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Comparing The Trueness of Two Scanning Techniques with Conventional Impressions for All-On-4 Implant Prostheses

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Abstract

Digital technologies have significantly transformed contemporary implant prosthodontics, particularly in the rehabilitation of edentulous patients with full-arch implant-supported prostheses. The purpose of this narrative review was to evaluate the contemporary digital workflow used in full-arch implant rehabilitation, with particular emphasis on intraoral scanning challenges, scan body variables, scanning strategies, accuracy assessment, and passive fit of implant-supported prostheses. Relevant literature related to digital implant impressions, scan bodies, CAD/CAM workflows, passive fit, and digital accuracy assessment was analyzed, including in vitro studies, clinical investigations, systematic reviews, and narrative reviews published in the field of implant prosthodontics. The reviewed literature demonstrated that digital workflows have significantly improved clinical efficiency, patient comfort, and restorative precision. However, several factors continue to influence the trueness and precision of digital implant impressions, including implant angulation, arch length, scan body geometry and material, scanning strategy, intraoral scanner technology, and operator experience. Long-span edentulous scanning remains one of the major limitations of current intraoral scanning systems because of stitching errors and the absence of stable anatomical landmarks. Despite these challenges, digital impressions frequently demonstrate comparable or superior accuracy relative to conventional impression techniques in many clinical situations. Digital workflows represent a promising and increasingly reliable approach for full-arch implant rehabilitation. Optimization of scan body selection, scanning strategy, and data acquisition protocols may significantly improve the passive fit and long-term success of implant-supported prostheses. Continued technological advances and standardized clinical protocols are expected to further enhance the predictability of complete-arch digital implant impressions.

Keywords: Digital workflow; Full-arch implant prostheses; Intraoral scanners; Scan bodies; Passive fit; All-on-4; CAD/CAM; Digital impressions.

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1. Introduction

The introduction of digital technologies into implant prosthodontics has fundamentally transformed contemporary restorative dentistry. Conventional workflows that previously relied on elastomeric impressions, gypsum casts, wax patterns, and labor-intensive laboratory procedures have progressively shifted toward digital workflows based on intraoral scanning, computer-aided design (CAD), and computer-aided manufacturing (CAM) technologies [1-2]. These developments have significantly improved the efficiency, precision, and predictability of implant-supported restorations. Full-arch implant rehabilitation represents one of most demanding clinical procedures in implant dentistry because accurate transfer of implant positions is critical for achieving passive fit and long-term prosthetic success [3]. Inaccurate impressions may result in mechanical complications such as screw loosening, prosthetic fracture, framework distortion, or implant overload, in addition to biological complications including peri-implant inflammation and marginal bone loss [4-5]. Consequently, impression accuracy remains a fundamental determinant of treatment success in implant prosthodontics. The All-on-4 concept has become increasingly popular for rehabilitation of edentulous arches due to its ability to maximize available bone while reducing the need for grafting procedures [6].

However, digital impressions for complete-arch implant restorations remain challenging because of the absence of stable anatomical landmarks, increased interimplant distances, and cumulative stitching errors associated with intraoral scanners [7]. Therefore, reliability of digital workflows in full-arch implant rehabilitation continues to be extensively investigated. Several variables influence the accuracy of digital implant impressions. These include scanner technology, implant distribution, implant angulation, scan body geometry, scan body material, scanning strategy, operator experience, and software algorithms [8-10]. Furthermore, increasing availability of customized scan bodies, photogrammetry systems, and advanced CAD/CAM technologies has introduced additional variables that may affect digital impression accuracy. The purpose of this narrative review is to discuss contemporary digital workflow used in full-arch implant rehabilitation, with emphasis on intraoral scanning challenges, scan body variables, scanning strategies, methods of accuracy assessment, and the relationship between digital impression accuracy and passive fit of implant-supported prostheses.

2. Digital Workflow in Full-Arch Implant Prosthodontics

2.1. Evolution of Digital Dentistry

Digital dentistry has evolved rapidly over the last two decades. Early CAD/CAM systems were initially limited to single-tooth restorations; however, technological improvements in scanner accuracy, processing speed, and manufacturing technologies have expanded their use to complex implant-supported rehabilitations [11]. Modern digital workflows now include intraoral scanners, laboratory scanners, facial scanners, cone-beam computed tomography (CBCT), and additive manufacturing systems. The digital workflow generally begins with data acquisition using an intraoral scanner or desktop scanner. acquired digital data are exported as standard tessellation language (STL) files, which are subsequently used for CAD design and CAM fabrication of definitive prosthesis [12]. These workflows minimize laboratory procedures, reduce treatment time, and improve communication b/w clinicians and dental technicians.

2.2. Advantages of Digital Workflows

Digital workflows offer several advantages compared with conventional techniques. Intraoral scanners improve patient comfort by eliminating impression trays and elastomeric materials [13]. Furthermore, digital impressions facilitate immediate visualization of scanned areas, allowing rescanning of deficient regions without repeating the entire impression procedure [14]. Digital workflows also reduce laboratory errors associated with stone expansion, impression distortion, and material shrinkage [15]. Additionally, digital data storage permits efficient communication, easy duplication of records, and long-term archiving.

2.3. Limitations of Digital Workflows

Despite these advantages, digital workflows continue to face several limitations. Long-span edentulous scanning remains challenging due to absence of anatomical landmarks required for image stitching [16]. Saliva contamination, patient movement, reflective surfaces, & soft tissue mobility may further compromise scanning accuracy [17]. Moreover, different scanner systems demonstrate variable levels of trueness and precision depending on the scanning technology employed. Several clinical and technical factors may influence trueness and precision of complete-arch digital implant impressions, including implant angulation, interimplant distance, scan body geometry, scanner technology, and operator experience (Table 1).

3. Challenges of Intraoral Scanning in Edentulous Arches

3.1. Lack of Anatomical Landmarks

One of the primary challenges associated with edentulous digital impressions is the lack of stable reference points for image stitching [18]. Most intraoral scanners rely on overlapping image acquisition to reconstruct three-dimensional surfaces. In dentate arches, teeth provide distinct morphological features that facilitate stitching accuracy. In contrast, edentulous arches often present smooth, featureless mucosal surfaces that reduce scanning reliability. Figure 1 demonstrates the absence of distinct anatomical landmarks in an edentulous arch, which may compromise image stitching and digital scanning accuracy during full-arch intraoral scanning.

3.2. Stitching Errors in Long-Span Scanning

Image stitching errors accumulate progressively during full-arch scanning [19]. Small inaccuracies generated during image overlap may become magnified across long scanning distances, resulting in cumulative distortion of the final digital model. These errors are particularly evident in complete-arch implant impressions where precise implant positioning is critical. Several studies demonstrated that scanning errors increase proportionally with arch length and interimplant distance [20]. Consequently, complete-arch digital impressions generally exhibit lower trueness compared with short-span implant restorations.

3.3. Soft Tissue Mobility

Soft tissue displacement during scanning may further affect digital impression accuracy [21]. Edentulous mucosa is often movable and compressible, particularly in patients with severe ridge resorption. Variations in soft tissue pressure during scanning may result in inaccurate representation of tissue contours and implant positions.

3.4. Saliva and Reflective Surfaces

Saliva accumulation and reflective metallic surfaces may interfere with optical scanning systems [22]. Excess saliva may create optical artifacts and incomplete image acquisition. Similarly, metallic scan bodies can generate light reflection and scattering that negatively influence scanning accuracy.

4. Influence of Implant Distribution and Angulation

4.1. All-on-4 Implant Concept

The All-on-4 concept involves placement of four implants to support a complete-arch fixed prosthesis, typically with posterior implants tilted distally to maximize anteroposterior spread and reduce cantilever length [23]. This approach provides predictable outcomes while minimizing the need for bone augmentation procedures.

4.2. Effect of Implant Angulation

Implant angulation has a significant influence on digital impression accuracy [24]. Increased implant divergence may complicate image acquisition and compromise scan body recognition by the scanner software. Several investigations reported greater deviations with highly angulated implants, particularly when interimplant distances were extensive [25]. However, some studies demonstrated that modern intraoral scanners can accurately capture tilted implants when appropriate scanning protocols are followed [26]. Therefore, the influence of implant angulation may depend on scanner technology, scan body design, and operator experience.

4.3. Interimplant Distance and Arch Curvature

Large interimplant distances increase the likelihood of cumulative stitching errors [27]. Additionally, curved arch morphology may complicate scanner movement and image overlap, resulting in increased distortion during complete-arch scanning.

5. Scan Bodies: Design, Material, and Geometry

5.1. Role of Scan Bodies

Scan bodies are essential components used to transfer implant position and orientation into the digital environment [28]. They are connected to implant fixtures or multiunit abutments during intraoral scanning and recognized by CAD software through dedicated digital libraries.

5.2. Scan Body Materials

Different scan body materials have been introduced, including polyetheretherketone (PEEK), titanium, resin, and hybrid materials [29]. PEEK scan bodies are commonly used because of their low reflectivity and favorable optical properties. Metallic scan bodies may generate reflection artifacts that reduce scanning accuracy.

5.3. Customized Scan Bodies

Customized scan bodies have recently gained attention due to their potential to improve scanner recognition and minimize stitching errors [30]. By increasing surface geometry and providing additional landmarks, customized scan bodies may enhance digital impression trueness in full-arch implant rehabilitations. Figure 2 illustrates different customized scan body geometries designed to improve scanner recognition and reduce stitching errors during digital implant impressions. Several studies demonstrated comparable or improved accuracy with customized scan bodies compared with conventional stock scan bodies [31]. However, the evidence remains inconclusive because outcomes vary according to scanner system, scanning protocol, and implant configuration.

5.4. Scan Body Wear and Reusability

Repeated tightening and sterilization of scan bodies may lead to surface wear and dimensional alterations [32]. These changes may compromise the precision of implant position transfer. Therefore, proper maintenance and replacement protocols are recommended.

6. Scanning Strategies and Image Acquisition

6.1. Importance of Scanning Strategy

Scanning strategy refers to the movement pattern followed during intraoral scanning [33]. Appropriate scanning protocols improve image overlap and minimize stitching errors.

6.2. Straight Scanning Strategy

The straight scanning strategy typically involves continuous scanning along the occlusal surfaces followed by buccal and lingual surfaces [34]. This method is simple and time-efficient, although it may generate inaccuracies in long-span edentulous arches.

6.3 Zigzag Scanning Strategy

The zigzag scanning strategy incorporates alternating buccal and lingual movements during image acquisition [35]. This technique may improve overlap between images and enhance stitching accuracy by increasing the number of reference points. Several studies compared straight and zigzag scanning strategies with variable outcomes. While some investigations reported improved trueness with zigzag scanning, others found no statistically significant differences between scanning protocols [36].

6.4. Operator Experience

Operator experience significantly influences scanning outcomes [37]. Experienced clinicians generally produce more accurate scans with reduced scanning time and fewer image stitching errors. Learning curve associated with intraoral scanners remains important consideration in clinical practice.

7. Accuracy Assessment in Digital Implant Impressions

7.1. Definition of Accuracy

According to ISO standards, accuracy consists of trueness and precision [38]. Trueness describes the closeness of a measurement to the true value, whereas precision refers to the reproducibility of repeated measurements (Figure 1).

7.2. Reference Models and Desktop Scanners

High-precision desktop scanners are frequently used to generate reference models for evaluating digital impression accuracy [39]. These systems provide highly accurate STL datasets that serve as baseline references for comparison.

7.3. Superimposition Techniques

Best-fit superimposition algorithms are commonly used to compare experimental scans with reference models [40]. Three-dimensional deviation analysis enables quantitative assessment of discrepancies between datasets.

7.4. Root Mean Square (RMS) Deviation

RMS deviation values frequently used to quantify digital impression trueness [41]. Lower RMS values indicate greater agreement b/w experimental and reference models.

7.5. Color Mapping Analysis

Three-dimensional color maps visually represent deviations between datasets [42]. Positive deviations are typically displayed in warm colors, whereas negative deviations are represented by cool colors.

8. Passive Fit and Prosthetic Complications

8.1. Definition of Passive Fit

Passive fit refers to the absence of strain between the prosthesis and supporting implants after screw tightening [43]. Achieving passive fit is critical for maintaining long-term mechanical and biological stability.

8.2. Mechanical Complications

Misfit of implant-supported prostheses may generate excessive stress concentrations, resulting in screw

Figure 1. Edentulous maxillary cast demonstrating the limited anatomical landmarks available for intraoral scanner image stitching in complete-arch digital impressions.

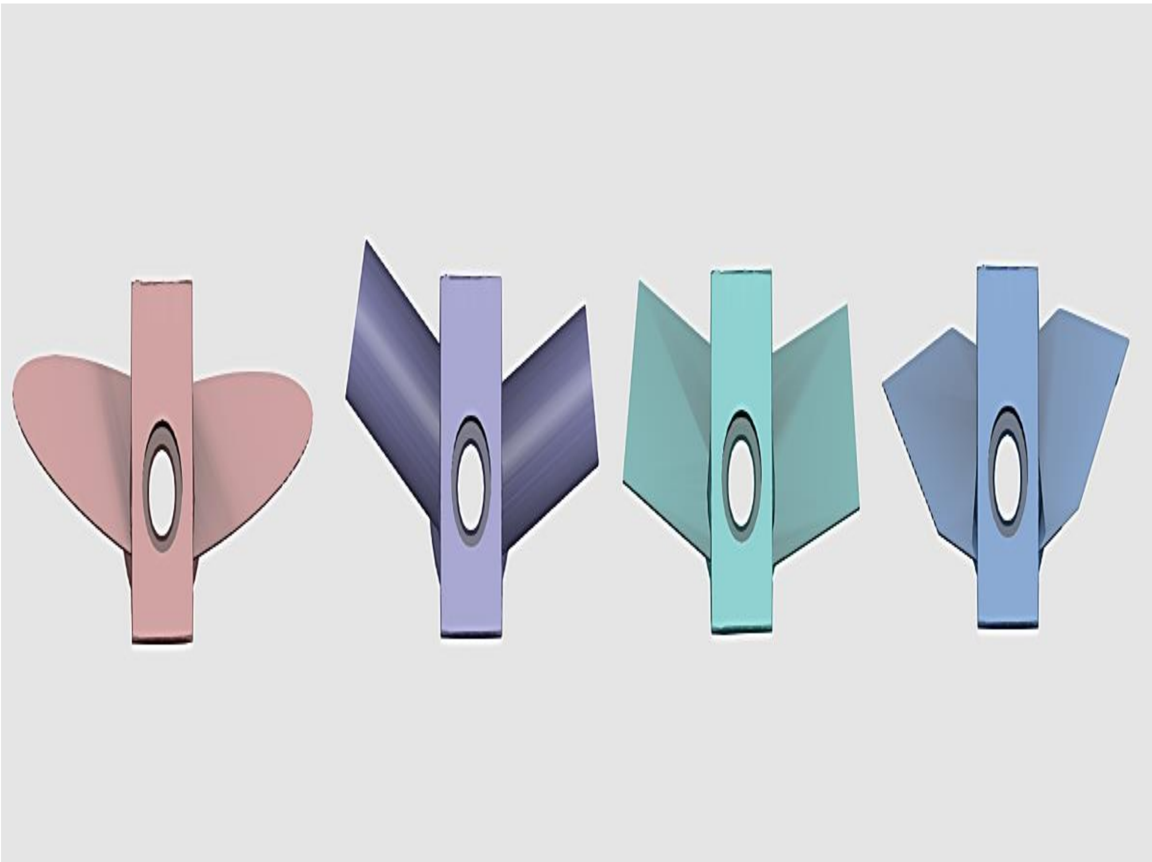

Figure 2. Examples of customized scan body geometries used to improve landmark recognition and enhance digital impression accuracy in complete-arch implant scanning.

Figure 3. Splinted implant impression copings connected with resin material during a conventional open-tray impression procedure for complete-arch implant rehabilitation.

Table 1: Factors Affecting Accuracy of Digital Implant Impressions in Full-Arch Rehabilitation

Factor	Influence on Accuracy	Clinical Impact
Implant angulation	Increased divergence may reduce scan accuracy	Greater deviation in implant position transfer
Interimplant distance	Longer distances increase stitching errors	Reduced trueness in complete-arch scans
Arch curvature	Complex curvature complicates image overlap	Distortion in digital models
Scan body material	Reflective materials reduce optical capture quality	Inaccurate scan body recognition
Scan body geometry	Limited geometry reduces scanner tracking	Reduced implant localization accuracy
Scanning strategy	Inadequate scan path increases cumulative errors	Lower precision and reproducibility
Operator experience	Inexperienced operators produce more stitching errors	Longer scanning time and rescanning
Saliva contamination	Optical artifacts interfere with data acquisition	Incomplete or distorted scans
Soft tissue mobility	Tissue displacement alters surface registration	Inaccurate mucosal representation
Scanner technology	Different optical principles exhibit variable trueness	Differences in full-arch scan reliability

Table 2: Comparison Between Conventional and Digital Implant Impression Techniques

Parameter	Conventional Impression	Digital Impression
Patient comfort	Lower due to trays and impression materials	Higher comfort and reduced gag reflex
Clinical time	Longer workflow	Reduced chairside time
Laboratory procedures	Multiple manual steps	Streamlined CAD/CAM workflow
Risk of material distortion	Present	Minimal
Data storage	Physical casts required	Digital STL file storage
Accuracy in short-span restorations	High	Comparable or superior
Accuracy in full-arch restorations	Traditionally superior	Improving with modern scanners
Technique sensitivity	High	Moderate
Need for rescanning	Entire impression repeated	Local rescanning possible
Communication with laboratory	Conventional shipment	Instant digital transfer

Table 3: Emerging Technologies and Future Perspectives in Digital Implant Prosthodontics

Technology	Proposed Benefit	Potential Clinical Impact
Artificial intelligence (AI)	Automated image processing and error correction	Improved scanning accuracy and reduced operator variability
Machine learning algorithms	Enhanced scan stitching and data interpretation	Increased predictability of digital impressions
Photogrammetry systems	Reduced stitching errors in full-arch scanning	Improved implant position accuracy
Dynamic scan bodies	Enhanced implant recognition during scanning	Better scan body detection and trueness
Smart markers	Additional reference landmarks for scanners	Improved image overlap and alignment
Additive manufacturing (3D printing)	Rapid fabrication of guides and prostheses	Improved workflow efficiency
CAD/CAM advancements	More precise prosthetic fabrication	Enhanced passive fit
Cloud-based digital workflows	Faster clinician-technician communication	Improved treatment coordination
Standardized scanning protocols	Reduced variability between operators	Greater reproducibility
Future intraoral scanner developments	Faster acquisition and higher trueness	Expanded clinical applicability

loosening, framework fracture, implant fracture, or veneering material chipping [44]. Long-span prostheses are particularly susceptible to complications associated with inaccurate impressions.

8.3. Biological Complications

Poor passive fit may also contribute to peri-implant inflammation and crestal bone loss due to stress-induced remodeling and bacterial microleakage [45]. Therefore, accurate digital impressions are essential for preserving peri-implant tissue health.

8.4. Relationship Between Digital Accuracy and Passive Fit

Several studies reported that improved digital impression accuracy is associated with enhanced passive fit of CAD/CAM prostheses [46]. However, passive fit is influenced by multiple factors beyond impression accuracy, including framework material, manufacturing method, and screw tightening protocol.

9. Conventional versus Digital Impressions

9.1. Conventional Impression Techniques

Conventional implant impressions are commonly performed using splinted or nonsplinted open-tray techniques [47]. Splinted techniques are generally considered more accurate because they minimize movement of impression copings during impression removal. Figure 3 shows a splinted open-tray implant impression setup used for conventional full-arch implant impressions.

9.2. Limitations of Conventional Techniques

Conventional impressions are technique-sensitive and involve multiple procedural steps that may introduce errors, including material distortion, tray deformation, gypsum expansion, and coping movement [48]. Furthermore, these techniques are often uncomfortable for patients and time-consuming for clinicians.

9.3. Comparison Between Conventional and Digital Impressions

Numerous studies compared digital & conventional implant impressions with inconsistent findings [24]. While some investigations reported superior accuracy for conventional impressions in complete-arch rehabilitations, others demonstrated comparable or superior accuracy for digital impressions. A comparison between conventional and digital implant impression techniques regarding accuracy, efficiency, patient comfort, and workflow characteristics is summarized in Table 2. Recent improvements in scanner technology and software algorithms have significantly enhanced predictability of digital workflows [49]. Consequently, digital impressions increasingly considered a viable alternative for complete-arch implant the rehabilitation.

9.4. Patient Satisfaction and Clinical Efficiency

Digital impressions generally provide greater patient comfort and shorter clinical appointments [50]. Elimination of impression materials reduces gag reflex and improves patient acceptance.

10. Future Perspectives in Digital Implant Prosthodontics

10.1. Artificial Intelligence and Machine Learning

Artificial intelligence (AI) is increasingly integrated into digital dentistry for automated image processing, error correction, and restoration design [51]. AI-driven software may enhance stitching accuracy and reduce operator-related variability.

10.2. Photogrammetry Systems

Photogrammetry systems have emerged as promising alternatives for full-arch implant impressions [52]. These systems use multiple photographic images to determine implant positions with high precision and minimal stitching errors.

10.3. Dynamic Scan Bodies

Novel dynamic scan bodies and smart markers are currently being investigated to improve implant recognition and digital accuracy [53]. These innovations may enhance full-arch scanning predictability.

10.4. Additive Manufacturing

Three-dimensional printing technologies continue to expand in implant prosthodontics [54]. Additive manufacturing facilitates fabrication of surgical guides, provisional restorations, verification jigs, and definitive prostheses.

10.5. Standardization of Clinical Protocols

Standardized scanning protocols remain essential for improving the reproducibility and reliability of digital implant impressions [55]. Future research should focus on establishing evidence-based clinical guidelines. Emerging technologies and future innovations expected to enhance digital implant prosthodontics are summarized in Table 3.

11. Conclusions

Digital workflows have become increasingly integrated into full-arch implant rehabilitation because of their potential to improve efficiency, patient comfort, and restorative accuracy. Nevertheless, complete-arch intraoral scanning remains technically challenging due to stitching errors, limited anatomical landmarks, and the influence of multiple clinical variables. The reviewed literature demonstrated that scan body design, scan body material, implant angulation, interimplant distance, scanning strategy, and operator experience significantly influence the trueness and precision of digital implant impressions. Contemporary intraoral scanners have shown promising accuracy for full-arch implant rehabilitation, frequently achieving comparable or superior outcomes relative to conventional impression techniques. Accurate digital impressions are closely associated with improved passive fit and reduced prosthetic complications. Therefore, optimization of digital workflows represents a critical factor for long-term success of implant-supported prostheses. Future technological advances, including artificial intelligence, photogrammetry systems, and standardized scanning protocols, are expected to further enhance the predictability and clinical application of digital implant prosthodontics.

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