

EVALUATION OF THE EFFECT OF DIMENSIONAL STABILITY OF SPLINTING MATERIAL ON ACCURACY OF MASTER CAST WITH CONVENTIONAL AND DIGITAL IMPRESSION TECHNIQUES: AN IN-VITRO STUDY

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ABSTRACT

Background: Accurate reproduction of implant positions is essential for achieving a passive fit of implant-supported prostheses. Dimensional inaccuracies in the definitive cast may contribute to complications such as screw loosening, component fracture, and marginal bone loss. The effects of different splinting materials and implant angulations on cast accuracy, and the reliability of digital impressions compared with conventional open-tray techniques, remain under discussion.

Purpose: This in vitro study evaluated the dimensional accuracy of master casts produced from open-tray impressions using polyvinyl siloxane (PVS) putty, auto polymerizing pattern resin, or flowable composite resin, and compared them with digital impressions obtained using intraoral scan bodies in parallel and angulated implant configurations.

Material and methods: Two 3D-printed reference models, each containing 4 implants, were used. The maxillary model had implants angulated at 15 and 30 degrees, whereas the mandibular model contained parallel implants. Forty specimens were divided into 4 groups (n=10). Conventional impressions were made with polyether, with impression copings splinted using PVS putty, sectioned-and-rejoined pattern resin, or light-polymerized flowable composite resin. Digital impressions were obtained using intraoral scan bodies. Inter-implant distances d (A–B), d (B–C), and d(C–D) were measured on digitized casts and compared with the reference models using CloudCompare. Data were analyzed using 1-way ANOVA and Tukey post hoc tests ($\alpha=.05$).

Results: For angulated implants, pattern resin demonstrated the lowest overall deviation (0.354 ± 0.067 mm), while PVS putty showed the highest (0.446 ± 0.150 mm). Digital impressions (0.390 ± 0.017 mm) and flowable composite (0.408 ± 0.102 mm) showed intermediate deviations. For parallel implants, digital impressions were most accurate (0.017 ± 0.007 mm), whereas PVS putty was least accurate (0.192 ± 0.043 mm), differing significantly from all other groups ($P<.001$). The greatest deviation occurred across d (B–C) in all groups.

Conclusions: Digital impressions provided superior accuracy for parallel implants, whereas sectioned-and-rejoined pattern resin was most reliable for angulated implants. Flowable composite provided clinically acceptable accuracy, while PVS putty showed the greatest distortion. Longer inter-implant spans reduced accuracy across all techniques.

Keywords: implant impression accuracy; digital impression; intraoral scanning; splinting materials; implant angulations; master cast accuracy

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INTRODUCTION

Edentulism is a disabling oral condition characterized by progressive anatomical and functional alterations that can negatively influence masticatory performance, facial aesthetics, and psychological well-being, thereby reducing oral health-related quality of life.¹ Continued resorption of the residual alveolar ridge further compromises the performance of conventional complete dentures, particularly in the mandibular arch, where patients frequently encounter poor retention and stability, mucosal discomfort, and a gradual deterioration in oral function.²

Implant-supported prosthetic rehabilitation has become a reliable and well-established treatment option for patients with partial or complete tooth loss.³

A major objective in implant prosthodontics is the achievement of an accurate and passive fit between the prosthetic framework and the underlying implants. An inadequate prosthetic fit may generate mechanical complications, such as loosening or fracture of retaining screws and abutment components, and may also contribute to biological complications, including marginal bone loss, pain, and compromised osseointegration.⁶

The accuracy of an implant impression can be affected by several variables, including the type of impression material, impression technique, implant angulations, and the number of implants involved.⁶ Among the available techniques, the direct open-tray approach maintains the impression copings within the impression during removal.

This approach can reduce the effect of implant angulations, limit distortion of the impression material during removal, and avoid errors associated with repositioning the impression copings into the impression.⁹ Brånemark initially proposed splinting impression copings with a rigid material to maintain their positional stability and minimize rotational, horizontal, and vertical displacement during impression procedures. Since its introduction, numerous splinting approaches and materials have been explored to improve the accuracy of implant impressions. Materials such as auto polymerizing acrylic resin, composite resin, and polyvinyl siloxane (PVS), among others, have been investigated for this purpose.⁶

The evolution of digital dentistry has subsequently introduced intraoral scanning as an alternative approach to conventional implant impression procedures. Digital implant impressions employ scan bodies connected to the implants, allowing their three-dimensional positions to be captured by an intraoral scanner and subsequently transferred to a virtual working model.

Therefore, the present in vitro study was designed to investigate the effect of three different splinting materials—PVS putty, auto polymerizing pattern resin, and flowable composite resin—on the dimensional accuracy of master casts produced using the conventional open-tray impression technique. Additionally, their accuracy was compared with digitally generated casts obtained using intraoral scan bodies in both angulated and parallel implant configurations.

MATERIALS AND METHODS

Research Methodology

The present in-vitro investigation included forty specimens (n=40), which were equally allocated into four experimental groups (n=10 per group) according to the splinting material or impression technique employed.

Fabrication of Reference Models

Standardized maxillary and mandibular resin models were fabricated using 3D printing technology and served as the reference models. Four ADIN implants were incorporated into each model. In the maxillary model, two implants were positioned at 15° angulations' in the canine regions, while two implants were placed at 30° angulations' in the first molar regions. In the mandibular model, all four implants were positioned parallel to each other, with two implants located in the canine regions and two in the first molar regions. The implants were sequentially designated A, B, C, and D from left to right for standardized dimensional assessment.

Thirty custom impression trays were fabricated over stone replicas of the reference models using auto polymerizing acrylic resin. A wax spacer measuring 10 mm in height and 6–8 mm in width was incorporated to provide adequate space for impression material, splinting material, and access to the open-tray coping screws. Access openings corresponding to all four implant positions

were created to facilitate engagement of the impression coping retaining screws.

Splinting Techniques

Group 1 – PVS Putty Splinting: Transfer impression copings were stabilized using dental floss. Addition silicone putty (Neopure A-Silicone Kit, Orikam) was mixed according to the manufacturer's instructions and adapted around the copings to form the splint.

Group 2 – Auto polymerizing Pattern Resin Splinting:

The transfer copings were secured with dental floss, followed by application of auto polymerizing pattern resin (GC Pattern Resin). After complete polymerization, the resin splint was sectioned between adjacent copings and subsequently rejoined to compensate for polymerization-related dimensional changes.

Group 3 – Flowable Composite Resin Splinting:

Following stabilization of the transfer copings with dental floss, flowable composite resin (TetricEvoFlow, Ivoclar Vivadent) was applied around the copings and polymerized using an iLed light-curing unit (Guilin Woodpecker Medical Instrument Co. Ltd.).

Group4-Digital

Impression:

ADIN intraoral scan bodies (Israel) were secured onto the implants of the reference models. The models were digitized using a Medit i600 intraoral scanner to obtain three-dimensional virtual models. No conventional impression or gypsum cast was produced for this group.

Control:

The original reference models were considered the control and served as the baseline for comparison with the experimental groups.

Conventional Impression Procedure

For Groups 1–3, monophasic polyether impression material (3M Impregum Soft, 3M India Ltd.) was prepared by mixing the base and catalyst pastes on a mixing pad with an agate spatula. The material was then loaded into the custom tray, and impressions were made with the splinted transfer copings positioned on the reference model. Following impression removal, laboratory implant analogs were connected to the corresponding impression copings and manually tightened.

Master Cast Fabrication

The recorded impressions were poured using Type IV dental stone (Kalastone, Kalabhai Karson Pvt. Ltd.) according to the manufacturer's recommended water-to-powder ratio. The stone was introduced into the impressions while vibrating to minimize air entrapment. After complete setting, the casts were carefully separated, trimmed, and labeled for subsequent dimensional analysis.

Dimensional Assessment

All fabricated master casts were digitized using a laboratory model scanner. The obtained three-dimensional datasets were imported into CloudCompare software for dimensional evaluation. Measurements were performed by a single calibrated examiner to minimize inter-examiner variability.

Three inter-implant distances were evaluated: d (A–B), d (B–C), and d(C–D), representing the distances between sequentially designated implants from left to right. Measurements obtained from the experimental casts were compared with the corresponding measurements of the reference models to determine dimensional deviations.

Statistical Evaluation

The collected data were analyzed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Intergroup differences were evaluated using one-way analysis of variance (ANOVA). When statistically significant differences were identified, Tukey post-hoc testing was performed for pairwise comparisons. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 40 master casts were evaluated, comprising 30 casts obtained from conventional open-tray polyether impressions using three different splinting materials and 10 casts generated through digital impressions using intraoral scan bodies. Inter-implant deviations were assessed at d (A–B), d (B–C), and d(C–D) and compared with the corresponding reference models. Statistical analysis was performed using one-way ANOVA followed by Tukey post-hoc testing, with statistical significance established at p<0.05.

Table 1. Overall dimensional deviation among the experimental groups

Implant configuration	PVS putty	Pattern resin	Flowable composite	Digital impression
Maxillary – Angulated	0.446 ± 0.150 mm	0.354 ± 0.067 mm	0.408 ± 0.102 mm	0.390 ± 0.017 mm

Mandibular – Parallel	0.1915 ± 0.0433 mm	0.0364 ± 0.0078 mm	0.0556 ± 0.0137 mm	0.0170 ± 0.0074 mm
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In the maxillary model with angulated implants, pattern resin demonstrated the lowest overall deviation (0.354 ± 0.067 mm), followed by digital impression (0.390 ± 0.017 mm), flowable composite (0.408 ± 0.102 mm), and PVS putty (0.446 ± 0.150 mm). In the mandibular model with parallel implants, digital impressions demonstrated

the lowest overall deviation (0.0170 ± 0.0074 mm), whereas PVS putty showed the highest deviation (0.1915 ± 0.0433 mm).

Table 2. Inter-implant distance deviations in the maxillary arch

Group	d(A–B) Mean $\pm$ SD (mm)	d(B–C) Mean $\pm$ SD (mm)	d(C–D) Mean $\pm$ SD (mm)	Overall deviation (mm)
PVS putty	0.147 ± 0.0584	0.406 ± 0.152	0.0923 ± 0.0270	0.446 ± 0.150
Pattern resin	0.0465 ± 0.0413	0.341 ± 0.0693	0.0720 ± 0.00911	0.354 ± 0.067
Flowable composite	0.0641 ± 0.0280	0.399 ± 0.105	0.0470 ± 0.0132	0.408 ± 0.102
Digital impression	0.0293 ± 0.0175	0.387 ± 0.0159	0.0331 ± 0.00433	0.390 ± 0.017

The d (B–C) segment exhibited the greatest deviation in all four groups. Pattern resin recorded the lowest

overall deviation, whereas PVS putty demonstrated the highest deviation in the maxillary arch.

Table 3. Inter-implant distance deviations in the mandibular arch

Group	d(A–B) Mean $\pm$ SD (mm)	d(B–C) Mean $\pm$ SD (mm)	d(C–D) Mean $\pm$ SD (mm)	Overall deviation (mm)
PVS putty	0.1365 ± 0.0489	0.3496 ± 0.1088	0.0873 ± 0.0190	0.1915 ± 0.0433
Pattern resin	0.0256 ± 0.0109	0.0482 ± 0.0185	0.0353 ± 0.0134	0.0364 ± 0.0078
Flowable composite	0.0433 ± 0.0152	0.0923 ± 0.0344	0.0312 ± 0.0096	0.0556 ± 0.0137
Digital impression	0.0118 ± 0.0069	0.0259 ± 0.0104	0.0146 ± 0.0076	0.0170 ± 0.0074

Digital impressions demonstrated the lowest overall deviation, followed by pattern resin and flowable composite resin. PVS putty exhibited the greatest deviation.

The d (B–C) segment showed the highest deviation across all groups.

Table 4. One-way ANOVA results for inter-implant distances

Implant configuration	Measurement	F value	p value	Significance
Maxillary	d(A–B)	9.378	0.00082	Significant
Maxillary	d(B–C)	0.437	0.730	Not significant
Maxillary	d(C–D)	13.561	0.00012	Significant
Mandibular	d(A–B)	23.227	<0.001	Significant
Mandibular	d(B–C)	32.444	<0.001	Significant
Mandibular	d(C–D)	25.635	<0.001	Significant

For the maxillary configuration, significant intergroup differences were observed for d (A–B) and d(C–D), whereas d (B–C) did not demonstrate a statistically significant difference ($p=0.730$). For the mandibular configuration, statistically significant differences were observed for all three inter-implant measurements ($p<0.001$).

Summary of Results

Across both implant configurations, PVS putty demonstrated the greatest overall dimensional deviation. In the maxillary model with angulated implants, auto polymerizing pattern resin showed the highest dimensional accuracy, with an overall deviation of 0.354 ± 0.067 mm. Digital impression, flowable composite resin, and PVS putty demonstrated progressively greater deviations of 0.390 ± 0.017 mm, 0.408 ± 0.102 mm, and 0.446 ± 0.150 mm, respectively.

In the mandibular model with parallel implants, digital impressions demonstrated the highest accuracy, with the lowest overall deviation of 0.0170 ± 0.0074 mm. Pattern resin, flowable composite resin, and PVS putty showed overall deviations of 0.0364 ± 0.0078 mm, 0.0556 ± 0.0137 mm, and 0.1915 ± 0.0433 mm, respectively.

The d (B–C) segment consistently demonstrated the greatest deviation across the evaluated techniques. In the maxillary configuration, statistically significant intergroup differences were observed for d (A–B) and d(C–D), while d (B–C) showed no significant difference. In contrast, all three measured inter-implant distances demonstrated statistically significant intergroup differences in the mandibular configuration.

Overall, pattern resin provided the most accurate conventional impression approach for the angulated implant configuration, whereas digital impressions demonstrated the greatest accuracy for parallel implants. PVS putty consistently produced the highest dimensional deviation among the evaluated techniques.

DISCUSSION

Achieving a passive and accurate fit between an implant-supported prosthetic superstructure and the underlying implants remains a major concern in implant prosthodontics. Passive adaptation is considered essential for maintaining the long-term stability of osseointegration. Unlike natural teeth, which possess approximately 100 microns of physiological mobility within their sockets, osseointegrated implants exhibit considerably restricted movement of approximately 10 microns. Consequently, discrepancies in the fit of implant-supported prostheses may have more pronounced consequences than those associated with tooth-supported restorations. Mechanical complications

may include loosening of prosthetic retaining screws, locking or fracture of abutment screws, and fracture of other prosthetic components, potentially resulting in delayed component failure. Biological consequences may include pain, tenderness, marginal bone loss, and, in severe cases, compromised osseointegration.⁶

Implant impressions are generally obtained using either a direct or indirect approach. The direct technique commonly referred to as the open-tray or pick-up technique retains the impression copings within the impression during removal. The indirect approach, also known as the closed-tray or reposition technique, requires the copings to be repositioned after impression removal. Although the closed-tray approach may be relatively simpler to perform clinically, previous investigations have indicated that it may provide less predictable transfer of the three-dimensional implant position.³⁶

The open-tray technique offers the advantage of retaining the impression copings within the impression during removal from the oral cavity. This may minimize errors associated with implant angulations', deformation of the impression material, and repositioning of the copings into their corresponding locations.³⁶ Findings reported by Carr⁴⁷, Shankar YR et al.³², and Del'Acqua et al.⁴⁸ have supported the use of the open-tray technique for implant impressions.

Splinting of impression copings was initially emphasized by Brånemark et al., who described the use of dental floss as a scaffold covered with auto polymerizing pattern resin.²³ Splinting is intended to stabilize individual impression copings and reduce their movement during impression making and subsequent attachment of implant analogs. By minimizing rotational and positional displacement, splinting may contribute to improved dimensional accuracy of the definitive cast.⁴⁹ Several studies, including those conducted by Ongul et al.⁵², Al-Quran et al.⁵³, Papaspyridakos et al.⁵⁴, and De Faria et al.⁵⁵, have reported improved impression accuracy when splinted copings were used compared with nonsplinted techniques.

In the present study, auto polymerizing pattern resin demonstrated the most favorable accuracy among the conventional splinting techniques for the angulated implant configuration. These findings are consistent with observations reported by Sambit Subhas et al.⁴¹, Sang-Jik Lee et al.²³, Manesh Lahori et al.²⁴, and Shankar SD et al.³⁹, who supported the use of pattern resin with sectioning and subsequent rejoining to minimize the influence of polymerization shrinkage. The sectioning-and-rejoining procedure may help compensate for dimensional changes occurring during polymerization and

thereby improve the positional accuracy of the impression copings.

In contrast, PVS splinting demonstrated comparatively greater dimensional deviation in the present investigation. Similar deviations associated with PVS splinting have been reported by Sang-Jik Lee et al.²³. The comparatively lower rigidity or dimensional stability of the splinting material may contribute to increased coping displacement during impression procedures and analog attachment.

Flowable composite resin has also been proposed as an alternative splinting material because of its relatively simple application and light-activated setting mechanism. Parviz Amini⁵⁶, Oshin Dilip Sarate et al.⁵⁷, and Meet A Dodia⁵⁸ investigated flowable composite for coping splinting and reported clinical advantages, including reduced working time and improved patient acceptance. In the present study, flowable composite demonstrated clinically acceptable dimensional accuracy, supporting its potential use as an alternative to conventional pattern resin.

The accuracy of the impression material itself is another important consideration. Del Acqua et al.⁴⁸ and Sorrentino et al.⁵⁹ reported greater accuracy with polyether compared with PVS. The present investigation similarly employed polyether as the conventional impression material across the splinting groups, allowing the influence of the splinting material and implant configuration to be evaluated under standardized conditions.

Digital implant impressions have introduced an alternative workflow for recording implant positions. By using intraoral scan bodies, the spatial position of the implants can be digitally captured, thereby eliminating several conventional laboratory procedures involved in impression making and cast fabrication. The digital workflow also facilitates integration with CAD/CAM-based prosthetic procedures. Papaspyridakos et al.⁵⁴, Amin et al.⁶³, and Lee SJ⁶⁴ reported findings indicating no significant difference between digital impressions and conventional splinted techniques under the conditions evaluated in their respective studies.

In the present investigation, the effect of implant angulations' was evident in the performance of the different impression techniques. For the model containing angulated implants, casts produced using pattern resin splinting demonstrated the smallest deviation from the reference model. This finding agrees with the observations of Sang-Jik Lee et al.²³, who reported favorable accuracy with pattern resin splinting. Shankar et al.³² also emphasized the effectiveness of resin splinting when recording angulated implants.

For the parallel implant configuration, digital impressions demonstrated the greatest dimensional accuracy among the evaluated techniques. Within the conventional groups, pattern resin provided better accuracy than PVS putty and flowable composite resin. The PVS group exhibited the greatest dimensional distortion. These observations are in agreement with the findings of NitchakulJoensahakij et al.⁶⁵, Firas-Abdulameer Farhan⁶⁶, and Marzieh Alikhasi⁶⁷, who reported favorable accuracy with digital implant impressions compared with conventional approaches.

Overall, the findings indicate that the accuracy of implant impressions is influenced by both implant configuration and splinting technique. Pattern resin provided the most reliable conventional approach for angulated implants, whereas digital impressions demonstrated superior accuracy when implants were positioned parallel to one another. PVS putty exhibited the greatest dimensional discrepancy irrespective of implant configuration.

CONCLUSIONS

Within the limitations of the present in-vitro investigation, the following conclusions were drawn:

1. Digital impressions using intraoral scan bodies demonstrated the highest dimensional accuracy for parallel implant configurations.
2. Among the conventional impression techniques, autopolymerising pattern resin with the sectioning-and-rejoining approach demonstrated the greatest accuracy for angulated implant configurations.
3. Flowable composite resin demonstrated clinically acceptable dimensional accuracy and may serve as a practical alternative because of its light-curing mechanism and ease of application.
4. PVS putty exhibited the greatest dimensional deviation among the evaluated splinting materials in both implant configurations.
5. The inter-implant span influenced dimensional accuracy, with greater span length associated with increased deviation irrespective of the splinting material or impression technique used.

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