ARTICLES SCIENTIFIQUES

Intraoral Photogrammetry for Full-Arch Implant Rehabilitation: A Digital Approach to Improving Accuracy and Passive Fit

Photogrammétrie intra-orale pour une réhabilitation implantaire complète : Approche numérique pour une prothèse précise et passive

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Résumé

La photogrammétrie intra-orale s'est imposée comme une technologie clé dans le flux de travail numérique des réhabilitations implantaires complètes. Cette revue évalue sa précision, son intérêt clinique et ses limites par rapport aux empreintes conventionnelles et au scan intra-oral. Alors que les méthodes traditionnelles et optiques sont sujettes aux distorsions et aux erreurs d'assemblage, notamment sur les arcades étendues, la photogrammétrie permet un enregistrement très précis et reproductible de la position des implants, indépendamment de la longueur de l'arcade. Sa capacité à garantir un ajustement passif en fait un outil particulièrement adapté aux restaurations implantaires complexes. Toutefois, son coût élevé, sa sensibilité technique, les limites dans la capture des tissus mous et le manque de données cliniques à long terme constituent encore des freins à sa généralisation. Les avancées futures intégrant des systèmes hybrides, l'intelligence artificielle et les flux numériques CAD/CAM pourraient renforcer son intérêt clinique. Ainsi, la photogrammétrie intra-orale représente une technologie prometteuse pour améliorer la précision et la prévisibilité des réhabilitations implantaires complètes.

Mots clés : Photogrammétrie, réhabilitation implantaire complète, digital, armature passive

Abstract

Intraoral photogrammetry has emerged as a key technology in the digital workflow of full-arch implant rehabilitation. This review evaluates its accuracy, clinical relevance, and limitations compared with conventional impressions and intraoral scanning. While traditional and optical methods are affected by material distortion and stitching errors, especially in extended arches, photogrammetry provides highly accurate and reproducible implant position records independent of arch length. Its ability to achieve passive fit makes it particularly valuable in complex implant-supported prostheses. However, high costs, technical sensitivity, limited soft tissue capture, and the lack of long-term clinical outcome data remain challenges. Future developments integrating photogrammetry with hybrid scanning systems, artificial intelligence, and digital CAD/CAM workflows may further enhance its clinical applicability. Overall, intraoral photogrammetry represents a promising and evolving tool for improving precision and predictability in full-arch implant prosthodontics.

Key words : Photogrammetry, Full-Arch implant rehabilitation, digital, passive framework

INTRODUCTION

The management of fully edentulous patients continues to pose a significant clinical challenge in contemporary implant dentistry. Severe alveolar ridge resorption and the complexity of full-arch reconstruction often make treatment planning challenging.

Traditionally, full-arch implant-supported prostheses have relied on analog workflows involving physical impressions and cast fabrication. While widely used, these techniques are prone to cumulative inaccuracies that can compromise the passive fit of the final prosthesis, leading to mechanical and biological complications.

Digital technology has transformed this field by offering more precise and efficient workflows. However, conventional intraoral scanners may still struggle to capture fully edentulous arches accurately due to stitching errors and the absence of stable landmarks. In this context, intraoral photogrammetry has emerged as a highly accurate solution for multi-implant impressions. By recording the exact 3D position and angulation of implants through triangulation, photogrammetry provides a reliable dataset with micron-level precision.

The aim of this article is to present the use of intraoral photogrammetry in full-arch implant dentistry through a clinical case report and to highlight its advantages, limitations, and potential for improving passive fit and overall treatment outcomes.

CLINICAL OBSERVATION

Patient A.C., a 64-year-old, in good general health, was referred to the outpatient department of the Monastir Dental Medicine Clinic for a complete occluso-prosthetic rehabilitation using an implant-supported prosthesis (Fig. 1, 2).

Extra oral Examination

The patient was in good general health. Facial analysis showed overall symmetry with a noticeable collapse of the lower facial third. No lymphadenopathy was detected. Mouth opening was adequate, corresponding to four patient fingers, with a straight opening path.

The patient reported no joint noises or pain.

Figure 1 Initial situation: patient's smile

Figure 2 Initial situation: rest

Intra oral Examination

Oral hygiene was insufficient. The patient wore a maxillary removable complete denture, which had caused an epulis fissuratum. The gingiva appeared pale pink and firm, and the oral mucosa presented a normal aspect. The periodontal biotype was thin. The maxillary arch showed complete edentulism, while the mandibular arch retained only tooth 47, which exhibited an occluso-proximal amalgam restoration (Fig. 3, 4).

Figure 3 Mandibular arch

Figure 4 Maxillary arch

Radiological Examination

To complete the pre-implant assessment, radiographic imaging included an ortho-pantomogram (OPG) and a cone-beam computed tomography (CBCT) scan. The diagnosis established was complete maxillary edentulism and subtotal mandibular edentulism, leading to the decision to rehabilitate the patient with an implant-supported complete prosthesis.

Figure 5 Oblique coronal slices showing the mandibular bone

Planning

<u>Phase 1: Data Collection (step 1 & 2)</u>

Step 1: Initial Data Acquisition - Intraoral Scan of Mandibular Arch (Fig. 6, 7).

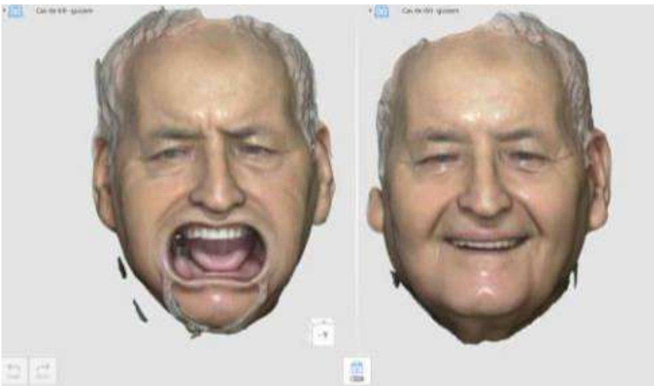

Figure 6 Facial scan

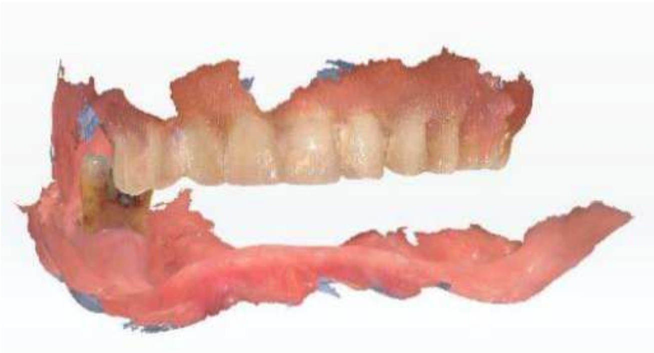

Figure 7 A screenshot of the software showing the scanned jaw

Step 2: Pre-operative Assessment - Cone Beam CT (CBCT) Scan (Fig. 8, 9).

Figure 8 A screenshot of the CBCT scan with the nerve canal highlighted

A CBCT scan is taken to visualize the underlying bone structure, nerve canals (like the inferior alveolar nerve), and sinus anatomy. This 3D radiographic data is crucial for assessing bone quality, quantity, and safe implant placement zones.

<u>Phase 2: Virtual Planning (Steps 3, 4, & 5)</u>

Step 3: Virtual Data Fusion - Merging STL and DICOM Files

Description: The digital model from the intraoral scan (STL file) is precisely superimposed onto the CBCT scan data (DICOM file) using specialized software. This fusion creates a single, accurate 3D model showing both the soft tissue/gingival contour and the underlying bone.

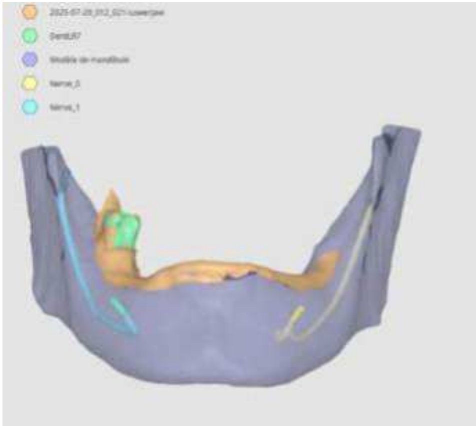

Figure 9 A screenshot of the software showing the scanned jaw after matching

Step 4: Virtual Prosthetic Setup - Ideal Tooth Position

Description: The final desired prosthetic outcome (the full arch bridge of teeth) is digitally designed in the correct aesthetic and functional position. This "virtual wax-up" serves as the blueprint that will dictate the ideal position and angle of the implants.

Step 5: Virtual Implant Placement - Determining Fixture Position

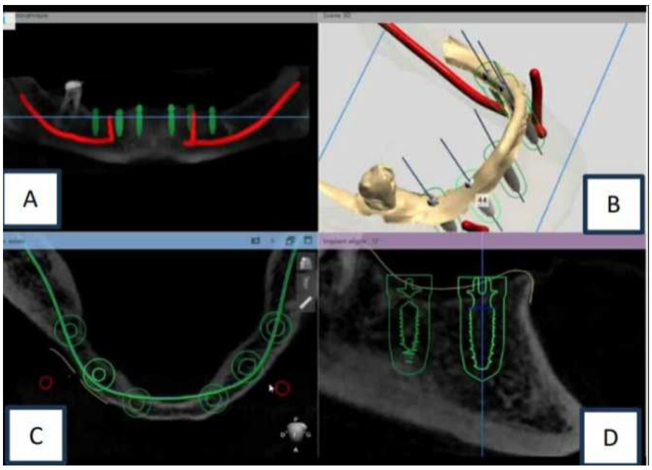

Figure 10 A screenshot of the implants placed in the bone.

Phase 3: Guide Design

Step 6: Surgical Guide Design - Creating the Guide Body
Description: The software is used to design the physical surgical guide. The guide's design incorporates the precise locations of the planned implants, creating sleeves that will guide the surgical drills during the actual procedure (Fig. 11).

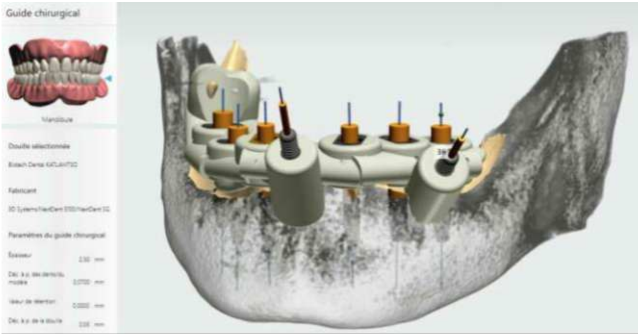

Figure 11 A screenshot of the Surgical Guide Design.

Surgical Protocol

1. Anesthesia: Began with a vestibular periapical infiltration anesthesia, supplemented by a palatal injection.
2. Fixing the surgical guide with fixation pins (Fig. 12, 13).

Figure 12 Double seated guide (dental and mucosal)

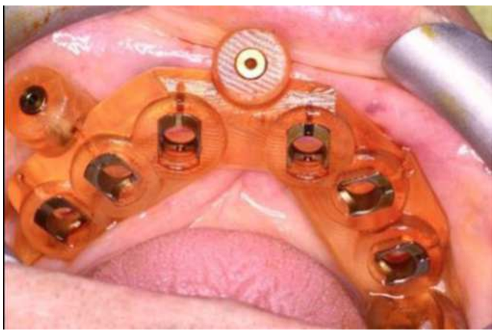

Figure 13 Surgical guide try in

3. Marking implant sites using pilot drill (Fig. 14).

Figure 14 Implants marking using pilot drill

4. Incisions: The incision design included:
- A supracrestal incision displaced 1mm to the lingual side to increase keratinized tissue.
- Two relieving incisions for better flap reflection.

5. Flap Reflection: A lingual flap was mobilized, while the vestibular flap was reflected, with two lateral sutures for better retraction (Fig. 15).

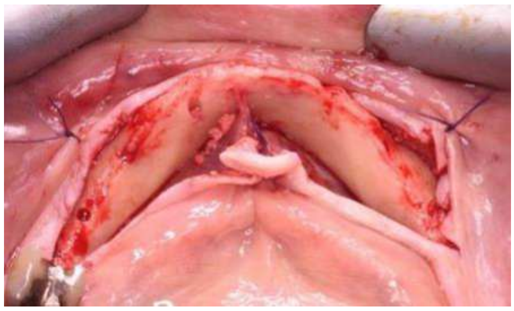

Figure 15 Flap reflection lingually and buccally

6. Complete Drilling through the guide sleeves using the guide. The drilling sequence was performed using drills of increasing diameters up to the final drill (Fig. 16).

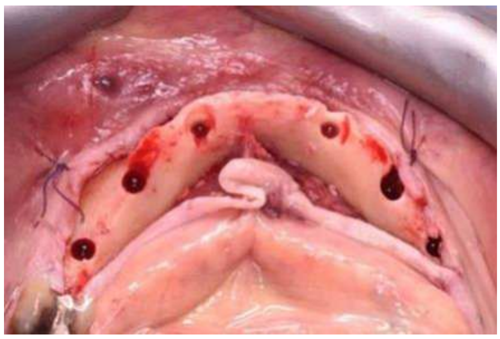

Figure 16 Fully guided drilling following the sequence of the surgical planning

Figure 17 Implant placement

Figure 18 Photo showing the torque attended 50N/cm2 allowing immediate loading

7. Multi-unit abutment placement

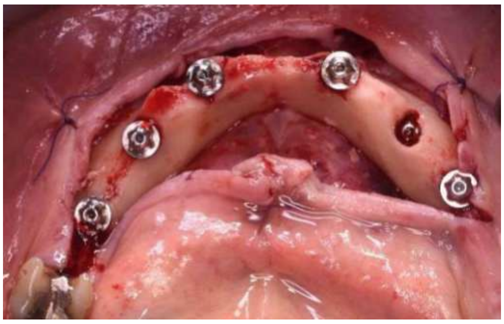

Figure 19 Multi-Unit placement

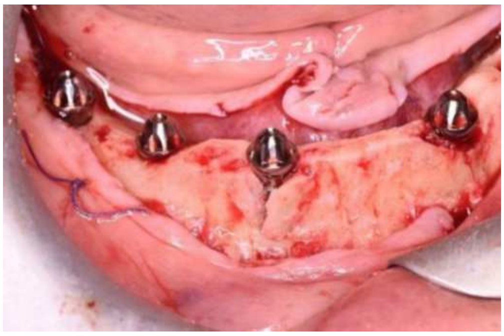

Figure 20 Cortical bone fractures during implant placement

8.Guided Bone Regeneration (GBR): Two substitutes types were applied to the vestibular cortex of the fractured sites, (50% autograft, 50% xenograft) followed by the placement of a resorbable collagen membrane to cover each site. This membrane ensures several biological functions:

- Histological compatibility of surfaces.
- Cellular exclusion.
- Early stabilization of the blood clot.
- Effective clot adhesion.
- Maintenance of the healing space.
- Cellular induction.

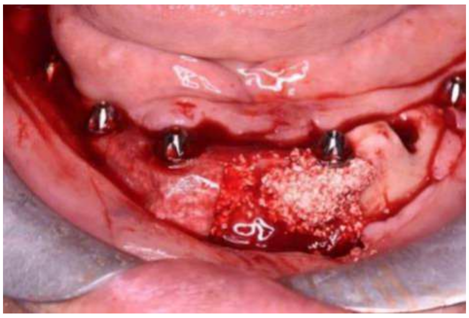

Figure 21 Bone graft placement above the fractured cortical bone

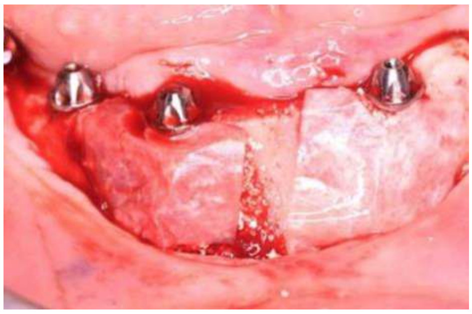

Figure 22 Collagenic membrane adaptation above grafted bone

9. Sutures: Periosteal releasing incisions were made to mobilize the flap and ensure tension-free closure. Suturing was performed with isolated interrupted "O" stitches.

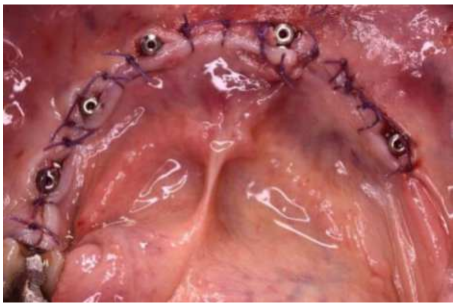

Figure 23 Sutures

10.Placement of Scan Bodies + Intraoral Photogrammetry.

Figure 24 Shining 3D horizontal scan bodies fixed on the Multi-units

11.Multi-unit abutment covering

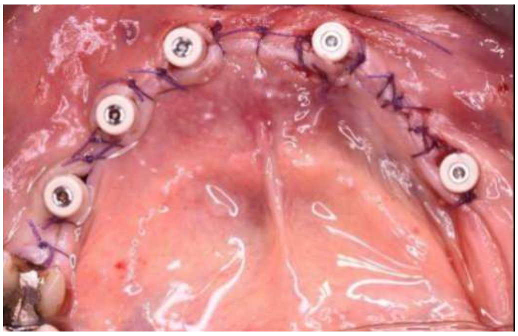

Figure 25 Multi-unit abutment healing cap placement

Figure 26 Vestibular view of the printed provisional

Figure 27 Occlusal view of the screw-retained temporary prosthesis

12. 3D printed screw-retained provisionals placement and occlusion equilibration

Figure 28 Temporary prosthesis try in

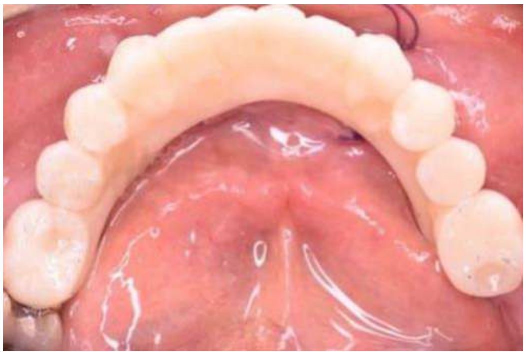

Figure 29 Occlusal view after occlusion Equilibration

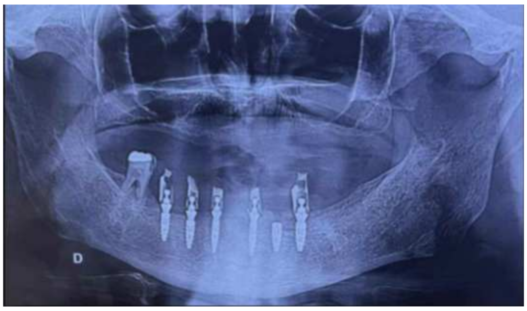

Figure 30 Post-op panoramic radiograph

DISCUSSION

1. Challenges of the Prosthetic Phase with Conventional Impressions

Conventional impression techniques have long been the standard for full-arch implant rehabilitations, yet they remain highly vulnerable to cumulative material and procedural inaccuracies. Distortion during impression removal, micromovements of copings, and gypsum expansion during cast fabrication all contribute to error stacking, which can exceed the 100–150 µm tolerance required for passive fit (1, 2, 3, 4). These inaccuracies are amplified across multiple implants distributed along a long arch, where small angular deviations translate into clinically significant discrepancies in the final framework.

Beyond accuracy issues, conventional impressions introduce notable clinical challenges.

Patient discomfort is common due to tray insertion, rigid materials, and long chair times, particularly among medically compromised or elderly individuals (5). Procedural complexity—radiographic verification of coping stability, handling divergent implants, and operator-dependent steps—increases the likelihood of errors and retakes (6, 4). These limitations collectively compromise prosthetic precision, workflow efficiency, and patient satisfaction, underscoring the need for more predictable digital alternatives.

2. The Shift to Digital: Contributions of Optical Impression Technologies

Digital dentistry has transformed prosthodontic workflows over the past two decades, offering more consistent and predictable outcomes than traditional analog methods (7, 4, 8).

Intraoral scanners (IOS) eliminate many variables inherent to impression materials and provide real-time visualization, immediate data validation, and seamless CAD/CAM integration (9, 10). Advances in optical sensor technology, computational processing, and surface registration algorithms have greatly expanded IOS applications from single-unit restorations to multi-unit prostheses (11, 12).

However, full-arch implant cases remain challenging for IOS due to stitching inaccuracies that accumulate over long scanning spans (13). The limited surface complexity of edentulous arches, patient movement, and software limitations all contribute to deviations that may exceed acceptable thresholds for passive fit (14, 15, 11, 16, 17). While IOS has revolutionized many restorative workflows, its inherent limitations in complex full-arch rehabilitation have motivated the search for more accurate imaging modalities, particularly intraoral photogrammetry (18, 19).

3. Definition and Principles of Intraoral Photogrammetry

Intraoral photogrammetry is a high-precision imaging technique that uses calibrated cameras, triangulation algorithms, and coded implant markers to capture three-dimensional implant positions with exceptional accuracy (18, 20, 8). Unlike IOS, which relies on sequential surface stitching, photogrammetry captures all markers simultaneously—eliminating cumulative alignment errors and reducing sensitivity to patient movement or soft-tissue variations (21, 22).

Modern photogrammetry systems such as PIC Dental, iCam4D, and Shining 3D operate with sub-micron accuracy, making them particularly suited for multi-implant, full-arch rehabilitations (23). By isolating implant-position capture from soft-tissue scanning, photogrammetry produces a precise coordinate file that can be directly integrated into CAD software (9, 24). The precision of the technology relies heavily on the design and manufacturing tolerances of coded markers, which must maintain dimensional stability under intraoral conditions (23, 25). Overall, intraoral photogrammetry represents a major conceptual shift from surface-based scanning to marker-based spatial mapping, offering significantly enhanced reliability for complex implant workflows.

4. Relevance of Photogrammetry in Full-Arch Implant Cases

Full-arch implant rehabilitations require exceptionally high accuracy, as minor deviations can compromise passive fit, induce mechanical stress, and affect long-term biological outcomes (13, 26, 27). Photogrammetry addresses the primary limitations of both conventional impressions and IOS by eliminating cumulative distortion and stitching errors. Studies demonstrate that photogrammetry achieves significantly lower linear and angular deviations than optical or analog techniques (28, 20, 13).

The absence of full-arch scanning and impression materials reduces operator fatigue, chair time, and the number of clinical appointments (21, 9). The workflow facilitates rapid production of provisional prostheses and improves efficiency for both clinicians and laboratories (8). From a patient perspective, reduced procedural complexity and shorter appointments enhance comfort and acceptance.

In addition to accuracy and efficiency, photogrammetry positively influences biomechanical outcomes. A more predictable passive fit reduces tension at the implant–abutment interface, lowering the risks of screw loosening, component fracture, and peri-implant complications. These advantages explain its increasing adoption in high-precision full-arch workflows, particularly in university and advanced prosthodontic centers (23).

5. Advantages and Limitations of Photogrammetry in the Literature

The literature highlights several strong advantages of intraoral photogrammetry: superior spatial accuracy, reproducibility, fast acquisition times, and increased patient comfort (23, 27). The method is operator-light, eliminates error-prone manual steps, and integrates effectively with digital design and manufacturing workflows. Collectively, these benefits make photogrammetry one of the most predictable modalities for full-arch implant impressions. However, important limitations persist. The systems require substantial financial investment, making them less accessible for low-volume or general practices (28, 9, 29). The learning curve can be steep, as clinicians must master marker placement, image acquisition protocols, and calibration procedures (22).

Workflow integration also remains occasionally challenging: photogrammetry captures implant positions, but a separate intraoral scan is often needed for soft-tissue and occlusal data, necessitating meticulous alignment steps (8). Finally, while accuracy studies are abundant, long-term clinical outcome studies and randomized trials remain relatively limited compared with conventional techniques and IOS. Despite these limitations, the accumulated evidence supports intraoral photogrammetry as a highly accurate and valuable technology for full-arch implant rehabilitation when precision and workflow efficiency are paramount. Toutefois, le praticien doit toujours envisager le traitement dans le cadre d'une approche globale : selon l'étiologie et l'ampleur du diastème, une prise en charge pluridisciplinaire (orthodontie, parodontologie, dentisterie esthétique) peut être nécessaire pour garantir un résultat durable et fonctionnel. Ainsi, les facettes céramiques demeurent une solution de choix pour la fermeture des diastèmes modérés, alliant exigence esthétique, durabilité clinique et préservation biomimétique.

CONCLUSION

Intraoral photogrammetry has evolved from a novel technology to a key tool for full-arch implant rehabilitation. Unlike conventional impressions or intraoral scanners, it captures precise implant positions with high trueness, eliminates stitching errors, speeds data acquisition, and improves patient comfort.

Limitations include high costs, calibration challenges, software integration issues, and limited long-term clinical evidence. Its full potential lies in integration with digital workflows, hybrid scanning devices, and AI-driven CAD/CAM, which could enable predictive, automated prosthetic design.

Overall, photogrammetry reduces cumulative errors in implant therapy and, as technology advances, is poised to become a standard tool for efficient, accurate, and patient-centered prosthodontics.

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