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ORIGINAL ARTICLE

Accuracy of Photogrammetry, intraoral scanning and conventional impressions for full-arch implant restorations: An in-vitro comparison

Minaal Verma[a], Prashanth Konatham Haribabu[b]

ABSTRACT

Objective: To evaluate and compare the accuracy of two photogrammetry systems (Micron Mapper and Tupel 3D), intraoral scanning (IOS), and conventional polyvinyl siloxane impressions for full-arch implant restorations in an in-vitro setting.

Materials and Methods: A maxillary resin model with four multi-unit abutments was used. Forty samples were divided into four groups (n=10 each): (1) conventional impressions, (2) Intraoral scanning with 3Shape Trios, (3) Micron Mapper (S.I.N Dental), and (4) Tupel 3D (UK). All .stl files were aligned to a master reference scan using Exocad with three-point best-fit alignment. Linear deviations were measured in microns (µm) to assess trueness and precision. One-way ANOVA with post-hoc Tukey testing determined group differences (α=0.05).

Results: Significant differences in accuracy were observed among the groups (p<0.05). Micron Mapper achieved the lowest mean deviation (19.96 µm), followed by Tupel 3D (24.83 µm), conventional impressions (37.96 µm), and IOS (45.59 µm). Both photogrammetric systems showed tighter clustering and superior trueness compared with IOS and conventional impressions. Photogrammetry was also the most time-efficient (<2 min acquisition), compared to IOS (~4 min) and conventional impressions (~15 min).

Conclusion: Within the limitations of this in-vitro study, photogrammetry demonstrated superior accuracy and efficiency for full-arch implant restorations compared with intraoral scanning and conventional impressions, though all methods remained within the clinically acceptable threshold of <100 µm. Further clinical studies are required to validate these findings in vivo.

Key words: Photogrammetry; Intraoral scanner; Full-arch restoration; Implant prosthesis; Accuracy; Digital dentistry

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INTRODUCTION

Full-arch fixed implant prostheses have become a widely accepted treatment option for edentulous patients, offering functional and aesthetic benefits[1]. Fabricating a complete arch implant-supported prosthesis involves various clinical and laboratory steps. Tan emphasised that each stage in the procedure can cause geometry distortions, resulting in a poor fit between implants and restorative components[2]. Improper fit between implants and frameworks can cause mechanical difficulties and component failures, such as screw loosening, stripped threads, and fractures[3]. A critical factor in their long-term success is achieving a precise and passive fit between the prosthesis and implants. Any discrepancy can lead to a misfit of the prosthesis.

[a] Assistant Professor, Department of Prosthodontics and Endodontics, School of Dental Medicine, Southern Illinois university Edwardsville, Illinois, USA
[b]Associate Professor & Director, Specialty Care Unit of Oral & Maxillofacial Surgery, Missouri School of Dentistry & Oral Health, USA

Literature suggests that a misfit of less than 100 µm is generally considered acceptable for such restorations[4].

To avoid mechanical problems, researchers are exploring ways to eliminate misfit. Efforts to reduce mechanical difficulties in implant prosthetics have centred on lowering framework misfits, with the fabrication process playing a crucial role. Al-Fadda and Drago concluded that CAD/CAM-milled titanium frames routinely outperform traditionally cast ones in terms of fit. However, Ortorp and Jemt et al pointed out that the precision of the definitive cast, rather than the fabrication process, remained a significant limiting factor[6].

Splinted impression techniques utilizing pre-polymerized acrylic resin, have been advocated to improve cast precision, particularly in full-arch cases[7]. While these procedures improve accuracy, they are still subject to process errors, are time-consuming, expensive, and can cause patient discomfort. Physical casts additionally pose a risk of damage or loss.

Digital alternatives, such as intraoral scanning with scan bodies, have gained momentum due to their efficiency and patient comfort. They are increasingly used for single units and partial-arch prostheses with favourable results[9]. However, their reliability in full-arch implant cases remains uncertain, primarily due to the potential for errors caused by the image-stitching process during scanning over longer spans[10].

Photogrammetry, a novel approach in implant dentistry, offers an innovative way to record implant positions by capturing multiple angled photographs of scan markers. These images are processed to generate a precise digital 3D model. This method eliminates several error-prone steps present in traditional workflows and has demonstrated promising accuracy in limited studies[11]. However, evidence is still emerging, especially concerning newer photogrammetry systems like Micron Mapper (S.I.N Dental) and Tupel 3D (UK), which have yet to be extensively evaluated in the literature. Both devices employ specialized cameras and proprietary algorithms to generate implant coordinate data, but neither has been extensively validated in peer-reviewed studies. These two photogrammetric systems are becoming increasingly popular due to their high level of clinical accuracy. Micron Mapper (S.I.N Dental) and Tupel 3D (UK) utilize specific scan bodies with geometries. The Micron Mapper scan bodies are white and angled with geometries that need to face towards the camera. Tupel 3D scan bodies are cylindrical and do not have to be positioned in a particular way in the patient's mouth. The external camera captures multiple images of these scan bodies within seconds. Both these systems have unique individual softwares that are loaded onto laptops where the processing of these images captured by the camera takes place and an .stl file is generated.

This in-vitro study aims to compare the accuracy of the conventional impression technique with intraoral scanning and photogrammetry for full-arch implant restoration fabrication. Accuracy is described in terms of trueness & precision. Trueness is used to describe the difference between the test file and reference file, and precision is used to describe the closeness between the two files. The null hypothesis posits that there is no significant difference in the accuracy between the four techniques evaluated.

METHODS

A maxillary resin model with four implant abutment replicas (Nobel RP) was used. Multi-unit abutments were already placed over these implant replicas, making it a multi-unit level model (Fig. 1).

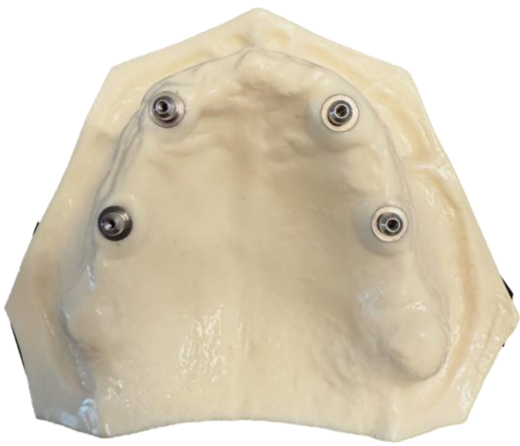

Figure 1: Multi-unit level master model

There were four groups with a sample size of 10 per group. A power calculation (α = 0.05, power = 0.8, effect size d = 0.8) confirmed that 10 samples per group were sufficient. Scan order was randomised across groups. All procedures were conducted by a single experienced operator under controlled ambient lighting. A single operator reduces variability but there are chances for operator-induces differences in real-time practice.

Group 1: Conventional Impressions: Four open-tray impression copings (Nobel Biocare multiunit impression copings) were placed on the multi-unit abutments and hand tightened. They were splinted using DuraLay resin (Reliance Dental Manufacturing Company) and dental floss (Fig. 2). The DuraLay resin (Reliance Dental Manufacturing Company) was splinted and rejoined to have passivity.

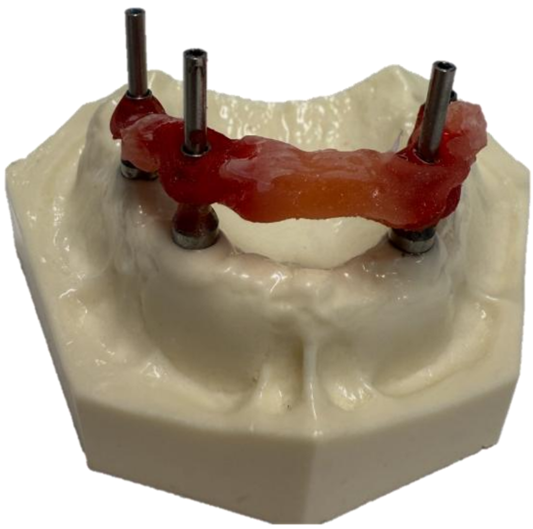

Figure 2: Splinted impression copings with DuraLay Resin (Reliance Dental Mfg Company) and dental floss

Polyvinyl siloxane Light body (Henry Schein Inc., USA) was injected around the implants and Polyvinyl siloxane heavy body (Henry Schein Inc. USA) in the custom tray. The tray was seated over the impression copings. After 10 minutes, the pins from the open tray impression copings were unscrewed using a hex driver. Then the impression was retrieved from the model after allowing for one hour for the type IV dental stone to set. (Fig. 3).

Multi-unit level implant analogs were placed in the impression and hand tightened (Fig. 4). Type 4 dental stone was poured in the impression to fabricate ten stone casts.

Figure 3: Polyvinyl siloxane (Henry Schein Inc. ,USA)

Figure 4: Multi-unit implant analogs placed in the Polyvinyl siloxane impression and hand tightened.

These stone casts were digitized using a reference lab scanner (Straumann Medit Lab scanner) and converted to .stl files.

Group 2: Multi-unit level Nobel Biocare scan bodies were placed over the implants on the master model (Fig. 5) for the intraoral scanning (IOS) group and hand-tightened. Ten intra-oral scans using a 3Shape Trios intraoral scanner were taken and exported into .stl files. The intra-oral scanner was calibrated before each scan. The scan was started on the left posterior scan body, and a continuous scan was taken till the right distal-most implant.

Group 3: Micron mapper: The Micron Mapper (S.I.N Dental) scan bodies were placed on the master model with the scannable surface facing towards the photogrammetric camera (Fig. 6). The camera was turned on and calibrated based on the manufacturer's recommendations. Then the camera was pointed at the scan bodies till the location of all four implants was recorded by the micron mapper software. There were 10 .stl files fabricated with this system without changing the scan body position.

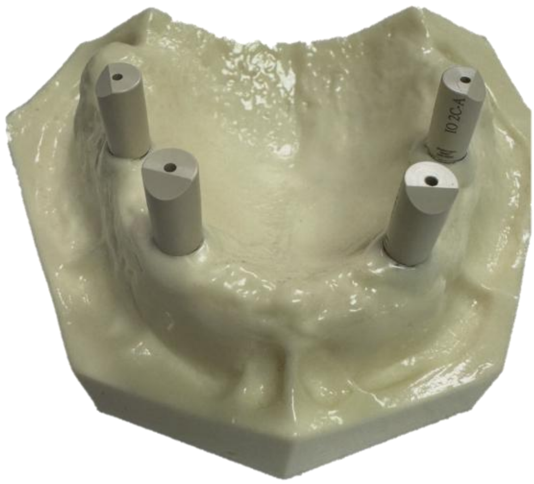

Figure 5: Nobel Biocare Scan bodies placed over the master model.

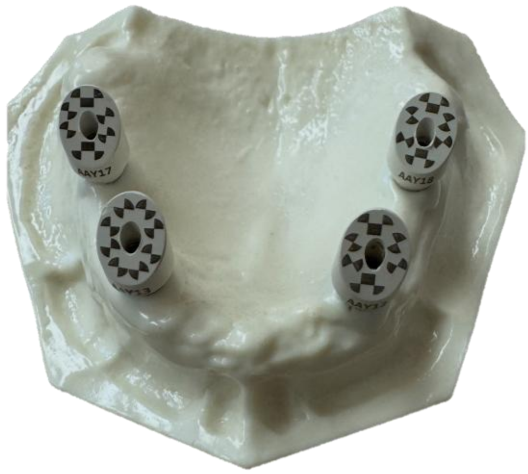

Figure 6: Micron Mapper (S.I.N Dental) scan bodies seated on master model, all facing forward towards the

Group 4: Tupel 3D: The scan bodies were placed on the master model (Fig. 7). The camera was turned on and calibrated as per the manufacturer's recommendations. Then the camera was pointed at the scan bodies till the location of all four implants was recorded by the Tupel 3D software. There were ten .stl files fabricated with this system.

Master model: The master model was digitized using a benchtop lab scanner (Straumann Medit T310) and converted to a .stl file. This was our control.

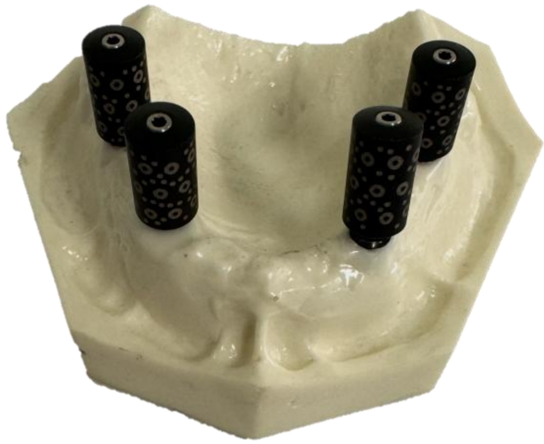

Figure 7: Tupel 3D scan bodies placed on the master

All the intraoral and photogrammetric scans, impressions were performed by one operator with 10 years of clinical experience.

All the .stl files (Fig. 8) were imported into the Exocad software. The scan bodies were converted to implant replicas in the software for each scan. Every scan utilized a three-point best-fit alignment. Deviations from the master reference were calculated as linear discrepancies. Angular deviation data were excluded as it was beyond the scope of the study. Descriptive statistics (mean, SD, IQR) were reported in microns (µm). One-way ANOVA with post-hoc Tukey's HSD tests and effect sizes (η^2) evaluated group differences.

Figure 8: .stl files generated a. Intraoral scanning system (IOS), b. Micron Mapper (S.I.N dental and c. Tupel 3D (UK) systems

RESULTS

All the .stl files from each group were exported into Exocad software. The scan bodies were converted to implant replicas in the software for each scan. For each scan, the .stl file was overlapped over the master .stl file and linear and angular measurements between the implants were measured at all four sites. An average of the four measurements was taken as the measurement for that scan. The same procedure was repeated for all 40 .stl files.

Table 1: Statistical analysis of trueness and precision of Micron Mapper, Tupel 3D, Intraoral scanning system (IOS) and conventional Polyvinyl siloxane impressions

	Mean (µm)	Median (µm)	IQR (µm)	SD (µm)
Micron Mapper	19.96	20.02	0.19	0.60
Tupel 3D	24.83	25.19	0.42	1.05
IOS	45.59	45.37	0.57	0.74
Conventional impressions	37.96	38.95	0.76	2.81

After all the measurements were recorded, an average measurement for each group was calculated to determine linear discrepancy in microns (Table 2). Micron Mapper achieved the lowest mean deviation (19.96 µm), followed by Tupel 3D (24.83 µm), conventional impressions (37.96 µm), and IOS (45.59 µm).

Table 2: Mean linear and angular deviation between Micron Mapper, Tupel 3D, Intraoral scanning system (IOS) and conventional Polyvinyl siloxane impression.

SYSTEM	Sample size	Linear deviation Mean (µm)
Micron Mapper	10	19.96
Tupel 3D	10	24.83
IOS	10	45.59
Conventional impressions	10	37.95

A one-way ANOVA test was conducted, which showed statistically significant differences among the groups ($p<0.05$). Paired t-test showed performance of Micron Mapper (S.I.N Dental) and Tupel 3D (UK) over intraoral scanning systems (IOS) and conventional impressions. Post-hoc testing confirmed Micron Mapper(S.I.N Dental) and Tupel 3D (UK) significantly outperformed intraoral scanning (IOS) and conventional impressions.

The boxplot (Fig. 9) shows median and IQR values for each group, which determines the trueness of the systems. It showed tight clustering for Micron Mapper(S.I.N Dental) and moderate variability for Tupel 3D, while intraoral scanning (IOS) and conventional impressions exhibited wider distributions. Outliers were noted in conventional impressions. Time efficiency favoured photogrammetry (<2 min), followed by intraoral scanning (IOS) (~4 min), and conventional polyvinyl siloxane impressions (~15 min). Micron mapper(S.I.N Dental) shows a tight distribution indicating high accuracy, followed by Tupel 3D (UK). Conventional impressions and the intraoral scanning (IOS) system show a wider range, suggesting less precision within the system.

DISCUSSION

This study compared the accuracy of two newer photogrammetric systems (Micron Mapper and Tupel 3D), intra-oral scanning and conventional impression for a full arch implant-supported restoration.

In this in-vitro study, Micron mapper (S.I.N Dental) had the highest precision, followed by Tupel 3D (UK). Intraoral scanning (IOS) system and conventional polyvinyl siloxane impressions had lower precision noted. Micron mapper (S.I.N Dental) and Tupel 3D (UK) also showed the least amount of deviation, suggesting the highest level of trueness. Intraoral scanners have cumulative stitching errors across long spans, while conventional impressions are susceptible to material shrinkage, stone expansion, and multiple manual steps, introducing variability in accuracy. The two photogrammetry systems have minor differences in deviation, which could be attributed to the camera of the system, scan body design, calibration or the algorithms.

Currently, research evaluating the accuracy of photogrammetry systems in implant dentistry remains limited and presents conflicting outcomes. Some investigations support the superiority of photogrammetry over conventional and digital impression techniques, while others challenge this claim. For instance, Tohme et al. (2022) reported that photogrammetry demonstrated higher accuracy when compared to both intraoral scanning and conventional impression methods, a finding that aligns with the present study's conclusions. Conversely, Revilla-León et al. (2021a) found that the photogrammetry system under evaluation produced the lowest accuracy among the three techniques, contradicting earlier positive assessments. In a subsequent publication, Revilla-León et al. (2021b) further reinforced these findings by concluding that photogrammetry was less accurate than the conventional impression technique.

The limitations of Intraoral scanning systems, requiring a continuous scan by stitching multiple images together, may introduce distortion in full-arch implant scans, which could lead to a lower level of accuracy for such cases.

Conventional impressions have been the standard for full arch restorations. Their limitation is that several steps are involved in these impressions, and an error/variable can be incorporated at any step. Thus, we still need to verify the cast fabricated with a full arch conventional PVS impression by using a verification jig.

Beyond accuracy, workflow efficiency is an important clinical consideration. Photogrammetry significantly reduced data acquisition time compared to intraoral scanning (IOS) and conventional impressions, offering advantages in chairside efficiency and patient comfort[15]. However, these systems require substantial financial investment and a period of clinician training before integration into routine practice. While intraoral scanning (IOS) technology is more widely available and familiar to clinicians, its limitations in full-arch implant applications remain significant[16].

Photogrammetric systems are gaining popularity in several countries. The cost of acquisition of any of these photogrammetric systems can be significantly high as compared to intraoral scanners or conventional polyvinyl siloxane impressions which can be a limiting factor for several dentists. Intraoral scanners are much widely available in dental offices as well as polyvinyl siloxane impression material, which may make dental professionals favour their usage.

The limitations of this study being an in-vitro study, it does not account for clinical variables such as saliva, patient movement, and soft tissue interference that may affect scan accuracy in vivo. Additionally, all scans were performed by a single experienced operator, which reduces inter-operator variability but introduces potential bias and limits generalizability. The reliance on manual alignment in Exocad software also presents a potential source of error. Software alignment and scan-body geometry may influence outcomes of the different systems.

CONCLUSION

Within the limitations of the study, there are significant differences in the accuracy and precision of the four impression techniques evaluated- Micron Mapper (S.I.N Dental), Tupel 3D (UK), Intraoral scanning (IOS) and conventional polyvinyl siloxane impressions for full arch fixed implant restorations. The photogrammetric systems (Micron mapper and Tupel 3D) demonstrated superior accuracy under in-vivo conditions in this study; however, clinical studies are required before firm recommendations can be made. All four techniques are present under the clinically acceptable range of less than 100 microns discrepancy.

Keywords

Photogrammetry; Intraoral scanner; Implant prosthesis; Accuracy; Full-arch restoration; Digital dentistry

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Conflict of Interest

The authors declare no conflicts of interest related to this study.

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Corresponding Author Details: Minaal Verma[a] Assistant Professor, Department of Prosthodontics and Endodontics, School of Dental Medicine, Southern Illinois university Edwardsville, Illinois, USA;
Email ID: minaalverma@gmail.com Ph No:-