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Research Article

Accuracy of Photogrammetry Versus Intraoral Scanning in Complete-Arch Implant-Supported Rehabilitations: A Structured Narrative Review

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Abstract

Background: Accurate implant position transfer is essential to achieve passive fit in complete-arch implant-supported rehabilitations. While intraoral scanners (IOS) are widely used, their accuracy in full-arch scenarios remains controversial. Photogrammetry has emerged as a potential alternative; however, comparative evidence is limited.

Methods: A structured narrative review was conducted following PRISMA principles. Electronic searches were performed in PubMed, Scopus, and Cochrane Library using predefined keywords. Studies published in the last 5 years evaluating accuracy (trueness and/or precision) of photogrammetry and/or IOS in full-arch implant configurations were included. After screening 26 records, 2 studies met the inclusion criteria and were qualitatively analyzed.

Results: Both included studies consistently showed higher accuracy of photogrammetry compared with intraoral scanners. IOS demonstrated deviations of approximately 20–40 mm, with accuracy decreasing as scan span increased due to cumulative stitching errors. In contrast, photogrammetry systems provided more stable measurements with lower deviations. Laboratory scanners, when used as reference, showed the highest accuracy overall.

Conclusions: Photogrammetry appears to provide greater accuracy than intraoral scanning in complete-arch implant-supported rehabilitations. The reliability of IOS in full-arch implant cases remains limited, particularly in the absence of anatomical reference points. Further clinical studies are required to confirm these findings and support their clinical translation.

Keywords: Photogrammetry; Intraoral Scanners (IOS)

Introduction

Implant-supported complete-arch prostheses represent a predictable and widely adopted treatment modality for the rehabilitation of edentulous patients, providing improved retention, stability, and long-term clinical outcomes [1,2,13]. A critical factor for the success of these restorations is the achievement of a passive fit, as even minimal misfit may lead to biological and mechanical complications, including screw loosening, framework fracture, and peri-implant bone loss.

To ensure passive fit, an accurate three-dimensional (3D) transfer of implant positions from the clinical setting to the working cast or digital model is mandatory. Traditionally, the splinted open-tray impression technique has been considered the gold standard for full-arch implant impressions due to its documented accuracy [6,7,10]. However, this approach is technique-sensitive, time-consuming, and often associated with patient discomfort. With the rapid evolution of digital dentistry, intraoral scanners (IOS) have gained widespread popularity, offering advantages such as improved

patient comfort, reduced clinical time, and streamlined workflows [6,8]. While IOS have demonstrated satisfactory accuracy in short-span and partially edentulous cases, their reliability in complete-arch implant rehabilitations remains controversial [12,13].

The absence of stable anatomical reference points in edentulous arches and the accumulation of stitching errors over long spans have been reported to negatively affect accuracy [6,14].

In this context, photogrammetry has emerged as a promising alternative digital technique. By capturing multiple images from different angles and using reference markers, photogrammetry systems allow the precise reconstruction of implant positions in three-dimensional space without direct contact [15].

Recent technological advancements have improved the reliability and efficiency of these systems, suggesting their potential as a viable alternative to both conventional and intraoral scanning techniques. Nevertheless, current evidence remains limited, particularly regarding their accuracy in full-arch implant-supported restorations and their comparison with established digital workflows [7,8].

Accuracy in digital impression systems is commonly described in terms of trueness and precision, as defined by international standards [6,15,16].

Trueness refers to the closeness of a measurement to the actual reference value, whereas precision describes the repeatability of measurements under consistent conditions [6-8,14].

Both parameters are essential for evaluating the performance of digital acquisition methods in implant prosthodontics.

Therefore, the aim of this study/review is to critically evaluate and compare the accuracy—expressed in terms of trueness and precision—of photogrammetry and intraoral scanning in complete-arch implant-supported rehabilitations, with particular focus on their clinical applicability and limitations [4,16].

Aim and Hypotheses

Primary aim

The primary aim of this narrative review is to critically evaluate and compare the accuracy of photogrammetry and intraoral scanning systems in complete-arch implant-supported rehabilitations, focusing on their ability to reliably capture the three-dimensional spatial position of multiple implants [6-8].

Secondary aims

The secondary aims of this review are to:

- Assess and compare trueness and precision values reported for photogrammetry and intraoral scanners in full-arch implant scenarios;
- Identify the main technical and clinical factors influencing accuracy (e.g., span length, number of implants, presence of reference landmarks, stitching errors);
- Evaluate the clinical implications of accuracy discrepancies in relation to passive fit and prosthetic complications;
- Analyze the current limitations of the available literature and highlight areas requiring further investigation.

Focused research question (PICO Framework)

- **Population (P):** Edentulous patients or *in vitro* complete-arch implant models
- **Intervention (I):** Photogrammetry-based digital acquisition systems
- **Comparison (C):** Intraoral scanners (IOS) and/or conventional impression techniques
- **Outcome (O):** Accuracy, expressed as trueness and precision of implant position transfer Research question

In complete-arch implant-supported rehabilitations, do photogrammetry systems provide higher accuracy (trueness and precision) compared with intraoral scanning techniques?

Hypotheses

Based on the current literature, the following hypotheses are proposed.

Primary hypothesis

Photogrammetry systems exhibit significantly higher trueness and precision than intraoral scanners in complete-arch implant-supported rehabilitations.

Secondary hypotheses

- The accuracy of intraoral scanners decreases as the inter-implant distance and scan span increase, due to cumulative stitching errors.

- Photogrammetry systems are less influenced by the absence of anatomical reference structures, resulting in more consistent measurements.
- Improved accuracy achieved with photogrammetry may contribute to a better passive fit and potentially reduce mechanical and biological complications.

To the best of the authors' knowledge, no previous review has specifically focused on the comparison between photogrammetry and intraoral scanning in full-arch implant-supported rehabilitations.

Materials and Methods

Study design

This study was conducted as a narrative review with a structured search strategy, following the main principles of the PRISMA statement to ensure transparency, reproducibility, and methodological rigor.

Search strategy

A comprehensive literature search was performed across:

- PubMed
- Scopus
- Cochrane Library Using the following: "full-arch implantology AND (photogrammetry OR intraoral digital impression) AND (accuracy OR precision)".

Filters applied:

- Publication within the last 5 years
- Human studies (when available)

Eligibility criteria

Inclusion criteria

- Studies evaluating accuracy (trueness and/or precision)
- Full-arch implant-supported rehabilitations (clinical or *in vitro*)
- Studies involving photogrammetry and/or intraoral scanners (IOS)
- Articles published within the last 5 years

Exclusion criteria

- Case reports
- Animal studies
- Studies not evaluating accuracy/precision
- Articles not accessible in full text
- Studies not relevant to full-arch implant workflows

Study selection (PRISMA Flow Description) Identification

- PubMed: 20 records
- Scopus: 6 records
- Cochrane Library: 0
- Total: 26 records

Screening

• After filters (humans + last 5 years): 18 records.

Eligibility

- 4 studies focused on photogrammetry
- 1 excluded (full text not available)
- 1 excluded (did not assess accuracy/precision).

Included

- Final included studies: 2 PRISMA Flow Diagram.

Data extraction and synthesis data extraction focused on:

- Trueness and precision values (RMS, mm)
- Type of acquisition system (photogrammetry vs IOS)
- Number and distribution of implants
- Measurement methodology
- Reported deviations and error patterns.

Given the limited number of included studies (n=2) and the heterogeneity in study design and outcome reporting, a quantitative meta-analysis was not feasible. Therefore, a qualitative synthesis was conducted.

Risk of bias assessment

A qualitative risk of bias assessment was performed considering.

Study design

Both included studies were primarily *in vitro*, limiting direct clinical extrapolation.

Measurement methods

- Use of RMS values and deviation maps
- Variability in reference standards (industrial scanners vs lab scanners)

Sample characteristics

- Limited number of implant configurations
- Lack of variability in clinical conditions (e.g., saliva, movement)

Operator and system bias

- Potential operator-dependent errors not always controlled
- Differences in software algorithms between systems

Overall assessment

The included studies present a moderate risk of bias, mainly due to:

- *In vitro* design
- Small sample sizes
- Methodological heterogeneity

However, both studies show consistent findings favoring photogrammetry, strengthening the reliability of the observed trend.

Results

Study characteristics

A total of 2 studies met the inclusion criteria and were included in the qualitative synthesis. Both investigations were conducted *in vitro* and evaluated the accuracy of digital acquisition methods in complete-arch implant-supported rehabilitations, comparing photogrammetry systems with intraoral scanners (IOS) and, in one study, also with laboratory scanners [2,4,13,16].

Accuracy outcomes (Trueness and Precision)

Study A: Comparative evaluation of digital acquisition systems

The first study evaluated multiple digital acquisition systems, including photogrammetry (PIC system), intraoral scanners (TRIOS 3, iTero), and laboratory scanners (D2000, S900), using an industrial scanner (GOM) as reference.

Trueness (4 implants)

- Photogrammetry (PIC): ~5.18 mm
- Laboratory scanners: ~2–4 mm
- IOS (TRIOS 3, iTero): ~20 mm

Precision (6 implants, RMS):

- Photogrammetry: ~13.88 mm
- Laboratory scanners: ~2–3 mm
- IOS:
- TRIOS 3: ~40.32 mm
- iTero: ~38.86 mm

These results demonstrate that:

- Photogrammetry provides substantially higher accuracy than IOS
- However, it remains less precise than high-end laboratory scanners
- IOS show significant deviation, especially in full-arch configurations Study B: Photogrammetry vs Intraoral Scanning

The second study directly compared photogrammetry and intraoral scanning systems in full-arch implant configurations, focusing on linear and angular deviations.

- Photogrammetry demonstrated:
- Lower linear deviations across all implant positions
- Reduced angular discrepancies
- High consistency regardless of inter-implant distance
- Intraoral scanners showed:
- Progressive increase in deviation with longer scan spans
- Greater susceptibility to stitching errors

- Reduced accuracy in absence of anatomical landmarks

Notably, deviation patterns in IOS were cumulative, with the highest errors observed in distal implant positions.

Comparative analysis

Across both studies, a consistent trend emerged:

- Photogrammetry systems outperformed intraoral scanners in terms of both trueness and precision in complete-arch implant scenarios
- IOS accuracy was significantly affected by scan span and implant distribution
- Photogrammetry appeared to be less dependent on operator technique and anatomical reference points

Additionally:

- Laboratory scanners (when included) showed the highest overall accuracy, confirming their role as reference standard
- Photogrammetry demonstrated clinically acceptable accuracy, bridging the gap between IOS and laboratory systems

Error Distribution and Clinical Implications Both studies highlighted that:

- IOS errors tend to be cumulative and non-uniform, increasing with scan length
- Photogrammetry produces more homogeneous and stable measurements

From a clinical perspective:

- The magnitude of error observed with IOS (up to ~40 mm) may compromise passive fit in full-arch implant prostheses
- Photogrammetry, with lower deviation values, may offer a more reliable transfer of implant position, potentially reducing mechanical complications

Discussion

The present narrative review aimed to evaluate and compare the accuracy of photogrammetry and intraoral scanning systems in complete-arch implant-supported rehabilitations. The findings of the included studies consistently demonstrated a superior accuracy of photogrammetry compared with intraoral scanners (IOS), particularly in full-arch implant configurations [4,14,17].

Interpretation of findings

A key finding emerging from this review is that photogrammetry provides higher trueness and precision than IOS, with reported deviations significantly lower than those observed for intraoral scanners [12,13].

While IOS showed deviations in the range of approximately 20–40 mm, photogrammetry systems demonstrated notably reduced discrepancies, suggesting a more reliable transfer of implant positions.

This difference can be primarily attributed to the distinct acquisition principles of the two technologies. Intraoral scanners rely on image stitching algorithms, which progressively merge multiple images to reconstruct a three-dimensional model. In full-arch scenarios, this process is particularly susceptible to cumulative stitching errors, especially in the absence of stable anatomical landmarks, as occurs in edentulous patients [12].

Conversely, photogrammetry systems capture implant positions through simultaneous multi-angle image acquisition using reference markers, thereby minimizing cumulative error propagation. This results in a more stable and consistent reconstruction of implant spatial relationships.

Clinical implications

From a clinical perspective, the accuracy of implant impressions is directly related to the achievement of a passive fit, which is essential for the long-term success of implant-supported prostheses. Even small discrepancies may lead to mechanical complications such as screw loosening or framework fracture, as well as biological consequences including peri-implant bone loss. The magnitude of error observed with intraoral scanners in full-arch configurations raises concerns regarding their reliability in complex implant rehabilitations. In contrast, photogrammetry appears to offer a clinically advantageous alternative, particularly in cases involving multiple implants and long-span restorations.

However, it is important to note that laboratory scanners still demonstrated the highest level of accuracy, confirming their role as a reference standard. Photogrammetry may therefore be

considered as an intermediate solution that combines clinical efficiency with improved accuracy compared to IOS.

Comparison with existing literature

The findings of this review are consistent with previous studies reporting limitations of intraoral scanners in edentulous full-arch cases, mainly due to the lack of geometric references and the accumulation of digital errors. Several investigations have highlighted that IOS accuracy decreases as the scanning span increases, supporting the observations reported in the included studies.

At the same time, the growing body of evidence on photogrammetry suggests that this technology may overcome many of these limitations [18,19].

Nevertheless, the current literature remains limited, and high-quality comparative studies are still scarce. The limited number of included studies reflects the current scarcity of high-quality evidence on photogrammetry in complete-arch implant rehabilitations rather than a limitation of the search strategy. This highlights an important gap in the literature and reinforces the need for further research in this field.

Although designed as a narrative review, a structured and reproducible search strategy based on PRISMA principles was adopted to enhance transparency and minimize selection bias.

The predominance of *in vitro* studies limits direct clinical extrapolation; however, such designs allow a controlled evaluation of accuracy, reducing confounding variables that are difficult to standardize in clinical settings [4,6,14,17].

Limitations

This review presents several limitations that should be acknowledged:

- The limited number of included studies (n=2) restricts the generalizability of the findings
- Both studies were conducted *in vitro*, which may not fully replicate clinical conditions
- There was heterogeneity in measurement methods (RMS values, linear and angular deviations)
- Differences in reference standards and experimental setups may have influenced the results These factors highlight the need for caution when extrapolating the findings to clinical practice.

Future perspectives

Future research should focus on:

- Well-designed clinical trials comparing photogrammetry and IOS
- Standardized protocols for measuring trueness and precision
- Evaluation of long-term clinical outcomes associated with different digital workflows
- Assessment of cost-effectiveness and workflow efficiency

Such investigations are essential to validate the clinical superiority of photogrammetry and to define its role in routine implant prosthodontics.

Conclusion

Within the limitations of the available evidence, photogrammetry appears to provide greater accuracy than intraoral scanning systems in complete-arch implant-supported rehabilitations. While intraoral scanners offer advantages in terms of usability and patient comfort, their reliability in full-arch implant scenarios remains limited, particularly in the absence of stable anatomical reference points.

Clinicians should exercise caution when relying solely on intraoral scanners for full-arch implant impressions and consider alternative workflows when high accuracy is required.

Further well-designed clinical studies are needed to validate these findings and support their routine clinical implementation.

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