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Full-arch dental impressions: Conventional, digital, and photogrammetric techniques

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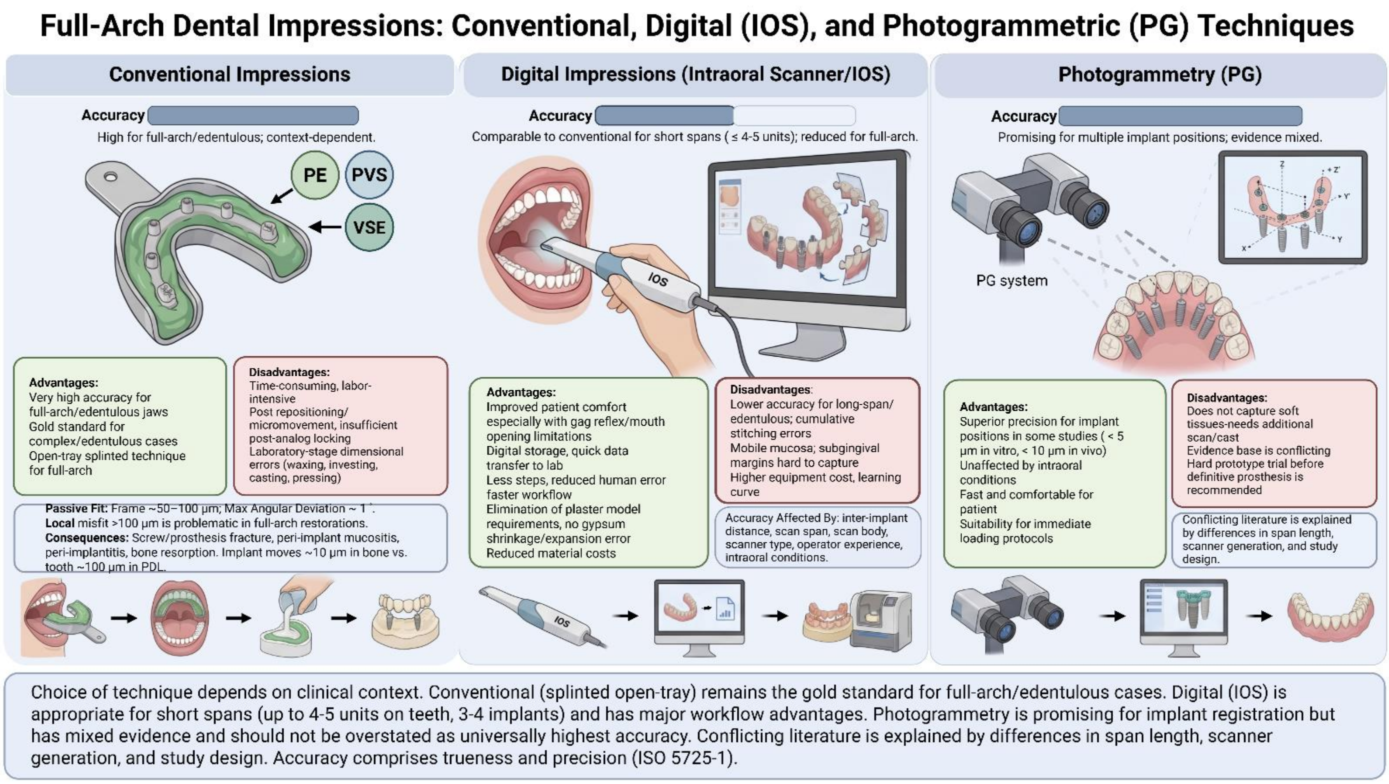
Abstract

Advances in digital dentistry now permit the fabrication of full-arch prosthetic restorations through a fully digital workflow, extending from impression acquisition to the production of the definitive prosthesis. Intraoral scanning has become an acceptable alternative to conventional impression techniques, providing valuable information for diagnosis, restorative dentistry, orthodontic analysis, and implant-supported prosthodontics. Despite the many advantages offered by digital methods, conventional impression techniques using polyether, polyvinyl siloxane, and vinyl siloxane ether materials remain widely used by clinicians because of their excellent dimensional stability and well-documented precision. This review compares and critically discusses conventional and digital impression techniques for acquiring full-arch dental registrations, with particular attention to their accuracy, advantages, limitations, and clinical indications. The accuracy of digital impressions is strongly influenced by inter-implant distance, scan span length, scan body geometry and material, scanner type, operator experience, and intraoral conditions such as mobile mucosa, saliva, and limited anatomical landmarks. For single-unit and short-span restorations of up to four or five units, intraoral scanning achieves accuracy comparable to that of conventional techniques. In long-span and full-arch restorations, however, accuracy tends to decline owing to cumulative image-stitching errors and the scarcity of reference points, a problem that is especially pronounced in completely edentulous arches. Photogrammetry has emerged as a promising alternative for the reliable registration of multiple implant positions, although it inadequately captures peri-implant soft tissues. Overall, technique selection depends primarily on the number of teeth or implants and the distance between them; conventional methods remain preferable for completely edentulous patients, whereas digital workflows are suitable for restorations spanning up to three or four implants. Despite persisting limitations, digital techniques are strong candidates to eventually outperform conventional approaches in dentistry.

Keywords: Full-arch impression, conventional impression, digital impression, intraoral scanner, photogrammetry, implant-supported prosthesis, impression accuracy

Graphical abstract



1. Introduction

Computer-Aided Design (CAD) /Computer-Aided Manufacturing (CAM) technology, which was developed in the 1980s for the production of single-unit restorations, makes it possible to produce full-arch prosthetic restorations today. Especially towards the end of the 2000s, a large number of high-quality intraoral scanners were produced (1). Intraoral scanning is an acceptable alternative to conventional impression techniques, providing information for various situations, such as diagnosis, restorative dentistry, orthodontic analysis, and implant-supported prosthodontics (2-5). Digital workflow is an increasingly preferred working-production process due to its many advantages in the clinical and laboratory phases of indirect restorations (6).

Full-arch impressions are required for diagnosis in orthodontics, preoperative evaluation in orthognathic surgery, and the fabrication of long-span restorations in prosthodontics (7). It has been reported that the accuracy and precision of digital impressions acquired with intraoral scanners of full-arch jaws are less than those acquired with elastomeric impression materials. In addition, it is more difficult to obtain consistent records of jaw relationship in full-arch restorations (8, 9). Ender et al. reported the highest accuracy for the conventional technique, even at short distances (8). This could be revealed by the decreased accuracy of digital matching or stitching for full-arch impressions due to the increased span length (10, 11). Atieh et al. concluded that digital impressions showed lower accuracy compared to vinyl siloxane ether impressions (12). Malik et al. reported that conventional full-arch impressions showed better mean accuracy than digital impressions made using two intraoral scanners (13). Schmidt et al. reported that for longer distances and also for completely crossing the quadrant, the conventional impression technique showed more accurate results for trueness and precision (6).

Regarding full-arch impressions for orthodontic purposes, Sfondrini et al. reported that the accuracy of digital and alginate impressions was similar (14). However, Tomita et al. stated that digital impressions showed higher accuracy than alginate and polyvinyl siloxane impressions (15).

In addition to digital impression techniques, which offer many advantages, conventional techniques are still frequently used by dentists (16).

This article aims to discuss conventional and digital impression techniques for acquiring full-arch dental impressions.

2. Conventional impressions

The success of prosthodontic restorations depends on the impression technique applied and the impression materials used (17). Polyether (PE) and polyvinyl siloxane (PVS) are the most commonly used conventional impression materials for definitive impressions in fixed prosthodontics. These materials exhibit excellent dimensional stability and precision and have been successfully used in fixed prosthodontics for many years (18). In addition, vinyl siloxane ether (VSE), introduced in prosthodontics, combines the properties of silicones and polyethers. Baig et al. reported that the accuracy of VSE impression material was comparable with PE for multi-implant abutment-level impressions (19). It should be noted that the impression accuracies of all conventional impression materials are different (19, 20).

Although quite accurate, the conventional impression technique is time-consuming and labor-intensive. With the advent of CAD-CAM technology in dentistry, digital impressions are increasingly replacing traditional techniques for fixed implant restorations in edentulous dental arches (21).

The open-tray splinted impression technique has represented an acceptable technique for full-arch implant rehabilitation for a long time. A systematic review reported that full-arch digital implant impressions have comparable accuracy with the open tray splinted impressions (22). A retrospective study reported that intraoral digital scans have similar accuracy as conventional full-arch implant impressions (23). Jasim et al. reported that the conventional implant-level impression technique showed greater in vitro and in vivo accuracy than the digital impression technique when used for full-arch maxillary fixed restorations on inclined implants (24).

Prefabricated plastic or metallic frameworks are recommended to reduce the effects of dimensional changes in open tray splinted conventional impression techniques. A three-dimensional (3D)-printed framework was more dimensionally stable and less time-consuming than dental floss (25, 26).

3. Factors affecting the accuracy of conventional impressions

In conventional impressions used in implant impressions, many factors, such as the failure to transfer the impression posts to the appropriate position or the change of position as a result of micro-movements within the impression, inadequate locking between the analog and impression post, dimensional changes in the impression materials, and the expansion of the plaster during polymerization, can affect the accuracy of the impression (27, 28). Also, laboratory steps for prosthesis fabrication such as waxing, investing, casting, or pressing may cause dimensional error and affect the fit of the definitive restoration (29).

4. Digital impressions

Intraoral scanners can capture images or videos of a limited area, and virtual models are created by stitching these images. Consequently, completely edentulous arches, a long span of mobile mucosa, and the use of multiple scan bodies can present challenges, and the lack of landmarks can lead to image stitching errors. These challenges require additional time for accurate scanning (30, 31). The scanners' software converts the data from the scans into standard tessellation language (STL) files, resulting in a three-dimensional image of the jaws. The accuracy of the obtained image depends on the matching algorithm (32). According to a systematic review, full-arch digital implant impressions taken using Intraoral Scanners (IOS) are not sufficiently accurate for clinical application. Accuracy changes greatly with interimplant distance, scan body (SB) type, IOS type, and operator experience (33). When performing a full-arch digital impression, the SB geometry, material, and position can affect the final accuracy (34, 35). Five in vitro studies that compared the accuracy of different IOSs for digital impressions reported that the IOS type had a significant effect (11, 36-39). According to the results of a study comparing the accuracy of intraoral digital impressions in full-arch implant supported fixed dental prostheses acquired with eight different IOSs, it was stated that not all IOSs are suitable for digital impressions in full-arch implant-supported fixed dental prostheses (39).

Zimmermann et al. and Flügge et al. reported that the larger the area scanned by the IOS, the larger the errors in digital scans can be; such large errors are due to the cumulative effects of scanning errors (40, 41). It has been reported that IOS systems do not show predictable results in acquiring impressions of full-arch implant-supported fixed prostheses (42-44). The more alignments intraoral scanners have to make to ensure the optimal superimposition of multiple images, the greater the potential for error (45). Therefore, reliability decreases as the number of implants analyzed increases (46). It has also been noted that limited references in large edentulous areas of full-arches reduce accuracy (47).

Digital scanning can be achieved in two ways: direct intraoral scanning and indirect scanning, where conventional impressions or plaster models are scanned using an extraoral scanner. In the digital workflow, restoration design can be performed more conveniently and esthetically by choosing and adapting desirable tooth forms from the software library after the impressions are taken after the preparation of the teeth or by using preoperative natural tooth, wax-up, and mock-up scans (48). Digital workflows in dentistry (49, 50) are shown in Figure 1.

Some currently available intraoral scanners are:

1. CEREC Omnicam, Bluecam, Primescan (Dentsply Sirona, Bensheim, Germany).
2. Trios 3, Trios 4, Trios 5, and Trios 6 (3Shape, Copenhagen, Denmark).

3. E4D, E4D NEVO (D4D Technologies, Richardson, TX, USA).
4. iTero Element 2, iTero Element 5D Plus, iTero Lumina™ (Align Technology, San Jose, CA, USA).
5. 3M True Definition Scanner (3M ESPE, St. Paul, MN, USA).
6. PlanScan (Planmeca, Helsinki, Finland).
7. Medit i700, Medit i900 (Medit, Seoul, South Korea).

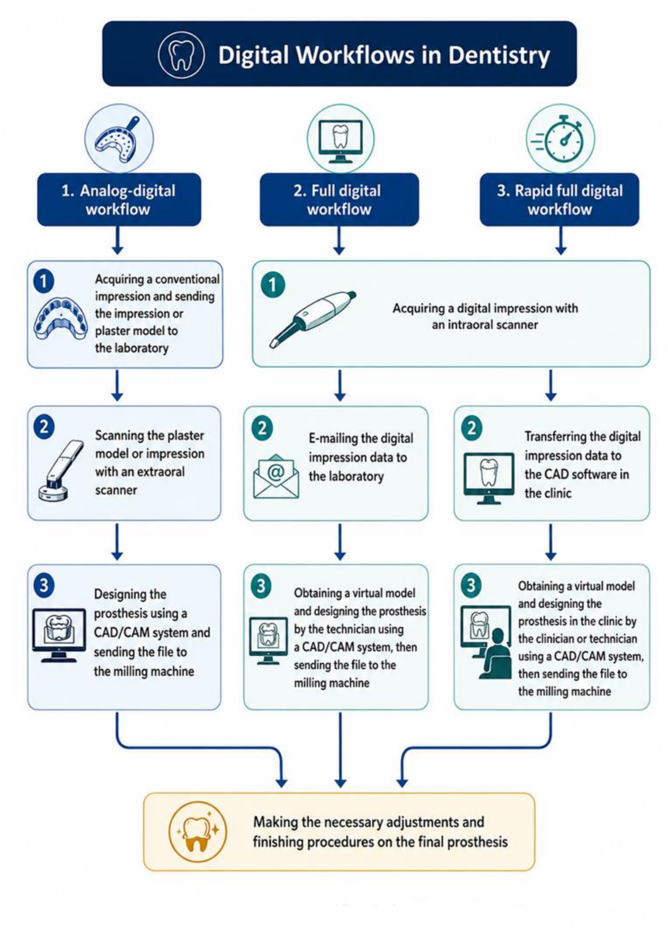


Figure 1. Digital workflows in dentistry.

5. Advantages of impressions taken with intraoral scanners

1. Acquiring impressions using IOS significantly increases patient comfort compared to conventional methods. It eliminates the need for conventional impression materials and impression trays, which are often unpleasant for the patient (51, 52). The digital technique allows for much more comfortable impressions, especially in patients with gag reflexes and mouth opening limitations. As reported in the literature, patients tend to prefer digital impressions to conventional impressions (33, 53).
2. Digital impressions eliminate the need for plaster models (51). Many potential dimensional changes, such as the contraction of the impression material and expansion of the plaster, are eliminated. Simultaneously, impressions can be stored digitally for a long time (54).
3. The digital impression technique has fewer steps than conventional impression and better standardization provided by technological devices. It is stated that digital impressions could minimize the human factor (55).
4. The digital technique facilitates communication between dentist and patient (56). By taking impressions with intraoral scanners, patients have become more involved in their treatment (37, 57).
5. With IOSs and software programs, the clinician and dental technician can simultaneously evaluate the quality of the impression. Immediately after the scan is made, the dentist can e-mail the scan to the laboratory, and the technician can check it (40). Therefore, communication between the dentist and the laboratory technician becomes easier and more effective (57).
6. Various studies have shown shorter working times than traditional impressions (58, 59).
7. Versatile analysis can be performed using three-dimensional models. It can be converted to multiple imaging sizes, and the data are converted to .stl and .ply formats that can be used in other systems. These data can be compared with those obtained using Computed Tomography (CT) and Cone Beam Computed Tomography (CBCT) (60, 61).
8. Since impression trays, splint materials, impression materials, and plasters are not used, savings can be made on the costs of these materials (54).
9. Some systems have programs that can assist dentists during treatment planning with color determination and photo scanning features (40).

6. Disadvantages of impressions taken with intraoral scanners

1. In areas where subgingival positioning of the crown margins is important, it may be more difficult for the light to accurately detect the entire gingival margin line than with a

conventional impression (62). The amount of subgingival depth is important in digital impressions (63).

2. Learning how to use the hardware and the software has a learning curve that requires experience (64). Operator experience is important in shortening the working time of intraoral scanning and ensuring that the images obtained have higher precision (62).
3. Various hard tissue reference points are needed to combine the images obtained and ensure impression integrity. Since the impression area is covered with mobile mucosa in full-arch implant cases, it is stated that the digital technique has various limitations in such cases (65).
4. Digital systems contain high-cost equipment (63). In addition, updating scanner software requires additional costs that vary from company to company (40, 66).

To date, the literature has shown that the accuracy of impressions obtained using intraoral scanners is clinically satisfactory. In cases of single-tooth restorations and fixed prostheses up to 4-5 units, the accuracy has been found to be similar to conventional impressions (67). However, it has been found that in cases of long span restorations such as fixed prostheses with more than 5 units, full-arch prostheses on natural teeth or implants, impressions taken with IOSs do not have the same accuracy as conventional impressions (68, 69). Digital impressions were reported to have higher local deviations within full-arch scans than conventional impressions (69).

7. Factors affecting the accuracy of digital impressions

According to the International Organization for Standardization (ISO 5725-1:1994), the accuracy of a measurement — and therefore the performance of an intraoral scanner — comprises both trueness and precision (70, 71). Precision describes the variability between repeated measurements of a measured object, while trueness describes the closeness to the original dimensions of the measured object (71).

The digital impression technique is affected by many features of the IOS used, such as processor speed, image resolution, software program, and the ability of the software to align, merge, and eliminate artifacts. The compatibility of the scan body with the implant company's digital laboratory, the scanning path, and many factors depending on the patient and the dentist can change the digital impression accuracy (6, 72). The use of the same scan body in several casts may increase discrepancies due to potential wear from successive tightening and loosening (73). The precision of digital impressions taken with intraoral scanners is affected by many factors, including the experience of the operator, the scanning environment, the scanning procedure, the camera position during scanning, the shape and size of the scanned object and the performance of the digital scanner (74).

In addition, arch curvature has been reported as a variable that affects the accuracy of the STL file generated from intraoral digital impressions (75). It was found that a greater arch curvature and anteroposterior distance affected the accuracy of the scan (76).

The complexity of intraoral conditions may affect the accuracy of digital impressions. Some in vitro studies have analyzed the accuracy of full-arch intraoral scanning under clinical conditions (77, 78). However, the oral environment cannot be fully simulated in vitro. Intraoral conditions (gingival thickness, oral mucosa and tongue movement, saliva and blood, reflective restorations, mobile mucosa, surface properties, respiratory pattern, patient movements, etc.) and external factors such as calibration, ambient light, inability of the scanner tip to reach posterior regions, and scanning protocols affect the clinical use of intraoral scanners (42, 47, 79). Rutkunas et al. reported that intraoral conditions moderately affected the precision and trueness of IOS; however, the deviations were not significantly different between the in vitro and in vivo groups. They also highlighted a tendency for decreasing accuracy parameters as the distance between the scan bodies increased (75).

The scanning protocol has a crucial effect on full-arch scans (8). Some studies have noted that the accuracy of IOS decreases as more teeth are scanned (80, 81). The presence of edentulous ridges affects accuracy due to the lack of clear and individual geometric formation for optical scanning (82). Schmalzl et al. concluded that the accuracy of surface digitization can be altered by generation changes of IOSs and that digital technology is less technique sensitive than conventional impression taking (83).

Flügge et al. explained that regardless of the various impression techniques, conventional impressions of inclined implants are significantly less accurate than conventional impressions of parallel implants. In contrast, they noted that there was no statistically significant difference in impression accuracy between the digital impressions of inclined implants and parallel implants (41). It has been suggested that linear deviations that occur during digital impression in full-arch situations can be reduced by reducing the distance between implants (84). Some studies have evaluated abutment-level accuracy, where conventional impressions may have advantages. In contrast, implant-level impressions require capturing the internal fit of the implant, a process that requires greater force to remove the impression tray, potentially leading to distortion of the impression material using traditional methods (85-87).

It has been reported that when a small scanner head is used, camera movement errors during scanning negatively affect the scanning because a larger number of scanned images are required. When large scanner heads are used, the accuracy of the scanners increases due to the enlargement of the imaging area, but large heads are more difficult to manipulate in terms of intraoral use (88).

Although companies producing intraoral scanners for full-arch scanning in jaws with natural dentition have established and recommended their own scanning protocols (8), Müller et al. reported that a scanning strategy that starts from the occlusal to palatal towards buccal provides the highest precision and trueness in full-arch scans and minimizes mistakes and inaccuracies (89). According to a study in which four different scanning protocols were tested; the OWBP technique (Fig. 2), which starts with a slight wiggling movement while scanning the occlusal surface and then scans the buccal and palatal surfaces, showed higher accuracy and lower error rates, especially for implant-supported full-arch prosthesis impressions. According to the same study, other scanning protocols can be safely used for shorter arch impressions (90).

Vandeweghe et al., who compared digital impression accuracy on a mandibular full-arch implant model with six implants, found the lowest accuracy in implants located in the most distal areas, 36 and 46 (11). Researchers stated that these regions are the end points of the scanned arch and that they cause more distortion due to the quadrant effect. The posterior regions provide a better reference for the scanner because they have a larger surface area. Therefore, it is recommended that they are in the 1st quadrant, i.e., start scanning from the posterior regions (91). As the scanned arch distance increases, it becomes difficult to obtain sufficient reference points between the point clouds. In this case, it is not possible to properly merge the separately acquired images, and as a result, either optical noises and distortions may occur in the obtained image, or the software may cut off some scanned areas (30, 31). Due to the lack of anatomical reference points in long-distance stitching, accumulated errors are at their highest level in fully edentulous arches (31). Therefore, the first scanned quadrants showed the best accuracy for digital impressions in some studies (44, 92).

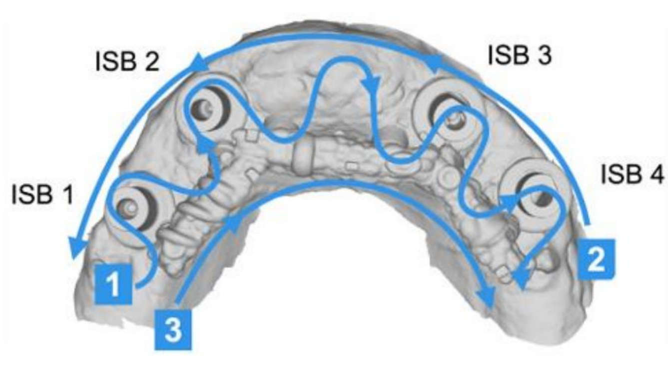


Figure 2. OWBP Digital Scanning Protocol (90).

8. Photogrammetry

Photogrammetry (PG) is a technique for detecting the geometrical characteristics of objects and their 3D spatial orientation by recording virtual images following a special protocol (93, 94). Photogrammetry is a new alternative for reliable, direct intraoral registration of the positions of multiple dental implants (94). However, PG is used to create a 3D digital model of the patient's face and dental arch, record occlusion, plan and document treatment, analyze the shape and position of teeth and maxillary and mandibular bones, apply rapid palate expansion techniques in orthodontics, evaluate tooth movements, plan and evaluate the results of jaw surgery by providing a record of soft tissues, and analyze the difference between the planned position of dental implants before and after surgery (42, 95). Specially designed and marketed extraoral systems are available in the dental market: PIC Camera (PICdental, Spain) and Icam4D (Imetric4D Imaging Sarl, Switzerland).

In the case report presented by Sánchez-Monescillo, in which they presented for the first time the all-on-four rehabilitation with the PG technique (PICcamera®), after 1 year, clinical and radiographic results showed that the peri-implant tissues were in good condition without any mechanical and biological complications (96). In a study by Penarrocha et al., in which they performed immediate loading with the PG technique in full-arch rehabilitation in the maxilla and delivered the final prosthesis to the patient 3 months later, no biological or prosthetic complications were recorded in the controls after immediate loading (46).

Bergin et al. claimed that the photogrammetric method is an alternative to full-arch implant-supported prostheses impressions; they reported that its precision was higher than that of conventional impression techniques, while overall accuracy was similar (97). It has been reported that the PG technique has a margin of error of less than 5 µm in in-vitro studies and 10 µm in in-vivo studies, regardless of the number of implants (98). It has been noted that the PG technique can potentially provide greater precision and better prosthesis fit, since the information determining the position of the implants in this technique is obtained from each photograph without superimpositions (46, 94). According to an in vitro study, PG demonstrated superior accuracy and precision in meeting the mismatch thresholds for implant-supported full-arch prostheses. Although as accurate as conventional impressions, intraoral scanning exhibited cross-arch angular and linear deviations. The addition of a splint to the scan body did not improve intraoral scanning accuracy. Different full-arch impression techniques are illustrated in Figure 3 (21).

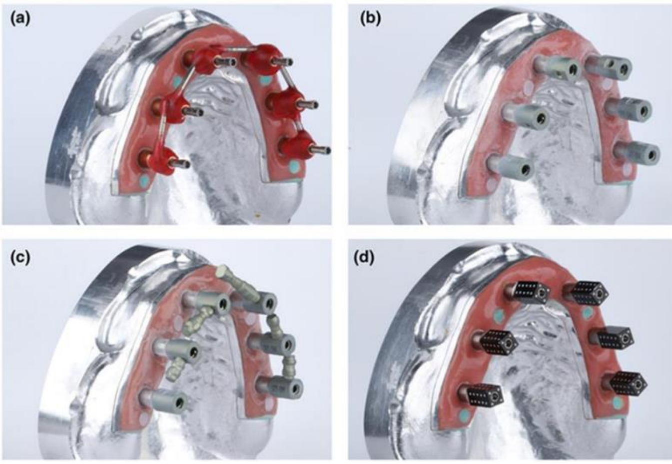


Figure 3. Comparison of different full-arch impression techniques. (a) Conventional impression. (b) Standard intraoral scanning. (c) Intraoral scanning with splinting. (d) Stereophotogrammetry (21).

9. Advantages of photogrammetry technique

1. Intraoral conditions do not affect the measurement accuracy (46, 99).
2. The use of optical markers is better tolerated by the patient than conventional impression materials, thus greatly increasing patient comfort and satisfaction (46, 97, 99).
3. The clinical applications are simplified, and impressions are obtained in a shorter time (99).
4. Immediate loading protocols can be achieved using devices that use PG technology (100).
5. Using the PG technique, multiple implant-supported prosthetic structures can be produced using CAD/CAM (46).
6. It has been reported that the PG technique can reduce economic costs in the long term (99).

10. Disadvantages of photogrammetry technique

Photogrammetric technique may not adequately record the patient's peri-implant soft tissues. To acquire the record of the soft tissue of the oral cavity, an intraoral scan or digitized conventional cast needs to be superimposed (45).

In an in vitro study comparing the accuracy of conventional, photogrammetry, and intraoral scanning impression techniques for full-arch implant-supported restorations, the PG system achieved the least accurate values and the highest 3D discrepancy among the techniques tested. The two IOSs tested provided a reliable digitizing procedure, as no significant differences were found between the linear discrepancy compared with the conventional impression technique (42). Based on an in vitro study, stereophotogrammetry (SPG) performed better than IOS and conventional open tray impression as the accuracy for full-arch implant registration (101). According to an in vivo study, SPG showed significantly higher linear and angular accuracy than intraoral digital impressions (102). Ma et al. reported that for full-arch implant rehabilitation, the PG system showed the best accuracy among all the evaluated impression techniques, followed by the conventional impression technique, and the IOS provided the least accuracy (103).

11. Digital record of edentulous dental arches

To date, the gold standard for master impressions of edentulous jaws is a two-stage impression with a thermoplastic material used for the border molding, followed by impressions with zinc oxide eugenol impression paste or silicone material (104). Full-arch impressions on edentulous patients are the most challenging clinical situations due to the absence of anatomic landmarks compared to partial edentulism (105). The shiny and smooth nature of the prosthesis-bearing areas and the lack of precise anatomical landmarks can lead to errors during stitching procedures (106).

Although IOSs are routinely used to take digital impressions of natural teeth and implants, recent studies have reported that intraoral scanners can also be used to digitalize edentulous jaws in the fabrication of complete dentures (107, 108). In addition, treatment protocols are being developed to register maxillo-mandibular relationships with IOSs for the production of complete dentures and to combine the images obtained with facial scans (109).

Some studies on the material and mechanical properties of CAD-CAM removable complete dentures (RCDs) have shown improved fit and increased retention of CAD-CAM RCDs (110). One retrospective clinical study reported that CAD-CAM and conventional complete RCDs required a similar number of treatment appointments. However, according to Arakawa et al., the digital workflow was less expensive in terms of overall costs and fewer clinical visits (111).

In the maxilla, the presence of palatal mucosa along with palatal rugae provides additional reference points for digital impressions (112). Some researchers have reported that when scanning edentulous maxillary jaws, markers placed on the palate facilitate the merging of reference images and increase the accuracy of scans (107, 113, 114).

Studies have reported that systems that work on the principle of receiving video data instead of the image stitching method are effective for acquiring impressions of edentulous areas (115). It aims to increase the accuracy of digital impressions in completely edentulous jaws with new developments in technical hardware and software (114).

12. Challenges in acquiring digital impressions of completely edentulous jaws

1. There may be difficulties in recording areas containing mobile tissue, such as the vestibular arch of the maxilla and mandible and the sublingual areas of the mandible, with IOSs (116).
2. The impressions of the gingiva and mucosa are recorded under passive mucostatic conditions using IOSs. No border molding is acquired to ensure a hermetic seal, and no post-dam area is used (107, 109).
3. The moist, smooth, translucent, and shiny nature of the oral mucosa and the lack of anatomical markers make stitching of images during scanning difficult and may lead to cumulative errors (113). To avoid this problem, composite or dermal markers are currently used (117).
4. Errors may occur in recording the functional depth of the vestibular sulcus and the position of the frenulum connections due to the procedures performed to retract the lips, cheeks, and tongue during scanning (118).
5. Functional border molding and digital recording of jaw relationships remain the main challenges in the rehabilitation of completely edentulous arches. While digital impressions taken in dentate arches can be aligned with digital bite records, in completely edentulous arches, this recording cannot be achieved in a completely digital environment and requires the use of a physical recording material (119).

In 2018, Goodacre et al. presented the first case report in which digital complete dentures were produced from images obtained using an intraoral scanner (TRIOS3; 3Shape) in edentulous patients. They reported that maxillary complete dentures produced for edentulous patients were not affected by the marking methods used on the palate during scanning and provided sufficient functional satisfaction, but in mandibular complete dentures, IOSs recorded a limited image, especially in the sublingual regions containing mobile tissue areas, and suggested that it would be more appropriate to use a modified impression technique that includes conventional impressions in mandibular complete dentures (118). An in vitro study reported an inversely proportional relationship between the scan distance and 3D data accuracy of five intraoral scanners for scanning edentulous and dentate complete-arch mandibular casts (120). In their clinical study, Lo Russo et al. compared the impressions acquired from the maxilla and mandible of 10 edentulous patients with the IOS with the impressions acquired with the conventional method and found that there was no statistically and clinically significant difference between the two methods (109). In another study, Lo Russo et al. stated that the inability to functionally mold the border area that will provide a peripheral seal in the digital impression of edentulous arches is not a disadvantage. The surface tension created by the compatibility of the denture base with the tissue allows shorter denture edges without affecting retention. However, excessively short denture edges should be avoided due to the possibility of decreased retention and stability (121).

According to the results of a clinical study by Chebib et al., two-stage conventional impressions showed better performance in the retention of complete denture bases than digital recordings acquired with an IOS. Digital impressions can be especially useful in the mucostatic recording of edentulous arches with unsupported crests or undercuts, where conventional impression taking may be difficult (122). Chebib et al. reported that the accuracy of intraoral scanning was similar to that of the conventional two-stage impression with border molding but was not significantly different from that of the impression without border molding. These results confirm that the digitization of edentulous arches is a reliable technique (107). Although in vivo studies have demonstrated the accuracy of intraoral scanning of edentulous arches, their practicability in all clinical scenarios and suitability for routine clinical use remain controversial (116, 123).

Although IOS recordings can be applied to completely edentulous arches, case selection is still very important. Conventional impressions with border molding should be preferred to digital intraoral scanning, especially when unfavorable ridge anatomy is encountered and when mucocompressive impressions are needed (106).

13. Discussion

A randomized clinical trial reported that the IOS has satisfactory accuracy and predictability and is a reliable alternative in clinical practice to the conventional workflow for implant full-arch rehabilitations. In addition, the digital workflow appears to be a valid choice for full-arch rehabilitations as it is a less invasive option for patients and shortens the chairside (124). One meta-analysis stated that digital impressions were significantly faster than conventional impressions, with a mean difference of 10.01 min, advising that digital scans offer an advantage in terms of efficiency (59). A study used photogrammetry system, which involved a conventional impression for registering soft tissue contours; the digital group had a significantly faster procedure time (mean 15.6 ±1.2 minutes) compared with that of the conventional group (mean 27.1 ±1.3 minutes) (97).

Most manufacturers of intraoral scanners have a specific scanning strategy for their systems. To fully utilize the performance of the IOS, it is important to follow the manufacturer's instructions and calibrate the scanner accurately (125).

Some studies have reported higher accuracy with smaller scan areas than with full-arch scans (126). Gimenez et al. claimed that the distance deviation increased significantly when the scanner changed from the first to the second quadrant, and the first scanned quadrant was significantly more accurate than the second (44).

Kim et al. stated that digital implant impressions have reduced accuracy when used on full-arch scans compared to conventional impressions at the implant level (85). Gherlone et al. stated that by using multi-unit abutments that correct implant angulation, it was possible to develop clinically acceptable CAD/CAM full-arch rehabilitations using digital impressions compared to conventional impressions for all-on-four implant restorations (127). Another in vitro study reported that full-arch digital implant impression using two different IOS had the same degree of accuracy as the conventional splinted open tray technique (36, 128).

An osseointegrated implant has a limited ability to move within 10 µm in the bone, whereas a natural tooth can move up to 100 µm in the periodontal ligament, which can help compensate for a certain amount of misfit. Therefore, the fit of implant-supported dentures is more critical than tooth-supported dentures in ensuring a precise fit (129). In complete oral rehabilitation with multi-supported implant prosthesis, the passivity of the framework is crucial for the long-term survival of the implants and prosthetic restoration (130, 131). Misfit and lack of passive fit may cause various component losses, ranging from fracture of implants, screws, and substructures, biomechanical failures such as distortion of the substructure and chipping of the veneering ceramic, as well as biological complications such as peri-implant mucositis, peri-implantitis, and bone resorption (97, 130, 131). A study showed that an average distance deviation of 50 to 100 µm and a maximum angular deviation of 1° were required to ensure framework passivity in implant-supported full-arch prostheses (131). Local deviations of more than 100 µm can cause problems in full-arch restorations. The accuracy of the impression and the fit of the prosthesis depend on each stage of the workflow process. In traditional techniques, each step must be performed precisely to achieve the best fit. Instead, CAD/CAM systems usually require fewer steps; therefore, the number of sources of error is less than that in traditional methods (69). Drancourt et al. reported that the distance deviation of the four digital impressions was between 170 and 270 µm, while the conventional impression had the smallest distance deviation (132 µm). They showed that the conventional impression had been more accurate than the digital impressions. However, for angular deviations, their results revealed that three of the intraoral scans performed better, but both the conventional and digital impressions were below the value of 1° (125). However, in clinical studies, the 3D accuracy measured in vivo showed a mean deviation of 207.82 µm. Rutkunas et al. also reached this conclusion and explained that this may be due to the limited space, movement of patients, and compromise of more accumulated images (75). Marginal discrepancy causes periodontal and peri-implant pathologies, which invariably lead to the failure of prosthetic treatments (132). In an in vitro study, it was reported that full-arch digital impressions with a marginal discrepancy of 63.1 µm had a higher accuracy rate than conventional impressions with a marginal discrepancy of 135.1 µm (131). Fixed dental restorations fabricated using digital impressions showed smaller marginal gaps and significantly smaller internal gaps than those fabricated using the traditional impression technique, but this was not statistically significant (133).

An in vitro study reported the threshold at 59-72 µm linear and 0.4° angular displacement between implants (87). This corresponds to a maximum lateral movement of the implant in the bone of 50 µm (134). Revell et al. stated that any angular deviations below 0.75 degrees will not have adverse clinical effects (35). However, different reviews have concluded that there is no consensus (39).

Digital scans acquired with mainstream IOS brands demonstrate accuracy within a clinically acceptable range for edentulous arches and show potential clinical benefit for edentulous patients, particularly with inclined implants (135). According to a systematic review, the digital impression technique provides more accurate results than the conventional method for full-arch implant-supported prostheses (136).

Sometimes data needs to be integrated with IOS data in the PG technique, which involves merging the files to complete the digital impression process (137). No complications related to the use of PG have been reported in several case reports covering the 6-24 month maintenance phase (94, 98-100). The IOSs tended to produce greater angular and linear deviations in the cross-arch region. As the scanning range increases due to the lack of anatomical landmarks in the edentulous jaw, the deviation in the cross-arch region of the IOS increases (138).

According to Kong et al., the accuracy of digital and alginate full-arch impressions is similar, and both impression techniques show high precision; for orthodontic patients with completely natural dentition, digital impressions obtained directly by intraoral scanning can be considered a suitable alternative to alginate impressions (7). A clinical study which assessed the transfer accuracy of full-arch impressions in orthodontic patients with multibracket appliances showed that the transfer accuracy of IOS was better than or at least equivalent to the conventional alginate impression, except the longest distance (58). Janosi et al. reported that the intraoral scanning can be considered as an alternative to the conventional impression for performing study model analysis during orthodontic treatment planning (139). IOSs are commonly used in orthodontics for pre-treatment diagnostics or the manufacturing of orthodontic appliances (63, 66). According to an in vitro study, IOSs can be recommended for impression taking with or without fixed orthodontic appliances (140). Guided scanning procedures may be highly promising for clinical application, especially for digital orthodontic workflows (141).

Some researchers have reported that intraoral digital scanning is more accurate for a full-arch impression than conventional impressions (5, 142). Pera et al. reported that the accuracy of full-arch implant-supported metal frameworks obtained with the digital impression system was clinically similar to those obtained with the conventional impression technique (143). Some studies reported that digital scanning exhibited less accuracy for longer spans or full-arch impressions than the conventional impression approach (11, 41). However, digital scans were more accurate than conventional open-tray splinted impressions, according to an in-vitro study. Prefabricated landmarks significantly improved the accuracy of full-arch implant digital scans, regardless of the scanner used (144). Pozzi et al. developed a noncommercial, 3D-printed splint that was fixed to a scan body. The resin splint facilitated image fusion and provided a trackable scan path, improving the accuracy of full-arch digital impressions (145).

D'haese et al. reported that digital impressions for full-arch implant-supported prostheses may be as accurate as conventional impressions, depending on the IOS and software (86). A systematic review and meta-analysis reported that for full-arch implant-supported prostheses, digital impressions made using IOS provided equivalent or better linear accuracy than traditional impression techniques (146).

According to De Angelis et al., digital impression is a viable alternative to conventional impression for the full-arch immediate-loading prostheses. The digital impression technique and guided surgery protocol shorten the operative time and increase the precision of the framework (147).

Some systematic reviews report that impressions obtained with IOSs are not accurate enough for the fabrication of long-span restorations (33, 148). As the number of implants increases, the accuracy of both traditional and digital methods tends to decrease (149). The accuracy of digital impressions is greatly affected by the inter-implant distance and scanning range. The accuracy of digital scans in all-on-6 was significantly lower than that in all-on-8, which was primarily related to the short inter-implant distance in all-on-8 (84).

In completely edentulous arches, with inter-implant angles of 0-15 degrees, no significant difference in accuracy was observed between digital methods and conventional splinted open tray methods at the implant level; both outperformed conventional methods without the open tray splinted technique (36).

The protocol most commonly recommended by IOS manufacturers begins with acquisition of the occlusal surface from right to left, followed by a return scan of the buccal surface from left to right, and finally a palatal scan from right to left. This scanning procedure leads to a redistribution of the error along the arch (150).

One systematic review and meta-analysis reported that the use of digital scans did not result in significant differences in radiographic marginal bone loss compared with conventional impressions in full-arch implant-supported prostheses (59).

A study that compared the accuracy of conventional impression, gypsum cast, and digital impression scans to acquire a full-arch digital model reported that gypsum cast scans showed the highest accuracy, followed by conventional impression and digital impression scans, with no clinical significance (151). According to a clinical study, current IOS equipped with the latest software versions showed less deviation for short-span distances than the conventional impression technique, and for long-span distances, the conventional impression technique provided the lowest deviation. Schmidt et al. reported that the hardware components of a digital scanner influenced the transfer accuracy (6).

A systematic review showed that intraoral scanning is a clinically acceptable method for producing accurate fixed implant-supported prostheses in completely edentulous arches, especially for inclined implants (105). The conventional splinted open-tray implant impression technique is still considered the gold standard for full-arch prostheses (152). Previous studies have evaluated the accuracy of various IOSs for full-arch implant impressions, but no consensus has been reached on the practicability of this technique in clinical routine (36, 153). A recent in vitro study examining the PG device reported that it may be a clinically acceptable alternative to conventional full-arch implant impressions. However, the splinted elastomeric impression method achieved statistically significantly higher accuracy between systems (154). According to an in vivo prospective comparative study, the clinical application of PG should be performed carefully, and a hard prototype trial is recommended before fabricating definitive screw-retained full-arch prostheses (102).

According to a systematic review, digital methods generally demonstrated greater accuracy than conventional impression techniques for full-arch implant-supported prostheses. In particular, PG has shown significant potential for accurately calculating implant positions (136). Full-arch digital scans and a full digital workflow may be clinically feasible in the fabrication of fixed implant supported restorations in the edentulous maxilla (153).

The results obtained from different studies are affected by many factors, such as the evaluation method used, the type of study design, the type of intraoral scanner used, and the impression material used in the conventional impression technique (53). These methodological differences largely explain the apparent disagreement in the literature: studies reporting digital superiority tend to assess shorter spans, newer scanner generations, or photogrammetric systems, whereas those favouring the conventional technique predominantly evaluate long-span and fully edentulous arches at the implant level. Accordingly, the choice of technique should be interpreted in the context of span length, scanner generation, and the clinical situation rather than as a general superiority of one approach.

14. Conclusion

According to the data obtained from the literature, the following conclusions can be made:

- Polyether, polyvinyl siloxane, and vinyl siloxane ether impression materials provide clear and accurate impressions in the conventional workflow.
- The preference for digital or conventional impression technique is affected by the number of teeth/implants and the distance between teeth/implants in the jaw. In the digital impression technique, as the distance between the implants increases, the accuracy of the impression decreases. Therefore, while conventional impression methods are recommended for completely edentulous patients, the digital method can be used for the impression of implants with up to three or four units.
- In conclusion, despite the different literature data, digital techniques are candidates to outperform conventional methods in the field of dentistry. Although digital systems have advantages over conventional systems, some issues still need to be addressed.

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