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Dimensional Accuracy of Corrected Vinyl Polysiloxane Impressions with Localized Finish-Line Defects: An *In vitro* 3D Digital Analysis

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Abstract: Background: Accurate impression-making is essential for fixed prosthodontic success. Although conventional vinyl polysiloxane (VPS) impressions remain widely used, localized voids along the preparation finish line can compromise restoration fit, frequently necessitating full remakes. Clinicians often repair these defects using light-body VPS but data validating this approach are scarce. This study aimed to evaluate the dimensional accuracy of corrected VPS impressions featuring localized voids using three-dimensional (3D) digital analysis. **Materials and Methods:** Twenty VPS impressions were fabricated and allocated to a control group (n = 10) and a corrected group (n = 10) containing standardized 1-mm and 2-mm finish-line defects. The control group consisted of impressions made from a defect-free prepared mandibular first molar. The corrected group was generated using a standardized die incorporating both a 1 mm defect at the Mid-Buccal (MB) finish line and a 2 mm defect at the Mid-Lingual (ML) finish line. Following impression-making, the defects were repaired using a standardized light-body VPS corrective technique. Each corrected specimen therefore contributed measurements from both defect locations. All impressions were digitally scanned and converted into STL files. Dimensional accuracy was assessed by three-dimensional superimposition against a reference die and deviations were quantified at the MB and ML finish-line locations. **Results:** Three-dimensional superimposition demonstrated high agreement between the corrected impressions and the reference die, with overall deviations ranging from 3 to 6 µm. At the MB location, the corrected-control mean difference was 0.15 µm (95% CI, -0.37 to 0.67; P = 0.553; Hedges' g = 0.26). At the ML location, the mean difference was 0.43 µm (95% CI, -0.18 to 1.04; p = 0.157; Hedges' g = 0.63). No statistically significant difference was detected between the groups at either location. **Conclusion:** Within the limitations of this *in vitro* study, localized correction of small impression voids using light-body VPS produced dimensional outcomes comparable to those of defect-free impressions under the experimental conditions evaluated. However, the available evidence is insufficient to establish equivalence or clinical interchangeability.

Key Words: Impression Materials, Digital Scanning, Dimensional Accuracy

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INTRODUCTION

Impression-making represents one of the foundational cornerstones of fixed prosthodontics. Accurate replication of the abutment preparation is critical to ensure the marginal fit, functional adaptation and long-term prognosis of indirect restorations, including crowns, fixed partial dentures and implant-supported prostheses. Any dimensional discrepancy introduced during this initial phase can propagate throughout subsequent laboratory workflows, leading to compromised marginal integrity, accelerated plaque accumulation, secondary periodontal inflammation and the ultimate failure of the definitive restoration [1,2].

Conventional impression materials are broadly classified into non-elastic and elastic categories. Hydrocolloids, including reversible agar and irreversible

alginate, possess limited elastic properties and are primarily reserved for diagnostic applications. Conversely, synthetic elastomeric materials are preferred for definitive impressions due to their superior accuracy and dimensional stability. Among these elastomers, vinyl polysiloxane (VPS) has long retained its status as the gold standard in fixed prosthodontics. This material is highly favoured for its exceptional physical properties, including excellent elastic recovery, high dimensional stability and superior tear resistance, particularly within restricted anatomical regions such as interproximal spaces and undercuts [3,4].

In recent years, advances in digital dentistry and intraoral scanning technologies have rapidly gained prominence in dental practice. Nevertheless, conventional impression techniques continue to be widely employed owing to their accessibility, cost-effectiveness and well-documented clinical reliability [5-7]. However, conventional techniques remain inherently technique-sensitive and are susceptible to procedural errors, including void formation, air entrapment and material tearing during impression removal.

The formation of voids within critical regions, particularly along the finish line, represents a prevalent and clinically relevant complication of conventional impression procedures. An investigation evaluating 1,157 impression samples reported marginal voids in 24% of cases [8], whereas the overall prevalence of impression defects, including voids, air entrapment and tearing, has been reported to range from 92-96% [9]. Upon cast fabrication, these negative defects may be reproduced as positive nodules that interfere with the accurate reproduction of the preparation margins and potentially compromise restoration fit. Multiple factors contribute to void formation, including clinical variables such as moisture contamination and temperature fluctuations, material-related factors such as hydrophobicity, viscosity and polymerization behaviour and operator-dependent variables including mixing technique, tray loading and seating pressure [10,11].

Traditionally, impressions containing defects in critical areas are remade entirely. However, complete impression remakes increase chairside time, material consumption and patient inconvenience [12]. Consequently, clinicians frequently attempt to correct localized defects through the application of additional light-body VPS material. Although the corrective relining of impression defects has been widely adopted in clinical practice, the available evidence has primarily focused on impression defects in general rather than the dimensional consequences of repairing localized defects. Furthermore, limited information exists regarding the accuracy of correcting small finish-line voids and whether defect size influences the outcome of the corrective procedure.

Digital scanning and three-dimensional (3D) superimposition techniques have enhanced the assessment of dental impressions by enabling highly sensitive and objective evaluations of surface deviations [13-17]. Similar digital approaches have also been applied to compare dimensional accuracy among modified conventional impression techniques, demonstrating the utility of three-dimensional analysis for impression research [22]. Previous *in vitro* studies employing these methodologies have suggested that surface discrepancies below approximately 20 µm may be associated with acceptable levels of reproduction accuracy in digitally assessed dental models [18]. However, this threshold should be interpreted as a reference value for dimensional deviation reported in previous digital analyses rather than as definitive evidence of clinical acceptability for all measurement methods or clinical situations. Therefore, the dimensional deviations observed in the present study were interpreted primarily through direct comparison between corrected and defect-free impressions.

To date, there is limited evidence specifically evaluating the dimensional accuracy of correcting localized finish-line voids measuring 1 mm and 2 mm using light-body VPS material. Moreover, it remains unclear whether void size affects the accuracy of the corrected impression when assessed using contemporary 3D digital analysis techniques. Hence, the aim of the current study was to assess the accuracy of the corrected impression technique by applying a controlled amount of light-body VPS material to localized voids and evaluating the effect of different void sizes (1 and 2 mm) on dimensional accuracy using a three-dimensional (3D) digital analysis method. The formulated null hypothesis was that no statistically significant difference exists in dimensional accuracy between corrected impressions and conventional, defect-free impressions, regardless of the void size.

METHODS

Study Design and Ethical Approval

This *in vitro* investigation evaluated the dimensional accuracy of a corrective impression technique for managing localized impression defects in fixed prosthodontics. Ethical approval for the study protocol was obtained from the Research Ethics Committee of the Faculty of Dentistry, King Abdulaziz University (Approval No. 190-11-19).

Tooth Preparation

A standardized full-coverage metal crown preparation was performed on a plastic mandibular left first molar model (#36, KaVo). To simulate clinical conditions, preparation was completed under copious water irrigation using a high-speed handpiece. Axial and occlusal reductions were accomplished with a medium-grit round-end tapered diamond bur (ISO 016). The final preparation incorporated a circumferential chamfer finish line with a uniform depth of 1 mm and an occlusal reduction of 1.5-2.0 mm.

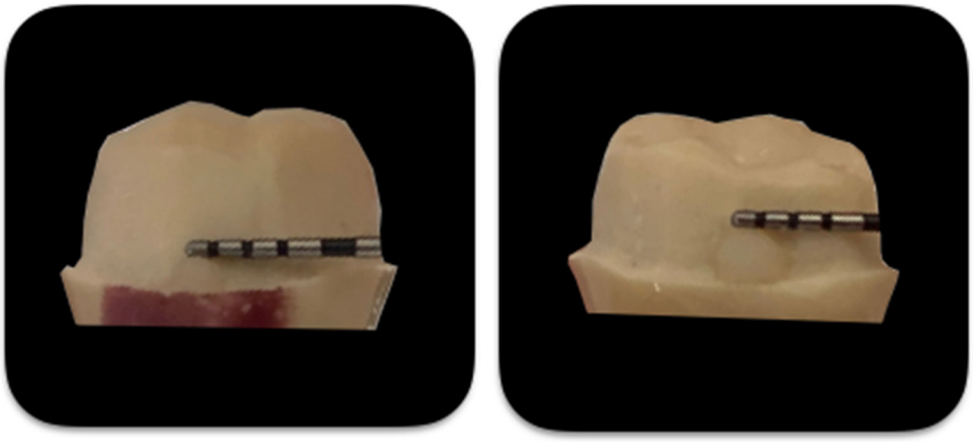


Figure 1: Tooth Preparation with Composite Bulge to Simulate Size of 1×1 mm and 2×2 mm Voids Located Mid-Buccally and Mid-Lingually on the Finish Line

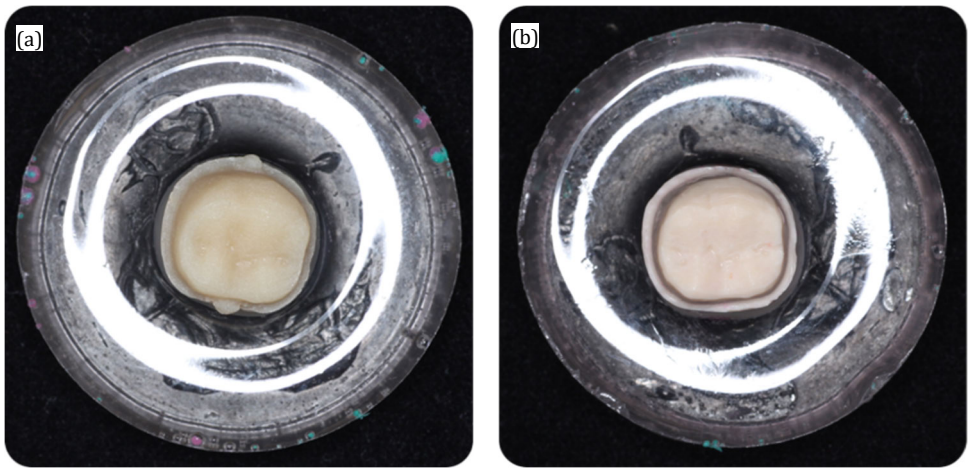


Figure 2(a-b): (a) Acrylic Replica with Void Sizes of 1 and 2 mm at the Mid-Buccal and Mid-Lingual Locations, Respectively (Die 1) and (b) Defect-Free Prepared Plastic Tooth (Die 2)

Simulation of Voids on the Finish Line

Standardized defect formers were fabricated using a packable micro-hybrid composite resin (Filtek Universal Restorative; 3M ESD, St. Paul, MN, USA) to simulate localized voids occurring at the preparation margin. Two spherical composite projections with nominal diameters of 1 mm and 2 mm were fabricated and positioned at predetermined locations along the finish line: Mid-Buccal (MB) and Mid-Lingual (ML), respectively (Figure 1).

The dimensions of the composite projections were initially established using a Williams periodontal probe and subsequently verified with digital caliper measurements (accuracy ±0.01 mm) prior to bonding. For the purpose of standardization, the reported dimensions represent the maximum diameter of each spherical projection. The spheres were bonded using a seventh-generation self-etch adhesive system (Single Bond Universal; 3M ESD) and served as standardized defect formers for the experimental phase.

Standardized Acrylic Replica Fabrication

To ensure reproducibility of the preparation geometry and defect dimensions, a replica of the prepared plastic tooth containing the composite defect formers was fabricated using a silicone matrix and an autopolymerizing acrylic resin powder-liquid system. The resulting acrylic die containing the 1-mm and 2-mm spherical projections was designated as Die 1 and was used to generate impressions containing standardized marginal defects.

Following fabrication of Die 1, the composite projections were carefully removed from the original prepared plastic tooth to create a defect-free preparation. This preparation was designated as Die 2 and served as the reference die throughout the study (Figure 2).

Custom Mold Fabrication

To provide structural stability during impression making and scanning procedures, each reference die was

embedded individually within a standardized silicone matrix measuring 3 cm in diameter. The matrix was fabricated using addition silicone putty (Aquasil; Dentsply Sirona) mixed according to the manufacturer's instructions. A stable mounting base was subsequently produced using clear epoxy resin (Graffiti Resin) mixed at a 2:1 ratio and allowed to polymerize for 24 h at room temperature.

Experimental Workflow

The experimental workflow consisted of the following sequential steps:

- Preparation of a standardized mandibular first molar crown preparation
- Fabrication of Die 1 containing standardized 1-mm and 2-mm defect formers at the mid-buccal and mid-lingual finish-line locations
- Fabrication of Die 2 without defect formers, which served as the defect-free reference die
- Production of ten conventional VPS impressions using Die 2 (control group)
- Production of ten VPS impressions using Die 1 to generate standardized impression defects
- Correction of the defects in each impression using a standardized light-body VPS relining procedure
- Digital scanning of all impressions and generation of STL files
- Three-dimensional superimposition of all scanned impressions against the reference die (Die 2) for dimensional analysis

Impression Procedure

All experimental procedures were performed by a single calibrated investigator to minimize operator-related variability. The study consisted of two groups (n = 10 per group), resulting in a total of 20 impressions: Control Group (n = 10): Die 2 (defect-free preparation) was used as the impression-making substrate. Ten conventional impressions were fabricated using vinyl polysiloxane (VPS) impression material. These impressions represented defect-free impressions without marginal defects and served as the control group. Corrected Impression Group (n = 10): Die 1, containing the standardized 1-mm and 2-mm defect formers, was used to produce impressions exhibiting localized defects. Ten impressions were fabricated using the same VPS protocol. The resulting impressions contained standardized negative voids corresponding to the defect formers positioned at the MB and ML finish-line locations.

Each defective impression was subsequently corrected using the corrective impression technique. Following correction, the modified impressions constituted the corrected impression group and were subjected to digital analysis. All impressions were fabricated using vinyl polysiloxane (VPS) impression materials in light-body and medium-body consistencies (Hydrorise; Zhermack, Badia Polesine, Italy). A two-phase, one-step impression technique was employed according to the manufacturer's instructions. Medium-body VPS was dispensed into a circular plastic mold simulating an impression tray, while light-body VPS was simultaneously syringed around the prepared tooth to record fine marginal detail. The material was allowed to polymerize for 6 min before retrieval. For the corrective procedure, a standardized quantity of light-body VPS material was delivered to each defect location using the same disposable syringe tip, ensuring complete filling of the defect area without overextension. Any excess material extruded beyond the defect margins upon reseating was removed immediately prior to polymerization. The corrected impression was reseated onto Die 2 using a standardized manual seating procedure performed by the same operator until complete polymerization. Die 2 was used during the correction procedure because it represented the defect-free reference preparation geometry. This allowed the corrective material to adapt to the intended preparation contours without interference from the defect formers present on Die 1. The same correction protocol, material type, application method *and* setting time were used for all specimens to ensure procedural standardization (Figure 3).

Digital Scanning and 3D Data Acquisition

Following polymerization, all 20 impressions were digitized using a laboratory optical scanner (E3 Scanner; 3Shape, Copenhagen, Denmark). The scan data were processed using 3Shape Dental System software to generate three-dimensional surface meshes in Standard Tessellation Language (STL) format. Die 2 served as the reference model for all digital comparisons. STL files generated from both the control and corrected impression groups were imported into CloudCompare software (Version 2.10.2) and superimposed onto the STL file of the reference die using a best-fit alignment algorithm.

Dimensional discrepancies between each test specimen and the reference model were quantified through color-coded deviation maps (heat maps) expressed in micrometres (µm). Positive and negative deviations were identified and analysed at the predefined measurement sites corresponding to the mid-buccal and mid-lingual finish-line locations. Standardized sectioning and measurement tools within the software were used to ensure consistent and reproducible quantitative evaluation across all specimens.

Sample Size Consideration

This study was conducted as an *in vitro* pilot investigation to evaluate the dimensional accuracy of a corrective vinyl polysiloxane (VPS) impression technique under standardized experimental conditions. A total of 20 impressions were evaluated, with 10 specimens allocated

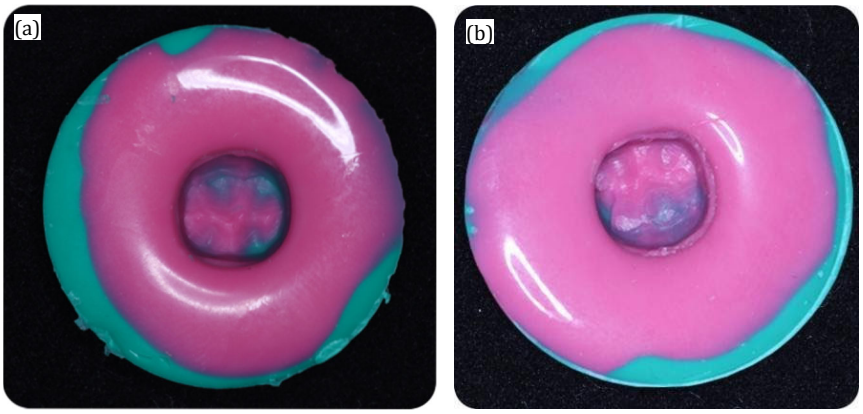


Figure 3(a-b): (a) Sample of the Control Impression and (b) Sample of the Corrected Impression

Table 1: Descriptive Statistics for the 3D Deviation Measurements for Each Location, Mid-Buccal (MB) with Void Size 1 mm and Mid-Lingual (ML) with Void Size 2 mm

Group	Sample size (n)	Mean (µm)	Standard deviation±(µm)	Minimum value (µm)	Maximum value (µm)
Conventional impression (Control, Die 2)	10	4.27	0.65	3.19	5.16
Corrected impression (Mid-buccal, Die 1)	10	4.42	0.44	3.77	5.10
Conventional impression (Control, Die 2)	10	4.41	0.68	3.23	5.21
Corrected impression (Mid-lingual, Die 1)	10	4.84	0.62	4.10	6.10

to the control group and 10 specimens allocated to the corrected impression group. The selected sample size was consistent with previously published laboratory-based studies investigating impression accuracy and dimensional discrepancies in fixed prosthodontics. The findings of this study provide preliminary data regarding the performance of the corrective impression technique and may serve as a foundation for the design of future investigations involving larger sample sizes and broader statistical validation.

Experimental Unit

The individual impression was considered the experimental unit. Each specimen in the corrected group contained both the 1 mm mid-buccal defect and the 2 mm mid-lingual defect and dimensional deviations were evaluated separately at the two predefined locations within the same impression. Accordingly, measurements obtained from the MB and ML sites originated from the same specimen but represented distinct predefined assessment locations.

Statistical analysis

For each specimen, CloudCompare software generated color-coded heat maps and descriptive parameters, including the mean, standard deviation, minimum deviation and maximum deviation. Descriptive analyses were performed to characterize dimensional accuracy across all specimens. Prior to inferential analysis, data were evaluated for compliance with the assumptions of normality and homogeneity of variance. Comparisons among the study groups were performed using One-way analysis of variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) post hoc test for pairwise comparisons. Mean differences and their 95% Confidence Intervals (CIs) were calculated. Hedges' *g* was calculated as the bias-corrected standardized effect size. Statistical significance was established at $\alpha = 0.05$.

RESULTS

Qualitative Analysis (Heat Map Evaluation)

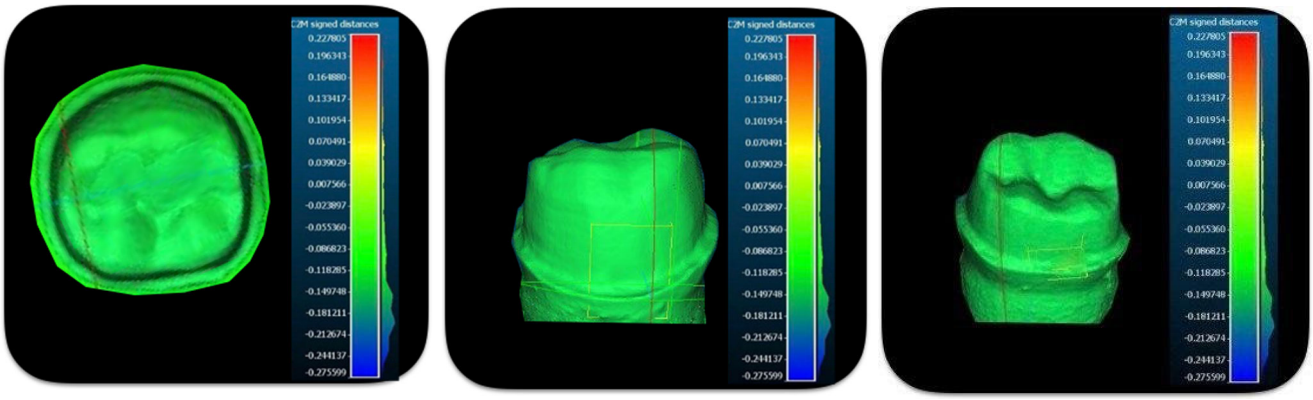
Three-dimensional quantitative assessments of the color-coded deviation maps indicated a high level of agreement between the corrected impressions and the reference die. The majority of the superimposed corrected surfaces at the standardized mid-buccal and mid-lingual locations fell within the green zone, demonstrating minimal volumetric deviation. (Figure 4) illustrates the superimposition of the corrected and control impressions against the reference die. The recorded deviations ranged from 3-6 µm, confirming the high dimensional accuracy of the corrected impressions.

Quantitative 3D Deviation Analysis

Descriptive statistics for the three-dimensional (3D) deviation measurements at the mid-buccal (MB; 1 mm void) and mid-lingual (ML; 2 mm void) locations are presented in Table 1. At the MB location, the mean deviation was 4.27±0.65 µm for the control group and 4.42±0.44 µm for the corrected group, corresponding to a corrected-control mean difference of 0.15 µm (95% CI, -0.37 to 0.67; $p = 0.553$). At the ML location, the respective mean deviations were 4.41±0.68 µm and 4.84±0.62 µm, with a mean difference of 0.43 µm (95% CI, -0.18 to 1.04; $p = 0.157$). The corresponding Hedges' g values were 0.26 at the MB location and 0.63 at the ML location (Table 2).

Table 2: Between-Group Comparisons of 3D Deviation Measurements at the MB and ML

Location	Mean difference (µm)	95% CI	p-value	Hedges' *g*
MB (1 mm void)	0.15	-0.37 to 0.67	0.553	0.26
ML (2 mm void)	0.43	-0.18 to 1.04	0.157	0.63



The control sample

1 mm void in corrected impression group (Mid-Buccal)

2 mm void in corrected impression group (Mid-Lingual)

Figure 4: Colour Coded Heat Maps for Scanned Impression of the Control Impression (Occlusal View) and Corrected Impression (Buccal and Lingual View)

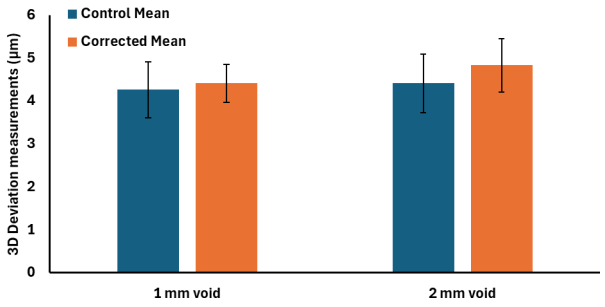


Figure 5: Mean 3D Deviation Measurements (µm) for the Control and Corrected Impression Groups at the Mid-Buccal (1 mm Defect) and Mid-Lingual (2 mm Defect) Locations

Error bars represent standard deviations (SD)

No statistically significant difference was detected between the control and corrected groups at either measurement location. Figure 5 presents the mean 3D deviation measurements for both groups at the MB and ML locations.

DISCUSSION

This *in vitro* study evaluated the accuracy of a corrective impression technique involving the addition of a controlled amount of light-body vinyl polysiloxane (VPS) material to standardized void sites. The effect of void size (1 and 2 mm) at the mid-buccal and mid-lingual aspects along the finish line of a prepared crown was assessed. Accuracy was determined by comparing the corrected impressions with a reference die using three-dimensional (3D) digital superimposition analysis.

The results demonstrated that the corrected impressions exhibited dimensional deviations comparable to those observed for the conventional defect-free impressions, with no statistically significant differences detected between the groups ($p>0.05$). These findings support the null hypothesis and suggest that, under the controlled laboratory conditions of the present study, the localized correction of voids using light-body VPS material did not result in detectable adverse effects on dimensional accuracy within the range of defect sizes evaluated. However, it should be noted that the absence of a statistically significant difference does not, by itself, establish equivalence or non-inferiority between the corrected and control impressions. Rather, the findings indicate that no measurable differences were identified under the study conditions.

The high level of agreement observed between the corrected impression specimens and the reference die may be attributed to the favorable physical properties of VPS materials, including adequate flow characteristics, superior elastic recovery and excellent dimensional stability [3,4,11]. When correcting localized voids along the finish line, these properties may facilitate adaptation of a small quantity of light-body material into the defect area during reseating while minimizing distortion. The deviation values observed in the present study (3-6 µm) were substantially lower than the dimensional discrepancies reported in previous digital analyses of impression accuracy [18], indicating a high degree of dimensional similarity between the corrected and reference datasets. Nevertheless, such dimensional agreement should not be interpreted as direct evidence of clinical performance, as outcomes such as restoration fit, remake rates or long-term success were not evaluated in the present investigation.

Previous studies employing digital scanning and three-dimensional (3D) superimposition methods have

demonstrated the usefulness of these techniques for evaluating impression accuracy and dimensional discrepancies among dental impressions [13-17]. Furthermore, several investigations utilizing digital analytical methods have demonstrated the reproducibility and sensitivity of these approaches for evaluating impression accuracy compared with conventional assessment techniques [5,14].

Evidence regarding corrective or relining impression techniques remains limited. Bomberg and Hatch reported that the need for remaking defective impressions could be reduced when addition silicone materials were used to selectively correct localized defects [19]. Similarly, Gullett and Podshadley described practical advantages associated with corrective relining procedures, including reductions in material usage and chairside time [12]. Historical studies evaluating relined elastomeric impressions have also suggested that correction of minor defects has minimal influence on dimensional accuracy [20].

The findings of the current study are consistent with this body of evidence, as no statistically significant differences were observed between the corrected and corresponding control impressions at either defect location. Within the limitations of the present experimental model, these results suggest that correction of localized defects produced dimensional outcomes similar to those of defect-free impressions when assessed by digital superimposition. The favorable flow properties of light-body VPS may facilitate reproduction of fine marginal details in confined areas while minimizing the development of internal stresses that could contribute to distortion [1,3].

The selection of VPS as the corrective material was based on its well-documented properties, including high elastic recovery, tear resistance, dimensional stability and ability to reproduce fine surface details [3]. Previous investigations assessing the two-phase, one-step impression technique also reported no statistically significant differences in accuracy compared with the two-step technique when VPS materials were used, further supporting the methodological approach adopted in the present study [6,21]. The digital workflow employed in this investigation, comprising scanning with the E3 scanner followed by analysis using CloudCompare software, provided a reliable and reproducible approach for assessing impression accuracy. Similar digital analytical workflows have been successfully employed in previous investigations evaluating dimensional accuracy among modified impression techniques [22]. Nevertheless, factors such as mesh resolution, tessellation patterns and surface topography may influence digital analyses and should be considered when interpreting the findings [14,16]. Nedelcu et al. demonstrated that geometric variations may be influenced by the software algorithms and processing methods used during digital data acquisition and analysis [15].

The color-coded deviation maps generated through digital superimposition provided both quantitative and qualitative information regarding the relationship between the scanned specimens and the reference die. This approach offers a level of visualization and analytical sensitivity that is difficult to achieve using conventional inspection methods alone [5]. Moreover, three-dimensional evaluation facilitates identification of localized discrepancies that might not be apparent through traditional assessment techniques, thereby contributing to a more comprehensive analysis of impression accuracy.

The predominance of green areas within the heat maps indicated a high degree of correspondence between the corrected and control impressions. These findings suggest that localized correction of minor voids using light-body VPS can produce dimensional results similar to those obtained from defect-free impressions under controlled laboratory conditions. Previous work by Gullett et al. reported that corrective relining procedures reduced material consumption by 22.22 g and shortened treatment time by approximately 7.6 minutes compared with complete impression remakes [12]. Although such observations highlight potential practical benefits, the present study was not designed to evaluate clinical outcomes. Therefore, conclusions regarding clinical acceptability, restoration fit, treatment success or long-term performance cannot be drawn from the current findings.

CONCLUSIONS

Within the limitations of this *in vitro* study, localized correction of small VPS impression defects using light-body material may represent a practical approach under controlled laboratory conditions. However, the findings are insufficient to establish equivalence or clinical interchangeability with defect-free impressions. Further studies specifically designed to assess equivalence under clinically relevant conditions are required.

Limitations

Several limitations should be considered when interpreting the results. This investigation was conducted under controlled laboratory conditions using a single operator, a single standardized tooth preparation, one VPS impression system and a limited number of defect locations restricted to the mid-buccal and mid-lingual finish-line regions. In addition, the experimental model did not incorporate common clinical variables such as saliva, blood, gingival crevicular fluid, moisture contamination, patient-related factors or variations in soft-tissue management and intraoral access [8,9]. Consequently, while the study design allowed standardization and reduction of confounding factors, it does not fully replicate the complexity of the oral environment. Additionally, the dimensional deviations measured in the present study were derived from a digital

scanning workflow and may have been influenced by scanner-related and software-related measurement uncertainty inherent to the data acquisition and processing procedures. Future *in vivo* studies involving a broader range of clinical conditions, defect configurations, operators and impression systems are therefore required to validate the applicability of this corrective impression protocol in routine clinical practice.

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