

Accuracy of Implant Impressions for Multiple Angulated Implants Using Different Impression Copings and Splinting Materials: An In Vitro Study

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ABSTRACT

Purpose: Accurate implant impressions are essential for achieving passive fit and long-term success of implant-supported prostheses, particularly in cases involving multiple and angulated implants. This in vitro study evaluated and compared the accuracy of implant impressions obtained using different impression coping designs (hex, non-hex, and multi-unit copings) with various splinting techniques.

Materials and Methods: A total of 117 acrylic maxillary edentulous models with six implants placed at predetermined angulations were fabricated and divided into three groups according to impression coping design: hex, non-hex, and multi-unit copings (n = 39 each). Each group was further subdivided into three subgroups based on splinting protocol (n = 13): non-splinted, pattern resin splinted, and composite resin splinted. Open-tray impressions were made using polyether impression material. Definitive casts were fabricated using Type IV dental stone, and implant positional deviations were evaluated using a stereomicroscope. Data were statistically analysed using Shapiro–Wilk test, Kruskal–Wallis test, one-way ANOVA, Bonferroni post hoc test, and Tukey’s post hoc test ($p < 0.05$).

Results: Splinting significantly improved impression accuracy in all coping systems compared with non-splinted techniques. Pattern resin splinting demonstrated the least deviation values across all groups, followed by composite resin splinting, whereas non-splinted groups showed the highest deviation values. In the hex coping group, statistically significant differences were observed among all subgroups ($p < 0.05$). In the non-hex coping group, both splinted techniques demonstrated significantly lower deviation compared with the non-splinted subgroup, although no significant difference was observed between pattern resin and composite resin splinting ($p > 0.05$). In the multi-unit coping group, pattern resin splinting demonstrated the highest accuracy with statistically significant differences among all subgroups ($p < 0.001$). Overall, multi-unit and non-hex copings demonstrated superior accuracy compared with hex copings.

Conclusion: Splinting of impression copings significantly enhances the accuracy of implant impressions in multiple angulated implant situations. Pattern resin demonstrated superior accuracy among the splinting materials evaluated, while composite resin showed clinically acceptable performance. Non-hex and multi-unit coping systems produced more accurate impressions than hex copings, particularly when used with splinting techniques.

Keywords: Dental implants; Implant impression accuracy; Angulated implants; Impression copings; Hex coping; non-hex coping; multi-unit coping; Pattern resin splinting; Composite splinting; Open-tray impression technique; Implant prosthodontics; Passive fit.

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INTRODUCTION

Dental implants are widely regarded as a predictable and reliable treatment modality for the rehabilitation of partially and completely edentulous patients, restoring both function and esthetics. Continuous advancements in implant design, surface characteristics, and prosthetic components have significantly improved the long-term success and survival of implant-supported prostheses. However, the longevity of implant restorations depends not only on successful osseointegration but also on the accuracy and passive fit of the definitive prosthesis.

Passive fit is considered a critical factor for the long-term success of implant-supported restorations. Misfit between implant components and the prosthetic framework may result in biological and biomechanical complications such as screw loosening or fracture, increased plaque accumulation, peri-implant bone loss, fracture of prosthetic components, and eventual loss of osseointegration.[1] Therefore, obtaining an accurate implant impression is essential, as it represents the first and most important step in transferring the three-dimensional intraoral implant position to the definitive working cast.[2]

Several factors influence the accuracy of implant impressions, including the impression technique, impression material, implant angulation, number of implants, implant connection design, and type of impression coping used. [2,3] Among these variables, impressions involving multiple and angulated implants present a significant clinical challenge. Previous studies have demonstrated that impressions made from parallel implants are generally more accurate than those obtained from angulated implants, particularly when multiple implants are involved. [4–6]

In clinical situations, ideal parallel implant placement is often difficult to achieve because of anatomical limitations such as alveolar ridge resorption, proximity to the maxillary sinus, and esthetic requirements, especially in the anterior maxilla. Consequently, implants are frequently placed with varying degrees of angulation, resulting in divergence between impression copings. When the angulation difference between implants exceeds 15°, open-tray impression techniques combined with splinting of impression copings have been recommended to improve impression accuracy. [7,8]

Polyether impression materials are commonly used for implant impressions because of their excellent dimensional stability and elastic recovery. [7,9] In cases involving angulated implants, impression materials with high elastic recovery are preferred to minimize permanent deformation during impression removal. Additionally, splinting of impression copings has been advocated to reduce coping movement and minimize distortion during the attachment of implant analogues to the copings. [10,11] Several studies have reported improved accuracy with splinted impression techniques in complete-arch rehabilitations involving multiple implants. [12–15]

Implant-abutment connection design also plays an important role in impression accuracy. Internal connection implant systems, which are widely used in contemporary implant dentistry, have been reported to demonstrate reduced impression accuracy in angulated implant situations because of increased contact between the implant and impression coping surfaces. [4,16,17] To overcome these limitations, non-hex impression copings with reduced engagement depth have been introduced and are recommended by manufacturers for use in multiple and angulated implant scenarios, particularly when splinting techniques are employed. [18]

Implant impressions can be made at either the implant level or the abutment level. Implant-level impressions provide greater flexibility in abutment selection and customization, whereas abutment-level impressions using multi-unit abutments are frequently preferred in full-arch rehabilitations involving multiple and angulated implants. Multi-unit abutments may compensate for implant angulation and reduce distortion during impression removal by eliminating direct engagement between the impression coping and implant interface. [19,20] However, evidence comparing the accuracy of implant-level and abutment-level impression techniques in cases involving multiple angulated implants remains limited. [21,22]

Although numerous studies have evaluated the effects of impression techniques, coping designs, and splinting methods individually, there is still no consensus regarding the most accurate impression approach for multiple angulated implants. [7,9,20,23] Therefore, further investigation is necessary to establish evidence-based guidelines for impression procedures in complex implant rehabilitation cases.

Aim

To comparatively evaluate the accuracy of implant impressions for multiple angulated implants using different impression coping designs (hex, non-hex, and multi-unit copings) with different splinting protocols in an in vitro model.

Objectives

1. To evaluate the accuracy of implant impressions made using hex impression copings with:
 - no splinting,
 - pattern resin splinting, and
 - composite resin splinting.
2. To evaluate the accuracy of implant impressions made using non-hex impression copings with:
 - no splinting,
 - pattern resin splinting, and
 - composite resin splinting.
3. To evaluate the accuracy of implant impressions made using multi-unit impression copings with:
 - no splinting,
 - pattern resin splinting, and
 - composite resin splinting.

4. To compare the accuracy of splinted and non-splinted impression techniques within each coping system.

5. To determine the most accurate impression coping and splinting combination for multiple angulated implants.

MATERIALS AND METHODS

Study Design

This in vitro experimental comparative study was conducted in the Department of Prosthodontics, Crown and Bridge, and Implantology at Geetanjali Dental and Research Institute after obtaining institutional ethical clearance from the Institutional Research and Review Committee, Geetanjali University (GU/HREC/EC/2024/2442; dated 29 April 2024).

Sample Size and Grouping

A total of 117 acrylic maxillary edentulous master models were fabricated. The sample size was calculated using G*Power 3.1 software with a significance level of 5%, statistical power of 80%, and anticipated effect size of 1.32.

The specimens were divided into three primary groups according to the type of impression coping used ($n = 39/\text{group}$):

- Group A: Hex impression copings
- Group B: Non-hex impression copings
- Group C: Multi-unit impression copings

Each group was further subdivided into three subgroups ($n = 13/\text{subgroup}$) based on the splinting protocol:

- Subgroup 1: Non-splinted (control)
- Subgroup 2: Pattern resin splinting
- Subgroup 3: Composite resin splinting

Inclusion Criteria

- Dimensionally accurate impression materials
- Implants from the same manufacturer
- Implants with intact surface anatomy and threads
- Proper implant–coping connections

Exclusion Criteria

- Models with dimensional defects or voids
- Inaccurately placed implants

Armamentariums

The materials in this study includes clear auto-polymerizing acrylic resin, polyether impression material, pattern resin, composite resin, elastomeric materials, Type IV dental stone, and saline.

The equipment utilized included dummy Noris implants, Noris implant kit, physio-dispenser, All-on-Six surgical guide, impression copings, laboratory analogues, stereomicroscope, custom trays, and acrylic trimming instruments.

Master Model Fabrication

Standardized edentulous maxillary models were fabricated using clear auto-polymerizing acrylic resin poured into silicone molds of an ideal edentulous maxillary arch. The acrylic resin was mixed according to manufacturer instructions and packed into the molds during the dough stage. Following polymerization, the

models were retrieved, trimmed, and polished to obtain standardized specimens.

Implant Placement Protocol

Six implants were placed in predetermined positions in each specimen model to simulate multiple angulated implant conditions. Implant positions and angulations were standardized as follows:

- Lateral incisor region: 20° angulation
- Premolar region: 0° angulation
- Second molar region: 10° angulation

Three implants were placed in each quadrant, resulting in six implants per model.

Osteotomy preparation was performed using the Noris implant drilling system with an All-on-Six surgical guide to ensure standardized implant positioning and angulation. Sequential drilling was carried out under continuous saline irrigation using a physio-dispenser. Dummy implants were inserted with controlled torque until complete seating was achieved.

Impression Coping Groups

- Group A: Hex impression copings
- Group B: Non-hex impression copings
- Group C: Multi-unit impression copings

Impression Procedures

Subgroup 1: Non-Splinted Technique

Open-tray impressions were made without splinting. Custom trays with access openings corresponding to implant positions were fabricated. Polyether impression material was injected around the impression copings and loaded into the tray before seating over the model.

Subgroup 2: Pattern Resin Splinting

Impression copings were splinted using pattern resin reinforced with a high-gauge metal wire framework. The resin was applied incrementally and allowed to polymerize completely before making open-tray impressions using polyether impression material.

Subgroup 3: Composite Resin Splinting

A metal wire framework was adapted around the impression copings, and composite resin was incrementally applied and light-cured to achieve rigid splinting. Open-tray impressions were subsequently made using polyether impression material.

Fabrication of Definitive Casts

Following impression making, implant analogues were attached to the impression copings embedded within the impressions. Type IV dental stone was mixed according to manufacturer instructions and poured into the impressions using a mechanical vibrator to minimize air entrapment. After complete setting, definitive casts were retrieved and used for analysis.

Stereomicroscopic Evaluation

The definitive casts were analysed using a stereomicroscope to evaluate positional and angular accuracy relative to the master model.

The following parameters were assessed:

- Inter-implant linear distance
- Angular deviation
- Three-dimensional spatial relationship among implants

All measurements were performed under standardized magnification by a single evaluator to minimize inter-operator variability. Measurements were repeated to ensure reliability, and the stereomicroscope was calibrated before analysis.

Outcome Assessment

Accuracy was determined by comparing deviations between the definitive casts and the master model. Lower deviation values indicated greater impression accuracy.

Statistical Analysis

The obtained data were statistically analyzed to compare the accuracy among the different coping systems and splinting techniques. Statistical significance was set at $p < 0.05$.

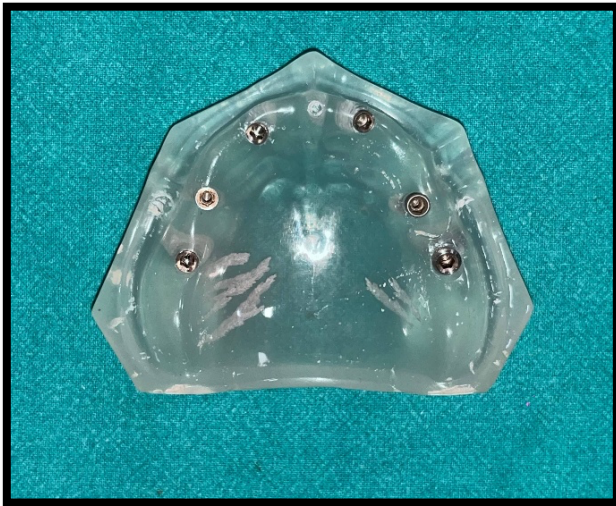


FIG 1: DUMMY IMPLANTS PLACED ON ACRYLIC MODEL AT VARIOUS ANGULATIONS

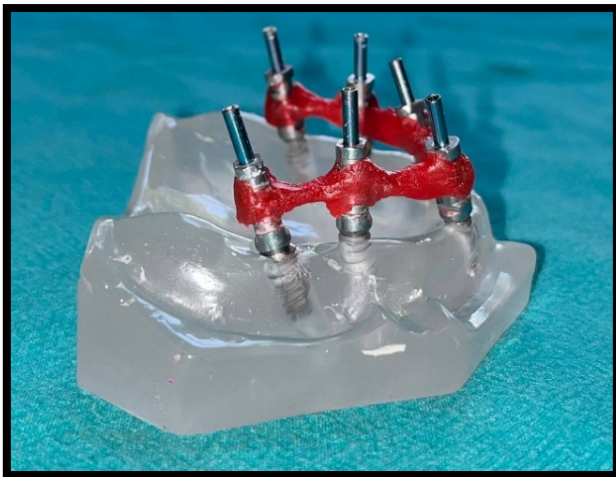


FIG 2: SPLINTING OF HEX COPINGS WITH PATTERN RESIN

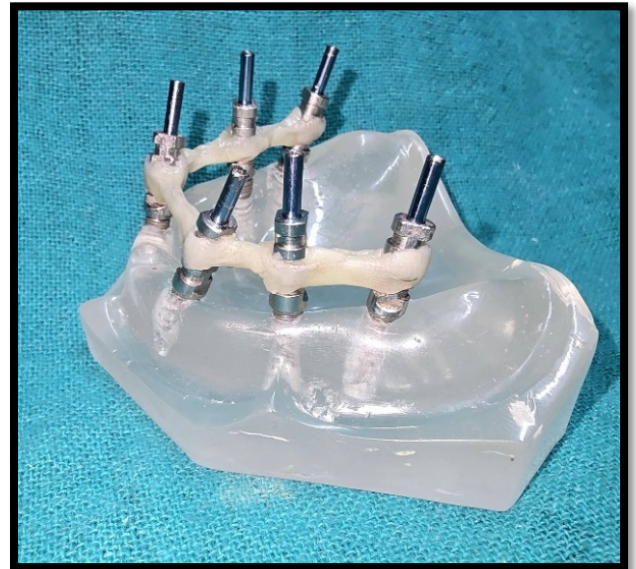


FIG 3: SPLINTING OF HEX COPINGS WITH COMPOSITE RESIN

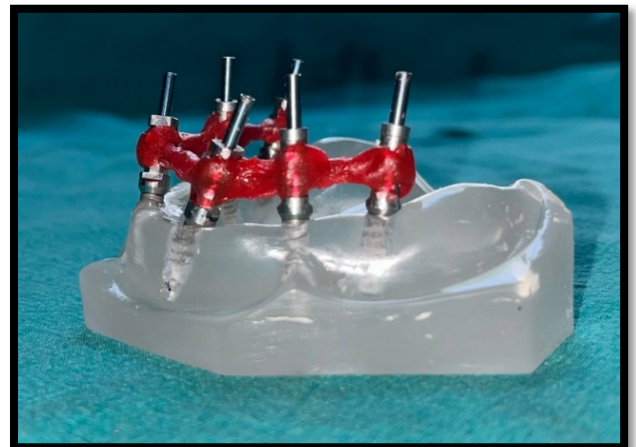


FIG 4: SPLINTING OF NON HEX COPINGS WITH PATTERN RESIN

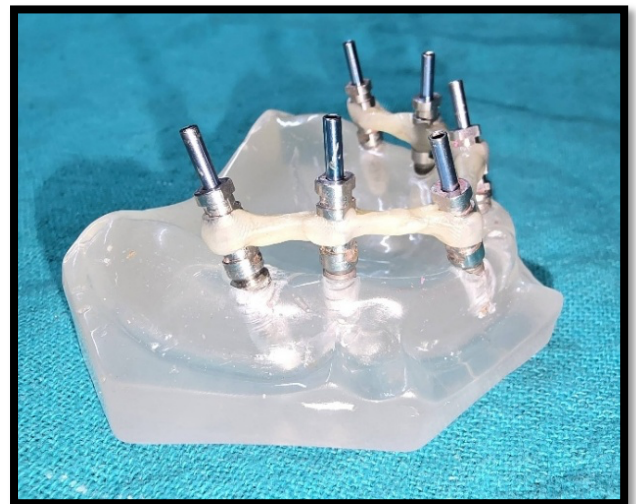


FIG 5: SPLINTING OF NON-HEX COPINGS WITH COMPOSITE RESIN



FIG 6: SPLINTING OF MULTIUNIT COPINGS WITH PATTERN RESIN

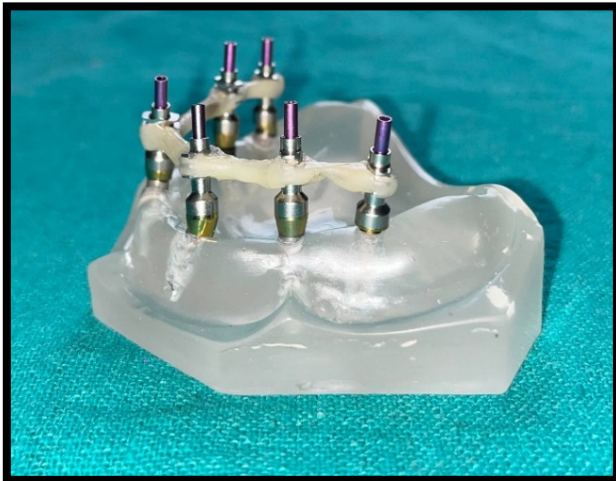


FIG 7: SPLINTING OF MULTIUNIT COPINGS WITH COMPOSITE RESIN

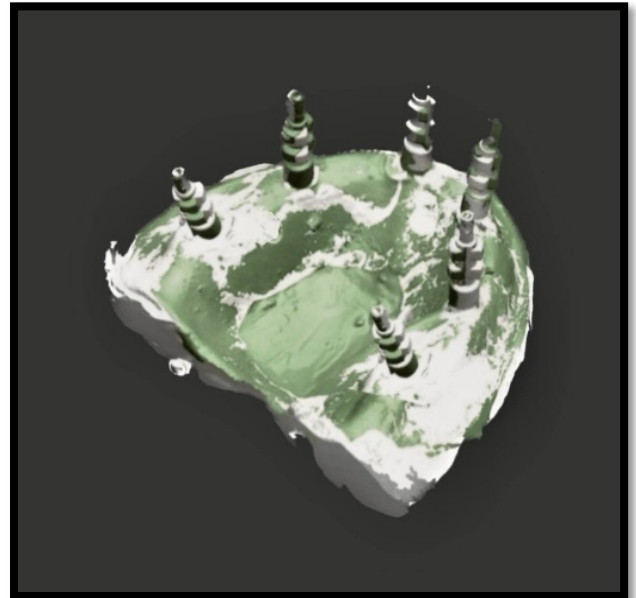
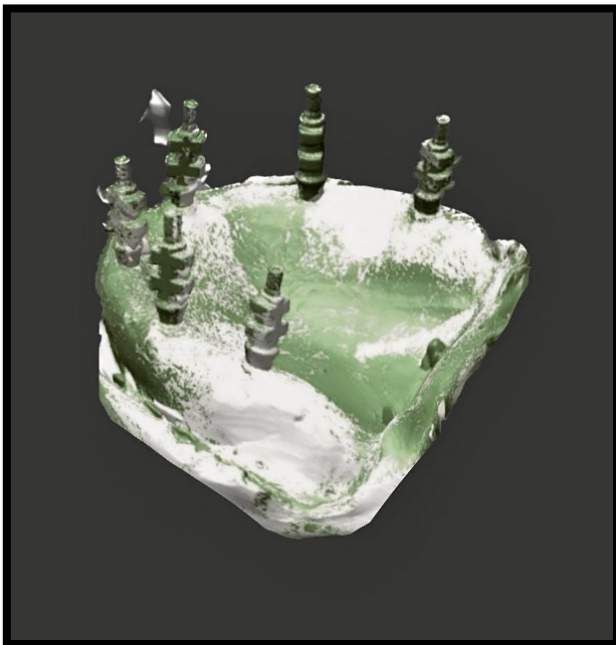


FIG 8: SUPERIMPOSITION-BASED ALIGNMENT OF REFERENCE POINTS BETWEEN IDEAL AND MASTER MODELS



FIG 9: WORKING ON STEREOMICROSCOPE

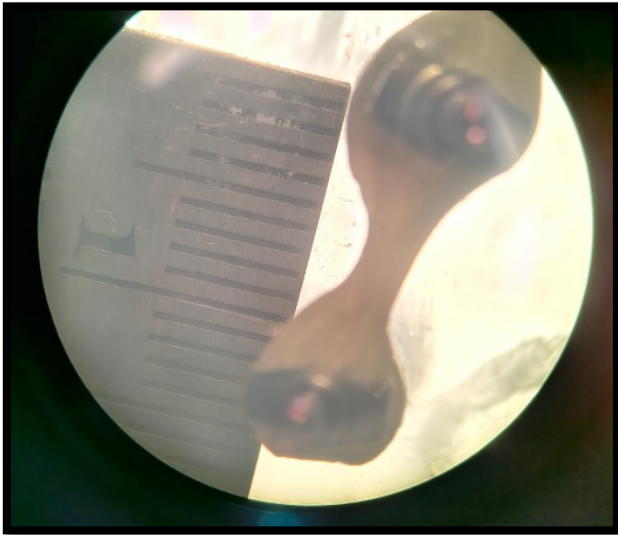


FIG 10: READING SEEN THROUGH STEREOMICROSCOPE

RESULTS

This in vitro study evaluated the accuracy of implant impressions for multiple angulated implants using three impression coping designs (hex, non-hex, and multi-unit) under three splinting conditions: pattern resin, composite resin, and non-splinting. A total of 117 samples were analysed. Implant positional deviation was measured in millimetres using a stereomicroscope under standardized conditions.

The obtained data were expressed as mean $\pm$ standard deviation (SD). Data normality was assessed using the Shapiro–Wilk test. Depending on the distribution pattern, appropriate parametric and non-parametric statistical tests were applied. Kruskal–Wallis test followed by Bonferroni post hoc analysis was used for non-normally distributed data, whereas one-way analysis of variance (ANOVA) followed by Tukey’s post hoc test was used for normally distributed data. Statistical significance was set at $p < 0.05$.

Normality Assessment

The Shapiro–Wilk test demonstrated non-normal distribution in several subgroups. In the hex coping group, the non-splinted subgroup showed significant deviation from normality ($p = 0.033$). In the non-hex coping group, the pattern resin ($p < 0.001$) and composite resin ($p = 0.035$) subgroups demonstrated non-normal distribution, whereas the non-splinted subgroup followed normal distribution ($p = 0.524$). All multi-unit coping subgroups showed normal distribution ($p > 0.05$). Therefore, both parametric and non-parametric statistical analyses were applied accordingly.

Hex Coping Group

A statistically significant difference in deviation values was observed among the three splinting techniques in the hex coping group ($\chi^2 = 29.092$, $p < 0.001$).

The pattern resin subgroup demonstrated the least deviation (0.067 ± 0.007 mm), followed by the composite resin subgroup (0.087 ± 0.016 mm), whereas

the non-splinted subgroup exhibited the highest deviation values (0.116 ± 0.007 mm).

Post hoc pairwise comparison revealed statistically significant differences between all subgroups. Pattern resin splinting demonstrated significantly lower deviation compared with composite resin ($p = 0.048$) and non-splinting ($p < 0.001$). Composite resin splinting also showed significantly lower deviation than the non-splinted subgroup ($p = 0.009$).

Non-Hex Coping Group

A statistically significant difference was observed among the splinting techniques in the non-hex coping group ($\chi^2 = 21.684$, $p < 0.001$).

The pattern resin subgroup demonstrated the lowest deviation values (0.046 ± 0.014 mm), followed by the composite resin subgroup (0.058 ± 0.017 mm), while the non-splinted subgroup showed the highest deviation values (0.082 ± 0.004 mm).

Post hoc analysis demonstrated no statistically significant difference between pattern resin and composite resin splinting ($p = 0.506$). However, both splinted groups showed significantly lower deviation compared with the non-splinted subgroup ($p < 0.001$ and $p = 0.004$, respectively).

Multi-Unit Coping Group

One-way ANOVA demonstrated a highly statistically significant difference among the splinting techniques in the multi-unit coping group ($F = 41.364$, $p < 0.001$).

The pattern resin subgroup exhibited the lowest deviation values (0.012 ± 0.006 mm), followed by the composite resin subgroup (0.029 ± 0.015 mm), whereas the non-splinted subgroup showed the highest deviation values (0.048 ± 0.007 mm).

Post hoc analysis demonstrated statistically significant differences among all subgroups ($p < 0.001$). Pattern resin splinting demonstrated significantly lower deviation compared with both composite resin and non-splinted groups, while composite resin splinting also showed significantly lower deviation compared with the non-splinted subgroup.

Overall Findings

Among all impression techniques evaluated, pattern resin splinting consistently demonstrated the highest accuracy with the least deviation values across all coping systems. Composite resin splinting showed intermediate accuracy, whereas non-splinted techniques demonstrated the greatest deviation.

Among the coping systems evaluated, multi-unit copings with pattern resin splinting demonstrated the least overall deviation and the highest impression accuracy.

DISCUSSION

Accurate transfer of the three-dimensional spatial relationship of implants from the intraoral environment to the definitive cast is essential for achieving passive fit of implant-supported prostheses.[45] Inaccuracies during impression making may result in biomechanical complications such as screw loosening, framework misfit, and component fracture, as well as biological complications including peri-implant bone loss.[3,45]

These challenges become more pronounced in cases involving multiple angulated implants, as evaluated in the present study.

In the present investigation, implants were placed at varying angulations (20° anteriorly, 0° in the premolar region, and 10° posteriorly) to simulate clinically relevant implant configurations commonly encountered in the maxilla. Previous studies have demonstrated that increasing implant angulation adversely affects impression accuracy because of increased deformation of the impression material and difficulty in removal along a non-parallel path.[45] The present findings are consistent with those observations, particularly in the non-splinted groups, which demonstrated the highest deviation values.

Splinting of impression copings significantly improved impression accuracy in all coping systems evaluated. Splinting minimizes micromovement and rotational discrepancies of impression copings during impression removal and analogue attachment, thereby improving positional stability. [46,47] Similar findings were reported by Thakur and Parlani,[47] who observed superior positional accuracy with splinted impression techniques in multiple implant situations. Jayaswal [46] also demonstrated that splinted techniques produced more accurate definitive casts compared with non-splinted approaches.

Among the splinting materials evaluated, pattern resin demonstrated superior accuracy and lower deviation values compared with composite resin across all coping groups. The improved performance of pattern resin may be attributed to its increased rigidity and dimensional stability, which reduce distortion during impression making.[48] Incremental application of pattern resin may further minimize polymerization shrinkage and enhance stability. [47,48]

Composite resin splinting also demonstrated clinically acceptable accuracy and showed significantly lower deviation compared with non-splinted techniques. Advantages of composite resin include ease of manipulation, shorter working time, and controlled polymerization. [46,48] Although pattern resin exhibited comparatively better results, the differences between the two splinting materials remained within clinically acceptable limits.

The stereomicroscope used in this study enabled accurate evaluation of positional and angular discrepancies at a micrometric level. Similar methodologies have been utilized in previous in vitro investigations evaluating implant impression accuracy. [46,48] Standardization of magnification and measurement procedures enhanced the reliability and reproducibility of the obtained results.

Among the coping systems evaluated, hex copings demonstrated comparatively greater deviation, particularly in non-splinted conditions. The engaging design of hex copings may increase resistance during impression removal and restrict rotational freedom, thereby increasing distortion in angulated implant

situations. In contrast, non-hex copings demonstrated improved accuracy because of reduced interfacial resistance and greater rotational freedom during impression removal.[45]

Multi-unit copings demonstrated the highest overall accuracy, especially when splinted with pattern resin. Their non-engaging design and conical interface may facilitate more passive removal of impressions in angulated implant situations, thereby reducing distortion. These findings support the clinical use of multi-unit impression systems in full-arch implant rehabilitations involving non-parallel implants. [47,48] The present study demonstrated that implant angulation significantly influences impression accuracy. Greater discrepancies were observed in non-splinted groups because angulated implants create divergent paths of removal, resulting in deformation of the impression material and displacement of impression copings. Splinting effectively minimized these discrepancies by stabilizing the copings and distributing stresses more evenly during impression removal.[45]

Within the clinically acceptable range of implant discrepancy, the findings of this study suggest that splinting should be strongly recommended for impressions involving multiple angulated implants. Pattern resin may be preferred in situations requiring maximum rigidity and precision, whereas composite resin may serve as a clinically acceptable and time-efficient alternative. Furthermore, non-engaging coping systems demonstrated superior accuracy compared with engaging hex copings in complex implant configurations.

Despite the standardized methodology, this study has certain limitations. Being an in vitro investigation, intraoral variables such as saliva contamination, soft tissue resiliency, and thermal fluctuations could not be reproduced completely. Additionally, only specific implant angulations were evaluated, and complete three-dimensional distortion analysis was not performed. Future clinical studies using advanced digital scanning and three-dimensional evaluation methods are recommended to further validate these findings. [45,48]

CONCLUSION

Within the limitations of this in vitro study, splinting of impression copings significantly improved the accuracy of implant impressions compared with non-splinted techniques in multiple angulated implant situations.

Among the splinting materials evaluated, pattern resin demonstrated the least deviation and highest overall accuracy, followed by composite resin, whereas non-splinted techniques exhibited the greatest deviation values. In the hex coping group, statistically significant differences were observed among all subgroups, with pattern resin splinting producing superior accuracy compared with composite resin and non-splinted techniques. In the non-hex coping group, both splinted techniques demonstrated significantly lower deviation than the non-splinted group, although the difference between pattern resin and composite resin was not

statistically significant. Similarly, in the multi-unit coping group, splinted techniques demonstrated significantly greater accuracy compared with non-splinted impressions.

Overall, splinted impression techniques produced more accurate definitive casts irrespective of coping design. Non-hex and multi-unit copings demonstrated comparatively better accuracy than hex copings in multiple angulated implant situations, particularly when used with splinting techniques.

Implant angulation significantly influenced impression accuracy, with greater angulation associated with increased deviation. These findings emphasize the importance of appropriate coping selection and splinting procedures in complex implant rehabilitation cases.

Within the parameters of this study, pattern resin splinting may be recommended as the preferred technique for achieving optimal impression accuracy in multiple and angulated implant scenarios using the open-tray impression technique. Composite resin may also be considered a clinically acceptable alternative because of its satisfactory accuracy and ease of manipulation.

Further in vivo studies with larger sample sizes and advanced three-dimensional digital evaluation methods are recommended to validate the clinical applicability of these findings.

Clinical Significance Statement

Accurate transfer of implant position is essential for achieving passive fit of implant-supported prostheses, particularly in cases involving multiple and angulated implants. The findings of this in vitro study indicate that splinted impression techniques significantly enhance impression accuracy compared to non-splinted methods. Among the splinting materials evaluated, pattern resin demonstrated superior dimensional stability and the least deviation, suggesting its greater reliability in complex full-arch implant rehabilitations.

Conflict Of Interest

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

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This study did not receive any external funding or financial support. All materials and resources were provided by the Department of Prosthodontics, Geetanjali Dental & Research Institute.

Ethical Approval Statement

This in vitro study was conducted after obtaining approval from the Institutional Human Research Ethics Committee (IRCC), Geetanjali University (Approval No: GU/HREC/EC/2024/2442 dated 29th April 2024). The study was performed in accordance with institutional ethical guidelines for laboratory-based experimental research. No human participants or animal subjects were involved in this study.

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