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REVIEW

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Intraoral digital implant scans: Parameters to improve accuracy

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Abstract

Purpose: To report the means to maximize the predictability and accuracy of intraoral digital implant scans through the evaluation of operator and patient-related factors.

Materials and Methods: A search of published articles related to factors that can decrease the scanning accuracy of intraoral digital implant scans was completed in four data sources:MEDLINE, EMBASE, EBSCO, and Web of Science. All studies related to variables that can influence the accuracy of intraoral digital implant scans obtained by using intraoral scanners (IOSs) were considered. These variables included ambient lighting, scanning pattern, implant scan body (ISB) design, techniques for splinting ISBs, arch location, implant position, and inter-implant distance.

Results: Among operator-related factors, ambient lighting conditions, scanning pattern, and ISB design (material, geometry, and retention design) can impact the accuracy of intraoral digital implant scans. The optimal ISB for maximizing IOS accuracy is unclear; however, polymer ISB can wear with multiple reuse and sterilization methods. Among patient-related factors, additional variables should be considered, namely arch (maxillary vs. mandibular arch), implant position in the arch, inter-implant distance, implant depth, and angulation.

Conclusions: Ambient lighting conditions should be established based on the IOS selected to optimize the accuracy of intraoral digital implant scans. The optimal scanning pattern may vary based on the IOS, clinical situation, and the number of implants. The optimal ISB design may vary depending on the IOS used. Metallic implant scan bodies are preferred over polymer ISB designs to minimize wear due to multiple use and sterilization distortion. Among patient-related factors, additional variables should be considered namely the arch scanned, implant position in the arch, inter-implant distance, implant depth, and angulation. The impact of these factors may vary depending on the IOS selected.

KEYWORDS
accuracy, digital impressions, digital scans, implant scans, influencing factors, intraoral scanners, intraoral conditions, patient factors, operator factors

The implementation of intraoral scanners (IOSs) for varying dental interventions has grown in recent years.[1] In 2021, an investigation that evaluated the market penetration of IOSs in the US reported that the main reason for acquiring this technology was to improve clinical efficiency, followed by facilitating the transition from an analog to a digital practice.[1] However, in order to maximize the efficiency and accuracy of IOSs, it is fundamental to know the factors that can influence the scanning process and its outcomes.

Dental literature has identified operator and patient-related variables that can impact the accuracy of IOSs.[2,3] The operator factors include IOS technology and system,[4,5] scanning head size,[6] calibration,[7] ambient lighting illuminance conditions,[8–10] scanning pattern,[11,12] experience of the operator,[13,14] cutting-off, rescanning, and overlapping techniques,[15,16] extension of the scan,[4,12,17] and scanning depth and angulation.[18,19] Patient-related factors include the

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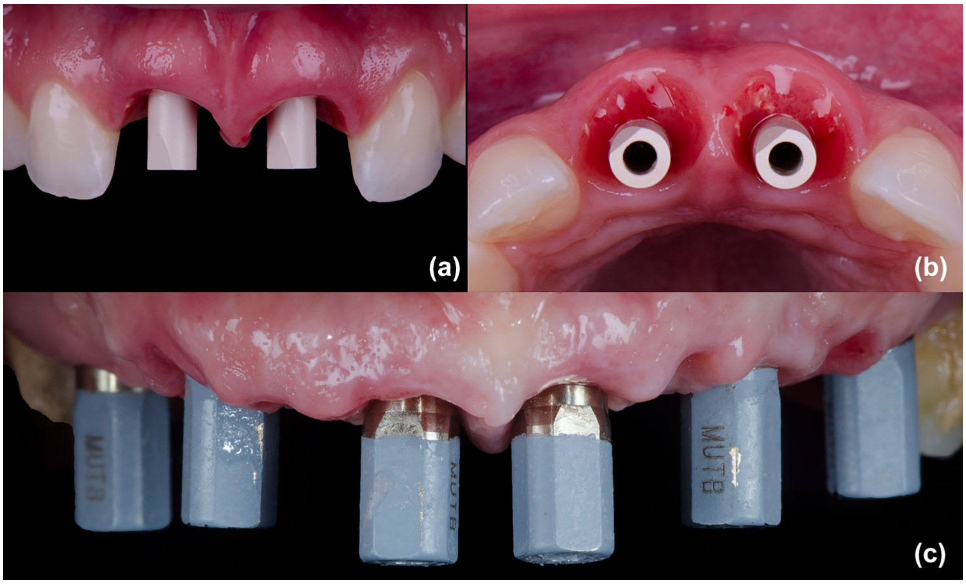

FIGURE 1 Implant scan bodies assist with the 3D implant position recording by using intraoral scanners. (a) 1-piece PEEK ISBs positioned for recording an intraoral digital implant scan. (b) Occlusal view of the 1-piece PEEK ISBs positioned for recording an intraoral digital implant scan. (c) 2-piece PEEK ISBs. ISB, Implant scan body.

intraoral conditions of the patient being scanned such as tooth type,[20] interdental spaces,[21,22] arch width,[23,24] palate characteristics,[25] wetness,[26,27] existing restorations,[28,29] geometry characteristics of the tooth preparation,[30–35] and edentulous areas.[36] However, the effect of some of these variables differ when obtaining intraoral digital implant scans namely ambient lighting conditions,[37] scanning pattern,[38–40] and interdental space (adjacent tooth and implant scan body). Furthermore, additional factors should be considered when recording intraoral implant digital scans such as implant depth and angulation,[41–45] inter-implant distance,[27,46,47] and implant scan body design (material, geometry, and retention system).[48–54]

The factors that can decrease intraoral scanning accuracy generate an accumulated scanning distortion.[2,3] Therefore, understanding and recognizing these influencing factors can help increase the predictability and reliability of dental treatments completed by using digital workflows. The objective of this manuscript is to describe the operator and patient-related factors that can reduce the accuracy of intraoral digital implant scans.

MATERIALS AND METHODS

A search of published articles related to factors that can decrease the scanning accuracy of intraoral digital implant scans was completed in four data sources: MEDLINE, EMBASE, EBSCO, and Web of Science. All studies related to variables that can influence the accuracy of intraoral digital implant scans obtained by using intraoral scanners (IOSs) were considered. These variables included ambient lighting, scanning pattern, implant scan body (ISB) design, techniques for splinting ISBs, arch location, implant position, and inter-implant distance.

TABLE 1 Operator and patient variables that can influence the scanning accuracy of intraoral digital implant scans.

Factor type	Factor
Operator	Ambient lighting conditions
	Scanning pattern
	Implant scan body design (material, geometry, and retention system)
	Scan body splinting techniques
Patient	Arch location
	Implant position in the dental arch
	Interimplant distance and implant depth and angulation
	Interdental space (adjacent tooth and implant scan body)

*Additional operator and patient factors have been identified that can reduce intraoral scanning accuracy. This table only reflects the variables related to the accuracy of intraoral digital implant scans.

RESULTS

Operator-related factors

Operator-related factors include the clinician's skill and decisions that can impact the scanning accuracy of IOSs.[2] There are mainly four operator-related variables: ambient lighting conditions,[37] scanning pattern,[38–40] implant scan body design,[48-54] and scanning technique used (scanbody splinting methods). When acquiring intraoral digital implant scans compared to scanning teeth, it is also important to consider the specific implant scan body (ISB) used (Figure 1). The implant scan body design[48–54] is the third operator-related factor that can influence the scanning accuracy with IOSs (Table 1).

TABLE 2 Recommended ambient lighting conditions for digitizing implant scan bodies.

Intraoral Scanner; Manufacturer	Optimal ambient lighting conditions
CS 3600; Carestream	500 Lux[37]
CS 3700; Carestream	100 Lux[37]
i500; Medit	1000 Lux[37]
iTero Element 5D; Align technologies	100 Lux[37]
PrimeScan; Dentsply Sirona	10,000 Lux[37]
Trios 3; 3Shape A/S	100 Lux[37]

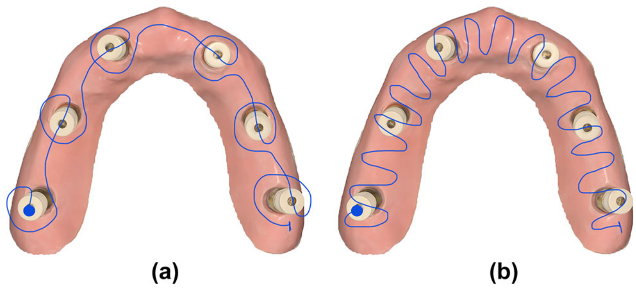

FIGURE 3 (a) Circumferential and (b) zigzag scanning patterns analyzed in the dental literature for obtaining intraoral digital implant scans.

Ambient lighting conditions

Ambient illuminance conditions can be defined as the intensity of the light (lux) of the room where the intraoral digital scan is obtained.[2] In order to measure the intensity of the light intraorally, a luxmeter is required. Previous in vitro and clinical studies on the influence of ambient light illuminance conditions on the accuracy of IOSs in completely dentate conditions[8–10,37,55,56] revealed that the optimal lighting condition for scanning completely dentate patients varies depending on the IOS selected.[2,8–10,55,56] Based on these studies, the trueness of an intraoral digital scan in completely dentate conditions can be reduced with an increase in deviations anywhere from 20 to 250 μm, while precision can be reduced with an increase in deviations anywhere from 10 to 110 μm depending on the lighting condition.[8–10] Therefore, it may be recommended to optimize and standardize ambient light conditions by using luxmeters.[2,8–10,37] Additionally, a room without windows may facilitate standardization by avoiding the influence of external light that changes.

One in vitro investigation assessed the influence of varying ambient light conditions on the scanning accuracy of complete-arch intraoral digital implant scans.[37] The results confirmed that the ambient lighting conditions impacted the accuracy of IOSs tested and that the optimal ambient lighting condition varied based on the IOS selected.[37] The optimal ambient illuminance condition for scanning completely dentate situations may be different than when scanning implant scan bodies (Table 2).[37]

Scanning pattern

Scanning pattern can be defined as the sequence at which the intraoral digital scan is acquired.[2] Generally, it is recommended to follow the scanning pattern recommended by the manufacturer of the IOS selected (Figure 2). Previous studies have demonstrated that the accuracy of an intraoral digital scan can be influenced by altering the scanning pattern.[11,12,57–62] However, the majority of these studies were performed on completely dentate conditions.[11,12,57–62] Limited studies have analyzed the influence of the scanning pattern on scanning accuracy of half- and complete-arch intraoral digital scans (Figure 3), reporting contradictory results (Table 3).[38–40,63,64]

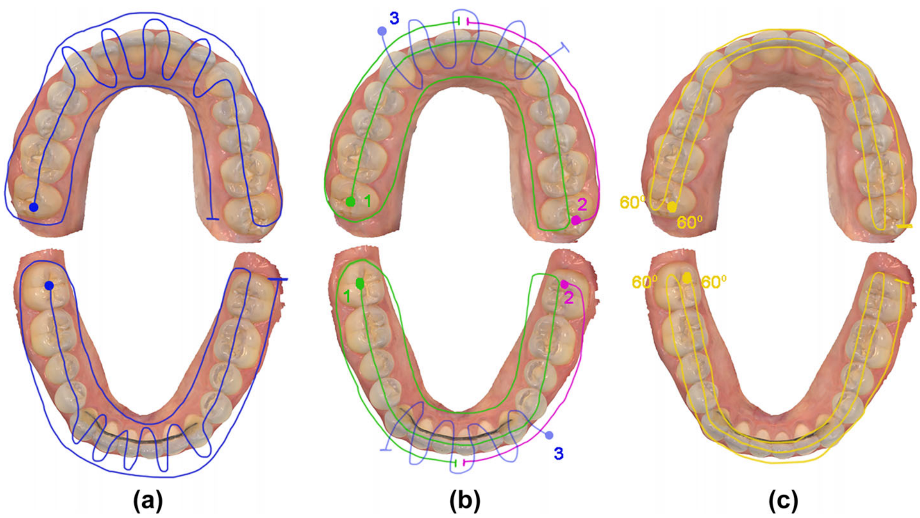

FIGURE 2 Scanning pattern recommended by the IOS manufacturer for completely dentate patients. (a) scanning pattern recommended for any generation of Trios from 3Shape A/S, IOSs from Medit, and IOSs from Carestream. (b) Scanning pattern recommended for any generation of iTero IOS from Align Technologies. (c) Scanning pattern recommended for Primescan from Denstply Sirona.

TABLE 3 Studies assessing the influence of the scanning pattern on the scanning accuracy of half- and complete-arch intraoral digital scans.

Study	Type study	IOS tested	Conditions	Implant scan body	Scanning patterns	Results
(Donmez et al.,[63] 2022)	In vitro ($n = 8$)	Trios 3, cart, v.1.4.7.5; 3Shape A/S	Partially edentulous cast with three implant analogs (right central incisor, first premolar, and first molar)	Snap on PEEK ISB, placed over PEEK healing abutment (ScanPeg; Neoss Implant System)	SP1- OLB, followed by occlusal zigzag and scanning the palate SP2 - OLB, followed by occlusal zigzag in ISB area SP3 - zigzag SP4 - OLB, followed by OLB in the ISB area	The CI implant had higher trueness than that of located at the PM site when SP2 and SP4 were used. The M implant had trueness either similar to when SP2 was used, or lower than when SP4 was used. Scans of the CI and PM implants had the lowest trueness when scanned with SP1, while the scans of M implant showed higher trueness when performed by using SP2 and SP3 when compared with SP4. When SP4 was used, the M implant had lower precision than the implants located at the CI and PM. Scan patterns affected the scan precision of CI implant, as SP4 led to a higher precision than SP1.
(Yilmaz et al.,[64] 2022)	In vitro ($n = 8$)	Trios 3, v.NA; 3Shape A/S	Mandibular partially edentulous cast with one implant analog (right first molar)	Snap on PEEK ISB, placed over PEEK healing abutment (ScanPeg; Neoss Implant System)	SP1- OLB, followed by occlusal zigzag SP2 - OLB, followed by occlusal zigzag in ISB area SP3 - zigzag SP4 - OLB, followed by OLB in the ISB area	Scan pattern affected the trueness and precision when angular deviations were considered. SP4 obtained the lowest accuracy.
(Li et al.,[38] 2022)	In vitro ($n = 10$)	Trios 3, v.1.7.3.1; 3Shape A/S CS 3600, v.7.0.20.7; Carestream	Edentulous maxillary cast with six implant analogs	1-piece PEEK ISB (CARES Mono scan body; Straumann)	SP1 - OBL SP2 - BL SP3 - B followed by L segmental SP4 - B segmental followed by L segmental SP5- Circumferential SP6 - Zigzag	For Trios, SP1 had higher trueness than the other SP tested, except SP6. SP1 had higher precision than SP2, SP3, and SP5. For CS, SP1 had lowest trueness, except SP5.
(Kanjanasavitree et al.,[39] 2022)	In vitro ($n = 10$)	Trios 4, v.NA; 3Shape A/S	Edentulous mandibular cast with four implant analogs	1-piece PEEK ISB (Osstem Implant Co.)	SP1 - LB SP2 - Circumferential SP3 – left quadrant LB, followed right quadrant LB	SP1 obtained the lowest accuracy compared with the other SP tested.
(Gómez-Polo et al.,[40] 2023)	In vitro ($n = 15$)	Trios 4, v.21.3; 3Shape A/S	Edentulous maxillary and mandibular cast with six implant abutment analogs each	1-piece PEEK ISB (Core Scanbody Transepithelial 1811; Core 3D centers)	SP1 - OBL SP2 - OLB SP3 - BLO SP4 - LBO SP5- Circumferential SP6 - Zigzag	The maxillary group obtained poorer trueness and precision than the mandibular group. The SP5 obtained the best trueness and precision values, but was not significantly different from the SP1, SP3, and SP4. The SP5 obtained the worst trueness and precision values.

Abbreviations: B, buccal; IOS, intraoral scanner; ISB, implant scan body; L, lingual; NA, not available; O, occlusal; SP, scanning protocol.

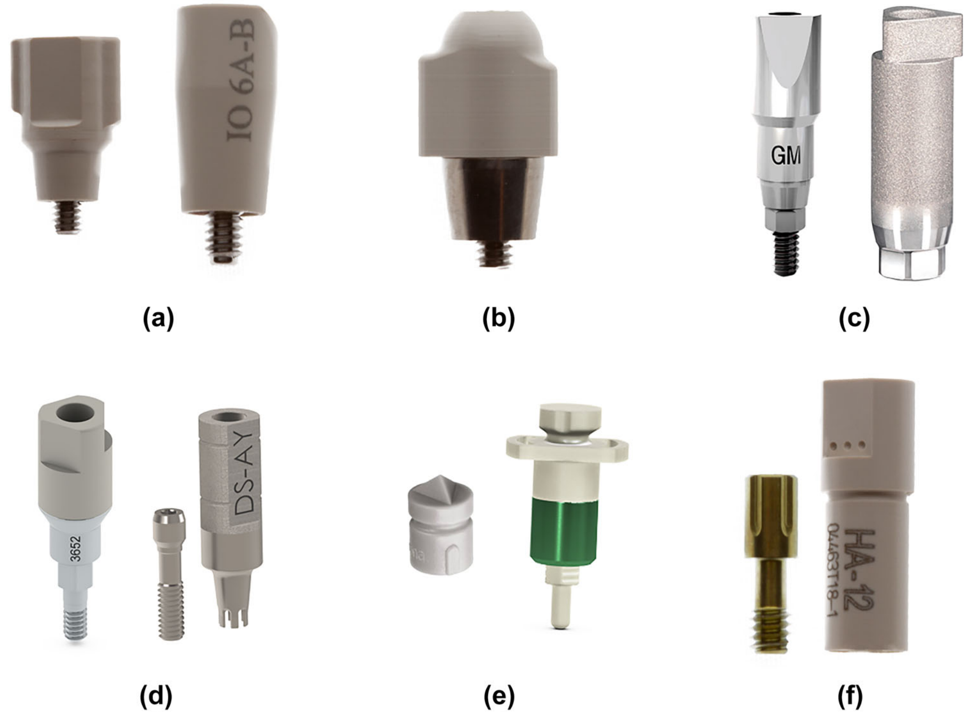

FIGURE 4 Examples of implant scan body designs. (a) 1-piece PEEK ISB. (b) 2-piece PEEK ISB. (c) Metallic ISB. (d) Screw-retained ISB. (e) Snapped-on ISB. (f) Magnet retained ISB. This ISB is composed of a screw-retained implant piece that has a magnet-retained PEEK body. ISB, implant scan body. PEEK, polyetheretherketone.

FIGURE 5 ISBs with the same geometry but manufactured with different materials: PEEK and titanium with a white coat.

Implant scan body design

Different implant scan body (ISB) designs are available in the market (Figures 4 and 5). The ISBs can be classified considering the material they are made of or their retention system (Table 4). Multiple ISB geometry and diameter designs are available. Additionally, some manufacturers also provide the same ISB at varying heights. However, it is fundamental to review the intraoral digital implant scan obtained and ensure that there are no scanning errors that may compromise the reliability of the data captured (Figure 6).

A few studies have assessed the influence of the ISB geometry and material on the scanning accuracy of intraoral digital scans involving single or multiple implants (Table 5).[48–54,65,66] These data, primarily from in vitro studies, do not support a systematic recommendation for selecting an ISB design. Furthermore, there may be no ISB design that optimally performs for all IOSs available.

Additional aspects should be considered when recording intraoral digital implant scans such as manufacturing tolerance of implant scan body[67] and position distortion caused by tightening torque[68–70] or repeated use.[71,72] Available data analyzing these three factors and how these variables impact intraoral scanning accuracy is scarce, which makes it difficult to establish systematic clinical recommendations.[67–70]

One in vitro study evaluated the manufacturing accuracy of six different ISBs by measuring the dimensions of five specimens of each ISB type tested.[67] Although the sample size was small, the authors reported mean discrepancy ranging from 13 to 58 μm in height, from 2 to 13 μm in diameter, and from 8 to 53 μm in the angle of the flat face on the top (plane).[67]

A limited number of studies have examined the influence of the tightening torque of ISBs on the vertical axis position and on the accuracy of intraoral digital implant scans (Table 6).[68–70] Overall, 1-piece polyetheretherketone (PEEK) ISB designs exhibited higher displacements compared with metallic ISBs.[68–70] Additionally, sterilization procedures might also affect the ISB positioning and

TABLE 4 Implant scan body classification.

Classification	Types	Definition
Material	1-piece PEEK	The entire ISB is fabricated with polymer material (majority of the time with PEEK).
	2-piece PEEK	The implant interface is metallic and the coronal part of the ISB is fabricated with polymer material (majority of the time with PEEK).
	Metallic	The entire ISB is metallic. The surface of the ISB is coated or treated aiming to facilitate the ISB scan ability properties.
Retention system	Screw-retained	The ISB is screwed into the implant or implant abutment. The recommended torque varies among the ISB manufacturers.
	Snap-on or friction	The ISB is snapped into the implant, implant abutment, or healing abutment, without the need for a screw.
	Magnet-retained	This retention system is usually related to a 2-piece PEEK ISB. The ISB is composed by 2 pieces: the metallic one that is screwed into the implant and the PEEK piece that is positioned over the metallic piece by using a magnet-retained system.

Abbreviations: ISB, implant scan body; PEEK, polyetheretherketone.

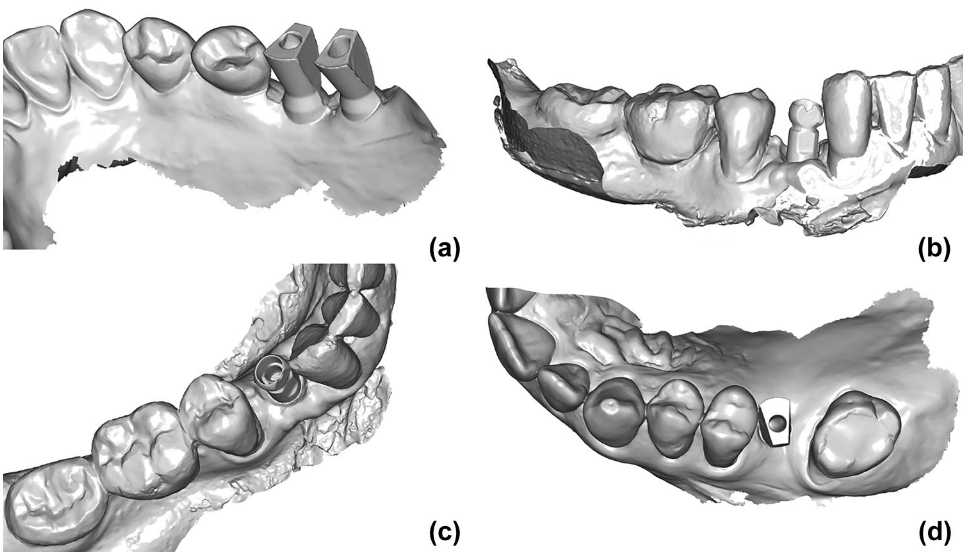

FIGURE 6 Examples of intraoral digital implant scans with scanning errors. (a) Inadequate geometry at the lingual surface of both ISBs due to stitching error caused by inadequate scanning pattern. (b) Improper scanning of the ISB geometry. (c) Lack of space between the ISB and the adjacent tooth. (d) Lack of space between the ISB and the adjacent tooth. ISB, implant scan body.

accuracy.[70] Therefore, based on available limited data, it might be recommended to choose a metallic ISB design, aiming to reduce displacement due to tightening or sterilization distortion of the PEEK material.[68–70] These results further support a single use for 1-piece PEEK ISBs.[70]

Repeated use of the ISBs can cause distortion of the ISB and impact the accuracy of intraoral digital implant scans.[71,72] Sawyers et al.[71] assessed the influence of 1-piece PEEK ISB wear (10 reuses without sterilization) on the accuracy of digital implant scans (laboratory scanner) in a partially edentulous cast with two dental implants in the right posterior area. The 3D mean discrepancy for all reused ISBs ranged from 39 to 143 μm. Additionally, the reuse of the ISB up to 10 times did not statistically affect the accuracy of the digital scan, except for one specimen.[71]

Arcuri et al.[72] tested the influence of ISB wear (30 reuses without sterilization) on the accuracy of complete-arch intraoral digital implant scans. The 1-piece PEEK ISB tested was torqued at 10 Ncm on each of the four implant analogs of the completely edentulous mandibular typodont. Authors reported a 3D mean discrepancy for all the reused ISB that ranged from 8 to 347 μm (mean of 82 μm). Data suggested that the higher the number of uses, the higher the distortion measured, being more accentuated in angulated implants.[72]

Scan body splinting techniques

Dental literature has analyzed the effect of different techniques for ISB splinting to maximize the accuracy of intraoral digital implant scans.[73] A recent systematic review analyzed different implant scan body splinting techniques to record complete-arch intraoral digital implant scans.[73] This study, published in 2021, revealed that 17 different

TABLE 5 Studies assessing the influence of the implant scan body design (material or geometry) on the accuracy of intraoral digital implant scans.

Study	Type study	IOS tested	Conditions	ISB material	ISB geometry	Results
(Arcuri et al.,[48] 2020)	In vitro ($n = 5$)	Trios 3, v.1.4.7.5; 3Shape A/S	Edentulous maxillary cast with six implant analogs	ISB-1: 1-piece PEEK ISB-2: 2-piece PEEK ISB-3: Metallic	Same geometry for all ISBs tested	The ISB material influenced scanning accuracy with ISB-1 showing the best results on both linear and angular measurements, followed by ISB-3, with ISB-2 showing the worst results.
(Schmidt et al.,[49] 2021)	In vitro ($n = 10$)	Trios 3, v.1.4.7.4; 3Shape A/S	Partially edentulous maxillary cast with four implant analogs (1 PM and 1 M)	ISB-1: 2-piece PEEK (Nt Trading) ISB-2: 2-piece PEEK (Kulzer) ISB-3: 1-piece PEEK (Medentika)	Each one presented varying geometry	No differences in trueness among the different ISB tested. Precision was found for right 1PM implant using ISB-1 and ISB-3 and left 1PM implant using ISB-1 and ISB-2.
(Tan et al.,[50] 2022)	In vitro ($n = 10$)	NA	Cast with 10 implants	ISB-1: 1-piece PEEK (Medentika) ISB-2: 1-piece PEEK (Straumann) ISB-3: 2-piece PEEK (Core 3D) ISB-4: 1-piece PEEK (Straumann) Lab ISB-1: Metallic (Nobel Procera) Lab ISB-2: Metallic (Sirona InPost) Lab ISB-3: 1-piece PEEK (Amann Girrbach) Lab ISB-4: 1-piece PEEK (Straumann) Lab ISB-5: 2-piece PEEK (Core 3D) Lab ISB-6: 1-piece PEEK (Straumann)	Each one presented varying geometry	Overall, ISB-4 and Lab ISB-6 were the least accurate
(Althubaitiy et al.,[51] 2022)	In vitro ($n = 11$)	Extraoral (E1; 3Shape A/S) IOS (Trios 3, v.NA; 3Shape A/S)	Partially edentulous mandibular cast with four implant analogs (PMs and 1Ms). Right side narrow implants, left side regular diameter	ISB-1: 1-piece PEEK (CARES Mono NP, RP; Straumann) ISB-2: Metallic (L1400, L1410; Medentika)	Same geometry for ISB-1 and ISB-2	The best results were obtained with the extraoral scanner with ISB-2, and the diameter was regular.
(Moslemion et al.,[66] 2020)	In vitro ($n = 10$)	Trios 3, v.1.4.7.5; 3Shape A/S	Edentulous maxillary cast with four implant analogs	ISB-1: 1-piece PEEK (Dess) ISB-2: 2-piece PEEK (Nt-Trading) ISB-3: Metallic (Doowon)	Each one presented varying geometry	ISB type and shape, and implant connection and angulation affected scanning accuracy. In general, this study showed greater changes in use of external implant connection and ISB-1.
(Lawand et al.,[52] 2022)	In vitro ($n = 15$)	Trios 3, Cart, v.20.1.1; 3Shape A/S	Edentulous maxillary cast with four implant analogs	Same ISB 1-piece PEEK (CARES Mono; Straumann)	3 ISB geometry modifications: - None - Subtractive (SM) - Additive (AM)	Discrepancies in 3D surface deviation were highest for the AM group (0.266 ±0.030 mm), and the lowest mean angular deviation values were for the SM group (0.993 ±0.062 degrees).
(Pan et al.,[65] 2022)	In vitro ($n = 10$)	Laboratory scanner (Evolution plus+; Zfx)	Edentulous maxillary cast with six implant abutments	ISB-1: 2-piece PEEK (Intrascan matchholder H4; Zfx) ISB-2: 2-piece PEEK (Evolution matchholder; Zfx)	Each ISB had a different geometry ISB-1: Dome-shaped ISB-2: Cuboidal shape	ISB-1 had less deviations than ISB-2.

Abbreviations: IOS, intraoral scanner; ISB, implant scan body; Lab, laboratory; M, molar; PEEK, polyetheretherketone; PM, premolar; Ti, titanium.

TABLE 6 Studies assessing the influence of implant scan body tightening on the implant scan body displacement.

Study	Type study	IOS tested	Conditions	ISB design	ISB torque	Results
(Kim et al.,[70] 2020)	In vitro ($n = 15$)	Laboratory scanner (NA)	Implant embedded into acrylic resin block	ISB-1: 1-piece PEEK (CARES Mono RN; Straumann) ISB-2: 1-piece PEEK (IOS Healing Abutment, Dentium) ISB-3: 2-piece PEEK (All PEEK Scanbody, Myfit)	Hand-torqued 5 Ncm 10 Ncm	The ISB displacement by tightening torque differed depending on the ISB tested. There was a vertical displacement <100 μm at 5 Ncm and 10 Ncm. But the hand torque resulted in vertical displacements >100 μm in ISB-2 and ISB-3.
(Shi et al.,[68] 2022)	In vitro	Trios 3, v.1.6.4.4; 3Shape A/S	Partially edentulous mandibular cast with one internal connection implant analog (right 1 M)	ISB had 2 pieces: - Screw-retained metallic implant abutment (ScanPost S BL4.1L; Dentsply Sirona) - Snap-op PEEK part (Scanbody for Omnicam; Dentsply Sirona)	Control – 15 Ncm Experimental: 20, 25, 30, and 35 Ncm.	Torque impacted on the vertical implant scan body position (*z*-axis). The largest mean was 13.5 ±4.1 μm with a torque of 35 Ncm.
(Diker et al.,[69] 2023)	In vitro ($n = 20$)	Digital image correlation analysis	Two dental implants mounted into polymeric sleeves	ISB-1: 1-piece PEEK (Zfx) ISB-2: Metallic (Ti MPS; Zimmer)	Control – 5 Ncm Experimental: 10 and 15 Ncm.	ISB-2 had lower displacements than ISB-1. ISB-1 had higher displacements than ISB-2, regardless of the torque value. 15 Ncm lead to higher displacements of the ISB-1, regardless of the sterilization condition.

Abbreviations: IOS, intraoral scanner; ISB, implant scan body; M, molar; NA, not available; PEEK, polyetheretherketone; Ti, titanium.

techniques have been described in the dental literature. Therefore, there might be more techniques that have been described since then. Independent of the ISB splinting material or device used, the concept is that a rigid material or device connects the contiguous implant scan bodies aiming to facilitate the intraoral digitizing procedures and increase intraoral scanning accuracy.[73–75] However, due to the heterogeneity and limited number of studies and varying IOS technologies and systems, it is challenging to determine the optimal implant scan body splinting method based on the IOS selected for maximized accuracy of intraoral digital implant scans.

An in vivo study compared two different implant scan body (1-piece PEEK ISBs) splinting methods (non-splinting, dental floss, or bis-acryl composite resin) on the accuracy of complete-arch intraoral digital implant scans (Trios; 3Shape A/S).[74] This clinical study involved five patients having six implants on the maxillary arch. The results revealed that the non-splinting group obtained the highest mean trueness (41 ± 11 μm) and precision (48 ± 7 μm) values among the techniques tested.[74] The lowest mean trueness value (55 ± 8 μm) was measured in the bis-acryl composite resin group and the lowest mean precision value (50 ± 7 μm) was obtained in the dental floss group.[74] Therefore, it is unclear if the statistical difference reported on the trueness and precision values among the splinting methods tested has an impact on the clinical outcomes of implant-supported prostheses.

A calibrated splinting framework has been described aiming to maximize the accuracy of the definitive implant cast.[76] An initial intraoral digital scan is used to fabricate a patient-specific or custom metal-printed splinting framework.[76] This framework has screw-retained milled cones. After manufacturing, the cones of the framework are palpated by using a coordinate measurement machine; therefore, the position and angulation of the cones in the framework are known.[76] Then, the custom framework is used to connect the implant scan bodies and obtain a complete-arch intraoral digital implant scan. The implant position obtained in the intraoral digital scan is corrected by using the known cone position of the framework.[76]

As an alternative to splinting methods for complete-arch intraoral digital implant scans, a reverse impression method has been described.[77] This technique involves the use of implant analog scan bodies that are connected to the interim implant-supported prostheses and then digitized extraorally by using an IOS or laboratory scanner.[77]

Patient-related factors

The intraoral condition of the patient may impact the accuracy of IOSs.[3] Specifically, when recording the 3D position of implants by using IOSs, additional factors should be understood and considered[3] including the arch being scanned (maxilla vs. mandible), implant position in the dental arch, inter-implant distance,[27,46,47] implant depth and angulation,[41–45] and interdental space between the ISB and the adjacent teeth.

Arch location

The dental literature analyzing the influence of the arch being scanned (maxillary vs. mandibular arch) when acquiring intraoral digital implant scans is scarce.[40,78,79] In these studies, contradictory results have been reported. Gómez-Polo et al.[40] compared the accuracy of maxillary and mandibular complete-arch intraoral digital implant scans. The maxillary scans did not include the palate. Authors reported lower trueness and precision mean values of maxillary intraoral digital implant scans compared with mandibular scans. However, a clinical study reported no difference in the accuracy of maxillary and mandibular complete-arch intraoral digital scans.[78] Authors did not describe if the palate was included in the maxillary intraoral digital scans.[78]

Additionally, another clinical study analyzed the extraoral and intraoral (Trios 2, v. 21.2.0; 3Shape A/S) scanning accuracy between maxillary and mandibular intraoral digital implant scans.[79] Six participants received a custom acrylic resin-made holder containing two implant analogs that fitted in the maxillary and mandibular anterior or posterior regions. Authors reported lower trueness in maxillary-posterior and mandibular-posterior regions compared with maxillary-anterior and mandibular anterior.[79]

One in vitro study compared the scanning accuracy of maxillary complete-arch intraoral digital implant scans (Trios 3; 3Shape A/S) with and without the inclusion of the palate.[80] The results revealed that the accuracy of digital scans of the edentulous maxillary arch with four implants when the palate was scanned compared with the scans that did not scan the palate was similar.[80] However, the generalization of the results should be avoided as in this unique in vitro study analyzing this variable, a single IOS, a specific arch width, and clinical condition were tested.

Implant position in the dental arch

The implant position in the dental arch can also impact the accuracy of complete-arch intraoral digital implant scan of partially[63,79,81] and completely edentulous[45,79,82] patients with different numbers of implants placed. However, limited dental studies have considered this variable.

In partially edentulous conditions, two in vitro studies[63,81] and one in vivo[79] study have assessed the influence of the implant position on intraoral scanning accuracy; however, contradictory results were reported. Both in vitro studies were developed by the same research team, same ISB and IOS (Trios 3; 3Shape A/S), and similar reference partially edentulous cast with three implant analogs was used, if not the same.[63,80] One study considered implant position and scanning pattern as research variables reporting varying accuracy values for anterior and posterior implants depending on the scanning pattern used to acquire the data.[63] The other investigation analyzed implant position and operator as study variables, reporting better trueness for the anterior implant compared with the posterior implants. Additionally, the posterior the implant location, the lower the precision of the scan.[80] The in vivo study, compared the maxillary and mandibular anterior or posterior regions.[79] Results revealed significant differences between the implants located in the anterior or posterior regions, for both maxillary and mandibular intraoral digital implant scans.[79]

In completely edentulous conditions, to the best authors' knowledge, only three in vitro studies have assessed the influence of implant position in the arch on intraoral scanning accuracy.[45,80,82] Two of these studies reported higher distortion on the contralateral implant where the intraoral digital scan was started,[45,82] while the other study concluded that the higher distortion was obtained on the implant where the intraoral digital scan was started.[80] Additionally, these studies tested the same IOS (Trios from 3Shape A/S) and 1-piece PEEK ISBs.

Gómez-Polo et al.[45] assessed the influence of implant angulation and implant position on the scanning accuracy of intraoral digital implant scans in a completely edentulous cast with six implant abutment analogs captured by using an IOS (Trios 3; 3Shape A/S). Results demonstrated that the implant positioned in the dental arch at the contralateral side where the intraoral digital scan started resulted in significantly higher distortion than the initial one.[45] Similarly, Mizumoto et al.[80] assessed the effect of scanning the palate and implant position on the scanning accuracy of intraoral digital implant scans (Trios 3; 3Shape A/S) in a maxillary completely edentulous cast with four implant analogs. Trueness was affected by the implant position; it was lower on the implant positioned at the contralateral side where the intraoral digital scan was started.[80] Çakmak at al.[82] evaluated the influence of the implant position on the scanning accuracy of complete-arch intraoral digital implant scans by using 2 IOSs (Trios 3; 3Shape A/S and Virtuo Vivo; Dentalwings) and a laboratory scanner (CARES 7 series; Straumann). The authors used an edentulous maxillary cast with four implant abutment analogs. Implant position influenced the accuracy of the virtual definitive implant cast differently, based on the scanning method selected.[82]

Interimplant distance and implant depth and angulation

The distance between two adjacent implants and implant angulation and depth have been identified as factors that can reduce intraoral scanning accuracy (Table 7).[3,27,41–48,83] A limited number of studies have examined the influence of interimplant distance on scanning accuracy of intraoral digital implant scans.[27,46,47,83] The results obtained by these

TABLE 7 Studies assessing the influence of the inter-implant distance and implant position on the scanning accuracy of intraoral digital implant scans.

Study	Type study	IOS tested	Variable	Settings	Results
(Andriessen et al.,[82] 2014)	In vivo ($n = 21$)	iTero, v.3.5.0; Align Technologies	Inter-implant distance	Twenty-one patients with two implants in the mandibular arch with varying inter-implant distances	Mean linear discrepancy: 226 μm (21-631 μm)
(Tan et al.,[47] 2019)	In vitro ($n = 5$)	Trios, v.NA; 3Shape A/s True Definition; 3 M ESPE	Inter-implant distance	Two edentulous maxillary casts with six implants at varying inter-implant distance (between implant one and implant one or arch width): 13 and 20 mm.	The higher the inter-implant distance, the lower the intraoral scanning accuracy.
(Thanasrisuebwong et al.,[46] 2021)	In vitro ($n = 15$)	Trios 3 v.NA; 3Shape A/S Onmicam, v.NA; Denstply Sirona	Inter-implant distance	Three casts with three inter-implant distances: 7, 14, and 21 mm.	The trueness and precision decreased as the distance between implants increased.
(Gómez-Polo et al.,[27] 2022)	In vitro ($n = 15$)	Trios 3, v.1.7.19.0; 3Shape A/S	Inter-implant distance and implant angulation	Two edentulous maxillary casts with four implant abutment analogs: parallel (P) and angulated (NP) (up to 30 degrees). Inter-implant distances: Euclidean distances analyzed	The NP group obtained significantly lower trueness and precision mean values compared with the P group. The trueness and precision decreased as the linear Euclidean distance increased.
(Giménez et al.,[84] 2014)	In vitro ($n = 5$)	iTero, v.4.5.0.151; Align Technologies	Implant depth and angulation	Maxillary completely edentulous cast with six implant analogs at different depths (0, 2, and 4 mm) and angulations (up to 30 degrees)	Angulated implants did not impact scanning accuracy. Implants at 0-mm depth had less accuracy than 2- and 4-mm depth.
(Giménez et al.,[85] 2015)	In vitro ($n = 5$)	Lava COS, v.0.3.0.3; 3 M ESPE	Implant depth and angulation	Maxillary completely edentulous cast with six implant analogs at different depths (0, 2, and 4 mm) and angulations (up to 30 degrees)	Angulated implants and the deeply placed implants did not seem to decrease the accuracy in digital impressions with the digital scanning system tested.
(Giménez et al.,[86] 2015)	In vitro ($n = 5$)	3D Progress IOS scanv.NA; MHT Zfx intrascan; Zfx	Implant depth and angulation	Maxillary completely edentulous cast with six implant analogs at different depths (0, 2, and 4 mm) and angulations (up to 30 degrees)	Implant depth and angulation did not impact scanning accuracy
(Giménez et al.,[87] 2017)	In vitro ($n = 5$)	True Definition; 3 M ESPE	Implant depth and angulation	Maxillary completely edentulous cast with six implant analogs at different depths (0, 2, and 4 mm) and angulations (up to 30 degrees)	Implant scan body visibility affected accuracy. The angulated position of the implants did not influence scanning accuracy.
(Laohverapanich et al.,[42] 20)	In vitro ($n = 6$)	Trios 3, v.NA; 3Shape A/S DWIO, v.NA; Dentalwings Omnicam, v.NA; Dentsply Sirona True Definition; 3 M ESPE	Implant depth	Half arch cast with one implant analog at different depths: 3, 6, and 9 mm.	Overall, the 6-mm group had lower 3D distortion than the 3- and 9-mm groups.
(Gómez-Polo et al.,[43] 2022)	In vitro ($n = 10$)	Trios 3, v.1.7.19.0; 3Shape A/S	Implant angulation and depth	Two edentulous maxillary casts with four implant abutment analogs: parallel (P) and angulated (NP) (up to 30 degrees).	Implant angulation and depth influenced scanning accuracy. The lowest clinical implant scan body height tested had the lowest accuracy in both parallel and angulated implants, but statistically significant differences were found only in the angulated group.

(Continues)

TABLE 7 (Continued)

Study	Type study	IOS tested	Variable	Settings	Results
(Sequeira et al.,[44] 2023)	In vitro ($n = 15$)	Zfx Scan III, Zfx GmbH	Implant depth	Partially edentulous cast with one implant analog at different depth (clinical implant scan body height): 2, 3, 6, and 9 mm (corresponding implant depths of 7, 6, 3, and 0 mm)	Trueness and precision were highest when the implant was placed at 0 mm depth, with complete visibility of the implant scan body, and decreased with subgingival implant placement. No significant increase in inaccuracies was noted in the first 3 mm of implant submergence.
(Gómez-Polo et al.,[45] 2022)	In vitro ($n = 15$)	Trios 3, v.1.7.19.0; 3Shape A/S	Position of the geometry bevel of the implant scan body and implant angulation	Two edentulous maxillary casts with four implant abutment analogs: parallel (P) and angulated (NP) (up to 30 degrees). Position of the geometry bevel of the implant scan body: B, L, M, D, or random.	The scan body geometry bevel location and implant angulation and position influenced the accuracy of the IOS tested. The lingual orientation obtained better accuracy values compared with the other positions. The parallel implant analog position obtained better accuracy than the angulated positions. Lastly, the implant positioned in the dental arch where the intraoral digital scan was finished obtained significantly higher distortion than the contralateral implant.

Abbreviations: B, buccal; D, distal; IOS; intraoral scanner; M, mesial; NA, not available; L, lingual.

studies were mainly consistent with the expectation that errors would increase as scanning distance or interimplant distance increased.[27,46,47,83]

Contradictory results have been reported regarding the influence of implant angulation and depth on intraoral scanning accuracy.[42–45,84–87] Implant depth is related to clinical implant scan body height.[42–44,84–87] Some studies have reported that implant angulation decreased the accuracy of the digital scans compared to the conventional impressions, or that implant angulation decreased the scanning accuracy of IOSs.[42,45] However, other studies have shown that implant angulation had no effect on intraoral scanning accuracy.[37,84–87] Similarly, studies have analyzed the influence of implant depth on intraoral scanning accuracy with contradictory results reported.[42–44,84–87]

Interdental space (between implant scan body and adjacent teeth)

Dental literature has reported the influence of interdental space between teeth or tooth preparation and adjacent teeth on the accuracy of intraoral digital scans.[22,32,88] The presence of diastemas or limited space between tooth preparations and adjacent teeth generates scanner accessibility problems and limits the scanning angle, which may result in reduced scanning accuracy.[22,32,88]

DISCUSSION

Different studies have assessed the influence of ambient light illuminance conditions on the accuracy of IOSs reporting that the optimal illuminance condition varies among the different IOSs.[2,8–10,55,56] However, the majority of the studies considered completely dentate conditions and only one in vitro study considered complete-arch implant digital scans obtained by using metallic ISBs.[37] Therefore, it is unclear if a different ISB geometry and material would have led to a different outcome. Additional studies are needed to assess the influence of ambient lighting conditions on intraoral scanning accuracy when using different implant scan body designs under different clinical conditions. Moreover, the optimal illuminance condition when scanning different clinical situations such as partially edentulous conditions is uncertain.

Limited studies have assessed the influence of different scanning patterns on the accuracy of intraoral digital implant scans, reporting contradictory results.[38–40,63,64] The scanning pattern for scanning teeth may differ when scanning implant scan bodies.[38–40,63,64] Furthermore, when obtaining intraoral digital scans in partially edentulous patients with dental implants, it is also unclear the optimal scanning pattern for maximizing scanning accuracy based on the IOS selected. Additionally, the high heterogenicity among the studies makes it difficult to compare the results. The scanning pattern for digitizing completely dentate patients may be different than the one for scanning partially or completely edentulous patients with implants (Figure 3).[38–40,63,64]

Few studies have assessed the influence of the ISB geometry and material on the scanning accuracy of intraoral digital scans involving single or multiple implants.[48–54,65,66] However, the available published data do not support a systematic recommendation for choosing an ISB design.

Limited studies have analyzed the manufacturing tolerance of ISBs.[67] The manufacturing tolerance may impact the accuracy of the ISB alignment between the intraoral digital implant scan and the library of the computer-aided design (CAD) software program, which may influence the accuracy of the virtual definitive implant cast, and ultimately the accuracy of the interim or definitive restoration. Additional studies are needed to further evaluate the manufacturing tolerance of different ISBs.

Additional studies are needed to further evaluate the wear and multiple-use distortion of varying ISB designs with and without sterilization procedures.[68–72] The influence of ISB wear on the accuracy of intraoral digital implant scans should be analyzed considering the ISB retention system design (screw-retained, snapped-on, or magnet-retained). All studies analyzing the ISB wear caused by ISB multiple uses have considered screw-retained ISB designs; therefore, the wear of the snapped-on PEEK ISBs or magnet-retained systems remains unclear. For repeatable results, clinicians should consider the manufacturer's recommendation regarding the number of times that an implant scan body can be reused without affecting its performance, as well as the manufacturer's suggested torque when connecting them to the implants.

Dental literature has analyzed the effect of different techniques for ISB splinting to maximize the accuracy of intraoral digital implant scans.[73] ISB splitting methods may improve the accuracy of intraoral digital implant scans; however, due to the limited studies is challenging to state a general conclusion. Additionally, the selection of an ISB splinting method should be considered carefully.[74,75] Limited studies have directly compared the accuracy outcomes of different splinting methods so it is unclear what the best method is for maximizing intraoral scanning accuracy based on the IOS selected.[74,75] The material selected (plaster, auto- or light-polymerizing resin, polyvinyl siloxane occlusal registration material, or printed device) to connect ISBs may distort the ISB position due to the polymerization shrinkage of the material.[75] Additionally, limited data is available regarding the accuracy of the calibrated splinting framework technique (IOSFix; IOSFix)[76] or the reverse impression method;[77] moreover, its accuracy is unknown. Studies are recommended to assess the accuracy of the complete-arch intraoral digital scans obtained by using the described calibrated framework and the reverse impression method.

The dental literature analyzing the influence of the arch being scanned (maxillary vs. mandibular arch) when acquiring intraoral digital implant scans is scarce, reporting contradictory results.[40,78,79] Additional studies are needed to further analyze the influence of arch location and incorporating the palate in maxillary scans on the accuracy of intraoral digital implant scans before a general statement can be made and a systematic clinical recommendation can be performed.

Limited dental studies have considered the influence of the implant position in the dental arch on the accuracy of complete-arch intraoral digital implant scans of partially[63,79,81] and completely edentulous[45,79,82] patients. Additional studies are recommended to further evaluate the influence of implant position on scanning accuracy of partially edentulous settings with varying IOS technologies and systems. The different scanning technologies, stitching methods, and post-processing methods may lead to different results. Because of the limited available data, it is challenging to establish a general conclusion.

The distance between two adjacent implants and implant angulation and depth have been identified as factors that can reduce intraoral scanning accuracy.[3,27,41–48,83] The results obtained demonstrated that increasing interimplant distance increased scanning errors.[27,46,47,83] Additionally, implant-position-related variables (angulation and depth) may have varying impacts, depending on the IOS technology and system selected to capture intraoral digital implant scans. Due to the disagreement in the literature, it is challenging to make conclusions on how these factors may impact scanning accuracy.

Dental literature has reported the influence of interdental space between teeth or tooth preparation and adjacent teeth on the accuracy of intraoral digital scans;[22,32,88] however, it is unclear if the distance between an adjacent tooth and an ISB may impact scanning accuracy and to what degree. Further studies are needed to assess the influence of presence of space between ISB and adjacent tooth on the accuracy of intraoral digital implant scans.

CONCLUSIONS

Among operator factors, ambient lighting conditions, scanning pattern, implant scan body design, and splinting of implant scan bodies may impact the accuracy of intraoral digital implant scans. Literature analyzing these factors is scarce; therefore, the establishment of a systematic clinical recommendation is not feasible. Ambient lighting conditions should be established based on the intraoral scanner selected to optimize the accuracy of intraoral digital implant scans. Additionally, the optimal scanning pattern may vary when scanning completely or partially dentate and completely edentulous patients, with different numbers of implants. Additionally, the optimal scanning pattern may change not only based on the clinical condition of the patient, but also depending on the intraoral scanner selected. The optimal implant scan body design (material, geometry, and retention system) may vary depending on the intraoral scanner used. Metallic implant scan bodies are preferred over polymer designs, aiming to minimize the wear due to multiple use and sterilization distortions. Lastly, implant scan body splitting methods may improve the accuracy of intraoral digital implant scans.

Among patient-related factors, additional variables should be considered, namely arch scanned, implant position in the arch, inter-implant distance, implant depth, and angulation. The effect of these factors may differ depending on the IOS technology and system selected to capture intraoral digital implant scans. However, contradictory results have been reported; therefore, it is challenging to obtain conclusions on how these factors may impact scanning accuracy.

CONFLICT OF INTEREST STATEMENT

The authors do not have any conflict of interest, financial or personal, in any of the materials described in this study.

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