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Review article

Intraoral scanners in implant prosthodontics. A narrative review

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ABSTRACT

Objectives: To review the developments in intraoral scanner (IOS) technologies applied in implant prosthodontics, emphasizing their influence on the accuracy of digital impressions, occlusal registrations, and the fit of implant-supported restorations.
Data: A collection of published articles related to implant prosthodontics, the accuracy of digital impressions, occlusal registration, and the fit of implant-supported fixed restorations.
Sources: Three search engines were selected: Medline/PubMed, EBSCO, and Cochrane. A manual search was also conducted.
Study selection: A literature search screened relevant databases and journals for studies on IOS applications in digital implant prosthodontic workflows from Dec 2018 to Dec 2023. Inclusion criteria encompassed randomized control trials, clinical trials, case series, and in vitro research focused on the use of IOS in digital implant prosthodontics.
Conclusions: The increased utilization of digital dental technologies has led to significant integration of digital implant prosthodontic workflows into clinicians' clinical practice. Several variables affect the accuracy of digital impressions generated by IOS. Generally, the prevailing opinion in academic papers is that digital workflows are suitable for addressing short-span implant-supported restorations. However, when it comes to long-span defects, the accuracy of digital workflows is still a matter of debate. Digital bite registration is an integral part of the workflow. It depends mainly on the defect size and location, scan strategy, anatomical tooth variations, overbite and other factors. The overall fit of digitally prefabricated implant restorations comprises of proximal, occlusal contacts and how accurately the restoration connects with implants. Research methodologies need standardization for further validation.
Clinical significance: In clinical practice, it is essential to have a thorough and up-to-date comprehension of various factors that can affect the accuracy of digital impressions and the fit of the final prosthesis in implant prosthodontics.

1. Introduction

In contemporary dental implant prosthodontics, a digital workflow aims to enhance clinical accuracy, operational efficiency, and elevated patient comfort [1,2]. In clinical practice, a key element of digital workflow is the intraoral scanner (IOS). High-resolution IOS captures three-dimensional images of the teeth and surrounding objects. It eliminates the need for traditional impression techniques. In the restorative phase of implant dentistry, digital scanning is pivotal in accurately capturing implant position and information integration into the computer-aided design and manufacturing (CAD/CAM) process of the final prosthetic restoration [3–5]. This comprehensive digital approach leads to accurate, aesthetic results and significantly enhances the patient's overall experience, making dental treatment protocols more efficient [6,7]. The accuracy of intraoral scanners in digital dentistry represents a fundamental aspect of achieving superior clinical outcomes. Accuracy is essential for designing and fabricating dental restorations, ensuring a clinically acceptable fit and optimal function. According to ISO 5725-1, accuracy consists of trueness (proximity of measurement results to the true value) and precision (repeatability or reproducibility of the measurement) [8].

Considering the studies of Revilla-León et al. [9] and Rutkūnas et al. [10], two main categories influence the accuracy of IOS: factors related to the patient and those related to the operator [9]. Patient-related

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elements include several aspects: total number of implants, spacing between implants (or the number of units), angle of implants, dental arch involved (either maxillary or mandibular), implant's position within the arch (anterior or posterior), and implant depth (including supramucosal height of a scan body). On the other hand, factors linked to the operator include the IOS device and software, operator experience, environmental lighting conditions, scanning technique, span of the scan, design of the implant scan body (which involves the material, shape, and retention system), scan body splinting methods, scan body repositioning, and the accuracy of the scan body itself. In recent years, many reviews have discussed these factors and their influence on intraoral scan accuracy [2,11–13]. Thus, this review aims to look at the improvements and clinical implications of IOS technology in implant prosthodontics, focusing on three essential areas: the accuracy of digital impressions, the accuracy of occlusal registrations, and the overall fit of implant prostheses.

2. Methods

A digital search was conducted for research papers published from December 2018 to December 2023. A five-year cut-off point was selected because of the rate of advancement of digital dental technologies, including IOS software and hardware. PICO questions and search strategy are presented in Table 1.

An electronic search was performed in selected databases: MEDLINE/PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science, and Google Scholar. Only English-language publications were included in this systematic review. The last search was conducted on December 20, 2023. The search strategy was constructed by combining free text and MeSH (Medical Subject Headings) terms with Boolean operators (AND or OR): ((“implant*” AND (“abutment*” OR “coping” OR “prosth*” OR “crown*” OR “framework*” OR “denture*” OR “Dental Prosthesis, Implant-Supported”[Mesh])) OR (“occlus*” OR “intermaxill*” OR “interarch*” OR “maxillo-mandibular” OR “maxillomandibular*” OR “interocclus*” OR “inter-occlus*” OR “articul*” OR “bite”)) AND (“Dimensional Measurement Accuracy”[Mesh] OR “accuracy” OR “fit” OR “misfit” OR “adaptation” OR “discrepancy*” OR “trueness” OR “precision”) AND ("intraoral*" OR "intra-oral*" OR "IOS") AND “scan*”.

The contents of the following journals were searched additionally using electronic and manual search: Journal of Prosthetic Dentistry, Journal of Engineering in Medicine, Journal of Prosthodontics, The International Journal of Prosthodontics, The Journal of Advanced Prosthodontics, Journal of Prosthodontic Research, Journal of Oral Rehabilitation, Medical & Biological Engineering & Computing.

Table 1
PICO question and Boolean search.

PICO Question	Boolean search strategy
P (problem or population), partially or completely edentulous dental arch or replica with implants I (intervention), digital impressions with intraoral scanners using different strategies C (comparison), accuracy (trueness and precision or trueness only) of digital implant impressions, bite registrations, and implant-supported restorations produced from digital impressions O (outcome), quantitative estimation of accuracy (trueness and precision) of implant position or bite registration or the fit of the final prosthesis	((“implant*” AND (“abutment*” OR “coping” OR “prosth*” OR “crown*” OR “framework*” OR “denture*” OR “Dental Prosthesis, Implant-Supported”[Mesh])) OR (“occlus*” OR “intermaxill*” OR “interarch*” OR “maxillo-mandibular” OR “maxillomandibular*” OR “interocclus*” OR “inter-occlus*” OR “articul*” OR “bite”)) AND (“Dimensional Measurement Accuracy”[Mesh] OR “accuracy” OR “fit” OR “misfit” OR “adaptation” OR “discrepancy*” OR “trueness” OR “precision”) AND ("intraoral*" OR "intra-oral*" OR "IOS") AND “scan*”

Firstly, all titles and abstracts were assessed. Articles that evaluated the accuracy of digital implant impressions, bite registrations, and implant-supported restorations produced from digital impressions were included in the current study. Two calibrated reviewers (J.P. and L.A.) gathered the data from the selected articles into structured tables. Any disagreements were resolved by consensus, and a third examiner (V.R.) was consulted.

This review included randomized control clinical trials, clinical trials, case series, and in vitro studies focusing on using intraoral scanners and digital workflows in implant prosthodontics. Studies including partially or completely edentulous dental arches or arches or replicas (for *in vitro* studies) with implants and taking single-unit or multi-unit conventional and digital or only digital implant impressions with commercially available IOS, using scanbodies, were included. The research focused on the accuracy of auxiliary scanning devices (i.e., photogrammetric scanners or jaw motion trackers) was omitted. Studies comparing scanning accuracy among different IOS devices, both in vitro and in vivo, were incorporated. Furthermore, studies that compared the accuracy of intraoral digitization with conventional implant impressions were also included. Additionally, this review included articles on the fit of prosthetics that were manufactured using IOS data. Studies examining the fit of restorations produced from analog impressions were excluded. Similarly, case reports were also excluded. Additionally, the reference lists of the included papers were screened to ensure that no relevant articles were missed. The following questions were formulated and discussed in this narrative review:

1. Accuracy of digital implant impressions;
2. Accuracy of bite registration;
3. The fit of implant-supported restorations manufactured from IOS data.

3. Results

An initial search identified 567 publications. After reviewing the titles and abstracts, 143 articles were selected. After full-text analysis, 82 articles were excluded from the final list. The selected publications were divided into three groups according to the subject of interest: accuracy of digital implant impression (35 publications), accuracy of bite registration (16 publications), and fit of manufactured implant-supported restorations (16 publications). List of all identified publications are presented on Table 2.

3.1. Accuracy of digital implant impressions

Digital implant impression acquisition using an IOS is a sensitive procedure depending on several patient-associated factors that may influence the overall accuracy: number of implants, interimplant distance (also a number of units), implant angulation, arch (maxillary or mandibular), position in the arch (anterior or posterior), implant depth (also supramucosal height of a scan body) and other factors. It can be noted that accuracy tends to diminish with an increased number of implants and a greater interimplant distance [3,4,14–16]. The impact of implant angulation on accuracy is debatable, as some studies associate greater angulation with reduced accuracy [14,16], while others find no significant effect [17–19]. The specific arch (maxillary or mandibular) may also affect accuracy, as illustrated by a few studies showing higher accuracy in maxillary scans [20,21], a finding not supported by another in vitro study [22]. The position of the implant in the arch, whether anterior or posterior, is also a factor worth considering. Posterior implants can be more challenging to scan accurately due to the limited mouth opening and the presence of the cheek and tongue. An in vivo study by Ma et al. [23] found that anterior implants yield more accurate digital impressions than posterior ones. Factors influencing the accuracy of digital impressions, such as the depth of implant placement and the

Table 2
Summary of the factors that affect the accuracy of digital implant impressions.

	In vitro, ex vivo	In vivo
1. Scanbody position in model	Patient-associated: • Number of implants [3,4, 14–16] • Interimplant distance (or the number of units) [3,4, 14–16] • Implant angulation [14, 16–19] • Arch (maxillary or mandibular) [21,22] • Implant depth (also - supramucosal height of a scan body [18,24] Operator-associated: • IOS hardware, software [17, 25–28] • Operator experience [29, 30] • Ambient lighting conditions [31,32] • Scanning pattern [22] • Scan extension [33] • Scan body design (material, geometry, fixation) [5, 34–38] • Scan body splinting (artificial landmarks, special devices) [3,17,26, 40,42] • Scan body repositioning [44] • Accuracy of the scan body [45,46]	Patient-associated: • Arch (maxillary or mandibular) [20] • Position in the arch (anterior or posterior) [23] Operator-associated: • Scan body design (material, geometry, fixation) [39] • Scan body splinting (artificial landmarks, special devices) [41,43]
2. Bite registration	• Scan strategy [56,57] • Defect size [48,78] • Defect location [48,78] • IOS hardware [57,60,78, 79] • Alignment method [80]	• Bite force [59] • IOS hardware [52,54,60, 81] • Occlusal collisions [51]
3. The fit of implant-supported restorations	• IOS hardware [64,70,82] • Engaging/non-engaging component [67]	• Defect size [39,43,68,74, 75] • Angulation between implants [68] • Cement gap [69] • IOS hardware [64,70]

supramucosal height of the scan body, show mixed results in studies. Taghva et al. [24] conclude that the most coronal (1 mm subgingival) and the most apical (4 mm subgingival) positions of implants had significantly higher accuracy than the middle groups of implants placed 2 and 3 mm subgingivally. An in vitro study by Sicilia et al. [18] showed that the supramucosal height of the scan body did not significantly affect the accuracy of the intraoral scans.

The accuracy of digital implant impressions in dentistry is also significantly influenced by operator-associated factors, including the choice of IOS hardware, IOS software, operator experience, ambient lighting conditions, scanning pattern, scan extension (or span), the characteristics of the scan body itself (material, geometry, fixation), scanning techniques (such as scan body splinting and the use of artificial landmarks or special devices), scan body repositioning, and dimensional accuracy of the scan body. Different scanners come with varying capabilities in terms of resolution, speed, and software algorithms, which affect their performance in capturing data. Four studies were analyzed to evaluate the accuracy of complete-arch implant scanning [17,25–27]. For instance, Azevedo et al. [25] reported higher accuracy with CEREC Primescan (Dentsply Sirona; Charlotte, USA) over iTero Element 5D (Align Technology; San Jose, USA) and Trios 4 (3Shape A/S, Copenhagen, Denmark). Similarly, Ashraf et al. [17] found both Trios 4 (3Shape) and CEREC Primescan (Dentsply Sirona) to outperform Medit i600 (Medit, Seoul, South Korea). In an in vitro study of a fully edentulous case, Rutkūnas et al. [26] found that IOS of choice does have a significant effect, but different results were evident for distance, angle, and vertical shift measurements. Furthermore, Mangano et al. compared 12 intraoral scanners for making complete-arch implant digital impressions [27]. Using the nurbs/nurbs method of comparison, the iTero Element 5D showed the highest trueness, followed by Primescan, Trios 3, i-500, CS 3700, CS 3600, Virtuo Vivo, Runeyes, Emerald S, Omnicam, Emerald, and DWIO. In shorter-span fixed implant partial denture cases, the CEREC Primescan (Dentsply Sirona) was found to have similar or superior accuracy compared to Trios 3 (3Shape) in a study by Donmez et al. [28]. In recent studies by Arcuri et al. [29] and Revell et al. [30], the role of an operator was found to have negligible influence on the accuracy of digital implant impressions. Additionally, ambient lighting conditions, such as color temperature and illuminance, were shown to influence IOS accuracy, with optimal conditions varying for each device [31,32]. The scanning pattern is crucial for accuracy, especially in fully edentulous cases with implants. The scanning pattern determines the sequence and manner in which the dental arches and implants are captured. Gómez-Polo et al. [22] identified the circumferential pattern as the most accurate among six tested techniques in fully edentulous cases with six implants. As for the length of the scan itself, a decision guide was proposed by Revilla-León et al. [33]. A reduced scan extension could be recommended for single or short-span implant-supported fixed prostheses. For other clinical cases, complete-arch intraoral scans are indicated. While the scan body's material, geometry, and fixation method are considered crucial, studies provide no definitive conclusions regarding their impact on accuracy [5,34–37]. However, in their study, Gracis et al. [38] presented a set of favorable features for scan bodies, emphasizing the benefits of a one-piece, screw-retained, metal build that is radiopaque. The surface should be either rough (sandblasted) or coated, and different heights should be available for specific clinical conditions, like dentate or edentulous situations. Furthermore, they recommended a shape with minimal undercuts, a wide occlusal surface, and an automatic coding system to identify the implant platform beneath. Scan gauges could be considered a new type of scan body; their special design minimizes the gap between scan posts, potentially enhancing accuracy and resulting in a clinically acceptable fit of the prosthesis [39]. Scan body splinting, artificial landmarks, and other special devices are techniques employed to enhance the accuracy of digital impressions of multiple implants. They provide additional reference points for the scanner and maintain scanning at a similar height from the gingiva, thus improving the image-stitching process and the accuracy of the impression. Most recent studies approve using these techniques, especially in fully edentulous cases [3,17,26,40–43]. To the best of the authors' knowledge, only one study (meeting the inclusion criteria) evaluated the repositioning accuracy of the scan bodies [44]. The study suggests that repositioning inaccuracies may not significantly impact single-unit cases, but they could cumulatively affect more complex implant scenarios. Additionally, the accuracy of scan body dimensions and manufacturing tolerances remains a scarcely evaluated research topic. Schmidt et al. [45] measured multiple scan bodies from different manufacturers using X-ray computed tomography and concluded that dimensional inaccuracies of the tested scan bodies could lead to position deviations of up to 26 μm. Similarly, Lerner et al. [46] found significant dimensional differences and production tolerances among widely used scan bodies from manufacturers such as Nobel Biocare, Straumann, BIOTEC, and Megagen. In the study conducted by Button et al. [47], despite not utilizing implant-supported specimens, it was found that surfaces with 0 and 2-mm scanning distances, as well as those with 0 or 15-degree angulations, exhibited the highest accuracy across various tested intraoral scanning (IOS) devices.

3.2. *Accuracy of bite registration*

In implant prosthodontics, establishing accurate maxillomandibular relation has been regarded as a crucial component of the workflow. Due to advancements in dental technologies, IOS devices are becoming increasingly common among practitioners. As concluded in previous studies, a fully digital workflow is only recommended for small defects for implant-supported restorations. One of the reasons is the occurrence of deviations in the bite registration process.

The size and location of the defect are some of the most important factors contributing to deviations that may occur in the final articulation of models. Based on an in vitro study by Ren et al. [48], it was found that the dimensions and anatomical location of edentulous regions greatly influence the accuracy of digital bite registration. According to the publication, the absence of a solitary posterior tooth does not substantially impact interocclusal registration, suggesting that a complete digital workflow can be applied in such instances. Finally, it has been observed that both unilateral and bilateral extended edentulous spans characterized by the absence of three or more posterior teeth and extended edentulous regions within the anterior aspect significantly compromise the accuracy of the interocclusal registration dimension. One of the notable limitations of this study is that reference dots from which interarch distances were calculated were placed close to the tooth surface, meaning that those details might have influenced overall bite registration scanning and processing during bite registration. In a recent in vivo study by Morsy et al. [49], a comparison was made between quadrant and full-arch cases of bite registration accuracy. It was determined that, for both quadrant arches and full-arch scan cases, virtual interocclusal records in maximal intercuspation (MIP) with IOS had substantially higher accuracy than traditional interocclusal records. Conclusions are in conjunction with several *in vitro* studies concluding that digital bite registration is notably more accurate than analog bite registration [50–55].

The bite scan strategy also plays a significant role in the accuracy of virtual bite records. In an *In vivo* study by Lee et al. [56], the standard bilateral bite registration method showed a mean deviation of 50 microns, which is clinically acceptable compared to a full arch bite scan. Similarly, Cheolho et al. [57], in their in vitro study, evaluated the difference between single anterior and two posterior bite scan accuracy on digital bite registration. As stated by the authors, bilateral posterior occlusal scans are recommended over single anterior occlusal scans to mount complete arch cases digitally. Conclusions are in agreement with Cha et al. study, with a similar methodology [57]. These findings from recently mentioned studies suggest that bite-scanning strategies recommended by manufacturers are to be followed.

Another point is that maxillary and mandibular intraoral scans are acquired while the subject is in an unloaded position with the mouth open, during which intraoral digital scans are captured [58]. This circumstance is altered during the acquisition of virtual occlusal records at MIP. Occlusal collisions or mesh interpenetrations have been identified as phenomena that occur during the penetration of virtual articulated models [58]. Occlusal collisions arise due to tooth movement from the plasticity of the periodontal ligament during the conversion from virtual occlusal records to intraoral digital scans. Furthermore, according to Okamoto et al., there is a significant difference in how strongly a patient bites during the bite registration procedure [59]. Naturally, with a stronger bite, the total occlusal contact area increases compared to a weak bite. Also, the authors concluded that stronger bite scans aligned better with original arch scans, having fewer 3D deviations. Additionally, intraoral scanning distortion and alignment procedures contribute to this discrepancy [58]. Using software applications of the IOSs, occlusal collisions that occur in virtual articulated casts can be eliminated automatically. Dental computer-aided design (CAD) software can autonomously identify and rectify occlusal collisions that may occur within the imported articulated intraoral digital scans. Nevertheless, the impact of occlusal collision corrections executed via IOSs or CAD programs on the accuracy of the maxillomandibular relationship, as registered at MIP, remains relatively unresearched. In an in vitro study by Revilla-Leon et al. [51], it is concluded that the trueness of the maxillomandibular relationship was affected by the scanner and program used to correct occlusal collisions. Compared to the CAD program, the IOS program adjusted the occlusal collisions with better trueness. The occlusal collision correction method did not significantly affect accuracy. Trimming digital models or opening vertical dimensions in CAD software to acquire better occlusion did not improve the results generated by the IOS software.

Some of the IOS systems offer functions to scan static and dynamic occlusion, namely Trios 3Shape Patient Specific Motion and Medit Mandibular movement options. These kinds of functionality are in the early stage of their clinical use. Thus, the scientific data on the accuracy of such procedures is scarce. Li et al. [60] conducted a clinical study on 3Shape's patient-specific motion feature. For a single mandibular molar crown, as the authors concluded, the generated occlusal surface was better adapted to dynamic occlusion than only static occlusion registration and average-value virtual articulator.

Additional research is required to assess the impact of different scenarios involving opposing dental arches, such as varying types of tooth loss and dental restorations, including removable, fixed partial dental, or implant restorations made of different materials. Moreover, some challenges present during the scanning of extensive edentulous regions may be overcome by adding reference objects on soft tissues or using auxiliary implant parts and/or objects to facilitate easier and potentially more accurate digital bite scans. Finally, the industry has developed advanced technologies that provide new solutions for bite registration, such as photogrammetric scanners, jaw motion trackers, and high-definition extraoral scanners. These technologies may improve the capture of maxillomandibular relations.

3.3. The fit of implant-supported restorations manufactured according to digital workflow

Among various factors, the accuracy of both scan body position and interocclusal records is one of the most important factors determining the fit of implant-supported restorations. Generally, the overall fit may be categorized into the interproximal, occlusal, and prosthetic-to-implant fit.

Even though there are studies discussing the fit of implant-supported restorations manufactured according to digital workflow, it is hard to summarize the information gathered after reviewing publications. One of the main reasons is the high variability in the methodology of these studies (type of restoration, materials used, outcomes measured, etc.)

For single-unit implant restoration, our review identified two studies comparing prosthetic outcomes. Delize et al. compared conventional and digital workflows for posterior single-implant restoration [61]. Among other outcomes measured, the authors identified that the fit of restorations made using digital workflows was acceptable and comparable to those made using conventional methods. Although using a slightly different manufacturing method, Lerner et al. found similar satisfactory results in their clinical study [62]. The authors concluded that marginal adaptation, occlusal, and interproximal contacts were excellent. Three-year survival and success rates were 99 % and 91 %, respectively. Similarly, digital workflow for single-unit cement-retained implant-supported restorations using digital impressions required fewer crown adjustments in a publication by Ren et al. [63].

Some previous studies also evaluated the accuracy of screw-retained CAD/CAM implant crowns [6]. No interproximal or occlusal adjustments were necessary for the digitally generated crowns. A randomized controlled trial was conducted to compare a conventional workflow with a fully digital workflow that did not utilize a physical model. The results indicated that the test group did not require interproximal or occlusal adjustments, whereas the control group required such adjustments in 40 % and 30 % of the reconstructions, respectively [7]. Comparably, in a more recent study, Pletkus et al. found similar accuracy and success rates for screw-retained single posterior implant crowns using model-free screw digital workflow [64].

Emerging studies indicate that a complete digital workflow for single-unit implant restorations, excluding casts, achieves comparable or even superior clinical fit compared to conventional methods despite the scarcity of available data. Thus making it a promising treatment strategy.

In fixed restorations involving two or more dental implants, achieving a passive fit is paramount to enduring prosthetic success. Passive fit implies that the adaptation between the implant and prosthetic component should be accomplished with no tension on the retaining screws [65]. The compromised fit between the contact surfaces of screw-retained implant-supported fixed restorations may create uncontrolled strains in the prosthetic components and peri-implant tissues, thus evoking biological and technical complications such as bone loss, screw loosening, component fractures, and loss of implants or restorations. As identified in a systematic review by Katsoulis et al., the degree of misfit that is clinically acceptable is still debatable [66]. Furthermore, there is no standardized and widely accepted way to measure misfit clinically [67]. The authors suggest a way to quantify the clinical misfit by measuring the angle of rotation while torquing the screw. One of the more recent articles on this topic by Rutkunas et al. [68] investigated the influence of distance and angulation between two implants on the passive fit of the prosthesis made using digital workflow in an *in vivo* environment. Among the conclusions, the authors noted that an implant angulation exceeding 10 degrees could potentially adversely impact the passive fit of digitally manufactured restorations. Furthermore, it was established that the distance between implants did not seem to significantly impact the accurate fit of restorations. An *in vitro* study by the same group investigated the difference between conventional and digital workflow in producing bars on two implants. The results showed that the cast-free digital workflow was associated with a smaller cement gap but a larger misfit on the verified master model [69]. Even though using more subjective methods, such as one-screw and screw resistance tests to investigate the passive fit of implant construction, Hashemi et al. conducted a clinical trial [70] looking into the prosthetic outcomes of three-unit implant-supported restorations. Based on the authors' conclusion, it can be inferred that the digital workflow for these procedures is comparable to the conventional workflow. It aligns with results presented in other recently published studies [71–73]. Considering full-arch restorations, Yilmaz et al. [45] determined that intraoral and laboratory scanners can exhibit significantly elevated discrepancies at the prosthetic and implant parts when producing the framework for a full-arch four-implant-supported restoration. Given the study's limitations, Nagata et al. [74] propose that implant prostheses for up to three units (where teeth are present on only one side of the edentulous space) can be fabricated using IOS digital impressions. Contrary to this, Cappare et al. compared digital and conventional workflows for full arch reconstructions on six implants [75]. The 25 cases test group of this *in vivo* study advocates a satisfactory accuracy and predictability of the IOS to be a reliable alternative in clinical practice to the conventional workflow for implant full-arch rehabilitations. Similarly, Imburgia et al. conducted a clinical trial demonstrating that digital workflow is clinically acceptable for long-span implant restorations [43]. Finally, the most recent study of the search time period by Klein et al. reported that all 37 full arch cases made using digital workflow were accurate upon delivery visit [39].

It is essential to acknowledge that most studies utilize additional steps, such as additional reference scans, etc., in the intraoral scanning of multiple implant cases. Therefore, it is crucial to exercise caution when comparing and extending conclusions from such studies and implementing them in clinical environments. Deep understanding of IOS technology, digital implant impressions is needed to be able to perform these kind of procedures.

It is also important to mention the importance of 3D printing in the context of manufacturing implant-supported restorations made using digital workflows. It is mandatory to use 3D printed models for procedures like preclinical evaluation of accuracy, final cementation of fabricated implant suprastructure. Even though a systematic review by Parize et al. indicates that 3D printed models are similarly accurate as cast gypsum models (the gold standard of prosthetic dentistry), conclusions are drawn from *in vitro* studies [76]. Authors indicate that there is a lack of clinical trials regarding the accuracy of 3D-printed models. As indicated by Piedra-Cascon et al. The accuracy and properties of additively manufactured dental devices depend on multiple parameters associated with technological properties [77]. Protocols for 3D printed models are constantly evolving, new materials are beeing introduced. Operators of these printing machines should have deep knowledge of this technology and always calibrate and check the outcome of 3D printing to ensure the best possible accuracy, which may influence the final outcome of implant-supported restoration.

Misfiting implant-supported restorations pose serious challenges in clinical practice. Ensuring the prevention of biological and technical complications in the implant and restoration process and minimizing the need for complex corrections or remakes during the manufacturing of restorations is of utmost importance in every clinical practice. Therefore, achieving satisfactory occlusal and interproximal contacts, as well as an accurate connection between implants and restorations, is crucial in the field of digital implant prosthodontics.

4. Conclusions

In conclusion, the accuracy of digital impressions and bite registrations is paramount in achieving the fit of implant prostheses. A clinically acceptable fit ensures optimal patient outcomes and long-term success in implant prosthodontics. Technological advancements in IOS have significantly impacted the field by reducing patient discomfort and streamlining the workflow. The accuracy of IOS procedures is also comparable in most scenarios to an anlogue workflow. These developments have contributed to enhanced patient satisfaction and greater predictability in implant therapy. Deviations in digital implant impressions are likely to increase with a greater number of implants, larger implant angulations, use of the mandibular arch, placement of the implant in the posterior position of the arch, absence of scan body splinting or additional reference markers, and accuracy as well as repositioning features of the scan body. Recent studies present mixed findings regarding the impact of other factors. The accuracy of digital bite registration may be compromised in cases with extensive edentulous areas and, in general, is a technique-sensitive procedure. The use of IOS automatic bite adjustments and dynamic occlusion recording appears to enhance workflow accuracy. While digitally fabricated single-unit implant-supported restorations, including those in model-free workflows, generally achieve clinically acceptable accuracy, restorations involving three or more units present greater challenges.

A deep understanding of technological nuances of digital implant destistry is paramount in achieving clinically acceptable results. As we continue to embrace and refine these digital tools, clinicians must prioritize their proficiency in understanding the limitations of IOS and utilizing them to capture accurate digital impressions and bite registrations and ensure the meticulous fit of implant prostheses, thus promoting the highest standard of care in implant prosthodontics.

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CRediT authorship contribution statement

Vygandas Rutkūnas: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing – review & editing, Visualization, Supervision, Project administration. **Liudas Auškalnis:** Investigation, Methodology, Writing – review & editing, Visualization. **Justinas Pletkus:** Conceptualization, Methodology, Validation, Writing –

original draft, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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