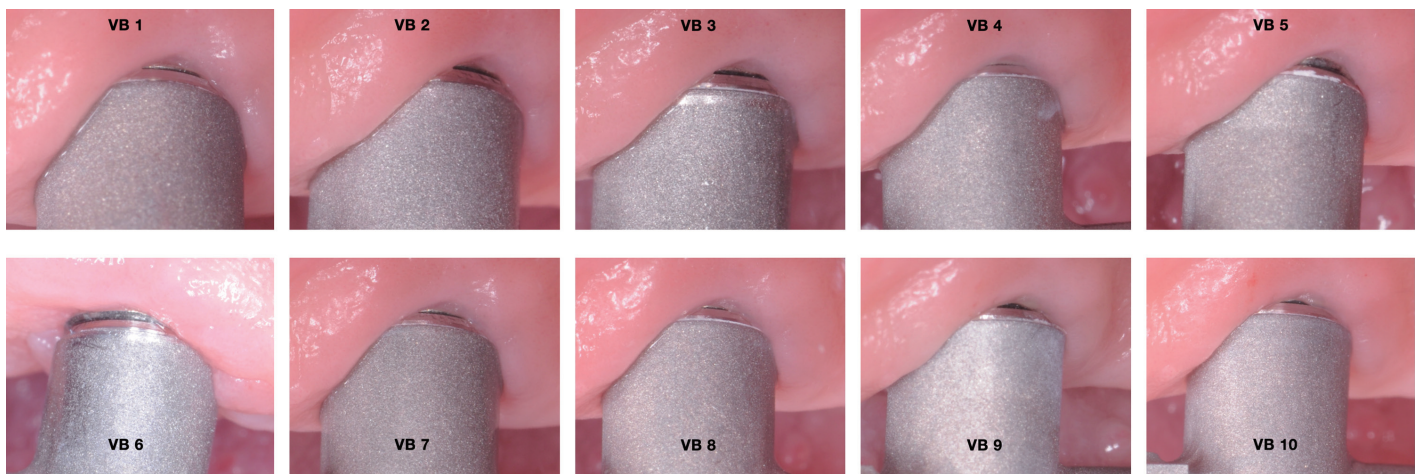


Fig. 4. Clinical evaluation of verification bars at the most distal implant during Sheffield test. All 10 verification bars show a visual gap to the implant shoulder (nonpassive fit).

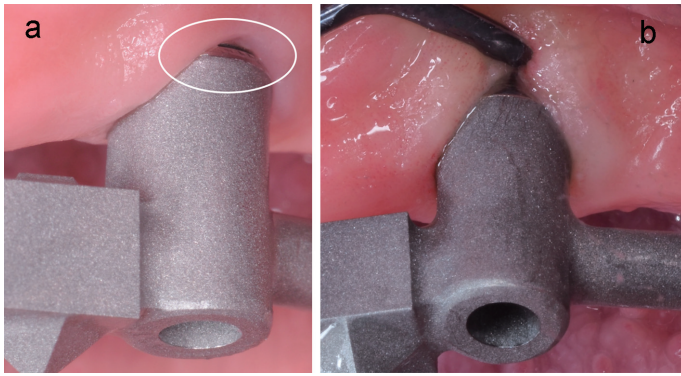


Fig. 5. Clinical comparison of the bar fit at the most distal implant during Sheffield test. a) nonpassive fit with a visible gap of a verification bar, b) no visible gap and a passive fit of a newly fabricated verification bar.

of Ti bases, a passive fit of the restorations was not achieved. However, by employing the described approach, comprising sectioning, intraoral reconnection, laboratory digitalization using reverse-scan bodies, and the integration of Ti bases into the superstructures, a passive fit of the restoration was successfully obtained.

The accuracy encompasses both trueness and precision[11]. Although precision, defined as the reproducibility among multiple virtual datasets, can be assessed in clinical studies, evaluating trueness remains challenging. Trueness is commonly assessed by comparing datasets against a reference dataset, which is often generated via the digitization of a conventionally fabricated model using a coordinate-measuring machine or high-precision optical scanner[30]. A major limitation of this method is the potential inaccuracies introduced during both the fabrication of the conventional model and subsequent digital scanning, which may distort the assessment of trueness. Therefore, a key strength of this study is the clinical evaluation of the restorations, which circumvents this limitation and facilitates the direct translation of the results into clinical practice.

During the clinical trial of the 10 VBs, none achieved a passive fit. Under the specific conditions tested in this patient, the initial workflow could not produce a passively fitting rigid restoration. As no universally accepted threshold exists, the commonly cited linear deviation of 100 μm between two implants was used as a pragmatic clinical benchmark rather than a strict cutoff[31]. Using this benchmark, four IOS-VB distance measurements exceeded 100 μm , whereas 20 VB-SVB measurements exceeded 100 μm , indicating that clinically required correction involved substantial positional change relative to the initially fabricated bars. The largest mean deviation occurred at the longest cross-arch distance (implants 1–4; 173 μm), and individual values reached 250 μm . Accordingly, the linear deviations for this distance exceeded those reported in other *in vivo* studies (162 μm) as summarized in a systematic review[32]. The finding of increasing deviations with longer distances aligns with previous observations that the interimplant distance can affect the accuracy of intraoral scans[33]. While this effect has been primarily described in *in vitro* studies[34–36], similar findings were reported in a clinical study involving 22 patients, documenting varying inter-implant distances between two mandibular implants using a common system at the time of the study (iTero v.3.5.0)[31]. This is because in larger edentulous scan areas, minor stitching errors tend to accumulate because of the lack of distinct anatomical landmarks[37]. Another

potential source of inaccuracy may be the model-free cementation of Ti bases. A previous *in vitro* study reported reduced trueness in model-free workflows; however, the results were comparable with those of workflows involving physical models[38]. Importantly, these findings are based on a single implant crown. In cases involving multiple implants connected by a restoration, as in the present study with four implants, minor deviations may accumulate and lead to clinically relevant inaccuracies. However, these results do not indicate a general limitation of the IOS, as no comparator workflow was included and only one scanner, scan-body design, and clinical scenario were assessed.

The NVBs were fabricated based on the SVBs that were previously digitized using a laboratory desktop scanner. All the NVBs demonstrated a passive clinical fit. This was supported by the interimplant distance deviations, which remained below 100 μm , with the highest mean difference observed at only 27 μm , except for one outlier (123 μm). No statistically significant differences in interimplant distances were observed between the SVBs and NVBs. These results indicate that the applied workflow using reverse-scan bodies and avoiding a model-free cementation of the Ti bases enabled an effective correction and passive fit of the restoration. Importantly, the improved fit should be interpreted as a combined effect of the corrective workflow rather than a single factor. As multiple variables were modified simultaneously, this study demonstrated the feasibility of the overall approach, but did not allow the identification of the primary contributing factor. An optical desktop scanner was used for the extraoral scans with reverse-scan bodies. This type of scanner achieved clinically acceptable accuracy, whereas most evaluated IOSs failed to meet this standard[24]. One reason for this superior performance is that the desktop scanner captured the entire object in a single acquisition, thereby eliminating the need to stitch multiple images. Additionally, desktop scanners operate in a controlled environment, making the scan results less susceptible to changes in lighting, temperature, or operator handling compared with IOS used extraorally. Generally, extraoral scanning avoids typical intraoral challenges, such as saliva contamination or tongue movement, which can negatively affect IOS performance[39]. Another potential reason for the superior passive fit of NVBs is the difference in the manufacturing process. Unlike SVBs, NVBs do not require the cementation of Ti bases after fabrication; the implant connection was milled directly as part of the structure. To the best of our knowledge, no previous study has compared the accuracy of restorations using multiple dental implants with and without cemented Ti bases.

The angular deviations between the implants exhibited a tendency similar to that of linear distances. Significant deviations were observed between IOS and SVB regarding the angles between implants 1–3, 1–4, 2–3, and 2–4; however, no significant differences were observed between the SVB and NVB. Regarding trueness with IOS, the debate on whether higher angulation between implants leads to reduced accuracy is ongoing[23]. However, most studies have reported a relevant impact on trueness only at implant angulations exceeding 30°[40,41]. Given that all angulations between the implants were below 25° in the present study, angulation can be considered a negligible or secondary factor for the observed IOS inaccuracies.

This study had several limitations. First, it was designed as a single-patient proof-of-concept investigation; the 10 repeated scans and manufactured bars characterized technical repeatability within one clinical scenario but did not substitute for interpatient biological

Table 1. Measured distances between implants (in mm) and resulting linear deviations (in μm) between IOS and VB (a), VB and SVB (b), and SVB and NVB (c)

a)

IOS-VB				
Distance	Mean (SD)		Mean diff (μm)	P-value
	IOS (mm)	VB (mm)		
1–2	16.883 (0.012)	16.869 (0.036)	14	0.24
1–3	31.998 (0.026)	31.949 (0.039)	49	<0.01
1–4	44.141 (0.047)	44.064 (0.052)	77	<0.01
2–3	18.893 (0.013)	18.842 (0.025)	51	<0.01
3–4	26.251 (0.015)	26.235 (0.05)	16	0.36
2–4	39.815 (0.028)	39.741 (0.048)	74	<0.01

b)

VB-SVB				
Distance	Mean (SD)		Mean diff (μm)	P-value
	VB (mm)	SVB (mm)		
1–2	16.869 (0.036)	16.918 (0.016)	49	<0.01
1–3	31.949 (0.039)	31.9 (0.026)	49	<0.01
1–4	44.064 (0.052)	43.891 (0.029)	173	<0.01
2–3	18.842 (0.025)	18.754 (0.015)	88	<0.01
3–4	26.235 (0.05)	26.27 (0.022)	35	0.06
2–4	39.741 (0.048)	39.642 (0.021)	99	<0.01

c)

SVB-NVB				
Distance	Mean (SD)		Mean diff (μm)	P-value
	SVB (mm)	NVB (mm)		
1–2	16.918 (0.016)	16.931 (0.047)	13	0.43
1–3	31.9 (0.026)	31.896 (0.058)	4	0.85
1–4	43.891 (0.029)	43.886 (0.048)	5	0.77
2–3	18.754 (0.015)	18.742 (0.043)	12	0.44
3–4	26.27 (0.022)	26.297 (0.05)	27	0.15
2–4	39.642 (0.021)	39.651 (0.038)	9	0.5

IOS: intraoral scan; VB: verification bar; SVB: re-splinted verification bar; NVB: new verification bar

variability. Accordingly, external validity is limited with respect to implant distribution, angulation, interimplant distances, soft-tissue morphology, mucosal thickness, and other anatomical variables. Second, no comparator workflow (e.g., conventional impressions, hybrid workflows, or photogrammetry) was included; therefore, the study could not determine whether the proposed approach offers superior, equivalent, or inferior performance relative to other established techniques. Third, the passive fit was assessed using visual and tactile examinations and the Sheffield test. Although these methods are clinically relevant and commonly used, they are subjective and operator dependent. In the present patient, the thickness and depth of the peri-implant mucosa limited direct visualization, predominantly to the clinically accessible aspects; therefore, discrepancies in the nonvisible or submucosal regions may have remained undetected. Finally, only one IOS, scan body type, restoration manufacturing technique, and laboratory scanner system were used, which further restricted the generalizability of the results[42]. Future comparative clinical trials involving larger patient cohorts are required to validate our findings across a broader spectrum of clinical conditions and technical parameters. In particular, the use of horizontal scan bod-

ies with distinct geometries requires further investigation as they may improve the accuracy of digital impressions in fully edentulous cases[43,44]. Horizontal scan bodies can minimize the risk of image-stitching errors. This approach aligns with techniques such as connecting vertical scan bodies or soft-tissue landmarks[45,46]. However, their frequent integration into closed proprietary software systems may limit their clinical flexibility and broad applicability. Moreover, photogrammetry has demonstrated highly promising outcomes in accurately capturing implant positions in edentulous jaws, offering excellent precision in implant-supported restorations[47–49]. However, its broader clinical adoption may be hindered by factors such as high equipment costs, limited availability, and need for specialized training. Furthermore, photogrammetry is limited to recording implant positions and requires the use of an IOS to capture the surrounding soft-tissue morphology.

5. Conclusions

This clinical proof-of-concept study showed that, under the specific conditions tested, intraoral scanning with vertical scan bodies

Table 2. Angular deviations between implants (in °) between IOS and VB (a), VB and SVB (b), and SVB and NVB (c)

a)

Angle	IOS-VB		Mean diff (°)	P-value
	Mean (SD)			
	IOS (°)	VB (°)		
1–2	5.42 (0.21)	5.36 (0.32)	0.06	0.61
1–3	11.81 (0.24)	11.55 (0.37)	0.26	0.08
1–4	20.37 (0.42)	20.05 (0.45)	0.32	0.12
2–3	14.19 (0.18)	13.73 (0.49)	0.46	0.01
3–4	11.2 (0.23)	11.05 (0.49)	0.15	0.38
2–4	24.33 (0.32)	23.8 (0.63)	0.53	0.03

b)

Angle	VB-SVB		Mean diff (°)	P-value
	Mean (SD)			
	VB (°)	SVB (°)		
1–2	5.36 (0.32)	5.38 (0.39)	0.02	0.92
1–3	11.55 (0.37)	10.89 (0.79)	0.66	0.03
1–4	20.05 (0.45)	19.4 (0.47)	0.65	0.01
2–3	13.73 (0.49)	13.35 (0.49)	0.38	0.1
3–4	11.05 (0.49)	11.09 (0.59)	0.04	0.86
2–4	23.8 (0.63)	23.44 (0.35)	0.36	0.14

c)

Angle	SVB-NVB		Mean diff (°)	P-value
	Mean (SD)			
	SVB (°)	NVB (°)		
1–2	5.38 (0.39)	5.76 (1.38)	0.38	0.41
1–3	10.89 (0.79)	10.67 (1.55)	0.22	0.69
1–4	19.4 (0.47)	19.42 (0.95)	0.02	0.95
2–3	13.35 (0.49)	13.13 (1.26)	0.22	0.61
3–4	11.09 (0.59)	11.68 (1.64)	0.59	0.30
2–4	23.44 (0.35)	23.68 (0.68)	0.24	0.35

IOS: intraoral scan; VB: verification bar; SVB: re-splinted verification bar; NVB: new verification bar

combined with model-free cementation of Ti bases did not yield a passively fitting restoration on four implants in an edentulous maxilla. In the same clinical scenario, intraoral separation and reconnection, followed by extraoral scanning with reverse-scan bodies and the integration of Ti bases into the superstructure, were feasible and resulted in a clinically acceptable passive fit. This digital approach may eliminate the need for conventional impressions or physical models and represent a feasible option to improve the accuracy and efficiency of digital workflows. However, as multiple variables were simultaneously modified within this corrective workflow, the specific contribution of each step to the final passive fit could not be isolated.

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Conflict of interest statement

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