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Review

Techniques to Improve the Accuracy of Intraoral Digital Impression in Complete Edentulous Arches: A Narrative Review

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Abstract: Complete edentulous arches have been considered as one of the main limitations of intraoral scanners (IOSs). In these clinical scenarios, the accuracy of IOSs can be reduced because of several anatomical factors. To overcome these limitations, some studies have proposed several techniques to increase the accuracy of the impressions by means of various materials and instruments. The aim of this narrative review was to describe these techniques and to compare the obtained results to understand if it is currently feasible to increase the accuracy of the digital impressions of complete edentulous arches. An accurate analysis of the literature was performed using PubMed (National Library of Medicine) as well as manual searching without time and language restrictions. The results showed that there are few articles in the indexed literature on this topic, and that all are in vitro studies. Although the results of the analyzed studies were encouraging and reported useful in vitro results for artificial landmarks as well as for the use of an auxiliary geometry part related to the splinting of intraoral scan bodies (ISBs), clinical trials are needed to confirm that these techniques are feasible in daily clinical practice.

Keywords: intraoral scanning; accuracy; complete dentulous arch; artificial landmarks; splinting scanbody; dentistry

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1. Introduction

Since their introduction more than 30 years ago, intraoral scanners (IOSs) have undergone a constant evolution that has led to the development of new software and devices [1]. Today, digital optical scanning through the use of IOSs can be considered a valid alternative to conventional impression materials when registering intraoral anatomy and implant position, improving the comfort and compliance of the patient [2,3]. Conventional impression techniques and materials have been extensively investigated in the literature and have been used routinely for years in dental clinical practice. Each step in conventional procedures can produce an error that can be accumulated or compensated for to achieve accurate restorations [4]. Conventional implant impression procedures require the use of transfer copings which are connected to the implants at the time in which the impression is taken and embedded together with the surrounding teeth and mucosa using elastomeric impression materials such as polyvinyl siloxane or polyether [5]. These procedures are operator dependent and potentially a source of error and inaccuracies [6]. An inaccurate transfer of the implant position can lead to the fabrication of an inadequate prosthesis and therefore to complications. Different approaches have been studied to reduce errors and increase the precision of the final impression: in patients with partial or complete edentulism, it has been shown that taking a final impression using splinted impression copings yielded better results and a more accurate cast compared to taking impressions without splinting them [7]. With the development of computer-aided design and computer-aided manufacturing (CAD-CAM) technology, it is possible to bypass this step and fabricate the dental prostheses through direct or indirect digitalization [8]. The indirect digitization system starts with a conventional impression that can be cast in plaster or scanned directly using a laboratory scanner without producing the physical cast [9]. Instead, a complete direct digital workflow was developed using only IOSs. The data acquired from using an IOS directly from a patient's mouth are sent to the CAD software and, once the prosthetic restorations have been designed, the data are sent directly to a milling machine for manufacturing. In the digital workflow, problems such as material distortion are eliminated, as well as the gag reflex, allergies to impression materials, or transmission of infection from patient to technician [10,11].

IOSs offer many advantages, including increased patient comfort, faster scanning, and lower storage and transport requirements [12]. The realization of a completely digital workflow through the use of IOSs in implants and prostheses involves the use of intraoral scan bodies (ISBs). However, the performance of IOSs can be negatively influenced by several factors, such as saliva, movements of the tongue and cheeks, the amount of keratinized gingiva, the length and shape of the edentulous ridge, the number and position of the implants, the inter-implant distance and angulation of the implants, as well as the characteristics of the ISBs and IOSs [3,13,14]. The passive adaptation between the prosthetic framework and the implants is considered to be the key element in the prevention of mechanical and biological complications and is crucial for the long-term success of the restoration [15].

The precise fit of an implant-supported fixed dental prosthesis (FDP) was directly related to the accuracy of the impression. The International Organization for Standardization (ISO) defines accuracy as a combination of trueness and precision [16]. Accuracy is reproducible after multiple measurements, while trueness is the proximity of measurements to the real value [17]. A scanner with high trueness generates a three-dimensional (3D) reproduction that is as similar as possible to the scanned object. On the other hand, a scanner with high precision generates more consistent results after repeated measurements [17].

Several studies have investigated the accuracy of IOSs, reporting encouraging results comparable to conventional impression techniques for single crown and short-span partial fixed dental prostheses [18]. IOSs record single consecutive images, which are assembled and realigned through a best-fit alignment algorithm using the processing software. Anatomical landmarks such as teeth, if present, improve this method of image processing called "stitching". In cases of dentate patients, IOSs reported an acceptable accuracy that was similar to polyether impressions and superior to alginate impressions [19]. Concerning FDPs, some studies have reported that digital impressions with ISBs of a single implant or units of three implants were as accurate as elastomer impressions [20]. In cases of edentulous patients, a complete arch scan remains a challenge for clinicians due to the lack of stable tissue landmarks, the distance between ISBs, and to the difficulty in distinguishing between multiple identical ISBs [21,22]. All these factors may limit the clinical application of IOSs.

The accuracy of the scan could also be influenced by the experience of the operator using the IOSs; however, no consensus on the learning curve of IOSs has yet been established. In 2014, Gimenez et al. determined that the accuracy of scanning using Itero IOSs (Align Technology Inc.) was influenced by operator performance, which was not necessarily associated with experience [23]. Similarly, a 2015 in vitro study demonstrated that the use of Lava C.O.S. IOSs (3M ESPE) by skilled operators resulted in more accurate scans compared to inexperienced operators [24]. Conversely, one study proved that, when using two different IOSs, 3D Progress (MHT) and ZFX Intrascan (Zimmer Dental), the accuracy was not affected by operator experience [25].

To overcome these limitations, some clinicians have proposed techniques to increase the accuracy of a scan of a complete edentulous arch through the use of various materials and instruments. The purpose of this narrative review was to analyze these techniques and to compare the results obtained to understand if it is currently possible to increase the accuracy of scans of complete edentulous arches.

2. Materials and Methods

2.1. Focused Question

What is the advantage of splinting the ISBs or placing artificial landmarks on the edentulous crest (O) in edentulous patients (P) when using IOSs to record intraoral anatomy (I) compared to taking a digital scan using only the ISBs (C)?

2.2. Eligibility Criteria

All levels of available evidence were included (randomized controlled trials, prospective studies, retrospective studies, technical reports, case reports, in vitro studies, studies in animal models, and case series). Commentaries and letters to the editor were not included.

2.3. Search Strategy

The Population, Intervention, Comparison, Outcome (PICO) model was used to perform this review, along with a literature search of the PubMed (MEDLINE) and Scopus electronic databases on 31 March 2023.

2.4. Research

The following combinations of keywords were used: ("Artificial landmarks" AND "Intraoral Scanner") OR ("Artificial landmarks" AND "Intraoral Scanner" AND "Dentistry") OR ("Artificial landmarks" AND "Intraoral Scanner" AND "Edentulous") OR ("Artificial landmarks" AND "Intraoral Scanner" AND "Dentistry" AND "Edentulous") OR ("Splinted Scanbody" AND "Intraoral Scanner") OR ("Splinted Scanbody" AND "Intraoral Scanner" AND "Dentistry") OR ("Splinted Scanbody" AND "Intraoral Scanner" AND "Edentulous") OR ("Splinted Scanbody" AND "Intraoral Scanner" AND "Dentistry" AND "Edentulous") [26].

3. Results

An initial search identified 11 studies. After an examination of the full texts, 10 studies were eligible for inclusion in this review. Data from these studies regarding artificial landmarks, an auxiliary geometric part, and splinting ISBs were extracted and are presented in Tables 1–3. The only study excluded [27] was a review of the direct digital workflow in fixed implant prosthodontics.

Table 1. Artificial landmarks to improve the accuracy of IOSs.

References	Study Type	Intraoral Scanner Used	Conclusions
Kim et al. [28]	In vitro study	Carestream CS3500 Cerec Omnicam 3Shape Trios	Increase in precision when the artificial landmark was placed, whereas trueness showed no differences with or without the artificial landmark
Mizumoto et al. [29]	In vitro study	3Shape Trios	Modification of the tissue surface did not show an improvement in accuracy
Kanjanasavitree et al. [30]	In vitro study	3Shape Trios 4	Artificial landmarks and scanning patterns have a significant effect on the trueness of the scans
Waldecker et al. [31]	In vitro study	Cerec Primescan	The use of an artificial landmark in the dorsal palate can significantly improve scanning accuracy
Rutkunas et al. [32]	In vitro study	Cerec Primescan 3Shape Trios 4 3Shape Trios 3 Medit i500 Carestream 3600	The accuracy of completely edentulous arches improved when the additional artificial landmark technique was used

Table 2. Use of auxiliary geometry part (AGP) to improve the accuracy of IOSs.

References	Study Type	Intraoral Scanner Used	Conclusions
Iturrate et al. [33]	In vitro study	3Shape Trios 3 3M™ True Definition Itero Element 1	When covering the edentulous ridges with AGP, there was a significant improvement in both trueness and precision
Pan et al. [34]	In vitro study	3Shape Trios 3	Auxiliary devices have significantly improved IOS scanning accuracy in complete-arch implant scanning

Table 3. Splinting ISBs to improve the accuracy of IOSs.

References	Study Type	Intraoral Scanner Used	Conclusions
Huang et al. [35]	In vitro study	3Shape Trios 3	Splinted ISBs could serve as a new approach to increase the accuracy of digital scanning in full-arch rehabilitation
Pozzi et al. [36]	In vitro study	3Shape Trios 3	Splinting ISBs positively influenced the accuracy of complete-arch digital impressions
Retana et al. [14]	In vitro study	Cerec Primescan Cerec Omnicam 3Shape Trios 4 3Shape Trios 3 Planmeca Emerald Medit i500 Carestream 3600	The splinting technique of the investigated ISBs improved the accuracy of the IOSs

4. Discussion

The aim of this narrative review was to analyze these techniques and to compare the results obtained to understand if it is currently possible to increase the accuracy of complete edentulous arch scans. The extensive use of IOSs in daily dental practice has shown the limitations of the devices. Consequently, several research studies have been conducted to push the devices to their limits to better understand which alternative solutions could be adopted by clinicians to overcome possible inaccuracies.

4.1. Artificial Landmarks to Improve the Accuracy of IOSs

In 2016, Kim et al. were the first to publish an in vitro study discussing the accuracy of digital intraoral scans associated with artificial landmarks [28]. In this study, they compared the accuracy of three different IOSs (CS3500; Carestream Dental, Cerec Omnicam; Sirona, Trios; 3Shape A/S) in an experiment which involved scanning a mandibular Dentiform model containing four prepared teeth and a 26-mm-long edentulous area. The model was first scanned without landmarks and after placing a 4 $\times$ 3 mm alumina marker (Alumina marker; Dio implant Co, Busan, 612-020, Korea). For standardization, datasets from each scan were converted to stereolithography (STL) file format. The obtained datasets were used to evaluate trueness and precision. To compare the precision and trueness measurements, the obtained STL data were superimposed using reverse engineering software (Rapidform 2006; INUS Technology Inc., Seoul, Korea). Without the use of an artificial landmark in the edentulous ridge, it took more time and more images to register the scan. Scans were performed successfully by all scanners except the Cerec Omnicam, which had stitching issues. The scans of all three IOSs were successful and faster when the artificial landmark was placed on the edentulous ridge. Without an artificial landmark on the edentulous area, the mean trueness for the TR was 36.1 $\pm$ 7.0 µm and 38.8 $\pm$ 17.5 µm for the CS. The mean trueness for the OM could not be obtained because of a scanning failure. With the presence of an artificial landmark on the edentulous area, the mean trueness for the TR was 30.6 $\pm$ 3.6 µm and 26.7 $\pm$ 3.5 µm for the CS. The mean trueness was not significantly different. The mean trueness for the OM, meanwhile, was 31.8 $\pm$ 5.4 µm. The results of this study showed a dramatic increase in precision when the artificial landmark was placed, whereas trueness showed no differences with or without the artificial landmark. Without a marker on the edentulous space, the mean precision for the TR was 13.0 ± 4.2 µm. However, the mean precision for the CS was 43.6 ± 23.4 mm. In contrast, with an artificial landmark placed on the edentulous space, the mean precision improved significantly ($p < 0.001$). For the TR, it was 9.2 ± 2.3 µm; for the CS, it was 12.4 ± 2.3 µm. For the OM, the mean precision was 10.5 ± 2.6 µm. This study shows how it was possible to acquire an accurate and reliable scan when an artificial landmark was used in the long edentulous area of the study model [28].

In a recent review, Scribante et al. [37] reported that, currently, the intraoral scanner is widely used with encouraging results, both functional and aesthetic, for the fabrication of individualized CAD/CAM and 3D printing meshes for implant and prosthetic rehabilitation in patients with vertical and mixed (vertical and horizontal) bone defects.

In 2020, Mizumoto et al. analyzed the accuracy and scan time using the TRIOS (3Shape) IOS, combined with four different intraoral scan techniques: unmodified master model (NO), glass fiduciary markers placed on the edentulous ridge (GB), pressure-indicating paste brushed over the ridge and palate (PP), and floss tied between the scan bodies (FL), as well as five different commercially available ISB systems: Atlantis I-Flo (AF), Core3D (C3D), Nt-Trading (NT), Dess-USA (DE), and Zimmer Biomet (ZI) [29]. Five edentulous models with four parallel dental implant analogs (TSV 4.1; Zimmer Biomet Dental) were used for the study. This is the first work to include different intraoral scanning techniques and different ISBs in the study of edentulous patients. Regarding distance deviation, ZI showed significantly less distance deviation than AF ($p = 0.041$), and FL showed significantly more distance deviation than GB ($p = 0.008$), PP ($p = 0.013$), and NO ($p = 0.002$). A significant difference in precision regarding distance deviation was noted from the tests conducted to assess the homogeneity of the variances ($p = 0.013$). In terms of angular deviation, a significant difference in precision was also noted for the angular deviation ($p = 0.003$), with the subgroup AS-FL being significantly less precise than both ZI-GB ($p = 0.021$) and ZI-PP ($p = 0.022$). Regarding scan time, simple main effect analysis demonstrated a statistically significant difference in the means of the scan time between the following scan bodies: C3D and NT ($p = 0.004$), DE and ZI ($p = 0.017$), and NT and ZI ($p < 0.001$). The mean scan times were significantly lower for the ZI group (2.11 min) than for the DE (2.54 min) and NT (2.77 min) groups, and the mean scan time for the C3D group (2.19 min) was significantly lower than that for the NT group (2.77 min). The results of this study suggest that ISBs by themselves could affect the accuracy of the scan. The Zimmer Biomet scan body had significantly less distance deviation, whereas splinting scan bodies with floss led to significantly more distance deviation. The scan time was significantly different depending on the type of ISBs used. Regarding the scanning techniques, those involving a modification of the tissue surface did not show an improvement in accuracy when compared with the techniques where the surface was not modified [29].

In 2022, Kanjanasavitree et al. compared the effects of artificial landmarks and three different scanning patterns (linguo-buccal pattern—LB, S-shaped pattern—SS, and quadrant pattern—QP) on the accuracy of the complete-arch implant intraoral digital scans using and IOS (Trios®4, 3Shape) [29]. For this study, they used an edentulous mandibular model with four dental implant analogs (GSTLA400, Osstem Implant Co., Avegno, Italy). Three different artificial landmarks were used to modify this model: pressure-indicating paste (3 mm × 2 mm) brushed over the ridge (PIP), liquid dam markers (3 mm in diameter) placed on the edentulous ridge (LD), and floss tied with pattern resin (9 mm × 3 mm × 2 mm) between the scan bodies (FL). As shown by this study [30], artificial landmarks and scanning patterns have a significant effect on the trueness of the scans. The artificial landmark was used to enhance the registration of the edentulous ridge. The artificial landmark was proposed as an indicator to improve the readability of the tissue. This is in agreement with Kim et al., who reported that the accuracy of intraoral scans was improved if an artificial landmark in the long edentulous span was used [28]. Artificial landmarks and scanning patterns affected the root mean square (RMS) values of trueness. In each artificial landmark group, QU scanning patterns were found to have the lowest

RMS values of trueness (all $p < 0.05$). For the scanning patterns of the SS and QU groups, the LD artificial landmark was found to have the lowest RMS values of trueness, while the highest RMS values of trueness were recorded in the CON and FL artificial landmarks (all $p < 0.05$). Artificial landmarks and scanning patterns affected the RMS values of precision. In each artificial landmark group, QU scanning patterns were found to have the lowest RMS values of precision (all $p < 0.05$). For the scanning patterns of the LB and QU groups, LD and FL artificial landmarks were found to have the lowest RMS values of precision, while the highest RMS values of precision were recorded in the CON artificial landmark (all $p < 0.05$). The present study showed that liquid dam markers were significantly more accurate than the other artificial landmarks. The complete-arch implant intraoral digital scans without artificial landmarks were less accurate than the other groups. Regarding the scanning pattern, the accuracy of the quadrant pattern was significantly higher than in the others. However, the results were contradicted by a previous study, which reported that scanning patterns did not significantly affect the accuracy when recording long-span digital scans with a Trios intraoral scanner [38].

In all previous studies, the artificial landmarks were positioned on the alveolar ridge [28,30]. In 2022, Waldecker et al. studied the effect of different artificial landmarks (bar or plates) attached to the dorsal palate on the accuracy of complete arch scans using the Primescan (Dentsply Sirona) IOS [31]. A test model (M) was produced that simulated a patient who was treated with a complete-arch fixed partial denture (FPD). Five ceramic precision balls (Optische Kalibrierkugel TOPIC white; Saphirwerk AG) were used for the calibration, and the center point of these balls were numbered with P1 next to the right second molar, P2 next to the left second molar, P3 next to the incisors, P4 next to the right canine, and P5 next to the left canine. The two different artificial landmarks used were a bar (B) and four plates (P) in the dorsal palate, designed with structured and geometrically nonidentical surfaces. The artificial landmarks were stereolithographically produced in a tooth-colored resin (FREEPRINT temp; Detax). For each of the three methods (manufacturer scan, bar scan, plates scan), the model was scanned 30 times by an experienced investigator. The scans were postprocessed using the manufacturer's software program and exported in standard tessellation language (STL) file format for further evaluation. For all three scanning methods, the largest absolute distance deviation occurred over the cross-arch span (249 μm in group M, 190 μm in group B, and 238 μm in group P). The comparison between group B and group P regarding their average absolute distance deviation revealed a slight tendency in favor of group P. However, the difference between both groups was not statistically significant ($p > 0.05$). Moreover, while the mean spread of the distance deviations for all other distances and all scanning methods was approximately in the same range, the mean spread for the cross-arch distance (P1–P2) was lower in groups B and P than in group M. No significant difference was found between either group M and group B or group P, or between group B and group P ($p > 0.05$), except for the distance between P2 and P3, for which group B and group P differed significantly ($p = 0.049$). Regarding precision balls 4 and 5 and the distance between the center points of the precision balls, the absolute mean vertical distance deviation and the vertical distance deviation mean spread were lower in group B and group P than in group M. Scanning with an artificial landmark reduced the mean absolute vertical distance deviations by 41% in group B and 50% in group P for precision ball 4 and by 47% in group B and 10% in group P for precision ball 5 compared with scanning using the manufacturer's strategy. This study proved that the use of an artificial landmark in the dorsal palate can significantly improve the scanning accuracy and reliability of vertical distance deviations [31].

Rutkunas et al., in their 2021 study, investigated the digital scanning accuracy of partially and completely edentulous jaws using five different IOSs with and without additional artificial landmarks [32]. The IOSs evaluated were Primescan (Dentsply Sirona), TRIOS 3 (3Shape), TRIOS 4 (3Shape), Carestream 3600 (Carestream dental), and Medit i500 (Medit). Two maxillary models were made: one model was missing the right premolars and molars, and dental implants (BLT Implant, Ø 4.1, Straumann AG) were inserted to replace them. The second model was completely edentulous, and four implants were inserted. The artificial landmark used was a polymerized glass-ionomer cement (Fuji Plus; GC) that was attached using an adhesive (Super Moment glue; Henkel). One was attached in the center of the edentulous area of the partially edentulous model, six in the completely edentulous model distributed between the ISBs, and three in the palate of the completely edentulous model. The results show that, for the distance measurements, the mean trueness values ranged from −46.7 ± 15.4 μm for the TRIOS 3 scanner to 392.1 ± 314.3 μm for the Medit i500 scanner in models without an additional artificial landmark; however, in models with additional artificial landmarks, the mean trueness of distance values ranged from −34.4 ± 13.0 μm for the TRIOS 4 IOS to 117.7 ± 232.3 μm for the CARESTREAM 3600 IOS. Mean trueness values of angulation varied from −0.0 ± 0.5 degrees for the CARESTREAM 3600 IOS to 0.2 ± 0.0 degrees for the PRIMESCAN IOS in models without additional artificial landmarks. Meanwhile, in models with artificial landmarks, the mean trueness values of angulation ranged from 0.0 ± 0.2 degrees for the TRIOS 3 IOS to 0.4 ± 0.5 degrees for the CARESTREAM 3600 IOS. For the vertical shift measurements in models without additional artificial landmarks, trueness varied from −108 ± 47.1 μm for the TRIOS 4 IOS to 107.2 ± 103.5 μm for the Medit i500 IOS. The mean trueness values of vertical shift in models with additional artificial landmarks ranged from −15 ± 45 μm of CARESTREAM 3600 IOS to −86.9 ± 42.1 μm. No statistically significant differences were found between the measurements of the models with or without additional artificial landmarks, except for the Medit i500 IOS in all parameters and PRIMESCAN in the angle measurements ($p < 0.05$). Regarding the partial edentulous model, the best results were demonstrated by the TRIOS 3 IOS in distance (12.8 ± 7.2 μm) and PRIMESCAN in angulation (0.0 ± 0.0 degrees) and vertical shift parameters (9 ± 7.4 μm). However, no statistically significant differences were found between the scans with and without additional artificial landmarks ($p > 0.05$) of any IOS tested, except Medit i500 in the distance and vertical shift parameters and CARESTREAM 3600 in vertical shift ($p < 0.05$). The precision and trueness of the digital scans of the completely edentulous areas were affected, except for the Medit i500 IOS for distance ($p = 0.08$, $p = 0.07$, and $p = 0.36$), PRIMESCAN ($p = 0.75$, $p = 0.26$, and $p = 0.67$), and TRIOS 4 ($p = 0.76$, $p = 0.7$, and $p = 0.84$) for angle, as well as all systems except TRIOS 4 ($p = 0.49$) for vertical shift precision. The results of this study showed that a limited effect of the additional artificial landmark was observed on the accuracy parameters when partially edentulous conditions were scanned, while the accuracy of completely edentulous arches improved when the additional artificial landmark technique was used. For partially edentulous conditions, additional artificial landmarks had a positive effect on the scanning trueness and precision of distance, angulation, and vertical shift of scan bodies, especially for recently developed IOSs. However, no statistically significant differences were found between the scans with and without additional artificial landmarks [32].

4.2. Use of Auxiliary Geometry Part to Improve the Accuracy of IOSs

In 2019, Iturrate et al. investigated the effects of the use of an auxiliary geometry part (AGP), simulating a jaw with teeth and different intraoral scanners on the accuracy (trueness and precision) of the intraoral scans of edentulous patients [33]. A stainless-steel model of a completely edentulous patient who had a restoration with four implants was scanned using three intraoral scanners: Trios 3 (3Shape A/S), 3M™ True Definition (3M ESPE), and Itero Element 1 (Align Technology Inc., Tempe, AZ, USA) with and without the AGP. The AGP was positioned by matching its circular holes with the ISBs screwed onto the implant analogs and fixed with light-polymerizing resin (CONLIGHT, Kuss Dental). According to this protocol, it was necessary to create four points, one in each model protrusion (parts resembling scan bodies), for the measurements. Each point was created at the intersection of a cylinder axis and a plane. By measuring three distances between these four points, three reference distances, D12, D13, and D14, were defined. Additional steps were required to use this protocol with AGP, such as the design and fabrication of the framework, placement in the mouth, and securing it to the soft tissues of the mandible or maxilla; however, accuracy results improved both in precision and trueness. At the D12 and D13 reference distances, the intraoral scanner had no statistically significant effect ($p > 0.05$) on trueness values, while the use of the AGP had statistically significant effects ($p < 0.05$). However, in D14, both the intraoral scanner used and the use of the AGP had a statistically significant effect ($p < 0.05$) on the deviation measurement and consequently on trueness. The lowest measured mean deviation value was 8 ± 6 μm. This was achieved from digital impressions obtained using the True Definition Scanner, using the AGP and D12 reference distance. The highest mean deviation value of 189 ± 70 μm was achieved with the Itero scanner without using the AGP and at a D14 reference distance. At both the reference distances (D12 and D13), neither the scanner nor the interaction between it and the AGP had statistically significant effects on the results ($p > 0.05$). However, at the reference distance D14, the intraoral scanner used did have statistically significant effects on the results ($p < 0.05$), while the use or not of the AGP and the interaction with the scanner used did not have statistically significant effects ($p > 0.05$). After analyzing the descriptive statistics, all mean precision values and corresponding standard deviations were obtained. The highest mean precision values were 8 ± 6 μm and 7 ± 7 μm. They were measured in digital impressions achieved using True Definition and Trios3, respectively, using the AGP and a D12 reference distance. The lowest mean precision values, 118 ± 97 μm, were achieved with the Itero IOS without using the AGP at the D14 reference distance. The improvement occurred with all IOSs analyzed and in all distances analyzed. The conclusion of this study was that, by covering the edentulous ridges with an AGP, the authors achieved a significant improvement in both the trueness and precision of the complete-arch digital impression of the edentulous maxilla, which also facilitated the scanning procedure [33].

In 2021, Pan et al. evaluated the accuracy of complete-arch implant scanning with the aid of an auxiliary device [34], which consisted of well-defined landmarks and a solid opaque surface. A master model (group 0) and three types of auxiliary devices were designed: group 1 included a base with a thickness of 1.5 mm that covered the master model with access openings at the implant sites; in group 2, a cuboid reference block (8.0 × 4.0 × 7.0 mm) and four fiduciary spheres (∅ 5.0 mm) were added onto the base. For group 3, the four spheres were replaced by standard premolars. A standard resin model of the edentulous maxilla with six bone-level dummy implants (NobelActive internal RP, ø4.3/10 mm) was used as the master model. The Trios 3 (3Shape) scanner was used for all scans. The linear distortions ranged from −94.2 to 363.0 μm in group 0, −367.6 to 72.6 μm in group 1, −279.0 to 86.2 μm in group 2, and −243.7 to 75.9 μm in group 3. The angular distortions ranged from −0.897 to 0.526° in group 0, −0.736 to 0.418° in group 1, −1.125 to 0.364° in group 2, and −0.881 to 0.332° in group 3. For group 0, the trueness ranged from 0.6 to 363.0 μm/0.041 to 0.630°, while the precision ranged from 5.1 to 290.3 μm/0.023–0.666. For group 1, the trueness ranged from 0.6 to 206.9 μm/0.021–0.983°, while the precision ranged from 1.8 to 184.2 μm/0.012–0.732° For group 2, the trueness ranged from 7.4 to 162.6 μm/0.036–0.918° while the precision ranged from 16.6 to 181.2 μm/0.059–0.929°. For group 3, the trueness ranged from 1.0 to 135.4 μm/0.020–0.680°, while the precision ranged from 3.7 to 103.4 μm/0.037–0.446°. With the devices, the number of linear and angular measurements with bias beyond the clinical threshold was significantly reduced. The authors found that the three types of auxiliary devices significantly improved the scanning accuracy of the IOS in complete-arch implant scanning; however, the fiduciary spheres might compromise the precision of the scanning [34].

4.3. Splinting ISBs to Improve the Accuracy of IOSs

In 2020, Huang et al. compared the accuracy of an original and two newly designed ISBs (CAD/CAM) used for digital scans with one another as well as with conventional implant impressions (group 4) for a completely edentulous mandibular model [35]. The original ISB (Straumann) (group 1) was compared to two CAD/CAM ISBs, the first without extensional structure (group 2) and the second with a one-piece unit extensional structure (group 3). All these scans were compared to a conventional splinted open-tray impression using abutment-level impression copings connected to the abutments on the reference model and splinted using self-cured pattern resin (GC Corporation). The digital scans were made using the IOS Trios3 (3Shape) and the conventional impressions were made using siloxane impression material (Silagum putty/light; DMG). This is the first study to introduce and evaluate a scan body with a rigid extensional structure to make the ISBs "splinted" together. A rigid extensional structure was designed to provide more characteristic reference points at the inter-implant regions than most of the commercially available cylindrical scan bodies, which could facilitate the identification and stitching procedures. The CAD/CAM ISBs made for this study were comprised of titanium alloy. The surface was sandblasted prior to the scanning procedure to reduce surface reflection. When compared to PEEK ISBs, titanium alloy ISBs have advantages related to decreased distortion associated with repeated use and sterilization cycles. The trueness and precision values were shown using the median and interquartile range (IQR) of the RMS values, which indicated significant differences for both trueness (p = 0.001) and precision. The median (IQR) of trueness was 35.85 (29.80–49.10) μm for group 1, 38.50 (35.35–52.58) μm for group 2, 28.45 (24.88–36.43) μm for group 3, and 25.55 (22.98–28.90) μm for group 4. The median (IQR) of precision was 48.40 (40.80–57.90) μm for group 1, 48.90 (38.70–85.40) μm for group 2, 27.30 (22.50–35.50) μm for group 3, and 19.00 (15.70–22.75) μm for group 4. Conventionally splinted open-tray impressions yielded the highest accuracy, followed by the digital impressions made using the CAD/CAM scan bodies with extensional structure. Digital impressions using the original ISBs and the CAD/CAM ISBs without extensional structure showed relatively low accuracy. The innovative design of the extensional structure used to splint the ISBs could serve as a new approach with which to increase the accuracy of a digital scan in full-arch rehabilitation [35].

In their 2022 study, Pozzi et al. investigated the accuracy of a novel implant complete-arch intraoral digital impression using ISB splinting (ISS) [36]. An edentulous mandibular model with four implant analogues (Nobel-Parallel RP 4.3, NobelBiocare) was fabricated. In an attempt to reproduce real clinical situations in vitro, the four implants were positioned with different depths, inclinations, and inter-implant distances. The IOS Trios3 (3Shape) was used to scan the model, and 30 scans were performed before the ISS and 30 after the ISBs were splinted. The ISS was fabricated using a 3D-printed (Accura resin XM24.7 and Ipro 8000, 3DSystems, Rock Hill, SC, USA) modular chain with an opaque detailed surface which was easy to assemble according to the implant positions and anatomy of the edentulous arch ridge. The modular chain was secured to the ISBs with a light-curable flow composite (Clearfil Majesty ES Flow, NoritakeKuraray). The investigated implant and complete-arch intraoral digital impression with ISB splinting (ISS+) improved the image stitching. In clinical scenarios, such as the one reproduced in this study, involving an edentulous patient rehabilitated with several implants, different depths and inclinations and long inter-implant distances could lead to a deterioration in accuracy and a slowing down of the scan [23]. The overall deviations between the reference STL file and the investigated test (n = 30) and control (n = 30) scans were measured for each analogue position (n = 240) on the Y-, X-, Z-axes and angulation. Considering the deviations on the three axes, a positive effect of the ISS was observed regarding the X-axis (longitudinal) (-1.6 ± 44.4 vs -12.5 ± 52.5 μm) and Z-axis (vertical) (-4.4 ± 18.6 vs -10.8 ± 41.5 μm), while similar results were reported for the Y-axis (lateral) (-21.1 ± 87.2 vs -23.2 ± 74.7 μm). Extreme negative values (deviation towards left) up to -398.5 μm were reported on the Y-axis (lateral), mainly found on position 3.6 (Y-axis deviation -131.2 ± 85.6 μm). Position 3.6 was also the most critical considering angular deviation (0.5489 ± 0.1866○). Position 4.7 showed the highest linear deviations (X-axis: 63.7 ± 27.7 μm).

This technique positively influenced the accuracy of the complete-arch digital impression, reducing the linear and angular deviations at the most critical posterior implant positions [34].

In 2023, Retana et al. investigated the trueness of seven different IOSs to take a complete-arch digital implant scan using a splinting technique and to compare the trueness of the splinted and non-splinted intraoral scanning procedures [14]. A model with four dental implant replicas (MIS Implant Technologies/Dentsply Sirona) was used for the measurements, and the reference model was scanned with ISBs that were not splinted in the control groups and which were splinted in the study groups. The IOSs investigated were Cerec Primescan (Dentsply Sirona), Cerec Omnicam (Dentsply Sirona), 3Shape Trios 4 (3Shape), 3Shape Trios 3 (3Shape), Planmeca Emerald (Planmeca), Medit i500 (Medit), and Carestream 3600 (Carestream Health). The splinting technique was performed using CAD-CAM 3D-printed splinting bars with a square cross-section of 5 × 5 mm, secured to the ISBs with clear polyvinyl siloxane material (Memosil 2; Kulzer).

A significant association was found between the trueness values and all three tested variables, including the splinting of the scan bodies, type of IOS, and inter-implant distance ($p < 0.001$). The highest trueness value was found in Primescan, followed by Omnicam, Carestream, Planmeca, Trios 4, Trios 3, and Medit, respectively. The overall trueness value of the Primescan scanner was significantly higher than that of the other scanners, except for Omnicam. No significant differences were found between Omnicam and Carestream, Carestream and Trios 4, Carestream and Planmeca, Trios 3 and Trios 4, and Planmeca and Trios 4 ($p > 0.05$). [39] Their results show that the type of scanner had a significant effect on the accuracy of the digital model, which is in agreement with the literature [36] and could be explained by the different hardware and software characteristics and different stitching algorithm adopted by the different scanners. The splinting of the scan bodies resulted in a significant improvement in the trueness of the digital scan, and the authors found that adding splinting bars improved the accuracy of the digital scans in most of the tested scanners. The splinting technique of the investigated ISBs improved the stitching process, providing a scanning track and avoiding the possibility that a scanner may mistakenly recognize one scan body as another, leading to inaccuracies and distortions in the final impression [40]. The main limitations of this review are related to the study design of the included studies, which were all in vitro, and the low number of high-quality studies that investigated this topic. Several in vivo randomized studies should be conducted to better understand the limits and potential of IOSs.

5. Conclusions

Within the limitations of this narrative review, this paper has shown that artificial landmarks could have a significant effect on the accuracy of complete-arch digital impression, and that the use of an auxiliary geometry part and the splinting of ISBs can improve the accuracy of complete-arch digital implant scans. Clinical cases with few implants, a long inter-implant distance, implant inclination, and different implant depths could increase the difficulty and lessen the accuracy of an intraoral scan. Moreover, movements of the tongue and floor of the mouth, which were not investigated in these in vitro studies, could create errors in the scan. In vivo studies are still required to effectively evaluate potential errors in the whole prosthetic production process, from the taking of the impression to the manufacturing of the prosthesis.

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References

1. Duret, F.; Preston, J.D. CAD/CAM imaging in dentistry. *Curr. Opin. Dent.* **1991**, *1*, 150–154. [PubMed]
2. Carosi, P.; Ferrigno, N.; De Renzi, G.; Laureti, M. Digital Workflow to Merge an Intraoral Scan and CBCT of Edentulous Maxilla: A Technical Report. *J. Prosthodont.* **2020**, *29*, 730–732. [CrossRef] [PubMed]

3. Arcuri, L.; Pozzi, A.; Lio, F.; Rompen, E.; Zechner, W.; Nardi, A. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: A randomized in vitro trial. *J. Prosthodont. Res.* **2020**, *64*, 128–136. [CrossRef] [PubMed]
4. Hoods-Moonsammy, V.J.; Owen, P.; Howes, D.G. A comparison of the accuracy of polyether, polyvinyl siloxane, and plaster impressions for long-span implant-supported prostheses. *Int. J. Prosthodont.* **2014**, *27*, 433–438. [CrossRef] [PubMed]
5. Lorenzi, C.; Lio, F.; Papi, P.; Mazzetti, V.; Laureti, A.; Arcuri, C. Clinical Reliability of Complete-Arch Fixed Prostheses Supported by Narrow-Diameter Implants to Support Complete-Arch Restorations. *Appl. Sci.* **2023**, *13*, 538. [CrossRef]
6. Kachhara, S.; Nallaswamy, D.; Ganapathy, D.M.; Sivaswamy, V.; Rajaraman, V. Assessment of intraoral scanning technology for multiple implant impressions—A systematic review and meta-analysis. *J. Indian Prosthodont. Soc.* **2020**, *20*, 141–152. [CrossRef]
7. Papaspyridakos, P.; Chen, C.J.; Gallucci, G.O.; Doukoudakis, A.; Weber, H.P.; Chronopoulos, V. Accuracy of implant impressions for partially and completely edentulous patients: A systematic review. *Int. J. Oral Maxillofac. Implants* **2014**, *29*, 836–845. [CrossRef]
8. Carosi, P.; Lorenzi, C.; Lio, F.; Cardelli, P.; Pinto, A.; Laureti, A.; Pozzi, A. Accuracy of Computer-Assisted Flapless Implant Placement by Means of Mucosa-Supported Templates in Complete-Arch Restorations: A Systematic Review. *Materials* **2022**, *15*, 1462. [CrossRef]
9. Quaas, S.; Rudolph, H.; Luthardt, R.G. Direct mechanical data acquisition of dental impressions for the manufacturing of CAD/CAM restorations. *J. Dent.* **2007**, *35*, 903–908. [CrossRef]
10. Carosi, P.; Ferrigno, N.; Arcuri, C.; Laureti, M. Computer-Aided Surgery and Immediate Loading to Rehabilitate Complete Arch with Four Dental Implants and Fixed Screw-Retained Prosthesis Up to 4 Years in Function: A Retrospective Study. *Int. J. Oral Maxillofac. Implants* **2021**, *36*, 1180–1187. [CrossRef]
11. Londono, J.; Abreu, A.; Baker, P.S.; Furness, A.R. Fabrication of a definitive obturator from a 3D cast with a chairside digital scanner for a patient with severe gag reflex: A clinical report. *J. Prosthet. Dent.* **2015**, *114*, 735–738. [CrossRef] [PubMed]
12. Ahrberg, D.; Lauer, H.C.; Ahrberg, M.; Weigl, P. Evaluation of fit and efficiency of CAD/CAM fabricated all-ceramic restorations based on direct and indirect digitalization: A double-blinded, randomized clinical trial. *Clin. Oral Investig.* **2016**, *20*, 291–300. [CrossRef] [PubMed]
13. Rutkūnas, V.; Gečiauskaitė, A.; Jegelevičius, D.; Vaitiekūnas, M. Accuracy of digital implant impressions with intraoral scanners. A systematic review. *Eur. J. Oral Implantol.* **2017**, *10* (Suppl. S1), 101–120. [PubMed]
14. Retana, L.; Nejat, A.H.; Pozzi, A. Effect of splinting scan bodies on trueness of complete-arch implant impression using different intraoral scanners: An in vitro study. *Int. J. Comput. Dent.* **2023**, *26*, 19–28. [CrossRef]
15. Albanchez-González, M.I.; Brinkmann, J.C.; Peláez-Rico, J.; López-Suárez, C.; Rodríguez-Alonso, V.; Suárez-García, M.J. Accuracy of Digital Dental Implants Impression Taking with Intraoral Scanners Compared with Conventional Impression Techniques: A Systematic Review of In Vitro Studies. *Int. J. Environ. Res. Public Health* **2022**, *19*, 2026. [CrossRef] [PubMed]
16. *ISO-5725e1*; Accuracy (Trueness and Precision) of Measurement Methods and Results d Part 1: General Principles and Definitions. International Organization for Standardization: Geneva, Switzerland, 1994.
17. Ender, A.; Mehl, A. Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision. *J. Prosthet. Dent.* **2013**, *109*, 121–128. [CrossRef]
18. Koch, G.K.; Gallucci, G.O.; Lee, S.J. Accuracy in the digital workflow: From data acquisition to the digitally milled cast. *J. Prosthet. Dent.* **2016**, *115*, 749–754. [CrossRef]
19. Ender, A.; Attin, T.; Mehl, A. In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. *J. Prosthet. Dent.* **2016**, *115*, 313–320. [CrossRef]
20. Yilmaz, B.; Gouveia, D.; Marques, V.R.; Diker, E.; Schimmel, M.; Abou-Ayash, S. The accuracy of single implant scans with a healing abutment-scanpeg system compared with the scans of a scanbody and conventional impressions: An in vitro study. *J. Dent.* **2021**, *110*, 103684. [CrossRef]
21. Andriessen, F.S.; Rijkens, D.R.; van der Meer, W.J.; Wismeijer, D.W. Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: A pilot study. *J. Prosthet. Dent.* **2014**, *111*, 186–194. [CrossRef]
22. Flügge, T.V.; Att, W.; Metzger, M.C.; Nelson, K. Precision of Dental Implant Digitization Using Intraoral Scanners. *Int. J. Prosthodont.* **2016**, *29*, 277–283. [CrossRef] [PubMed]
23. Giménez, B.; Özcan, M.; Martínez-Rus, F.; Pradíes, G. Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience and implant angulation and depth. *Int. J. Oral Maxillofac. Implants* **2014**, *29*, 853–862. [CrossRef] [PubMed]
24. Giménez, B.; Özcan, M.; Martínez-Rus, F.; Pradíes, G. Accuracy of a digital impression system based on active wavefront sampling technology for implants considering operator experience, implant angulation, and depth. *Clin. Implant Dent. Relat. Res.* **2015**, *17* (Suppl. S1), e54–e64. [CrossRef] [PubMed]
25. Giménez, B.; Pradíes, G.; Martínez-Rus, F.; Özcan, M. Accuracy of two digital implant impression systems based on confocal microscopy with variations in customized software and clinical parameters. *Int. J. Oral Maxillofac. Implants* **2015**, *30*, 56–64. [CrossRef]
26. Pulicari, F.; Pellegrini, M.; Scribante, A.; Kuhn, E.; Spadari, F. Pathological Background and Clinical Procedures in Oral Surgery Haemostasis Disorders: A Narrative Review. *Appl. Sci.* **2023**, *13*, 2076. [CrossRef]
27. Michelinakis, G.; Apostolakis, D.; Kamposiora, P.; Papavasiliou, G.; Özcan, M. The direct digital workflow in fixed implant prosthodontics: A narrative review. *BMC Oral Health* **2021**, *21*, 37. [CrossRef]

28. Kim, J.E.; Amelya, A.; Shin, Y.; Shim, J.S. Accuracy of intraoral digital impressions using an artificial landmark. *J. Prosthet. Dent.* **2017**, *117*, 755–761. [CrossRef]
29. Mizumoto, R.M.; Yilmaz, B.; McGlumphy, E.A., Jr.; Seidt, J.; Johnston, W.M. Accuracy of different digital scanning techniques and scan bodies for complete-arch implant-supported prostheses. *J. Prosthet. Dent.* **2020**, *123*, 96–104. [CrossRef]
30. Kanjanasavitree, P.; Thammajaruk, P.; Guazzato, M. Comparison of different artificial landmarks and scanning patterns on the complete-arch implant intraoral digital scans. *J. Dent.* **2022**, *125*, 104266. [CrossRef]
31. Waldecker, M.; Bömicke, W.; Awounvo Awounvo, S.; Rammelsberg, P.; Rues, S. Influence of artificial landmarks on the accuracy of complete arch scans in the partially edentulous maxilla: An in vitro study. *J. Prosthet. Dent.* 2022; *Epub ahead of print*. [CrossRef]
32. Rutkūnas, V.; Gedrimienė, A.; Al-Haj Husain, N.; Pletkus, J.; Barauskis, D.; Jegelevičius, D.; Özcan, M. Effect of additional reference objects on accuracy of five intraoral scanners in partially and completely edentulous jaws: An in vitro study. *J. Prosthet. Dent.* 2021; *in press*. [CrossRef]
33. Iturrate, M.; Eguiraun, H.; Solaberrieta, E. Accuracy of digital impressions for implant-supported complete-arch prosthesis, using an auxiliary geometry part-An in vitro study. *Clin. Oral Implants Res.* **2019**, *30*, 1250–1258. [CrossRef] [PubMed]
34. Pan, Y.; Tsoi, J.K.H.; Lam, W.Y.; Zhao, K.; Pow, E.H. Improving intraoral implant scanning with a novel auxiliary device: An in-vitro study. *Clin. Oral Implants Res.* **2021**, *32*, 1466–1473. [CrossRef]
35. Huang, R.; Liu, Y.; Huang, B.; Zhang, C.; Chen, Z.; Li, Z. Improved scanning accuracy with newly designed scan bodies: An in vitro study comparing digital versus conventional impression techniques for complete-arch implant rehabilitation. *Clin. Oral Implants Res.* **2020**, *31*, 625–633. [CrossRef] [PubMed]
36. Pozzi, A.; Arcuri, L.; Lio, F.; Papa, A.; Nardi, A.; Londono, J. Accuracy of complete-arch digital implant impression with or without scanbody splinting: An in vitro study. *J. Dent.* **2022**, *119*, 104072. [CrossRef] [PubMed]
37. Scribante, A.; Ghizzoni, M.; Pellegrini, M.; Pulicari, F.; Manfredini, M.; Poli, P.P.; Maiorana, C.; Spadari, F. Full-Digital Customized Meshes in Guided Bone Regeneration Procedures: A Scoping Review. *Prosthesis* **2023**, *5*, 480–495. [CrossRef]
38. Medina-Sotomayor, P.; Pascual-Moscardó, A.; Camps, I. Accuracy of four digital scanners according to scanning strategy in complete-arch impressions. *PLoS ONE* **2018**, *13*, e0202916. [CrossRef]
39. Kim, R.J.; Park, J.M.; Shim, J.S. Accuracy of 9 intraoral scanners for complete-arch image acquisition: A qualitative and quantitative evaluation. *J. Prosthet. Dent.* **2018**, *120*, 895–903.e1. [CrossRef]
40. Rutkunas, V.; Gedrimiene, A.; Akulauskas, M.; Fehmer, V.; Sailer, I.; Jegelevicius, D. In vitro and in vivo accuracy of full-arch digital implant impressions. *Clin. Oral Implants Res.* **2021**, *32*, 1444–1454. [CrossRef]