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ORIGINAL ARTICLE

Influence of implant scan body design (height, diameter, geometry, material, and retention system) on intraoral scanning accuracy: A systematic review

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Abstract

Purpose: To evaluate the influence of implant scan body (ISB) design (height, diameter, geometry, material, and retention system) on the accuracy of digital implant scans.

Material and Methods: A literature search was completed in five databases: PubMed/Medline, Scopus, Embase, World of Science, and Cochrane. A manual search was also conducted. Studies reporting the evaluation of ISB design on the accuracy of digital scans obtained by using IOSs were included. Two investigators evaluated the studies independently by applying the Joanna Briggs Institute critical appraisal. A third examiner was consulted to resolve any lack of consensus. Articles were classified based on the ISB features of height, geometry, material, and retention system.

Results: Twenty articles were included. Among the reviewed studies, 11 investigations analyzed the influence of different ISB geometries, 1 study assessed the impact of ISB diameter, 4 studies investigated the effect of ISB splinting, 2 articles evaluated ISB height, and 2 studies focused on the effect of ISB material on scan accuracy. In addition, 8 studies involved ISBs fabricated with different materials (1- and 2-piece polyetheretherketone and 1-piece titanium ISBs), and all of the reviewed articles tested screw-retained ISBs, except for 3 in vitro studies.

Conclusions: The findings did not enable concrete conclusions regarding the optimal ISB design, whether there is a relationship between IOS technology and a specific ISB design, or the clinical condition that maximizes intraoral scanning accuracy. Research efforts are needed to identify the optimal ISB design and its possible relationship with the IOS selected for acquiring intraoral digital implant scans.

KEYWORDS
accuracy, digital impression, implant scan body, prosthodontics

Computer-aided design and computer-aided manufacturing (CAD-CAM) technologies have revolutionized clinical practice, leading to the use of intraoral scanners (IOSs) as an alternative to conventional dental impressions.[1–4] This trend has also been integrated into implant prosthodontics by capturing implant position using a complete digital workflow.[5–7] This digital workflow is based on the digitization of implant scan bodies (ISBs) by using IOSs to transfer the position of implants and adjacent tissue information.[8–10]

TABLE 1 Boolean search terms for the different databases.

Database	MeSH terms and search terms
MEDLINE/PubMed and Cochrane	("Scan body" OR "scan body" OR "scanbodies" OR "scan bodies" OR "intraoral scanner" OR "digital impression scanner") AND ("implant dentistry" OR "Dental Prosthesis"[Mesh]) AND ("Dental Impression Technique"[Mesh] OR "Implant impression" OR "scanner dental lab" OR "desktop scanner" OR "coordinate measurement machine") AND ("Accuracy" OR "trueness" OR "precision" OR "reliability")
Embase, World of Science, and Scopus	("Scan body" OR "scan body" OR "scanbodies" OR "scan bodies" OR "intraoral scanner" OR "digital impression scanner") AND ("implant dentistry" OR "Dental Prosthesis") AND ("Dental Impression Technique" OR "Implant impression" OR "scanner dental lab" OR "desktop scanner" OR "coordinate measurement machine") AND ("Accuracy" OR "trueness" OR "precision" OR "reliability") NOT MEDLINE

Even though the acquisition of three-dimensional (3D) positional information of an implant with photogrammetry was reported in the late 20th century,[11] the first intraoral scannable implant component, which was an encoded healing abutment (The Bellatek Encode; Biomet 3i), was not introduced until 2004.[12,13] However, while some clinical studies on the use of this encoded healing abutment have reported pleasing treatment results,[13,14] scan accuracy of this system has been questionable when compared with conventional impressions.[15–18] In addition, the height and the position of the encoded healing abutment on the arch have been found to affect the trueness of IOS scans.[19]

ISBs were initially introduced in the early 21st century,[10,20] and various ISBs with different properties (geometry, material, retention system, and height) have been marketed ever since.[10,21–26] Previous studies have shown that the ISB geometry affects the accuracy of intraoral digital implant scans.[26–28] Researchers have also focused on improving the intraoral scanning accuracy while using ISBs either by offering new designs or modifying available designs as ISBs with specific characteristics may be advantageous for intraoral situations.[10] ISBs with extensional structures, which were fabricated by using milled titanium, were shown to result in higher accuracy when compared with ISBs without extensional structures.[29,30] Additive manufacturing has also been integrated into fabricating auxiliary equipment to improve scan accuracy and efficiency.[31–33] However, there is no agreement in the literature regarding the optimal ISB design (height, geometry, material, and retention system) to maximize scanning accuracy.

The efficiency of data acquisition using ISBs and IOSs, particularly for single-unit or short-span partial edentulous situations, has been well-reported.[34] Scan accuracy is fundamental for the passivity of an implant-supported prosthesis.[35] However, ISB-related factors are not the only parameters that should be considered while analyzing the accuracy of digital implant scans. Dental literature has analyzed different operator- and patient-related factors that can reduce the accuracy of IOSs and, therefore, the accuracy of digital implant scans.[36,37] These factors include IOS technology,[38] operator experience,[39] ambient light illumination,[40–43] calibration,[44] scan extension,[45] scan pattern,[46,47] scan distance and angulation,[48] rescanning techniques,[49,50] mobile tissue in edentulous areas,[51] humidity,[52,53] arch width,[54] tooth type,[55] and restorative materials.[56] These factors generate an accumulative scanning distortion.[36,37]

The purpose of the present systematic review was to evaluate the influence of ISB design (height, diameter, geometry, material, and retention system) on the scanning accuracy of intraoral digital implant scans.

MATERIAL AND METHODS

The protocol of this study followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA).[57] A PICO question was established for performing this systematic review, where P (population) was defined as ISBs for obtaining intraoral digital implant scans, I (intervention) comprised implant dentistry, implant digital scans, and dental prosthesis, C (comparison) involved conventional impression methods, laboratory scanners, and coordinate measurement machine (CMM), and O (outcome) included scanning accuracy, trueness, and precision (Table 1).

The literature search was performed in five electronic databases namely PubMed/Medline, Scopus, Embase, World of Science, and Cochrane. Additionally, a manual search was conducted. Inclusion criteria included in vivo and in vitro studies that evaluated the influence of ISB design on scanning accuracy, while exclusion criteria were defined as review studies, case report manuscripts, and any clinical and laboratory study that analyzed the accuracy of intraoral digital implant scans but did not consider ISB design as a research variable.

All titles and abstracts were first assessed following the described inclusion criteria. Afterward, the evaluation of the full texts of the articles was completed as per the previously defined criteria. Two calibrated independent reviewers (M.R.-L. and M.G.-P.) examined the articles, and a third independent reviewer (B.Y.) was consulted to resolve any disagreement. Data were collected in a spreadsheet, gathering study characteristics. Articles were classified based on the ISB feature tested, namely, height, diameter, geometry, material, and retention system. A qualitative analysis was performed to evaluate the inter-examiner agreements by using the Cohen Kappa coefficient. There was a significant agreement between the two reviewers regarding the selection of the articles based on their titles and abstracts (Cohen's Kappa

TABLE 2 Items for the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Quasi-Experimental Studies (non-randomized experimental studies).

Question	Answer
1. Is it clear in the study what is the "cause" and what is the "effect" (i.e., there is no confusion about which variable comes first)?	Yes, No, Unclear, or Not applicable
2. Were the participants included in any comparisons similar?	
3. Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?	
4. Was there a control group?	
5. Were there multiple measurements of the outcome both pre- and post-the intervention/exposure?	
6. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed?	
7. Were the outcomes of participants included in any comparisons measured in the same way?	
8. Were outcomes measured in a reliable way?	
9. Was appropriate statistical analysis used?	

= 0.84 (CI:0.75–0.94) $p < 0.05$). There was a significant agreement between the two reviewers regarding the selection of articles based on the full text (Cohen's Kappa = 0.88 (CI:0.71–1.04), $p < 0.05$).

The same two reviewers independently performed the quality assessment of the studies by applying the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Quasi-Experimental Studies (nonrandomized experimental studies) (Table 2).[58] The same third examiner was consulted to resolve any lack of consensus.

RESULTS

A total of 235 studies were found based on the search strategies. Among those articles, 14 were excluded due to duplication, and 221 articles were further evaluated by the titles and abstracts. Thirty-nine articles were found eligible for full-text review; however, 19 of them were excluded after review as 9 articles were not based on ISB design, and the remaining 10 were excluded as they either focused on other parameters (implant position, splinting tray, implant angulation, clinical ISB height, manufacturing tolerances, ISB wear, conventional impressions) or did not involve implants.

Twenty articles that were published between 2016 and 2022 were included in the present systematic review (Figure 1). While one of those studies was an animal study,[30] the remaining 19 articles were in vitro studies (Table 3).[2,6,7,9,19,22,24–29,31–33,59–62] Due to the variation in study methodology and data reporting, as well as the small number of identified studies, a statistical analysis was not feasible.

Within 20 reviewed articles, different numbers of implants and scan levels were evaluated. The number of implants included was one,[7] two,[6,19,28,30] three,[9,22,25] four,[2,26,29,32,33,59,60,62] and six.[24,27,31,61] Digital implant scans were performed at healing abutment,[6,7,19,59] implant,[2,7,9,22,27,28,30–32,60–62] or implant abutment level.[24–26,29,33] However, the accuracy of implant level and healing abutment level scans was compared in only one study. The authors reported lower linear discrepancies while using an implant-level ISB than when using a coded healing abutment.[7]

Digitization methods used to obtain reference files (control) and experimental scans varied among reviewed studies. The majority of the studies used either a laboratory[7,24,27,29,30,33,60,62] or an industrial[19,22,26,32,59,61] scanner to generate the control file, followed by a CMM analysis.[2,6,9,25,28,31] Only two studies[24,25] used a laboratory scanner to perform experimental scans, while the remaining studies selected an IOS.[2,6,7,9,19,22,26–33,59,60] Thirteen studies used the TRIOS 3 system from 3Shape A/S,[2,7,19,22,27–30,32,33,60–62] while the TRIOS system from 3Shape A/S without specifying the IOS generation tested,[26] Omnicam[27] and Primescan[28,31] from Dentsply Sirona, CS3600 from Carestream Dental,[28] LAVA COS from 3 M ESPE,[6] and iTero Element from Align Technologies[9] were used in the remaining studies.

Implant scan body height

Two of the included studies analyzed the effect of healing abutment height on scanning accuracy,[6,19] while one of them also investigated the effect of coded healing abutment location on intraoral scanning accuracy.[19] However, one of those studies tested coded healing abutments,[19] while the other one used standard healing abutments[6] as ISBs. Tested coded or standard healing abutment heights were 3,[19] 5,[6] 7,[6] and 8 mm in height.[19] Both studies reported that angular deviations were affected by the healing abutment height.[6,19] Batak et al.[19] reported that using an 8 mm coded healing abutment led to higher angular deviations than using a 3 mm coded healing abutment; however, coded healing abutment height did not affect linear discrepancies. Ajioka et al.[6] concluded that longer standard healing abutments led to lower angular discrepancies; however, the results regarding linear discrepancies between 5- and 7-mm coded healing abutments were not reported.

Coded healing abutment location affected distance deviations.[19] Batak et al.[19] reported lower linear discrepancies on anteriorly placed implants when compared with implants positioned in the posterior area.

Implant scan body diameter

One in vitro study has analyzed the impact of ISB diameter (narrow or regular platform) and material (PEEK or Ti)

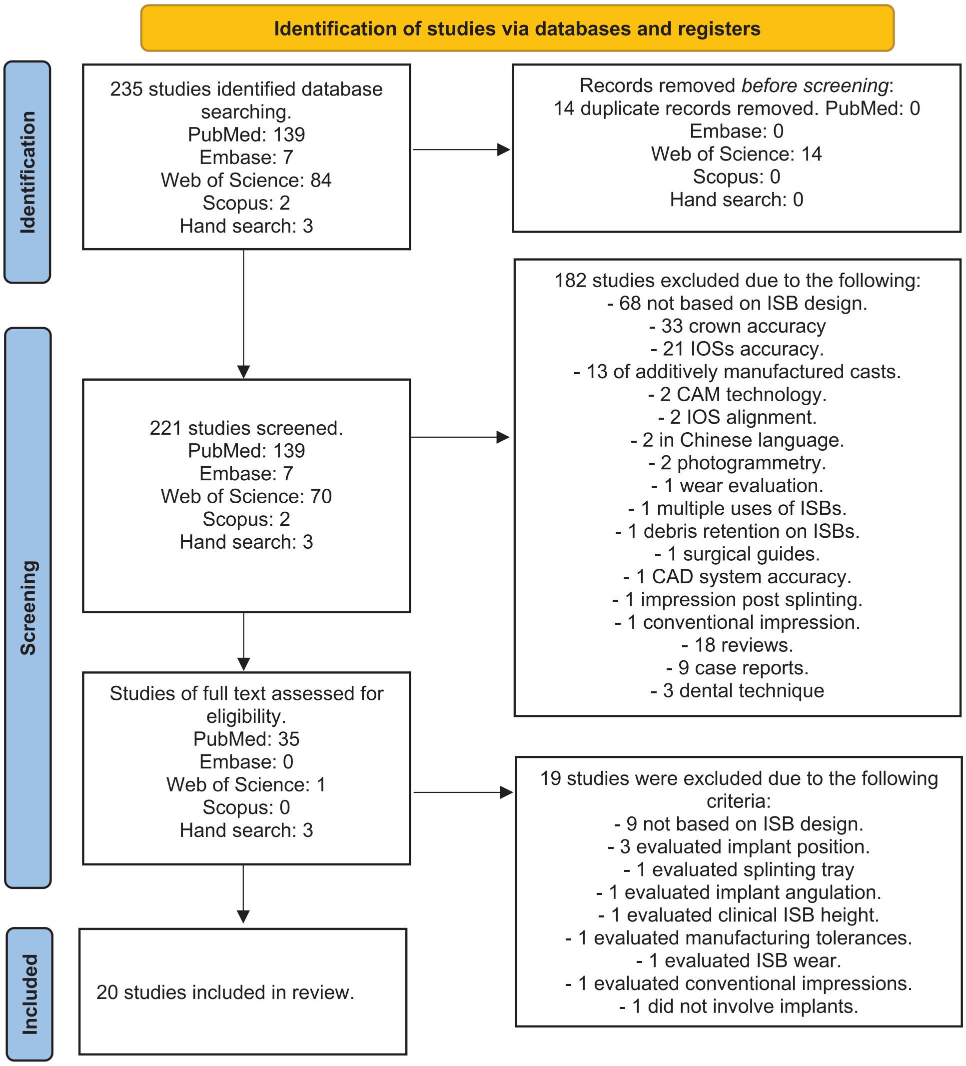

FIGURE 1 Prisma flow diagram.

on the accuracy of complete-arch implant scans.[62] The reference stone cast represented a partially edentulous situation, Kennedy Class III, modification 1, with 4 implant analogs (2 narrow and 2 regular diameter).[62] The Authors reported the highest scanning accuracy when narrow diameter and PEEK ISBs were used, followed by regular diameter PEEK ISBs, narrow diameter Ti ISBs, and regular diameter Ti ISBs.[62]

Implant scan body geometry

Varying ISB geometries have been tested among 11 different reviewed studies.[2,7,9,22,24–27,31,33,60] Variations on the research methodology were identified among included studies: reference cast with different implant positions, depths, and angulations, inter-implant distance, implant type and diameter, ISB geometries, digitizing methods, reference/control file, and measurement methods.[2,7,9,22,24–27,31,33,60] Additionally, the majority of reviewed studies did not report the effect of ambient lighting conditions, relative humidity, operator experience, IOS calibration, rescanning techniques, scanning pattern, or scanning distance and angulation while performing experimental intraoral digital implant scans.[2,7,9,22,24–27,31,33,60]

Ten studies reported that ISB geometry affected scanning accuracy,[2,7,9,22,24–27,33,60] whereas one investigation showed that tested ISB geometries (with or without customized scan body ring positioned on each ISB) resulted in similar accuracy.[31] Pan et al.[24] compared dome- and cuboidal-shaped ISBs of the same manufacturer and reported that dome-shaped ISBs had lower deviations on the ISB surface, while cuboidal-shaped ISBs had lower angular deviations. Motel et al.[22] highlighted the fact that the effect of ISB geometry on scan accuracy was scanning pattern dependent, while Mizumoto et al.[26] also showed that ISB geometry affected scanning time.

Two studies investigated the effect of ISB design on implant analog positional accuracy in virtual or printed definitive implant casts.[9,25] Both studies tested the same ISB designs (2 screw-retained 1-piece PEEK ISBs and an ISB

TABLE 3 Characteristics of the animal and in vitro studies included in the present systematic review.

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
Ajioka et al.[6]	In vitro ($n = 10$)	Height	Healing abutment level	ISB: Healing abutment Brånemark RP; Nobel Biocare (2 implants, Brånemark MkIII Groovy RP; Nobel Biocare)	1-piece Ti Heights: 5 mm (ISB-1) and 7 mm (ISB-2) Retention system: Screw-retained	- Reference model: Measurement of implant coordinates with a CMM - IOS Groups: Implant level IOS scans with ISBs, tightened with 15 Ncm	IOS: Lava COS; 3 M ESPE CMM: UPMC 550-CARAT; Carl Zeiss	Operator: NP Ambient conditions: 20 ± 0.5°C and 50 ± 10% humidity Scanning pattern: NP IOS calibration: NP Rescanning: NP	No comparison was completed between tested ISBs.
Batak et al.[19]	In vitro ($n = 10$)	Height	Healing abutment level	ISB: BellaTek Encode Impression system; Zimmer Biomet Dental (2 implants, 3i T3 platform switched Certain Tapered Implant; Zimmer Biomet Dental)	Material: 1-piece Ti Height: 3 mm (ISB-1) and 8 mm (ISB-2) Retention system: Screw-retained	- Reference Model: Advanced blue light optical LBS scan of master cast - IOS Groups: Implant level IOS scans with ISBs	IOS: Trios; 3Shape LBS: COMET L3D 8 M 150 Precision Structured Blue Light Scanner; ZEISS	NP	Posteriorly placed ISB-2 had higher angular deviations than posteriorly placed ISB-1 and anteriorly placed ISB-2.
Yilmaz et al.[7]	In vitro ($n = 10$)	Geometry and scan level	Healing abutment and implant level	ISB-1: Esthetic Healing Abutment and ScanPeg; Neoss Implant System ISB-2: Conventional ISB; Neoss Implant System (1 implant, Proactive Straight Implant; Neoss Implant System)	ISB-1: 1-piecePEEK healing abutment and medical grade acrylic resin ISB Retention system: Screw-retained healing abutment and friction fitted ISB ISB-2: 1-piece PEEK Retention system: Screw-retained	- Reference Model: LBS scan of master cast - Conventional polyvinyl siloxane impression, casts digitized by using an LBS - IOS scans with ISB-1 (healing abutment level) and ISB-2 (implant level), tightened with 10 Ncm	IOS: Trios 3; 3Shape A/S LBS: Ceramill Map 600; Amann Girrbach	Operator: 2 years of experience Ambient conditions: NP Scanning pattern: MR IOS calibration: NP Rescanning: NP	ISB-2 had lower distance deviations. ISB-1 and ISB-2 had similar angular deviations.
Çakmak et al.[59]	In vitro ($n = 14$)	Splinting	Healing abutment level	ISB: Esthetic Healing Abutment and ScanPeg; Neoss Implant System (4 implants, Neoss ProActive Straight; Neoss Implant System)	PEEK healing abutment and medical grade acrylic resin ISB Retention system: Screw-retained healing abutment and friction fitted ISB	- Reference Model: Master cast digitized by using industrial-grade blue light scanner - IOS Groups: Healing abutment level IOS scans of ISBs with three different techniques, hand-tightened	IOS: Trios 3; 3Shape A/S Industrial-grade blue light scanner: ATOS Core 80 5MP; GOM	Operator: NP Ambient conditions: NP Scanning pattern: Starting from occlusal, then lingual and buccal surfaces IOS calibration: NP Rescanning: NP	Different scanning techniques affected the trueness (distance and angular deviations) and precision (distance deviations) of scans.

(Continues)

TABLE 3 (Continued)

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
Schmidt et al.[2]	In vitro ($n = 10$)	Geometry	Implant level	ISB-1: 3D Guide H-Series; NT Trading ISB-2: Cara H10/20; Kulzer ISB-3: H1410; Medentika (4 implants, T3 Non-Platform Switched Certain Tapered Implants; Zimmer Biomet)	ISB-1: 2-piece PEEK Height: NP Retention system: Screw-retained ISB-2: 2-piece PEEK Height: NP Retention system: Screw-retained ISB-3: 1-piece PEEK Height: NP Retention system: Screw-retained	- Reference Model: Master cast digitized by using CMM with X-ray computed tomography - Conventional polyvinyl siloxane impression, coordinates of the implants on casts were measured with a CMM - Implant level IOS scans with ISBs, tightened with 15 Ncm	IOS: Trios 3; 3Shape A/S CMM: CMM RAPID; Thome CMM with X-ray computed tomography: Tomoscope-S; Werth Messtechnik	NP	ISBs had similar distance deviations. ISB-3 scans of the right first PM implant and ISB-2 scans of the left first PM implant had higher precision than those of ISB-1.
Revilla-León et al.[9]	In vitro ($n = 10$)	Geometry	Implant level	ISB-1: Elos Accurate Intraoral Scan Body; Nobel Biocare ISB-2: Scan body 3D Guide K Series; NT Digital Implant Technology ISB-3: ISB system with intraoral adaptor; Dynamic Abutment Solutions (3 implants, Implant replica RP Brånemark; Nobel Biocare Services AG)	ISB-1: 1-piece PEEK Retention system: Screw-retained ISB-2: 1-piece PEEK Retention system: Screw-retained ISB-3: 1-piece PEEK Retention system: Screw-retained and magnet-retained	- Reference Model: ISB positions measured by using a CMM - IOS Groups: IOS scans with ISBs, hand-tightened	IOS: iTero Element; Align Technologies CMM: CMM Contura G2; Carl Zeiss Industrielle Messtechnik GmbH	Operator: 8 years of experience. Ambient lighting: 1000 lux Scanning pattern: MR IOS calibration: Yes Rescanning: NP	ISB-3's positions could not be measured. ISB-1 and ISB-2 had similar linear discrepancies, while ISB-1 had higher XZ angular discrepancy.
Motel et al.[22]	In vitro ($n = 10$)	Geometry	Implant level	ISB-1: ELOS A/S ISB-2: NT-Trading GmbH ISB-3: TeamZiereis (3 implants, Nobel Replace Select; Nobel Biocare Services AG)	ISB-1: 1-piece PEEK Retention system: Screw-retained ISB-2: 1-piece PEEK Retention system: Screw-retained ISB-3: 2-piece PEEK Retention system: Screw-retained	- Reference Model: Industrial-grade white light scanner scan of master cast - IOS Groups: IOS scans with ISBs	IOS: Trios 3;3Shape A/S Industrial-grade white light scanner: ATOS So4 II; GOM GmbH	Operator: NP Ambient lighting: NP Scanning pattern: One-step and two-step scans IOS calibration: NP Rescanning: NP	ISB-2 had the highest deviations when ISBs and ridge were scanned simultaneously.

(Continues)

TABLE 3 (Continued)

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
Pan et al.[24]	In vitro ($n = 10$)	Geometry	Implant abutment level	ISB-1: Intrascan matchholder H4; Zimmer Biomet ISB-2: Zfx Evolution matchholder; Zimmer Biomet (6 implants, Nobel Active RP; Nobel Biocare AB)	ISB-1: 2-piece PEEK Retention system: Screw-retained ISB-2: 2-piece PEEK Retention system: Screw-retained	- Reference Model: CAD library file - Groups: Multi-unit abutment level LBS scans with ISB-1 (cuboidal) and ISB-2 (dome-shaped), tightened with 10Ncm	LBS: Zfx Evolution plus+; Zimmer Biomet	NP	ISB-2 had lower surface and multi-unit abutment centroid deviations, while ISB-1 had lower inter multi-unit abutment angular deviations.
Revilla-León et al.[25]	In vitro ($n = 10$)	Geometry	Implant abutment level	ISB-1: Elos Accurate Intraoral Scan Body; Nobel Biocare Services AG ISB-2: Scan body 3D Guide K Series; NT Digital Implant Technology ISB-3: ISB system with intraoral adaptor; Dynamic Abutment Solutions (3 implants, Implant replica RP Brånemark system; Nobel Biocare Services AG)	ISB-1: 1-piece PEEK Retention system: Screw-retained ISB-2: 1-piece PEEK Retention system: Screw-retained ISB-3: 1-piece PEEK Retention system: Screw-retained and magnet-retained	- Reference Model: Measurement of implant analog position by using a CMM -Casts made from conventional polyvinyl siloxane impression -Additively manufactured casts fabricated from implant level LBS scans with ISBs, hand-tightened	LBS: E3 Scanner; 3Shape A/S CMM: CMM Contura G2; Carl Zeiss Industrielle Messtechnik GmbH	NP	ISBs led to similar linear discrepancies. ISB-2 led to lower XZ angular discrepancies than ISB-1 and ISB-3 and led to lower angular discrepancies than ISB-3.

(Continues)

TABLE 3 (Continued)

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
Mizumoto et al.[26]	In vitro ($n = 5$)	Geometry	Implant abutment level	ISB-1: IO-Flo; Dentsply Sirona ISB-2: Nt-Trading GmbH & Co KG ISB-3: DESS ISB-4: Core3Dcentres ISB-5: Zimmer Biomet Dental (4 implants,TSV 4.1; Zimmer Biomet Dental)	ISB-1: 2-piece PEEK Retention system: Screw-retained ISB-2: 2-piece PEEK Retention system: Screw-retained ISB-3: 2-piece PEEK Retention system: Screw-retained ISB-4: 1-piece PEEK Retention system: Screw-retained ISB-5: 1-piece PEEK Retention system: Screw-retained	- Reference Model: Structured blue light industrial scanner scan of master cast - IOS Groups: IOS scans with ISBs by using four different techniques, tightened in line with MR	IOS: Trios (generation NP); 3Shape A/S Structured blue light industrial scanner: COMET L3D; Carl Zeiss Optotechnik GmbH	Operator: NP Ambient lighting: NP Scanning pattern: Starting from the occlusal surface, then the buccal surface, and then the palatal surface IOS calibration: NP Rescanning: NP	ISB-5 had lower distance deviations than ISB-1. ISB-2, ISB-3, and ISB-5 had lower angular deviations than ISB-1 when floss was tied between ISBs. ISB-2, ISB-3, and ISB-4 had lower angular deviations than ISB-1 when glass beads were placed between ISBs. ISB-3 and ISB-4 had lower angular deviations than ISB-2 when no modifications were used.
Alvarez et al.[27]	In vitro ($n = 10$)	Geometry	Implant abutment level	ISB-1: Elos Accurate Intraoral Scan Body; Nobel Biocare Services AG ISB-2: Implant level Intraoral STD Inhex Scanbody; Mozo-Grau ISB-3: Implant level Intraoral STD Inhex Scanbody; Mozo-Grau ISB-4: ISB system with intraoral adaptor; Dynamic Abutment Solutions (6 implants, Ticare INHEX Standard; Mozo-Grau)	ISB-1: 1-piece PEEK Retention system: Screw-retained ISB-2: 2-piece PEEK Retention system: Screw-retained ISB-3: 1-piece PEEK Retention system: Screw-retained ISB-4: 1-piece PEEK Retention system: Screw-retained and magnet-retained	- Reference Model: ISB positions measured by using a CMM - IOS Groups: IOS scans with ISBs by using two different IOSs, tightened with 5Ncm	IOSs: CEREC Omnicam; Dentsply Sirona and Trios 3; 3Shape A/S CMM: CMM Contura G2; Carl Zeiss Industrielle Messtechnik GmbH	Operator: NP Ambient lighting: NP Scanning pattern: One-step scan IOS calibration: NP Rescanning: NP	ISB-4 had lower distance deviations and ISB-3 had lower angular deviations than ISB-1.

(Continues)

TABLE 3 (Continued)

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
Althubaitiy et al.[62]	In vitro ($n = 11$)	Diameter and material	Implant level	ISB-1: Narrow diameter, Ti ISB-2: Narrow diameter, PEEK ISB-3: Regular diameter, Ti ISB-4: Regular diameter, PEEK Ti ISBs: L1400 and REF L1410; Medentika GmbH PEEK ISBs (CARES Mono Scanbody: 025.2915 and 025.4915; Straumann) (4 implants)	ISB-1: Narrow diameter, Ti ISB-2: Narrow diameter, PEEK ISB-3: Regular diameter, Ti ISB-4: Regular diameter, PEEK	- Reference model: Kennedy Class III, modification 1. Four implants (2 NC on the left PM and 1 M, 2 RC on the right PM and 1 M; Straumann Institute) Conventional PVS impression, poured, and digitized by using a LBS. - IOS group: IOS scans by using 4 different ISBs. Hand torqued. RMS error calculation (Geomagic Control X; 3D Systems)	LBS: E1; 3Shape A/S IOS: Trios 3; 3Shape A/S	Operator: NP Ambient lighting: NP Scanning pattern: NP IOS calibration: NP Rescanning: NP	An inverse relationship was noted between the LBS and IOS when varying the ISBs' material and diameter in the following order RD TI, ND TI, RD PEEK, ND PEEK.
Lee et al.[28]	In vitro ($n = 10$)	Material	Implant abutment level	ISB-1: MyFit; Yes Implant ISB-2: MyFit; Yes Implant (2 implants, IS-III active; Neobiotech Co.)	ISB-1: 2-piece PEEK Height: 8 mm Retention system: Screw-retained ISB-2: 1-piece Ti Height: 8 mm Retention system: Screw-retained	- Reference Model: LBS scans of master casts - IOS Groups: IOS scans with ISBs by using three different IOSs	IOSs: CS3600; Carestream Dental, Trios 3; 3Shape A/S, and CEREC Primescan; Dentsply Sirona LBS: Identica T500; Medit	Operator: NP Ambient lighting: 400–500 lux Scanning pattern: NP IOS calibration: NP Rescanning: NP	ISB-2 scans had higher trueness.
Arcuriet al.[61]	In vitro ($n = 5$)	Material	Implant level	ISB-1: Dental PEEK, not commercially available ISB-2: Titanium grade 5, not commercially available ISB-3: Dental PEEK, not commercially available (6 implants)	ISB-1: 1-piece PEEK Retention system: Screw-retained ISB-2: 2-piece PEEK Retention system: Screw-retained ISB-3: 1-piece Ti Retention system: Screw-retained	-Reference Model: Industrial scanner (ATOS 5 M; GOM - IOS scans with ISBs tightened with 10 Ncm. Complete-arch implant scans.	IOS: Trios 3; 3Shape A/S	Operator: No experience Ambient conditions: NP Scanning pattern: NP IOS calibration: NP Rescanning: NP	ISB-1 had highest accuracy (linear and angular discrepancies), followed by ISB-3 and ISB-2.

(Continues)

TABLE 3 (Continued)

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
Huang et al.[29]	In vitro ($n = 10$)	Splinting	Implant abutment level	ISB-1: Subtractively manufactured with extensional structures ISB-2: Subtractively manufactured without extensional structures ISB-3: CARES Mono Scan body for screw-retained abutment; Straumann AG (4 implants, Bone-level tapered RC; Straumann AG)	ISB-1: 1-piece Ti Height: 9 mm Retention system: Screw-retained ISB-2: 1-piece Ti Height: 9 mm Retention system: Screw-retained ISB-3: 1-piece PEEK Height: 9 mm Retention system: Screw-retained	- Reference Model: LBS scans of master cast - Conventional polyvinyl siloxane impression, casts digitized by using an LBS-Multi-unit abutment level - IOS scans with ISBs, tightened with 10 Ncm	IOS: Trios 3; 3Shape A/S LBS: D2000; 3Shape A/S	Operator: No experience Ambient conditions: NP Scanning pattern: NP IOS calibration: NP Rescanning: NP	ISB-1 had higher scan accuracy than ISB-2 and ISB-3.
Huang et al.[30]	Animal ($n = 5$)	Splinting	Implant level	ISB-1: Subtractively manufactured with extensional structures ISB-2: Subtractively manufactured without extensional structures (2 implants, Astra Tech Implant System; Dentsply Sirona)	ISB-1: 1-piece Ti Height: 9 mm Retention system: Screw-retained ISB-2: 1-piece Ti Height: 9 mm Retention system: Screw-retained	- Reference Model: LBS scan of dissected mandibles - IOS Groups: IOS scans with ISBs, tightened with 10 Ncm	IOS: Trios 3; 3Shape A/S LBS: D2000; 3Shape	NP	Scans of ISB-1 had higher trueness.

(Continues)

TABLE 3 (Continued)

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
García-Martínez et al.[31]	In vitro ($n = 10$)	Geometry	Implant level	ISB: Elos Accurate IOS 2C-A; Medtchech Pinol A/S (6 implants, Certain T3 platform switched tapered; Biomet 3i)	2-piece PEEK Retention system: Screw-retained	- Reference Model: Measurement of Euclidean reference distances by using a CMM - IOS Groups: IOS scans with or without customized over scan-body rings, tightened with 5 Ncm	IOS: CEREC Primescan; Dentsply Sirona CMM: Global Evo 09.15.08, serial number 906; Hexagon Manufacturing Intelligence	Operator: 7 years of experience Ambient conditions: 1000 lux, humidity of 45%, temperature of 21∘C, and air pressure 750 ± 5 mmHg Scanning pattern: MR IOS calibration: NP Rescanning: In case the uncovered surface of all the ISBs were not captured entirely without major holes, and the entire surface of the upper beveled notch and 1 cm of surrounding mucosa around them.	Customized over scan-body rings did not affect the scan accuracy.
Pozzi et al.[32]	In vitro ($n = 30$)	Splinting	Implant level	ISB: Subtractively manufactured custom PEEK ISBs (4 implants, Nobel Parallel RP; Nobel Biocare)	1-piece PEEK Height: 9 mm Retention system: Screw-retained	- Reference Model: Industrial-grade blue light scanner scan of master cast - IOS Groups: IOS scans of splinted and non-splinted ISBs, tightened with 10 Ncm	IOS: Trios 3; 3Shape A/S Industrial-grade blue light scanner: ATOS Compact Scan 5 M; GOM GmbH	Operator: 7 years of experience Ambient conditions: NP Scanning pattern: Starting from occluso-lingual surface with a 45° angle, capturing at least two surfaces and returning from the buccal side IOS calibration: MR Rescanning: NP	ISB splinting with modular chains increased the overall accuracy and reduced linear and angular deviations of the scans of posterior implants.

(Continues)

TABLE 3 (Continued)

Reference	Study type	ISB feature	Scan level	ISB systems (Number of implants)	Properties of ISBs	Groups and reference model	Scanners used	IOS influencing factors	Conclusions
Lawand et al.[33]	In vitro ($n = 15$)	Geometry	Implant abutment level	ISB-1: Unmodified CARES Mono Scanbody for screw-retained abutments; Institut Straumann AG ISB-2: Subtractively modified CARES Mono Scanbody for screw-retained abutments; Institut Straumann AG ISB-3: Additively modified CARES Mono Scanbody for screw-retained abutments; Institut Straumann AG (4, RC Bone Level Implant Analog; Institut Straumann AG)	1-piece PEEK Height: 9 mm Retention system: Screw-retained	- Reference Model: LBS scan of master cast - IOS Groups: IOS scans of ISBs, tightened with 10 Ncm	IOS: Trios 3; 3Shape A/S LBS: E3 Scanner; 3Shape A/S	Operator: 4 years of experience Ambient conditions: 1002 lux, 22°C and humidity of 45% Scanning pattern: MR IOS calibration: MR Rescanning: NP	ISB-3 had the highest 3D surface discrepancies, while ISB-2 had the lowest angular discrepancies. ISB-1 mostly had higher interimplant distance discrepancies.
Mosleimon et al.[60]	In vitro ($n = 10$)	Geometry	Implant level	ISB-1: 14.005; DESS ISB-2: 9.S3D4.300; NT-Trading ISB-3: B051; Doowon (4 implants, Nobel Replace Implant System and Brånemark Nobel Biocare Implant System; Nobel Biocare)	ISB-1: 1-piece PEEK Retention system: Screw-retained ISB-2: 2-piece PEEK Retention system: Screw-retained ISB-3: 1-piece Ti Retention system: Screw-retained	- Reference Model: Spatial coordinate measurements of master cast with an optical CMM - IOS Groups: IOS scans with ISBs, tightened according to MR	IOS: Trios 3; 3Shape A/S Optical CMM: ATOS Core 80 5MP; GOM	Operator: NP Ambient conditions: NP Scanning pattern: Starting from the lingual surfaces, then buccal and lingual surfaces IOS calibration: NP Rescanning: NP	ISB-1 had the lowest accuracy when implant position deviations, angular deviations (implants with external connection), distance from the guide pin, and interimplant distance were considered. ISB-2 had the highest accuracy when angular deviations (implants with internal connection) were considered.

Abbreviations: IOS, intraoral scanners; ISB, implant scan body; LBS, laboratory scanner; MR, manufacturer recommendation; NA, not applicable; ND, narrow diameter; NP, not provided; PEEK, polyetheretherketone; PM, premolar; RD, regular diameter; Ti, titanium.

that consisted of a screw-retained piece on top of which a magnet-retained 1-piece PEEK ISB is positioned) and the same coordinate measuring machine (CMM) to acquire the reference or control files. However, the magnet-retained ISB could not be evaluated due to the movement of the magnet-retained part during CMM analysis in one of those studies.[9] Nevertheless, both studies reported that tested ISB designs affected angular implant analog position and linear discrepancies ranging from 4 to 18.9 μm.[9,25]

Lawand et al.[33] evaluated the effect of subtractively and additively modified ISBs on intraoral scanning accuracy. The scans obtained by using additively modified ISBs had the highest surface discrepancies, while the scans performed by using subtractively modified ISBs had the lowest angular discrepancies.[33] The intraoral implant scans recorded with the ISB without modification mostly had higher interimplant distance discrepancies.[33]

ISB design modifications, with or without extensional structures, were evaluated in two of the included studies.[29,30] One of those two studies was an animal study on beagle dogs and evaluated the scan accuracy of a fixed partial denture condition with two implants.[30] The authors concluded that the ISB design with extensional structures improved the trueness of the scans when compared with the ISB design without extensional structures.[30] Similarly, the in vitro study reported increased precision for the design with extensional structures, when mandibular complete-arch implant scans were performed.[29] However, conventional impressions were shown to have higher trueness than the scans performed by using the tested ISB without extensional structures and higher precision than the ISB with the extensional structures.[29]

Efforts to improve the scan accuracy by using additively manufactured auxiliary equipment attached to ISBs have also been documented.[31,32] One of those studies introduced modular chain pieces that splint ISBs,[32] while a ring with eight concentric braces was introduced in the other study.[31] While placing rings over ISBs only improved the scan efficiency,[31] the use of modular chain pieces to splint ISBs increased the scan accuracy significantly.[32]

Implant scan body material

Among the included studies, standard ISBs (not coded healing abutments) fabricated with different materials have been tested: 1-piece PEEK,[2,7,9,22,25–27,29,30,32,33,60–62] 2-piece PEEK,[2,22,24,26–28,31,60,61] and 1-piece titanium (Ti) ISB.[28–30,60–62] Only five included articles tested 1-piece PEEK and 2-piece PEEK ISBs; however, these ISBs had different geometries.[2,10,26,27,60] Two studies evaluated 1-piece PEEK and 1-piece Ti, but also with different ISB geometry.[29,60] Two in vitro studies tested the same ISB geometry, having the ISBs fabricated by using 1-piece PEEK,[61,62] 2-piece PEEK,[61] and 1-piece Ti.[61,62]

Implant scan body retention system

None of the reviewed studies investigated the influence of ISB retention system on intraoral scanning accuracy. Except for studies by Yilmaz et al.[7] and Revilla-León et al.[9,25] all studies tested only screw-retained ISBs.

Quality of the reviewed studies

The JBI Critical Appraisal Checklist for Quasi-Experimental results showed a 100% low risk of bias in all included articles for questions 1, 2, 3, 4, 5, 7, 8, and 9. Question 6 was not applicable to any of the included studies.

DISCUSSION

Limited dental studies in the literature have analyzed the influence of ISB design (height, geometry, material, and retention system) on the accuracy of intraoral digital implant scans and only 18 articles were included in the present systematic review. Due to the variation in study methodology and data reporting, it was not feasible to provide conclusions regarding the optimal ISB design for maximizing intraoral scanning accuracy or whether there is a relationship between IOS technology and a specific ISB design or clinical condition that maximizes intraoral scanning accuracy.

Dental literature has identified operator- and patient-related factors that can reduce scanning accuracy.[36,37] Although included studies in the present systematic review aimed to assess the influence of ISB design on scanning accuracy, details on how experimental scans were captured, whether other factors that can reduce scanning accuracy were considered, and how scanning conditions and IOS handling were standardized were mostly not disclosed. This aspect of included studies highlights the need for further details in the dental literature while analyzing the accuracy of digital implant scans recorded by using IOSs.

Coded healing abutments with different heights and diameters may eliminate the need for ISBs while digitizing implants. Based on the findings of the present systematic review, the dental literature has scarcely analyzed the influence of coded healing abutment height on intraoral scanning accuracy.[6,19] In addition, only one in vitro study focused on the comparison of scan accuracy when coded healing abutments with different heights were used and reported that height impacted angular accuracy.[19] Therefore, additional studies are indicated to further assess the influence of coded healing abutment height on scan accuracy. The effect of standard ISB height on scanning accuracy has also been investigated; however, the actual ISB height was standard in those studies and the height of the scannable part varied according to the implant depth.[63,64] Therefore, those studies were not included in the present systematic review, and it is not possible to determine whether ISB height would affect the scan accuracy of IOSs or not.

The geometry of the ISBs was the most frequently investigated factor within the studies included in the present systematic review. [2,7,9,22,24–27,31,33,60] Most of the studies reported that ISB geometry affected implant scan accuracy, whereas only one study concluded that ISB geometry did not affect the accuracy of implant scans.[31] However, it should also be emphasized that among the studies that reported a significant effect of ISB geometry, only two compared ISBs from the same manufacturer.[7,24] Two studies tested the same ISBs[9,25] and reported similar results, even though either CMM[25] or IOS scans[9] were used to generate test group data. Modification of prefabricated ISBs to improve the implant scan accuracy was investigated in two studies,[31,33] and contradicting results have been reported. Garcia-Martinez et al.[31] showed that modifications by using additive manufacturing did not affect the scan accuracy, whereas Lawand et al.[33] showed that subtractive modifications decreased angular and additive modification increased surface discrepancies.

The accuracy of IOSs can decrease when digitizing restorative materials, due to the reflectance discrepancies when compared to hard dental tissues.[56] PEEK or Ti ISBs can be used to digitize implants. PEEK has the advantage of lower light reflectance, while Ti is more dimensionally stable.[24] The 1-piece Ti ISBs may require surface treatment with an anti-reflective scanning spray to facilitate digitization while using an IOS. Additionally, 1-piece PEEK ISBs can be distorted by multiple use[23,65] and sterilization,[23] and vertically displaced with ISB placement.[23] Considering the reported distortion with PEEK ISBs, their single-use or 2-piece PEEK or 1-piece Ti ISBs may be preferred. Based on the results of the present systematic review, only one in vitro study considered the influence of three different ISBs (1-piece PEEK, 2-piece PEEK, and 1-piece Ti) on scan accuracy.[60] Even though Mosleimon et al.[60] reported that 1-piece PEEK ISB resulted in the lowest accuracy for most of the parameters investigated and 2-piece PEEK ISB led to the highest accuracy when angular deviations were considered, these results should be interpreted carefully as tested ISBs had different geometries. Therefore, future studies are needed to evaluate the influence of ISB material on the scanning accuracy of different IOSs.

None of the reviewed studies investigated the influence of ISB retention system on intraoral scanning accuracy, therefore, the influence of different ISB retention systems namely screw-retained, Snap-On, and magnet-retained remains unknown. However, Revilla-León et al[9] reported the incapability of palpating the magnet retained 1-piece PEEK ISB tested and, therefore, the accuracy of the ISB group was not reported. This finding may indicate that the tested ISB design might move under minor pressure created by tongue movement or contact with the IOS while scanning. Studies are needed to assess the effect of ISB retention system on intraoral scanning.

Laboratory and clinical studies are indicated to identify the optimal ISB design based on the IOS selected for acquiring intraoral digital implant scans, as the optimal ISB design may vary for different IOS technologies and systems. Additionally, details on how experimental intraoral digital scans are obtained (ambient lighting conditions, relative humidity, calibration, scanning pattern, rescanning methods, and scanning distance) are fundamental for standardizing research methodologies for data comparison among studies, as well as measurement methods to assess scan accuracy.

CONCLUSIONS

Limited studies in the literature have analyzed the influence of ISB design (height, geometry, material, and retention system) on the scan accuracy of implants, and evaluation of the findings of existing studies did not provide concrete conclusions regarding optimal ISB design, whether there is a relationship between the IOS technology and specific ISB design or clinical condition to maximize intraoral scan accuracy. Research studies are needed to identify the optimal ISB design and its possible relationship with IOS used for acquiring intraoral digital implant scans.

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