Digital Evaluation of Trueness and Precision of Modern Impression Materials in Implant-Retained Mandibular Overdentures

Keywords

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ABSTRACT

Introduction: The purpose of this in vitro study was to evaluate the dimensional accuracy, trueness, and precision of vinyl siloxane ether (VSXE) and polyvinylsiloxane (PVS) impression materials using different impression techniques. Material and Methods: A three-dimensional (3D) printed mandibular model with implants and metal rods served as the reference model. Impressions were taken in custom trays, resulting in four groups: PVS-closed-tray, VSXE-closed-tray, PVS-open-tray, and VSXE-open-tray. The reference model and impressions were scanned and analyzed using 3D analysis software to assess the trueness and precision within each group. Results: There was significant difference in trueness between the groups, with PVS closed tray showing a higher deviation than VSXE-closed-tray and PVS-open-tray. VSXE-open-tray had the lowest deviation, which was statistically significant. In terms of precision, PVS-closed-tray showed the highest deviation, while no significant differences were found among the other groups. Conclusions: VSXE impression material with an open tray technique consistently demonstrated the highest levels of accuracy and precision. Conversely, PVS impression material with a closed tray technique yielded less favorable results. Clinical relevance: Better understanding of trueness and precision of new impression materials with new impression techniques will increase their clinical effectiveness.

INTRODUCTION

The traditional complete denture is still the most popular choice for treating complete edentulism. However, it often fails to meet patient's expectations and is associated with several drawbacks, especially its lack of stability. On the other hand, fixed or removable implant prostheses have revolutionized the field, significantly improving oral function and quality of life, and are considered a more effective form of therapy.[1]

Implant-supported prostheses are considered as a valuable treatment option.[2,3] One of the key factors in ensuring the long-term success and durability of implant-supported prostheses is the precise and passive fit between the implant supra-structure and abutment, which significantly reduces the prosthetic complications.[4]

Lack of passivity can lead to biological and/or mechanical complications such as fracture of implant components, screw loosening, and occlusal inaccuracy. Therefore, it is critical to ensure a precise and passive fit to avoid such complications when fabricating supra-structures.[5,6] In order to achieve a passive fit in the fabrication of implant supra-structures, the first and most critical step is to obtain an accurate impression that accurately conveys the inter-implant relationship.[7] The accuracy of implant impressions is influenced by many factors including impression material and technique, splinting of the impression coping, impression level and depth, and implant angulation.[5,8–12] Therefore, great emphasis should be placed on the accuracy of implant impressions in terms of the technique and material used.[4]

The open and closed impression techniques are used to transfer the implant position to the working casts. Studies have consistently shown that the direct technique is more precise and accurate than the indirect method[13–16] while some other studies favor the indirect technique.[5,10,13,17,18] It has been proposed to use the direct technique with multiple angulated implants, while the indirect technique can be used in parallel or divergent, two-implant situations.[6] In addition, the indirect technique is often preferred by clinicians, especially when implants are located in the posterior region, when patients have a high tendency to gag or when intermaxillary arch space is insufficient for opening.[8]

Various impression materials have also been proposed for taking an impression.[19] The selection of an impression material for clinical use requires consideration of several properties, including strength, accuracy, tear resistance, elastic properties, and dimensional stability. Among these, polyvinyl siloxane (PVS) and polyether have been identified as preferred materials due to their superior performance and have been successfully used to record implant positions.[20] Numerous studies have been conducted to investigate the accuracy of polyvinyl siloxane and polyether impression materials for recording implant positions, but there is still a difference of opinion as to which material is more accurate when compared to others.[21]

Advances in materials science have led to the invention of a new impression material, that incorporates the hydrophilic properties of polyether and polyvinyl siloxane into a newer material, vinyl siloxane ether (VSXE). It combines some of the most desirable properties in a single material.[22] Studies on the new vinyl siloxane polyether material are few because it is new to the market. It has the advantage of reaching its final hardness immediately after setting and can form a chemical bond with polyvinyl siloxane. However, its accuracy needs to be further established.[22] The accuracy of the impression material is evaluated based on its trueness and precision. In the current study, trueness was defined as the linear shift of each reference point center between the reference model and the test groups, while precision was described as the degree of closeness between repeated measurements in the same group.[23]

The purpose of this *in vitro* study was to evaluate the dimensional accuracy in terms of trueness and precision of VSXE and PVS impression materials using two different impression techniques.

MATERIALS AND METHODS

SAMPLE SIZE CALCULATION

Sample size was calculated based on a previous study[24] using PS power software 3.6.1. The minimum sample size was determined to be 5 samples per group, if the response within each subject group was normally distributed with standard deviation of 0.025, the true mean difference was 0.12, when the power was 80%, and the type I error probability was 0.05.

STUDY GROUPS

The impressions were made with medium consistency regular set materials and the groups were categorized according to impressions technique as follows:

Group I: Polyvinyl siloxane impression material with closed tray impression technique (n=5)

Group II: Vinyl siloxane ether impression material with closed tray impression technique (n=5)

Group III: Polyvinyl siloxane impression material with open tray impression technique (n=5)

Group IV: Vinyl siloxane ether impression material with open tray impression technique (n=5)

REFERENCE MODEL PREPARATION AND SPECIAL TRAY CONSTRUCTION

A 3D printed edentulous mandible was selected as the reference model. A trial denture base with artificial teeth was constructed over the alveolar ridge to determine the position of the canines. Two 4 mm x 10 mm implants (IS-II Active, CMI implant system; Neobiotech, Seoul, Korea) were placed in the canine region, and multiunit abutments were secured with a torque of 30 Ncm and designated as the A and B reference points. Three cylindrical metal rods were inserted: one at the midline and two posteriorly on either side of the mandibular retromolar pads at the crest of the jaw, all parallel to each other and were designated as C, D, and E reference points as shown in Figure 1E.

A condensation silicone material was used to obtain an impression of the reference model, which was then poured with type IV dental stone (Dental Stone A Hard; Zeta Industriazingerdi, Italy) and allowed to set for 1 hour before being separated. A custom reference tray was constructed with auto-polymerized acrylic resin over the stone model, and 3 acrylic pillars were added to the outer surface of the tray as reference positioning points.

The mold of the reference tray was fabricated using a duplicating flask and silicone material. This mold was then used to fabricate 20 identical custom trays using auto-polymerized acrylic resin.

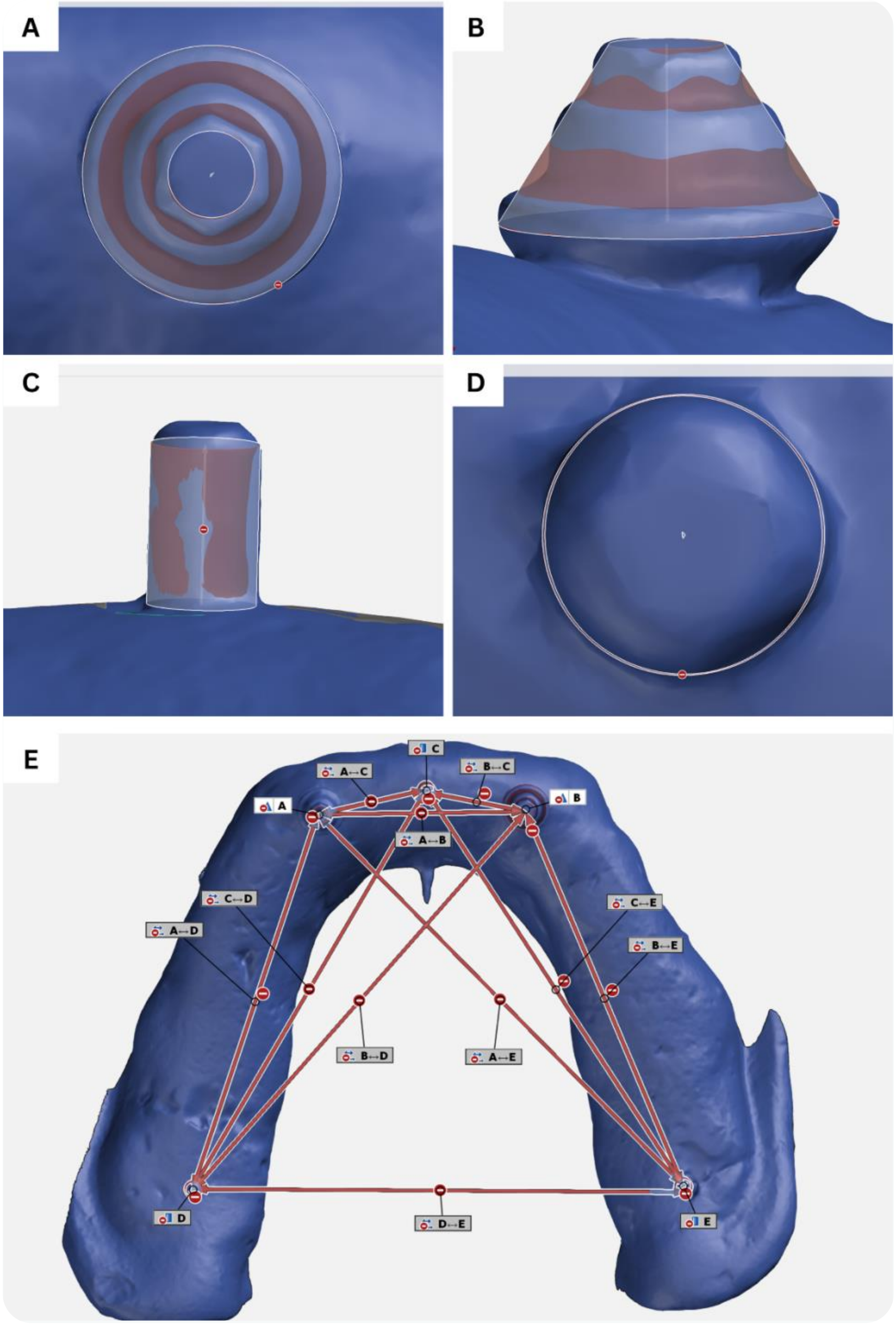

Figure 1: (A) Abutment defined by fitting cone option showing the center of the abutment in Z axis, (B) Fitting cone around abutment in X axis, (C) Metal rod defined by Fitting cylinder option around metal rod in X axis, (D) Fitting cylinder and the center of the metal rod in Z axis, (E) Reference model with reference points and the linear distances between them.

IMPRESSION MAKING

Impression Technique (Open and Closed Tray Impression Techniques)

For closed tray technique impressions, impression transfer copings were screwed onto multiunit abutments with a torque of 10 Ncm. An impression material cartridge was mounted on an auto-mixing device (PentamixTM 2; 3M ESPE AG, Seefeld, Germany), inserted into the tray, and placed over the reference model. The tray was then subjected to a continuous pressure of 22 psi at the reference positioning points using a hydraulic press.

For open-tray impressions, pick-up impression copings were screwed in place over the multiunit abutments and the same impression-taking steps were repeated.

Impression Making According to Impression Material Setting Time

To compensate for the difference in temperature and setting time between the oral cavity (37°C) and extraoral laboratory conditions (21°C ± 2°C), the PVS (Panasil monophase medium; Kettenbach GmbH & Co. Eschenburg, Germany) impression material cartridge (5:1; 380 ml) was allowed to set for 8 minutes which is twice the manufacturer's recommended setting time (4 minutes). While the VSXE (Identium medium; Kettenbach GmbH & Co. Eschenburg, Germany) impression material cartridge (5:1; 380 ml) was allowed to set for 9 minutes which is twice the recommended setting time (4 minutes and 30 seconds).[25]

All impressions were consistently taken by the same prosthodontist in the same controlled environment, with temperature maintained at 21°C, air pressure at 760±5 mmHg, and relative humidity at 45%.

SCANNING THE REFERENCE MODEL AND IMPRESSIONS

A uniform layer of an anti-reflective coating was applied to the multiunit abutments and reference points. A digital reference model was created using an optical desktop scanner (CS. NEO; CAD star GmbH, Bischofshofen, Austria). All impressions were then scanned in the laboratory using the same scanner, and the resulting scan data sets were exported in a binary Standard Tessellation Language (STL) file format.

DIGITAL EVALUATION OF IMPRESSIONS FOR TRUENESS AND PRECISION

The reference model STL file was imported into 3D analysis software (GOM Inspect 2021, Gom GmbH, Braunschweig, Germany) as a CAD body according to the manufacturer's instructions and aligned using the software's coordinate system to determine its X, Y, and Z axes.

In the Z plane, the multiunit abutment was digitally defined using the software's "fitting cone" option and the center of each abutment was then located and assigned as the letter A and B reference points as shown in Figure 1A and 1B.

In the X-plane, the software's "fitting cylinder" option was used to digitally define the three cylindrical metal rods, surrounding each individual cylinder. The software was then used to accurately determine the center of each cylinder, which were designated as reference points C, D, and E, as shown in Figure (1C and 1D). The lines between the reference points on the reference model were drawn using the software's "2-point distance" option as follows:

$\overline{AB}$, $\overline{AC}$, $\overline{AD}$, $\overline{AE}$, $\overline{BC}$, $\overline{BD}$, $\overline{BE}$, $\overline{CD}$, $\overline{CE}$, $\overline{DE}$ as shown in Figure 1E.

The impression STL file was imported as a mesh part according to the manufacturer's instructions and aligned with the reference model using the software's best-fit algorithm feature.

The edges of the impression material around each abutment and cylindrical metal rod were defined using the "fitting slotted hole" software option. The software was then used to digitally locate the center of each reference point and assigned letters as follows: Group I (A1, B1, C1, D1, E1), Group II (A2, B2, C2, D2, E2), Group III (A3, B3, C3, D3, E3), Group IV (A4, B4, C4, D4, E4) as shown in Figure (2A, 2B, 2C, 2D, 2E, and 2F).

The lines between the reference points of the impressions were drawn using the "2-point distance" software option in which Group I ($\overline{A1B1}$, $\overline{A1C1}$, $\overline{A1D1}$, $\overline{A1E1}$, $\overline{B1C1}$, $\overline{B1D1}$, $\overline{B1E1}$, $\overline{C1D1}$, $\overline{C1E1}$, $\overline{D1E1}$), Group II ($\overline{A2B2}$, $\overline{A2C2}$, $\overline{A2D2}$, $\overline{A2E2}$, $\overline{B2C2}$, $\overline{B2D2}$, $\overline{B2E2}$, $\overline{C2D2}$, $\overline{C2E2}$, $\overline{D2E2}$), Group III ($\overline{A3B3}$, $\overline{A3C3}$, $\overline{A3D3}$, $\overline{A3E3}$, $\overline{B3C3}$, $\overline{B3D3}$, $\overline{B3E3}$, $\overline{C3D3}$, $\overline{C3E3}$, $\overline{D3E3}$) and Group IV $\overline{A4B4}$, $\overline{A4C4}$, $\overline{A4D4}$, $\overline{A4E4}$, $\overline{B4C4}$, $\overline{B4D4}$, $\overline{B4E4}$, $\overline{C4D4}$, $\overline{C4E4}$, $\overline{D4E4}$) as shown in Figures 2C-F).

To evaluate trueness, the linear deviation, which represents the difference between a given line distance on the model and its equivalent on the impression, was automatically calculated by marking the two lines and measuring the difference in millimeters (mm). This process was repeated for all lines in both the model and the various impressions as shown in Figure (3A).

Precision is a statistical measure that quantifies the degree of similarity between repeated samples within the same group and was determined by calculating the linear deviations between individual measurements within each group, which provided an indication of the degree of variability or dispersion in the data as *(Figure 3B*). All data were collected, tabulated, and subjected to statistical analysis using an Excel spreadsheet.

STATISTICAL ANALYSIS

The methodology and results of the study were reviewed by an independent statistician. The investigators involved in all steps of the study were blinded. Researcher (A) was responsible for preparing the reference model, constructing the custom trays, and taking the impressions. Researcher (B) was responsible for reference model scanning, impression scanning, and digital measurements. Researcher (C) collected the data and submitted it to the statistical analyst while researchers (D) and (E) controlled and finalized the interpretation of the statistical analyses as well as critical revision, rewriting and editing of the manuscript. Data management and statistical analysis were performed using the statistical software package SPSS 20® (IBM SPSS Statistics, SPSS Inc, Chicago, Ill), Graph Pad Prism® (Graphpad Software, LLC, California, US), and Microsoft Excel 2016. The data were tested for normality using the Shapiro-Wilk test, and the results indicated that the data followed a normal distribution (parametric data) as the P value > 0.05, indicating a similarity to a normal bell curve. Comparison between different groups was performed by using one-way ANOVA test followed by Tukey's Post- hoc test for multiple comparisons.

RESULTS

TRUENESS EVALUATION

Comparison between different groups using one-way ANOVA test revealed significant differences in terms of linear deviation measured in millimeters (mm) ($p < 0.0001$). Post hoc comparisons using Tukey's test revealed that group I PVS closed tray (0.35 ± 0.03) had the highest deviation, which was significantly greater than that of group II VSXE closed tray (0.23 ± 0.05, $p < 0.0001$)

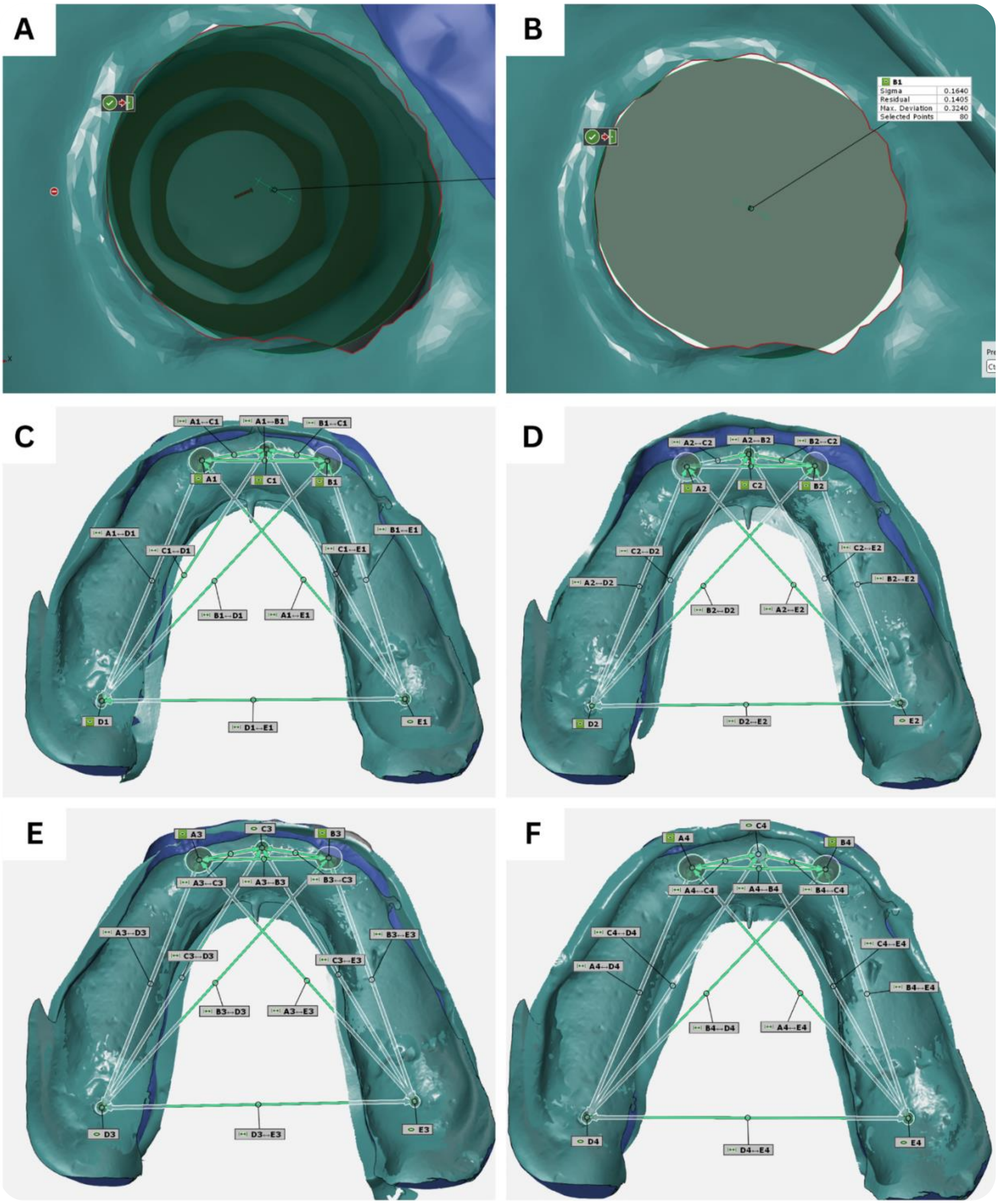

Figure 2: (A) The border of impression material (red line) around abutment on the fitting surface of the impression and the inner surface of the abutment, (B) Impression border was defined using fitting slotted hole option, (C) Reference points and linear distances between them in Group I, (D) Reference points and linear distances between them in Group II, (E) Reference points and linear distances between them in Group III, (F) Reference points and linear distances between them in Group IV.

group III PVS open tray (0.26 ± 0.02, p = 0.0007), and group IV VSXE open tray (0.17 ± 0.02, p < 0.0001) The differences between group II and group IV (p = 0.0273), group III and group IV (p = 0.0011) were statistically significant whilst the difference between group II and group III were insignificant (p > 0.05) *(Table 1, Figure 4)*.

PRECISION EVALUATION

Comparison between different groups using one-way ANOVA test showed a significant difference in terms of linear deviation measured in millimeters (mm) (p = 0.008). Post hoc comparisons using Tukey's test revealed that group I PVS closed tray (0.28 ± 0.08) had the highest deviation, which was

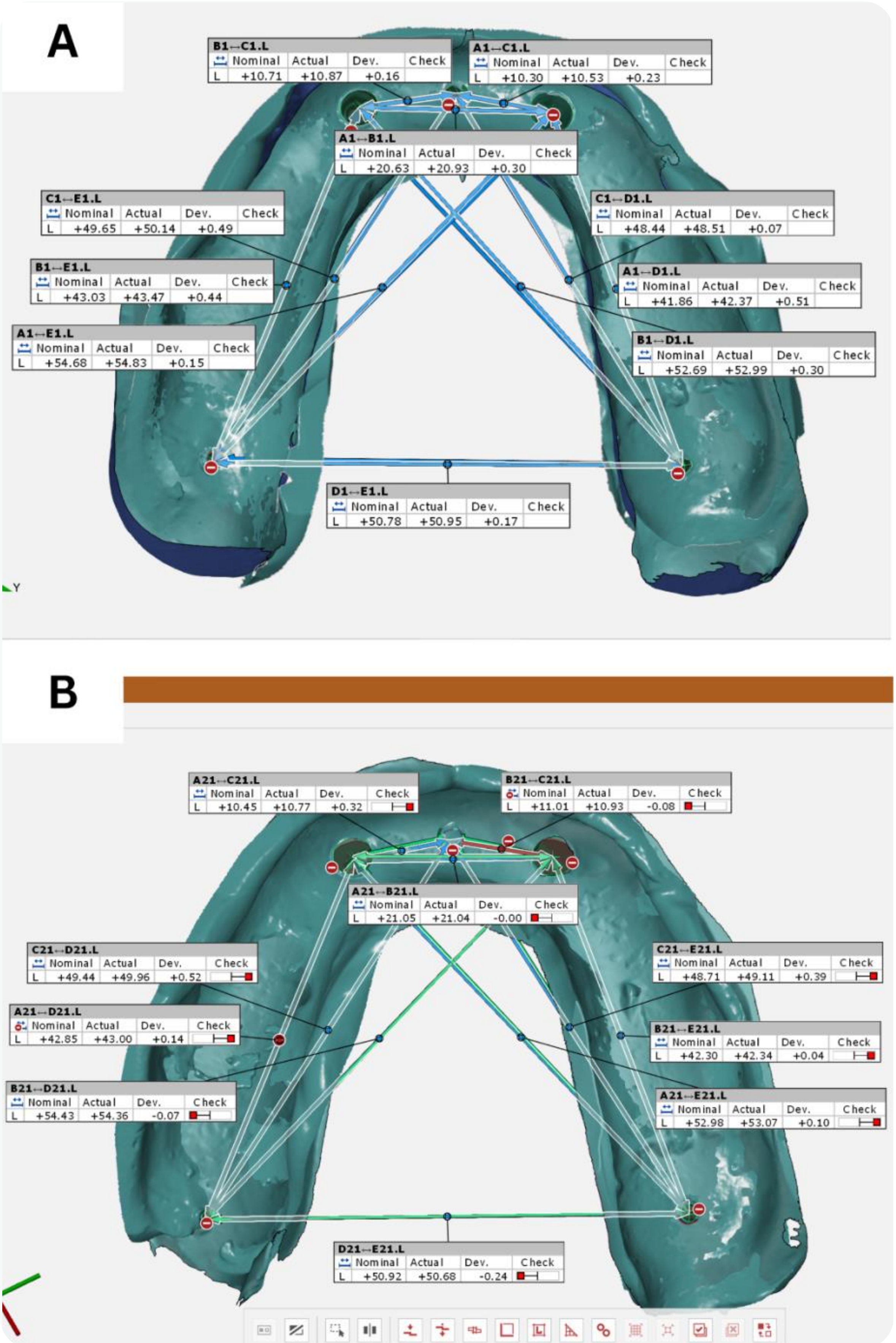

Figure 3: (A) The linear deviation between reference model and impression, (B) The linear deviation between two impressions of the same group.

Table 1. Comparison of linear deviation in millimeters for all groups in terms of trueness.

Multiple Comparison	Mean± SD	Mean Diff.	95.00% CI of diff.	P Value
Group I	0.35±0.03	0.124*	0.06987 to 0.1781	<0.0001
Group II	0.23±0.05			
Group I	0.35±0.03	0.094*	0.03987 to 0.1481	0.0007
Group III	0.26±0.02			
Group I	0.35±0.03	0.184*	0.1299 to 0.2381	<0.0001
Group IV	0.17±0.02			
Group II	0.23±0.05	-0.03	-0.08413 to 0.02413	0.4138
Group III	0.26±0.02			
Group II	0.23±0.05	0.06*	0.005867 to 0.1141	0.0273
Group IV	0.17±0.02			
Group III	0.26±0.02	0.09*	0.03587 to 0.1441	0.0011
Group IV	0.17±0.02			
p < 0.05				

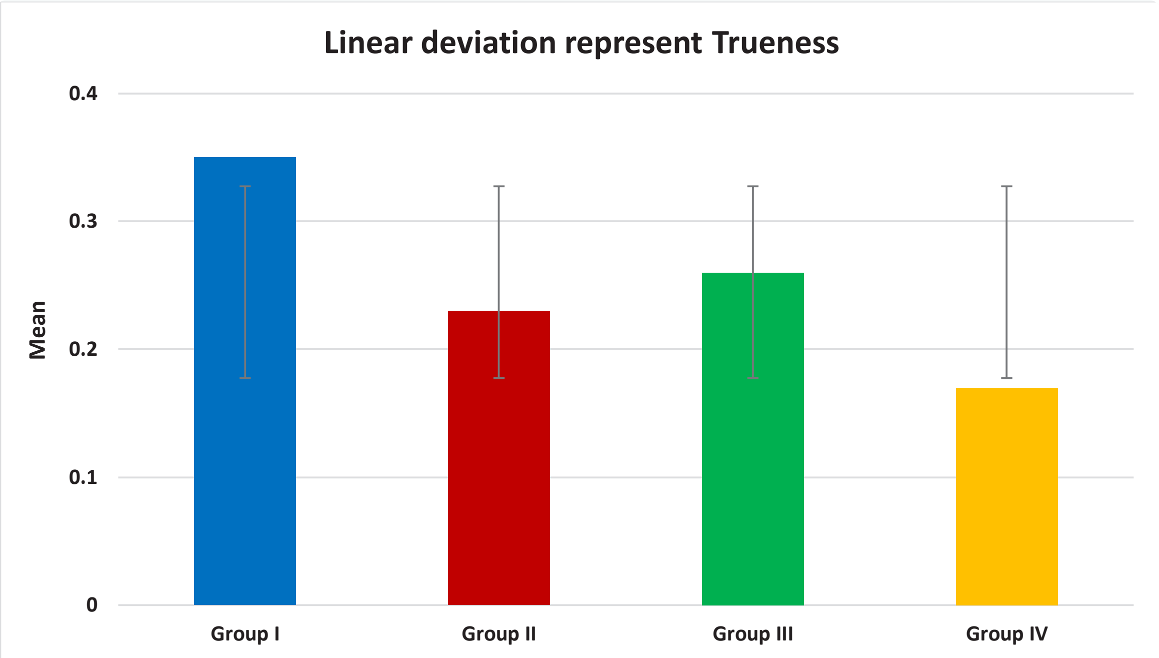

Figure 4: Bar chart showing linear deviation representing trueness of all groups.

significantly different from group II VSXE closed (0.13 ± 0.08, p = 0.0204), and from group IV VSXE open tray (0.11 ± 0.07, p = 0.0092) while all other pairwise comparisons presented insignificant difference (p > 0.05) *(Table 2, Figure 5)*.

DISCUSSION

The dimensional accuracy of an impression material is a critical factor in replicating oral soft and hard tissues and maintaining impression stability over time.[26] The material must exhibit low shrinkage during polymerization and maintain

Table 2. Comparison of linear deviation in millimeters for all groups in terms of precision.

Multiple Comparison	Mean± SD	Mean Diff.	95.00% CI of diff.	P Value
Group I	0.28±0.08	0.152*	0.02089 to 0.2831	0.0204
Group II	0.13±0.08			
Group I	0.28±0.08	0.114	-0.01711 to 0.2451	0.1003
Group III	0.17±0.05			
Group I	0.28±0.08	0.17*	0.03889 to 0.3011	0.0092
Group IV	0.11±0.07			
Group II	0.13±0.08	-0.038	-0.1691 to 0.09311	0.8398
Group III	0.17±0.05			
Group II	0.13±0.08	0.018	-0.1131 to 0.1491	0.9787
Group IV	0.11±0.07			
Group III	0.17±0.05	0.056	-0.07511 to 0.1871	0.6225
Group IV	0.11±0.07			

$p < 0.05$

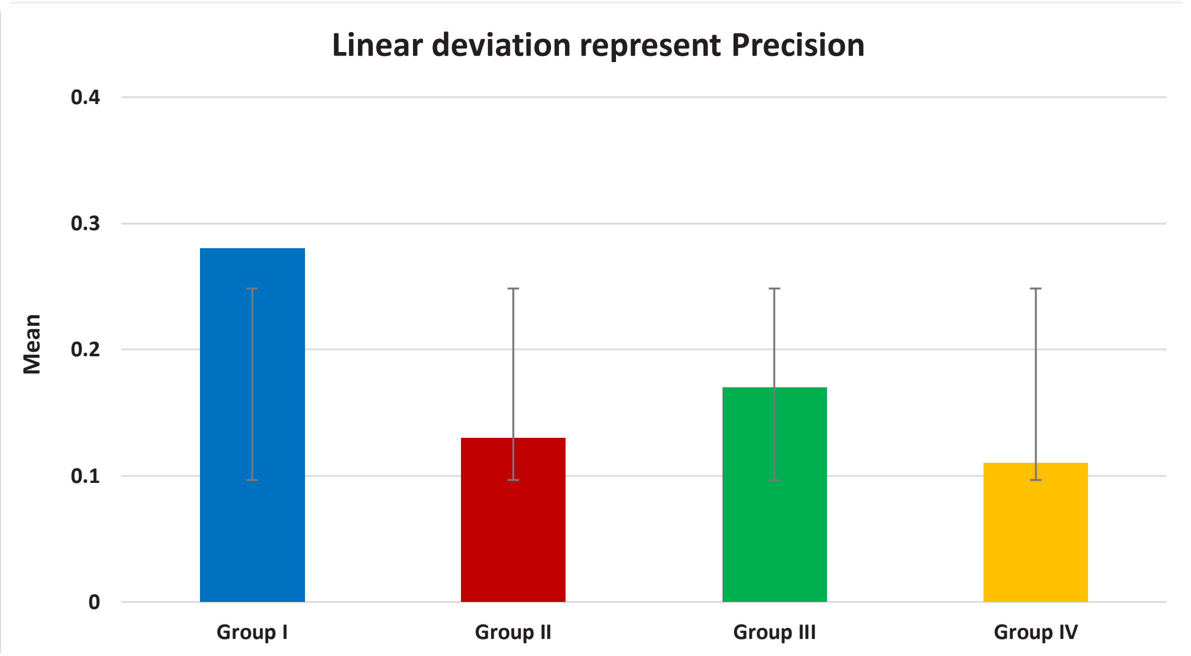

Figure 5: Bar chart showing linear deviation representing precision of all groups.

its stability to allow the impression to be poured for several days.[27] The accuracy of an impression depends on several factors, including chemical composition, setting reactions, by-product formation, and disinfection.[28,29]

The purpose of this study was to evaluate the dimensional accuracy in terms of trueness and precision of VSXE and PVS impression materials using two different impression techniques. A 3D-printed edentulous mandibular model was used to simulate a clinical situation, and the use of a multiunit abutment has the advantage of eliminating the increased contact area between the impression copings and the internal connection of the implants. This, in turn, reduces impression material deformation and movement of the copings during removal and transfer and neutralizes the effect of implant angulation on the impression accuracy.[20]

Custom-made trays with three acrylic pillars were used to ensure a uniform thickness of the impression material and to facilitate an even load distribution, which improves accuracy and reduces permanent deformation.[30–32] Both impression materials were formulated with a medium viscosity to provide a firmer impression, which resulted in better stability and adaptation of the impression copings, as well as improved penetration of the retention grooves of the impression copings.[33,34] To ensure accuracy; scanning and measurements were performed directly on the impression material, thus eliminating any potential discrepancies associated with the expansion of the stone material during the impression casting process.[35]

The extraoral scanner utilized in the study used a three-dimensional (3D) laser scanning method. Such a 3D laser scanner can define x, y, and z coordinates from the impression without touching the surface. It automatically tracks the coordinates with precision and stores the data as a number of points on the surface. The laser scanner measures the dimensions of dental impression materials precisely and accurately while avoiding subjective errors.[36] The integration of digital software in the calculation of linear deviation has increased the accuracy and speed of the calculations. A study had suggested that the distance between two objects could be minimized by using the iterative closest point (ICP) algorithm in the alignment procedure.[37] ICP is an algorithm that minimizes the difference between two sets of points, and is often used to reconstruct 2D or 3D surfaces from multiple scans for optimal path planning.[38]

Another study reported that the ICP algorithm can reduce errors in dental impressions.[39] The software superimposes the two objects by registering landmarks that serve as a reference surface and determines the best fit between their surfaces, the difference between the two surfaces is calculated between each point on one object surface and another object surface within a 0.5 mm range.[36]

The most commonly used implant impression techniques are open and closed tray impressions. A systematic review of impression techniques used in fully edentulous patients with implant-supported restorations showed that open tray impressions provided better accuracy than closed tray impressions.[40] The closed tray technique was found to be less accurate than the open tray technique, regardless of the impression material used. This is likely due to the distortion of the impression material around the abutment area during impression removal. In contrast, the open tray technique maintains the accuracy and integrity of the material by preventing potential movement of the impression copings during impression removal.[41]

The results of the present study showed that Group I (PVS closed tray) had the highest mean deviation value of 0.35 mm, while Group IV (VSXE open tray) had the lowest mean deviation value of 0.17 mm when comparing the trueness among the four groups. The precision results showed no significant difference between Group IV (VSXE open tray) with a mean value of 0.11mm and Group II (VSXE closed tray) with a mean value of 0.13 mm. These findings are consistent with an *in vitro* study conducted by Shankar *et al.*[42] that evaluated the accuracy of open and closed tray impression techniques using three different impression materials: PVS, polyether, and VSXE, on angulated implants. The study concluded that the VSXE impression material produced more accurate casts compared to PVS and PE. In addition, Khan *et al.*[43] found that VSXE impression material and open nonsplinted technique produced the most accurate replication of implant positions on the master cast, which is consistent with the results of the present study. Another study conducted by Hussein[44] evaluated several impression materials, including PVS, polyether, and VSXE. The objective of the study was to evaluate their accuracy using digital linear measurements and 3D surface analysis. The results showed that VSXE exhibited a remarkable ability to accurately reproduce surface details, while PVS had the lowest level of accuracy among the impression materials studied. These findings are consistent with the results of the present study.

In a study conducted by Vojdani *et al.*[45] to evaluate the effect of impression materials and implant angulations on the accuracy of impressions in both parallel and nonparallel implant conditions, the study found that the choice of impression material did not significantly affect the accuracy of implant impressions in parallel conditions. However, in nonparallel conditions, PVS emerged as the preferred option in terms of accuracy, followed by VSXE and polyether, respectively. In contrast, the present study observed a significant influence of both impression material and technique on the accuracy of impressions in parallel implant conditions. One other study by Siadat *et al.*[46] found that VSXE impressions had higher accuracy than PVS impressions. The study suggested VSXE as the material of choice for both closed and open tray impression techniques. This preference was attributed to VSXE's superior tensile strength and improved flow properties, which provide distinct advantages over other impression materials.

From a clinical standpoint, Enkling N *et al.*[14] found that VSXE has the advantage of good legibility, which allows for quick assessment of impression quality and identification of the need for a new impression. In addition, Stober *et al.*[28] conducted a study demonstrating that both monophase VSXE impressions and dual-viscosity VSXE impressions had acceptable levels of accuracy for clinical use with immersion disinfection. The study also showed that the accuracy of VSXE impressions was comparable to that of polyether and PVS material groups. In contrast, Schaefer *et al.*[47] concluded that PVS exhibited the highest accuracy, followed by VSXE and polyether.

According to the present study, all materials tested met and complied with ADA Specification No. 19, which recommends a maximum dimensional change of 0.5% after a minimum of 24 hours. In addition, the materials met the ISO 4823 specification, which allows for a dimensional change of less than 1.5%. These results are consistent with previous studies that have reported similar results.[28,48,49] The results of the present study showed that group IV (VSXE open tray) had the lowest deviation compared to group I (PVS closed) which had the highest deviation. This difference can be attributed to the higher tear strength and tear energy values, as well as the superior dimensional accuracy of VSXE compared to PVS.[50]

The tear energy of a material is an indication of its ability to resist tearing in thin interproximal areas and the depth of the gingival sulcus. This property is influenced by factors such as the chemical composition, consistency, and method of removal of the material.[50] Pandey *et al.*[51] observed that VSXE exhibited high tensile energy, which favored the removal of impressions and impression copings from the model without tearing or distortion. However, while PVS has the best elastic recovery which is a critical factor in determining the accuracy of an impression material, it has a lower tear strength which makes it more susceptible to tearing during removal from the model. Therefore, the tear strength and elastic recovery of a material should be balanced to achieve optimal impression accuracy.

The impression materials were tested under dry conditions without the use of disinfectant solutions in this study, which may not accurately reflect the clinical scenario. Future research should evaluate the effect of saliva or blood on the accuracy and properties of the impression materials. In this study non-parallel implant conditions were not analyzed. Thus, further studies are needed to investigate these conditions.

CONCLUSION

In terms of trueness and precision, the use of vinyl siloxane ether material and open tray technique exhibited superior results than polyvinyl siloxane material and closed tray technique.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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