https://doi.org/10.4047/jap.2025.17.2.70

Comparison of fixed dental prostheses digitally fabricated using various scan bodies: a clinical study

Fatmanur Demir Boz*, Kivanc Akca
Department of Prosthodontics, Faculty of Dentistry, Hacettepe University, Sihhiye, Ankara, Turkey

ORCID
Fatmanur Demir Boz
https://orcid.org/0000-0003-3817-0729
Kivanc Akca
https://orcid.org/0000-0003-3013-2533

PURPOSE. Digitalization in dentistry has increased interest in the use of intraoral scanners (IOs) in clinical practice. However, knowledge of implant digitalization is primarily limited to *in vitro* studies. This study aimed to compare implant-supported fixed dental prostheses (FDP) fabricated following complete digital workflow using various implant scan bodies (SB) in treatment of short-span partial edentulism. **MATERIALS AND METHODS.** Patients with 25 short-span posterior edentulous sites, each receiving two implants to support a fixed restoration, were included. Digital implant records were made consecutively with original, non-original, and generic SBs using IOs. A practitioner implemented a two-stage full-arch scanning protocol, beginning with continuous arch scanning, followed by individual scanning of SBs. For clinical evaluation, each site received screw-retained full-contour restorations to qualify the connection fit to the implants and contacts to the adjacent and antagonist teeth. For analytical comparison, implant axes calculated from SB scans were quantified using reverse engineering software to compare the differences three-dimensionally. Restorative outcomes and implant axes records were statistically analyzed using the chi-square test and generalized estimating equations, respectively. **RESULTS.** Clinical delivery conditions did not differ significantly among the three intraoral SBs ($P > .05$). The analytical implant-position calculations for non-original and generic SBs did not present significant differences compared to original SBs ($P > .05$). **CONCLUSION.** SBs with different hardware and software characteristics for an implant system are clinically acceptable for fabricating screw-retained short-span implant-supported FDPs using a complete digital workflow. [J Adv Prosthodont 2025;17:70-82]

KEYWORDS
CAD-CAM technology; Dental implants; Fixed implant prosthesis; Partial edentulous

Corresponding author
Fatmanur Demir Boz
Department of Prosthodontics, Faculty of Dentistry Hacettepe University, Sihhiye, Ankara 06100, Turkey
Tel +90 534 7993994
E-mail fatmanurd35@gmail.com

Received October 19, 2024 /
Last Revision March 24, 2025 /
Accepted April 18, 2025

This study was partially supported by the Hacettepe University Scientific Research Projects Coordination Unit (project: 18710).

pISSN 2005-7806 • eISSN 2005-7814

INTRODUCTION

Evolving digital technologies in dentistry, particularly computer-aided design and computer-aided manufacturing (CAD-CAM) software coupled with various additive and subtractive production devices, have increased the awareness of direct digital data acquisition in clinical practice.[1,2] Consequently, intraoral scanners are increasingly used for various restorative digital workflows in daily practice. In essence, intraoral data acquisition initializes the complete digital workflow whose efficiency is clinically verified compared to the conventional workflow.[3]

Direct processing on a numerically generated geometry, specifically the stereolithography (.stl) file of hard and neighboring soft tissues, is scientifically recommended for a wide range of teeth-supported fixed dental prosthesis (FDPs).[1,4-6] The capturing, positioning, and integration of dental implants into the digital workflow have become possible with the evolution of the data exchange process. This process is defined as the processing of data structured under a source schema and transforming it into a target schema.[7,8] For this purpose, a component connected to an implant, commonly known as a scan body (SB), was the surface scanned to match the geometric library .stl files for CAD processing.[9] In practice, SB scanning is similar to tooth scanning; however, it presents additional considerations related to the properties of SB and its CAD integration for clinically acceptable implant-supported FDPs.[10]

SBs have a one- or two-piece design based on the material produced; the former is either metal or PEEK, and the latter combines the two.[9] Regarding the material, tolerances in production[11] and mechanical stability upon multiple use[12] and differences in optical properties[13] of various SBs have been studied. In addition to material-related surface characteristics, difficulties in accurately scanning an SB with various geometric features[14] have been further addressed. However, the continuing discussions to understand the uncertainties with regards to SB are based on *in-vitro* studies without clinical validation considering the restorative accuracy. Beyond the hardware considerations, software engineering has led to the development of various SB options to choose from different CAD processing principles in digital design.

Today, restorative dentists can select from an original, non-original, or generic SB based not only on the differences in design but also on the implant library developed for CAD software. The original SB is manufactured by the same producer as the implant to be restored, with the brand's available prosthetic components. In contrast, a non-original SB is developed independently by a company other than the implant brand, aiming to market its compatible prosthetic components. Similarly, a generic SB is also manufactured by another producer but is termed such because it involves an approach related to the use of prosthetic components fabricated by either the implant producer or third-party competitors and approved by the implant producer.

Knowledge on implant digitalization is mostly limited to *in vitro* study conditions, which lack representation of challenging intraoral conditions such as saliva, movable soft tissues, accessibility to the edentulous arch, and patient compliance as well.[15-17] The main topics studied in this context include scanning accuracy pertaining to implant position and distribution, scanning strategy, and SB design.[13,18] Accurate SB digital recording alone may not be insufficient; compliance with the software properties concerning the implant library for CAD processing is also crucial for achieving acceptable CAM outcomes. Therefore, clinical adjustment requirements, including implant fit and inter- and intra-arch relationships for completely digital FDPs, could be optimized to reduce biological and mechanical complications.[19,20]

The effects of the hardware and software related properties of a SB on implant-supported FDPs fabricated through a complete digital workflow remain unclear. Therefore, this study aimed primarily to compare implant supported FDPs produced from intraoral scanning of various SBs and secondarily to evaluate the differences in SB scans to digitize implant positions. The null hypothesis posited that direct digitalization of implants with different hardware and software SB specifications is not an effective factor for the clinical adjustment requirementsof CAD-CAM-fabricated monolithic screw-retained implant FDP, and the differences in hardware properties of a SB do not affect the surface scanning to define implant positioning.

https://doi.org/10.4047/jap.2025.17.2.70

MATERIALS AND METHODS

In this clinical trial, original, non-original, and generic SBs were comparatively evaluated qualitatively using fixed restorations fabricated following a complete digital workflow, and implant axes were quantitively calculated with reverse engineering processes to interpret the clinical outcomes. Figure 1 displays the SBs, while Figure 2 presents an outline of the study design.

A randomization process was performed using a free-access internet-based application to follow up in a single session separately for consecutive scanning of the SBs and clinical evaluation of implant-supported FDPs in another session. The 3D implant-position transfers using SB scans were compared by evaluating virtual implant axes using a reverse engineering software. A single investigator (FD) performed the clinical procedures and the virtual analytical calculations.

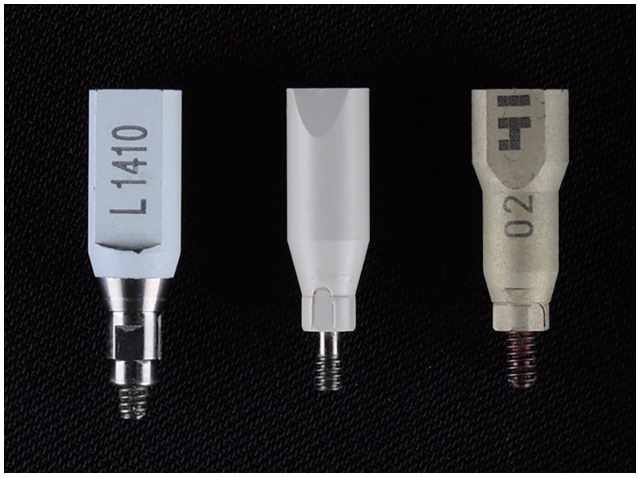

Fig. 1. From left to right, non-original, original and generic scan bodies with cylindrical geometry varying in features.

The study protocol was approved by the Hacettepe University Clinical Research Ethics Committee (protocol code: KA-19091) and the Ministry of Health, Turkish Medicines, and Medical Devices Agency (No. E.471606). The authors confirm that recognized standards were followed while conducting the study (Declaration of Helsinki, US Federal Policy for the Protection of Human Subjects, and European Medicines Agency Guidelines for Good Clinical Practice). The clinical trial was registered on Clinicaltrials.gov (ID: NCT05790148) and was conducted in a university setting between August 2020 and August 2022.

In order to detect an effect size of 0.33 units (partial eta-squared = 0.10) with 80% power and a Type I error rate of 5%, it was calculated that at least 25 edentulous sites need to be included in the study using G*Power 3.1 software.

Healthy adult patients without any local contraindications for implant treatment but with asymptomatic osseointegrated two bone-level implants (BLT/BL; RC/NC, Straumann Holding AG, Basel, Switzerland) to support a fixed restoration in the treatment of partially edentulous posterior sites were recruited for this study.

The inclusion criteria were as follows:

1. Patients with good oral hygiene habits;
2. Healthy gingiva with intact periodontium;[21]
3. No removable prostheses;
4. No need for occlusal surface treatment in the opposing arch;
5. No unrestored gap in the opposing arch;
6. Stable maxillomandibular relationship;
7. No temporomandibular disorder;

ENROLLMENT	PRACTICE	LABORATORY		RESTORATION	OUTCOME MEASUREMENTS	
Study Group	Scanning	CAD	CAM	Preparation	Clinical	Analytical
Partial Edentulism *Maxilla & mandible* *Posterior* *Implant FDP*	Digitalization *Full-arch 2-stage* *Scan body* *original* *non-original* *generic*	Implant Library *SB matching* *connection selection* Full-contour design	Manufacturing *subtractive* *PMMA*	Titanium insert connection *original x2* *compatible* Model-free Manual Resin cement	Restoration trial *fit to implants* *contacts to teeth* *adjacent* *opposing*	Position transfer *3D implant axes*

Fig. 2. Overview of the study design and the elements for treatment of short-span partial edentulism with implants following complete digital workflow (PMMA: polymethyl methacrylate).

8. First-time exposure to intraoral scanning technology.

Participants fulfilling the inclusion criteria signed an informed consent form.

The maximum number of implant-supported FDPs in a patient was one per quadrant, with a total of two restorations in the upper and lower jaws without being an antagonist to each other. The clinical protocol was performed simultaneously in patients with two partially edentulous sites.

The position of the implants in the dental arch was digitally recorded using a wireless intraoral scanner (TRIOS3; 3Shape A/S, Copenhagen, Denmark) with ultrafast optical sectioning technology running an image-stitching algorithm (TRIOS software 19.2.0; 3Shape A/S, Copenhagen, Denmark). All scans were performed by the same investigator (FD), who had 1 year of experience with the scanner and its user interface. The clinical procedure took place in the same room, with an operating chair positioned five meters away from the window. Scanner calibration was performed before each patient under consistent room temperature and ambient light conditions, and the dental chair light was kept off during the scanning procedures. Before scanning, brief information about the intraoral scanners was provided verbally to all patients.

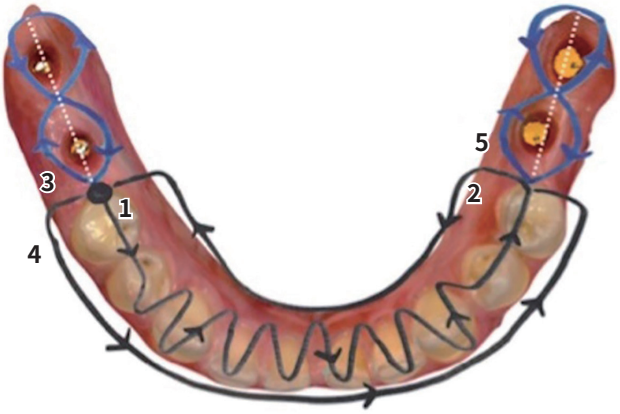

Fig. 3. Illustration of the continuous arch scanning strategy for the full-arch scan of the mandible with bilateral free-end edentulism. Paths with arrows in dentulous (black) and edentulous (blue) sites indicate three swipes (1: occlusal, 2: lingual, 4: buccal) and one wriggle (3: crestal and 5: crestal).

Original SBs (CARES Mono Scanbody; Straumann Holding AG, Basel, Switzerland), non-original SBs (Scanbody 2. Generation; Medentika GmbH, Hügelsheim, Germany), and generic SBs (3Shape Scanbody; 3Shape A/S, Copenhagen, Denmark) were consecutively used at random to digitize implant positions for each edentulous site.

A full-arch with a two-stage approach was performed for the jaw with implant digitalization. In the first stage, dental arch scanning was performed along three consecutive paths, followed by scanning of the edentulous ridge. During soft tissue scanning, the scanner tip was slightly inclined in the buccolingual direction, ensuring coverage without omitting the one-third keratinized mucosa on the crest of the alveolar ridge (Fig. 3). Any scans presenting visual stitching issues were deleted. Once the quality of the arch scan was verified, implant locations were marked to indicate the automated cutout area. Subsequently, the brand-new SBs were placed with the reference scan area facing the buccal region and hand-tightened using a screwdriver for digital implant positioning data. The second-stage scanning commenced from the occlusal surface of the tooth adjacent to the edentulous ridge, providing a recognizable area for the image-stitching algorithm to merge the SB scan correctly into the arch scan. Following convergence, SB scanning was individually completed, starting from the top and progressing to the bottom in a round motion, one after another. The SB scans were carefully evaluated for deformation-free geometry, completeness at the SB reference area, and sufficient integration with the first scan in the SB base area (Fig. 4). Scan navigation was concluded by regular full-arch scanning of the non-restorative opposing jaw, following the protocol recommended by the manufacturer. The static jaw relationship was recorded at the maximum intercuspal position without SBs, following the procedure previously described in detail (3). Before post-processing, all scans were analyzed and approved by an investigator (KA) with intraoral scanning expertise. The case, along with its original file extension, was sent to the dental laboratory through a data-sharing portal (3Shape Communicate; 3Shape A/S, Copenhagen, Denmark) for CAD-CAM processing.

To generate the second digital implant positioning

https://doi.org/10.4047/jap.2025.17.2.70

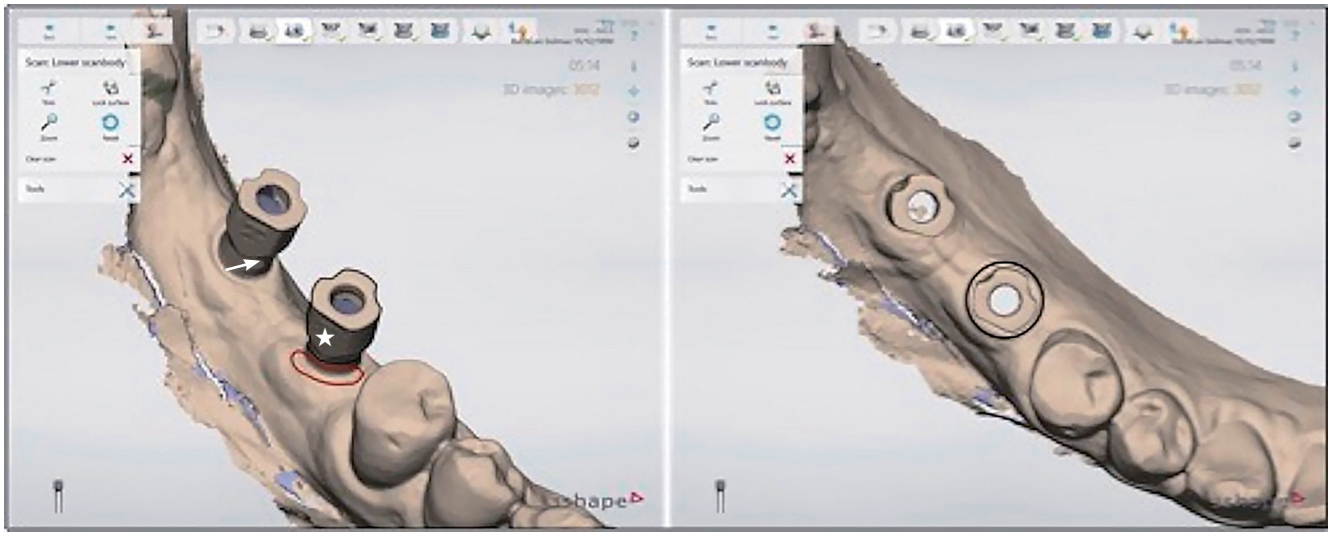

Fig. 4. Verification of SB scan appropriateness: deformation-free geometry (black outline), hole-free scan for reference area (white star), sufficient integration to arch scan (red circle), and surface smoothness (white arrow).

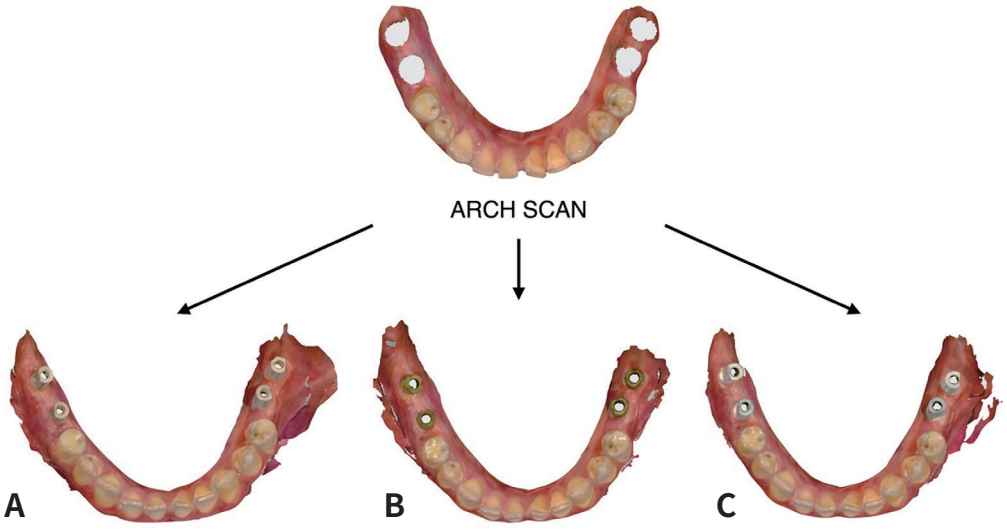

Fig. 5. Implant scanning with three different SBs for two edentulous sites in a patient following the full-arch two-stage scanning protocol. Notably, the arch-scan (1st stage) was kept as a reference for the SB scans (2nd stage). (A) Original SB, (B) Generic SB, (C) Non-original SB.

data for the next SB scan in a random order, the initial case was copied, and scan navigation was rearranged by resetting the SB scan while retaining the previously scanned arch. Only the SB scanning was reiterated following the second-stage procedure described above, and the results were sent to the dental laboratory without modifications to the opposing arch and bite scans. This process was iterated for the third SBs in the randomization sequence (Fig. 5).

Following acceptance of the order and the preparation of the intraoral scans, the dental laboratory configured the appropriate settings for the implant system to proceed with data medium exchange using dental CAD software (3Shape Dental System v.2020; 3Shape A/S, Copenhagen, Denmark). Accordingly, the SB reference area in the scan was selected to match the CAD library .stl file. After achieving accurate surface alignment, a digital-analog implant

of the correct connection type was automatically placed in the virtual model. Subsequently, a full-contour screw-retained restoration design with an appropriate abutment interface supplied by the SB library was completed. Before manufacturing the restoration, the researcher (FD) examined the proposed design, particularly for the emergence profile, to facilitate a clinical try-in without excessive compression of the peri-implant soft tissue. The final digital design was manufactured using a polymethylmethacrylate (PMMA) block (Dental PMMA, Tian Shwu Co., Ltd., TS, Tainan city, Taiwan) using a milling machine (CORITEC 350i Loader; Imes-icore GmbH, Eiterfeld, Germany).

Appropriate non-engaging titanium inserts, selected in CAD and available from the SB's implant library provider, were manually placed individually into the restoration. The circular fit between the restoration and the titanium insert bases was assessed using a dental loupe at 2.5× magnification. Subsequently, they were connected using dual-cure resin cement (RelyX U200, 3M ESPE, Neus, Germany). The cervical region of restoration including the metallic collar of ti-insert was carefully freed of excess cement to visually verify the fit, and the occlusal screw access as well. This procedure was replicated for other orders with different SBs. To approximate the CADs particularly at occlusal and proximal surfaces for comparable clinical evaluation, the first full-contour design was referred as pre-preparation for the others in the dental CAD software. Totally, three three implant-supported model-free, monolithic, PMMA FDPs were completed for an edentulous site included in the study. The restoration-related technical properties of SBs, CAD libraries, and titanium inserts are presented in Table 1.

In clinical evaluation of FDPs, a standardized approach to qualifying delivery conditions was applied by one researcher (FD) using a dental loupe at 2.5× magnification. Accordingly, restorations were randomly evaluated based on the sequence of the insertion path, adjacent contact(s), and relationship to the opposing arch. The procedure was performed consecutively for patients having two restorative sites.

Concerning the insertion path, first, the restoration without screws was placed gently over the implants at the edentulous site and slightly pressed with a finger until a tactile sensation of implant-abutment mating was felt.[22] Second, once the insertion path was perceived, the fit of the restoration was verified with

Table 1. SB hardware properties, software characteristics, and restorative connections with their developers according to the SBs used in the study

		SCAN-BODY	CAD LIBRARY	CONNECTION
BONE LEVEL IMPLANT BLT/BL; RC/NC, Straumann Holding AG, Basel, Switzerland	ORIGINAL	PEEK, 1-piece design cylindrical, beveled RA CARES Mono Scanbody RC/NC: 025.4912/025.2915 Straumann Holding AG Basel, Switzerland	free access https://www.straumann.com/digital/us/en/home/connectivity.html	non-engaging Variobase bridge/bar cylindrical RC/NC: 022.0111/022.0110 Straumann Holding AG Basel, Switzerland
	NON-ORIGINAL	PEEK-titanium, 2-piece design cylindrical, flat surfaced RA Scanbody L-Series RC/NC: L1410/L1400 Medentika GmbH Hügelsheim, Germany	free access https://www.straumann.com/digital/us/en/home/connectivity.html	non-engaging Ti-base bridge/bar 2nd generation RC/NC: L1510/ L1500 Medentika GmbH Hügelsheim, Germany
	GENERIC	aluminum, 1-piece design cylindrical, polygonal RA 3Shape Scanbodies Straumann bone-level: 80610246 3Shape A/S Copenhagen, Denmark	free access https://www.straumann.com/digital/us/en/home/connectivity.html	non-engaging Variobase bridge/bar cylindrical RC/NC: 022.0111/022.0110 Straumann Holding AG Basel, Switzerland

SB: scan body, RA: reference area, BL: bone level, BLT: bone level tapered, RC: regular cross-fit, NC: narrow cross-fit, Ti: titanium.

https://doi.org/10.4047/jap.2025.17.2.70

a one-screw test under visual inspection and tactile sensation during the tightening of the FDP.[23,24] In cases of pain secondary to peri-implant mucosal compression, the screws were hand-tightened gradually after confirmation of relief. Upon achieving an acceptable connection to the implants, intra- and inter-arch relationship evaluations were conducted using the adjusted anatomic form domain of the modified "California Dental Association" criteria (Table 2).[25] Proximal contact(s) were then graded using dental floss (Curaprox PTFE Dental Tape, Curaden AG, Kriens, Switzerland), while the occlusal interface quality was assessed based on adjustments made by articulating paper (100 μm), -film (12 μm) (Progress and Arti-Fol Metallic, Bausch, Nashua, NH, USA) in blue color, and articulating-paper in blue color (100 μm), red (40 μm) (Progress and Arti-Check, Bausch) for static- and dynamic-occlusion, respectively. Finally, the unscrewed restorations were carefully checked using a scaler for any separation failure between the titanium inserts and the restoration at the cement interface.

For reverse engineering process, implants were individually defined as mesial and distal, referring to the location with respect to the median line toward and away, respectively. To quantify the implant axis, a jaw scan including the SB scans without matching with its CAD library was exported from the software (3Shape TRIOS 19.2.0, 3Shape A/S, Copenhagen, Denmark) in a .stl file format and imported into reverse engineering software (Geomagic Design X v. 2016.1.0, 3D Systems Inc., Rock Hill, SC, USA). Cylindrically segmented sections of the SB were referred to identify the geometrical center of the surface scan data to create a vector representing the implant axis. Following the definition of the implant axes, the angulation of each vector relative to the reference planes (X, Y, and Z) was recorded. The procedure was repeated for the second and third SBs to complete a case of quantification of the digitized implant positions. Because the dental arch scan was maintained using the two-stage scanning protocol in which SB scans were modified, the coordinate positioning of an edentulous site with original, non-original, and generic SBs remained unchanged (Fig. 6).

Table 2. Grading occlusal and proximal contacts in the qualification of restorations

OCCLUSAL	1	EXCELLENT	no adjustment
	2	ACCEPTABLE	minor adjustment; 1-2 articulation paper use
	3	CORRECTION	major adjustment; 3-4 articulation paper use
	4	REPLACEMENT	destroyed surface or no contact
PROXIMAL	1	EXCELLENT	tight; strong flossing
	2	ACCEPTABLE	smooth; gentle flossing
	3	CORRECTION	slight; weak flossing
	4	REPLACEMENT	no contact

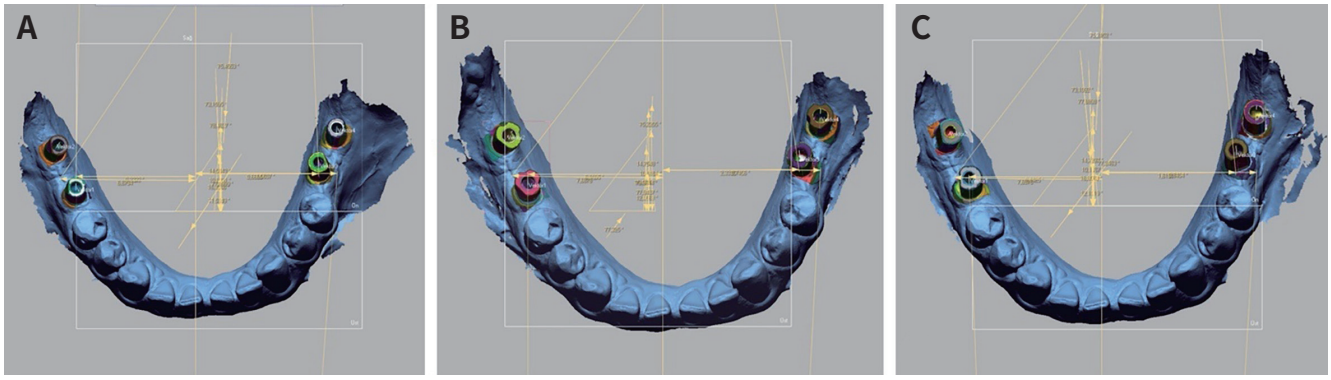

Fig. 6. Virtual identification of implant axes by circular segmenting of SB scans, and recording of axes angulations to X-, Y-, and Z-planes defined according to the reference arch scan. (A) Original SB, (B) Generic SB, (C) Non-original SB.

Upon completion of the research data collection, the participants received a implant-supported monolithic zirconia FDP fabricated from the scans with the original SB as a permanent restoration.

Clinically qualified restorative outcomes were statistically analyzed via the chi-square test, and their descriptive statistics with regards to SB type and restoration location were carried out as counts and percentages. Analytically quantified implant axes at -X, -Y and -Z dimensions were evaluated using generalized estimating equations, and their descriptive analysis with regards to SB type and implant location were evaluated using the mean (standard deviation) and median (interquartile range). The significance level was set at $P < .05$. All statistical analyses were performed using the SPSS software (v23.0; IBM Corp., New York, NY, USA).

This study was conducted in accordance with the SRQR (Standarts for Reporting Qualitative Research) guidelines.[26]

RESULTS

Nineteen patients, consisting of 8 males and 11 females, with a mean age of 51.1 and 47.4 years, respectively, were recruited for this study. The study population had a total of 50 implants supporting 25 FDPs. Thirteen patients had one edentulous site, while the rest had two sites. Of the six patients with two sites, four had bilateral edentulism, while the other two had cross-quadrant edentulism. Twenty-five fixed restorations were established in the 29 interproximal contacts (Table 3).

Twenty-five each for the original, non-original, and generic SBs, totaling 75 FDPs were clinically evaluated. Regarding the path of insertion, none of the restorations required adjustment for interproximal contacts, tension of the retaining screws, or both. Replacement was not indicated for any restoration in either the inter- or intra-arch relationship evaluations. Quality assessments of the proximal and occlusal contacts are presented in Table 4. The difference in proximal contact gradings for different SBs did not differ statistically between the lower and upper jaws ($P = .799$ and $P = .934$, respectively), nor did the difference in occlusal adjustments for the upper jaw ($P = .226$) and lower jaw ($P = .427$). None of the titanium inserts were disconnected from the restorations.

The descriptive statistics for the analytical implant axes recordings are summarized in Table 5. Upper and lower jaw scans with non-original and generic SBs did not present statistically significant differences in implant positions calculated in -X, -Y and -Z dimensions when compared to the original SBs for both mesial and distal implants ($P > .05$) (Table 6).

Table 3. Characteristics of partial edentulous posterior sites and the fabricated restorations

	EDENTULISM (CONTACT #)			RESTORATION		
	tooth-bounded	free-end	total	2-unit	3-unit	total
MAXILLA	6 (3)	11 (11)	17 (14)	3	11	14
MANDIBLE	2 (1)	10 (10)	12 (11)	5	6	11

Table 4. Counts and percentages of intra- and inter-arch relationships. Grade 4 and Grades 3 & 4 were not observed for any trial restoration for proximal and occlusal contacts, respectively

		PROXIMAL			OCCLUSAL	
		1	2	3	1	2
MAXILLA	original	8 / 47.05%	8 / 47.05%	1 / 5.88%	11 / 78.57%	3 / 21.43%
	non-original	9 / 52.92%	6 / 35.29%	2 / 11.76%	13 / 92.86%	1 / 7.14%
	generic	9 / 52.92%	7 / 41.16%	1 /5.88%	13 / 92.86%	1 / 7.14%
MANDIBLE	original	5 / 41,67%	5 / 41,67%	2 / 16,66%	10 / 90.9%	1 / 9.1%
	non-original	5 / 41.67%	4 / 33.33%	3 / 25%	9 / 81.8%	2 / 18.2%
	generic	7 / 58.34%	4 / 33.33%	1 / 8.33%	11 / 100%	-

https://doi.org/10.4047/jap.2025.17.2.70

Table 5. Descriptive statistics for quantified implant axes calculated by reverse engineering software

		MAXILLA								MANDIBLE							
		mean		SD		median		IQR		mean		SD		median		IQR	
		M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D
ORIGINAL	-x	8.35	8.27	5.816	5.893	7.65	6.35	7.94	6.23	4.50	6.55	3.788	4.752	4.68	6.43	5.72	4.24
	-y	11.10	9.73	9.229	6.264	7.56	9.61	12.38	10.00	10.19	11.88	5.147	6.823	11.79	9.78	10.62	8.75
	-z	75.28	76.16	10.25	7.001	75.98	77.16	11.07	11.16	79.23	74.30	4.848	5.493	78.72	75.58	8.75	9.50
NON-ORIGINAL	-x	8.50	8.20	5.967	5.658	7.89	6.67	7.89	6.06	4.31	6.29	3.136	4.928	5.11	6.01	4.49	3.65
	-y	10.97	9.56	8.813	6.605	7.79	8.69	12.47	9.59	10.23	12.14	5.268	6.951	12.18	10.64	10.37	9.01
	-z	75.28	76.10	9.924	7.017	75.49	77.04	10.02	10.79	79.55	75.14	4.733	5.964	79.01	76.32	8.33	10.87
GENERIC	-x	8.15	8.21	5.895	5.403	7.98	6.43	8.78	6.32	4.05	6.32	3.676	5.510	4.43	5.35	4.78	3.68
	-y	11.00	9.87	9.187	6.778	7.57	9.75	12.21	10.88	9.79	12.15	5.218	6.520	10.81	9.71	9.99	8.15
	-z	75.40	76.16	10.10	7.218	75.91	76.81	10.00	10.86	79.83	75.08	4.512	5.824	79.19	76.03	7.63	8.74

M: mesial implant. D: distal implant. SD: standard deviation. IQR: interquartile range.

Table 6. Statistics for implant axes with non-original and generic SBs connected to mesial & distal implants in comparison with original SBs. accepted as nominal

			MESIAL					DISTAL				
					95% Wald Confidence Interval		Hypothesis Test			95% Wald Confidence Interval		Hypothesis Test
			B	Std. Error	Lower	Upper	Sig.	B	Std. Error	Lower	Upper	Sig.
-x	MAXILLA	generic	-.451	.4974	-1.426	.524	.364	-.064	.2008	-.457	.330	.751
		non-original	-.187	.2512	-.679	.306	.457	-.076	.1530	-.375	.224	.622
		original	0[a]					0[a]				
	MANDIBLE	generic	-.197	.1804	-.551	.156	.274	-.231	.4719	-1.156	.694	.625
		non-original	.151	.1075	-.059	.362	.159	-.265	.2332	-.722	.192	.256
		original	0[a]					0[a]				
-y	MAXILLA	generic	-.107	.0951	-.293	.080	.262	.142	.2060	-.262	.545	.492
		non-original	-.134	.1614	-.450	.182	.407	.170	.3200	-.797	.457	.596
		original	0[a]					0[a]				
	MANDIBLE	generic	-.404	.4720	-1.329	.521	.392	.270	.3869	-.489	1.028	.486
		non-original	.033	.2397	-.437	.502	.892	.260	.1965	-.125	.645	.185
		original	0[a]					0[a]				
-z	MAXILLA	generic	.117	.1293	-.136	.371	.364	-.001	.1759	-.346	.343	.995
		non-original	.002	.1558	-.304	.307	.991	-.059	.0944	-.244	.126	.534
		original	0[a]					0[a]				
	MANDIBLE	generic	.593	.5377	-.461	1.647	.270	.786	1.0092	-1.192	2.764	.436
		non-original	.316	.1994	-.075	.707	.113	.844	1.0282	-1.171	2.859	.412
		original	0[a]					0[a]				

0[a]: redundant parameter set to zero. β: beta coefficient. Sig.: significance. $P = .05$.

DISCUSSION

This study found that the delivery conditions of screw-retained short-span full-contour digitally fabricated implant-supported FDPs using original, non-original, or generic SBs with different hardware specifications were clinically acceptable. Additionally, the quantified implant axes for non-original and generic SBs did not show statistically significant differences compared to those for original SBs. Therefore, the null hypothesis of this clinical trial was not rejected, suggesting that implant SB specifications are not crucial in the complete digital workflow.

Open-tray and closed-tray conventional impressions were compared with digital impressions of implants in the treatment of free-end partial edentulism in a controlled trial.[27] The study design included trueness evaluation using a best-fit algorithm to calculate discrepancies among superimposed scans, and the results were significantly better for the intraoral scanning of implants using SBs. The restorative accuracy of two implant-supported FDPs fabricated using conventional and digital impressions has been clinically evaluated in terms of fit and proximal and occlusal contacts.[28] The required adjustments were comparable for both impression techniques.

A meta-analysis analyzing clinical outcomes of implant-supported FDPs in majority limited to single tooth crowns concluded that digital and conventional impressions show no significant differences.[29] However, a randomized controlled clinical trial recently evidenced favorable short term clinical outcomes for two-implant supported FDPs fabricated from digital impressions.[30] The current study group, therefore, was established to expand the scientific knowledge related to implant-supported FDPs digitalization for short-span edentulous arches.

Full-arch scanning was employed in the current study to optimize bite registration with the available occlusal contacts at maximum intercuspation, and to follow daily clinical practice for partial edentulism as well. The trueness and precision of the hardware and the software used in the study are validated for partially edentulous arches with implants in a systematic review and network meta-analysis that comprehensively evaluated the accuracy of different intraoral scanners.[31]

Although the clinical outcomes for digital implant impressions with SBs are promising, the knowledge remain debatable for SBs with different specifications. Recently, the characteristics of SBs were systematically reviewed based on 28 *in vitro* studies.[32,33] Geometric and material differences were investigated in nine and six studies, respectively. The trueness and precision of 3D digital implant positioning were mostly evaluated without testing the restorative accuracy, and the results were inconclusive. Understanding the properties of SB is currently based on *in vitro* studies without any encouraging parameters; therefore, clinical interpretation is still needed. Furthermore, the understanding of uncertainties regarding implant SBs is reduced when different CAD library files are considered.

Therefore, to contribute to the growing body of knowledge, this clinical trial investigated intraoral implant scanning with original, non-original, and generic SBs with different hardware and software characteristics. Both qualitative evaluations for restorations and quantitative calculations for implant axes did not differ significantly among the SBs. To our knowledge, this study is the first to validate the finding that SBs differing in material and geometry can be accurately scanned for the digital lab processing of short-span implant-supported FDPs. To improve knowledge on implant scanning, the interpretation of outcomes may be optimized by simply discussing the scanning strategy.

Fewer commonalities, including the shape, color, and texture of the surface to be scanned, pose a challenge for the stitching algorithm to align the captured images without deformation. This becomes a potential problem in posterior edentulism, with multiple SBs surrounded by movable soft tissues that easily interfere with the scan area. In this study, a two-stage protocol involving arch and implant scanning was employed to follow a dissimilar strategy separately for anatomic versus non-anatomic surfaces. In this regard, a continuous swipe approach regularly suggested for dental restorations was carried out in the first stage, followed by individual scanning of the SBs after the second stage. We believe that this approach facilitates SB scanning in practice.

In essence, the two-stage approach involves the automated merging of an additional scan into intentionally prepared holes within the prior home scan. The accuracy of the final data was questioned *in vitro*[34,35] and whether the"cut out and rescan" procedure affects accuracy remains unclear. Nevertheless, Revilla-León *et al*.[36] clinically supported their earlier experimental outcomes, showing reduced trueness and precision in dentate quadrant arch scanning. However, the superimposition of scan data using the best-fit algorithm methodology, which was employed in the aforementioned studies, has the disadvantage of a significant deviation of the test surface from the reference owing to the calculation methodology.[37] Additionally, the "cut-out and rescan" procedure was considered for dental surfaces that required modifications without changes in the existing scan, in which expectations differ from implant scanning in a staged approach, such as the completeness of the prepared tooth surface vs. deformation-free SB surface scans. This study demonstrates the predictable restorative accuracy of digital implant positioning using staged scanning for short-span implant-supported FDPs. However, for scan accuracy, keeping similar lighting and temperature conditions for "cut-out & rescan" procedure and having sufficient experience to carefully follow the appropriate stitching of additional scan data into the cut-out section may be recommended.[36]

The scanning of geometric surfaces is susceptible to challenges related to the accurate alignment of additional images acquired continuously. Consequently, the accuracy of the digital positioning of distanced implants, particularly in the edentulous region, is susceptible. Rutkūnas *et al*.[38] presented a technique using additional reference objects that had a limited effect on accuracy parameters for digital impressions of implants placed in a partially edentulous experimental model. The defined digitalization protocol, employing an individual scanning tactic for SBs, in the current study resulted in a deformation-free reconstruction of the geometry to transfer distant implant positions.

The use of PMMA in the fabrication of FDPs to evaluate restorative accuracy may be considered a limitation due to its higher elasticity compared with permanent materials. Therefore, one may argue that the assessment of the restoration fit may be misleading in the identification of active screw connections to implants if they exist. However, clinical reports have presented the use of digitally designed and PMMA-milled prototype prostheses and verification jigs to assess the fit of screw-retained full-arch implant-supported FDPs.[39,40] Moreover, conventional verification jigs produced manually using auto-polymerizing PMMA from the test casts were digitally compared with the reference model and accepted as essential tools in the verification of passive fit before the fabrication of permanent restorations.[41] Nevertheless, assuming that the flexibility of PMMA may cause misleading information in cases presenting a misfit, the cement interface between the restoration and titanium inserts was carefully checked for disconnection in the current study.

One may question unblinded intraoral scans with various scan bodies as a methodological bias. However, the clear distinction between the appearances of the scan bodies precludes blinding of the investigator. The definition of the study group may be considered as a limitation of the present study. Future studies with larger sample size and different edentulous sites for longer span implant-supported FDPs would be helpful to generalize the outcomes of the current study.

CONCLUSION

Short span implant-supported FDPs produced following complete digital workflow using various SBs with different geometries, materials, types and CAD libraries are clinically predictable and acceptable. Additionally, various SBs can be safely surface scanned to match with their library files for 3D implant position transfer.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Pınar Öztürk for the statistical analysis.

REFERENCES

1. Christensen GJ. Impressions are changing: deciding on conventional, digital or digital plus in-office mill-

ing. J Am Dent Assoc 2009;140:1301-4.
2. Ireland AJ, McNamara C, Clover MJ, House K, Wenger N, Barbour ME, Alemzadeh K, Zhang L, Sandy JR. 3D surface imaging in dentistry - what we are looking at. Br Dent J 2008;205:387-92.
3. Karasan D, Sailer I, Lee H, Demir F, Zarauz C, Akca K. Occlusal adjustment of 3-unit tooth-supported fixed dental prostheses fabricated with complete-digital and -analog workflows: a crossover clinical trial. J Dent 2023;128:104365.
4. Ahlholm P, Sipilä K, Vallittu P, Jakonen M, Kotiranta U. Digital versus conventional impressions in fixed prosthodontics: a review. J Prosthodont 2018;27:35-41.
5. Christensen GJ. Will digital impressions eliminate the current problems with conventional impressions? J Am Dent Assoc 2008;139:761-3.
6. Seelbach P, Brueckel C, Wöstmann B. Accuracy of digital and conventional impression techniques and workflow. Clin Oral Investig 2013;17:1759-64.
7. Alikhasi M, Alsharbaty MHM, Moharrami M. Digital implant impression technique accuracy: a systematic review. Implant Dent 2017;26:929-35.
8. Sawase T, Kuroshima S. The current clinical relevancy of intraoral scanners in implant dentistry. Dent Mater J 2020;39:57-61.
9. Mizumoto RM, Yilmaz B. Intraoral scan bodies in implant dentistry: a systematic review. J Prosthet Dent 2018;120:343-52.
10. Mangano F, Lerner H, Margiani B, Solop I, Latuta N, Admakin O. Congruence between meshes and library files of implant scanbodies: an in vitro study comparing five intraoral scanners. J Clin Med 2020;9:2174.
11. Lerner H, Nagy K, Luongo F, Luongo G, Admakin O, Mangano FG. Tolerances in the production of six different implant scanbodies: a comparative study. Int J Prosthodont 2021;34:591-9.
12. Sawyers J, Baig MR, El-Masoud B. Effect of multiple use of impression copings and scanbodies on implant cast accuracy. Int J Oral Maxillofac Implants 2019;34:891-8.
13. Arcuri L, Pozzi A, Lio F, Rompen E, Zechner W, Nardi A. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: a randomized in vitro trial. J Prosthodont Res 2020;64:128-36.
14. Revilla-León M, Smith Z, Methani MM, Zandinejad A, Özcan M. Influence of scan body design on accuracy of the implant position as transferred to a virtual definitive implant cast. J Prosthet Dent 2021;125:918-23.
15. Çakmak G, Yilmaz H, Treviño A, Kökat AM, Yilmaz B. The effect of scanner type and scan body position on the accuracy of complete-arch digital implant scans. Clin Implant Dent Relat Res 2020;22:533-41.
16. Gimenez-Gonzalez B, Hassan B, Özcan M, Pradíes G. An in vitro study of factors influencing the performance of digital intraoral impressions operating on active wavefront sampling technology with multiple implants in the edentulous maxilla. J Prosthodont 2017;26:650-5.
17. Motel C, Kirchner E, Adler W, Wichmann M, Matta RE. Impact of different scan bodies and scan strategies on the accuracy of digital implant impressions assessed with an intraoral scanner: an in vitro study. J Prosthodont 2020;29:309-14.
18. Pesce P, Pera F, Setti P, Menini M. Precision and accuracy of a digital impression scanner in full-arch implant rehabilitation. Int J Prosthodont 2018;31:171-5.
19. Canneto JJ, Cattani-Lorente M, Durual S, Wiskott AH, Scherrer SS. Grinding damage assessment on four high-strength ceramics. Dent Mater 2016;32:171-82.
20. Hatanaka GR, Polli GS, Fais LMG, Reis JMDSN, Pinelli LAP. Zirconia changes after grinding and regeneration firing. J Prosthet Dent 2017;118:61-8.
21. Lang NP, Bartold PM. Periodontal health. J Periodontol 2018;89 Suppl 1:S9-S16.
22. Figueras-Alvarez O, Cantó-Navés O, Real-Voltas F, Roig M. Protocol for the clinical assessment of passive fit for multiple implant-supported prostheses: a dental technique. J Prosthet Dent 2021;126:727-30.
23. Kan JY, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. J Prosthet Dent 1999;81:7-13.
24. White GE. Osseointegrated dental technology. Carol Stream, IL: Quintessence Publishing Co, Inc; 1993.
25. Kokubo Y, Tsumita M, Nagayama Y, Sakurai S, Yamazaki S, Kuga M, Ohkubo C, Fukushima S. Clinical evaluation of in-ceram crowns fabricated using GN-I system: preliminary results after 24-39 months of use. Prosthodont Res Prac 2007;6:265-71.
26. O'Brien BC, Harris IB, Beckman TJ, Reed DA, Cook DA. Standards for reporting qualitative research: a synthesis of recommendations. Acad Med 2014;89:1245-

51.
27. Dohiem MM, Abdelaziz MS, Abdalla MF, Fawzy AM. Digital assessment of the accuracy of implant impression techniques in free end saddle partially edentulous patients. A controlled clinical trial. BMC Oral Health 2022;22:486.
28. Derksen W, Tahmaseb A, Wismeijer D. A randomized clinical trial comparing the clinical fit of CAD/CAM monolithic zirconia Fixed Dental Prostheses (FDP) on ti-base abutments based on digital or conventional impression techniques. One year follow-up. Int J Prosthodont 2021;34:733-43.
29. Mahat NS, Shetty NY, Kohli S, Jamayet NB, Patil P. Clinical outcomes of implant-supported and tooth-supported fixed prostheses fabricated from digital versus analogue impression: a systematic review and meta-analysis. Evid Based Dent 2023;24:142.
30. Derksen W, Wismeijer D. Three-year follow-up of a randomized clinical trial on screw-retained monolithic zirconia restorations on ti-base abutments based on digital or conventional impression techniques. Int J Prosthodont 2023;36:410-5.
31. Vitai V, Németh A, Sólyom E, Czumbel LM, Szabó B, Fazekas R, Gerber G, Hegyi P, Hermann P, Borbély J. Evaluation of the accuracy of intraoral scanners for complete-arch scanning: a systematic review and network meta-analysis. J Dent 2023;137:104636.
32. Pachiou A, Zervou E, Tsirogiannis P, Sykaras N, Tortopidis D, Kourtis S. Characteristics of intraoral scan bodies and their influence on impression accuracy: a systematic review. J Esthet Restor Dent 2023;35:1205-17.
33. Revilla-León M, Lanis A, Yilmaz B, Kois JC, Gallucci GO. Intraoral digital implant scans: parameters to improve accuracy. J Prosthodont 2023;32(S2):150-64.
34. Gómez-Polo M, Piedra-Cascón W, Methani MM, Quesada-Olmo N, Farjas-Abadia M, Revilla-León M. Influence of rescanning mesh holes and stitching procedures on the complete-arch scanning accuracy of an intraoral scanner: an in vitro study. J Dent 2021;110:103690.
35. Reich S, Yatmaz B, Raith S. Do “cut out-rescan” procedures have an impact on the accuracy of intraoral digital scans? J Prosthet Dent 2021;125:89-94.
36. Revilla-León M, Sicilia E, Agustín-Panadero R, Gómez-Polo M, Kois JC. Clinical evaluation of the effects of cutting off, overlapping, and rescanning procedures on intraoral scanning accuracy. J Prosthet Dent 2023;130:746-54.
37. Sanda M, Miyoshi K, Baba K. Trueness and precision of digital implant impressions by intraoral scanners: a literature review. Int J Implant Dent 2021;7:97.
38. Rutkūnas V, Gedrimienė A, Al-Haj Husain N, Pletkus J, Barauskis D, Jegelevičius D, Özcan M. Effect of additional reference objects on accuracy of five intraoral scanners in partially and completely edentulous jaws: an in vitro study. J Prosthet Dent 2023;130:111-8.
39. Papaspyridakos P, Chen YW, Gonzalez-Gusmao I, Att W. Complete digital workflow in prosthesis prototype fabrication for complete-arch implant rehabilitation: a technique. J Prosthet Dent 2019;122:189-92.
40. Sinada N, Papaspyridakos P. Digitally designed and milled verification jigs generated from photogrammetry data acquisition: a clinical report. J Prosthodont 2021;30:651-5.
41. Papaspyridakos P, Kim YJ, Finkelman M, El-Rafie K, Weber HP. Digital evaluation of three splinting materials used to fabricate verification jigs for full-arch implant prostheses: a comparative study. J Esthet Restor Dent 2017;29:102-9.