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ORIGINAL ARTICLE

Initial effect of dental loupe use on laminate veneer preparation accuracy: an in vitro 3D digital assessment

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Abstract

This study evaluated the initial effect of dental loupe use on the 3D accuracy of laminate veneer preparations performed by prosthodontic specialty residents under standardized in vitro conditions. Twenty-six residents completed two maxillary right central incisor (#11) typodont preparations using a within-participant fixed-order protocol (unaided vision followed by loupes). Prepared specimens were scanned, anonymized, and compared with a criterion reference preparation using Geomagic Control X–based 3D metrology analysis. The primary 3D accuracy outcome was root mean square (RMS) deviation across five regions of interest: the full prepared surface, cervical, middle, and incisal thirds, and a 0.5-mm marginal band. Average signed deviation (Avg) was used as a secondary descriptive measure to characterize the direction of preparation errors. No statistically significant differences were found between loupe-assisted and unaided preparations for RMS outcomes (all $p > 0.05$). Avg analysis showed a similar directional pattern under both conditions, with a tendency toward over-reduction in the cervical, middle, and marginal regions and under-reduction in the incisal region. Within the limitations of this in vitro study, immediate loupe introduction without an extended adaptation period did not significantly improve RMS-based laminate veneer preparation accuracy compared with unaided vision. In addition, Avg analysis showed no clear change in the directional pattern of preparation errors.

Keywords Dental loupes · Optical magnification · Laminate veneer · Tooth preparation · 3D metrology · Average signed deviation · RMS deviation

Introduction

Porcelain laminate veneers are widely used for achieving esthetic improvement with a conservative treatment approach [1–3]. Compared with full-coverage crowns, veneer preparation removes far less sound tooth structure [3, 4]. However, clinical performance depends on marginal integrity and internal adaptation, and excessive marginal gaps can increase microleakage and secondary caries [5, 6]. For reliable bonding, keeping the preparation within enamel is critical, while dentin margins may be harder to seal completely [7, 8]. These requirements make veneer preparation technically sensitive, especially at the margin and finish line [9]. In this context, preparation quality is multifactorial and relies on the integration of visual control, manual dexterity, tactile perception, and instrument mastery [10]. Because veneers are thin and lack a true mechanical retention mechanism, they may be more susceptible to fracture and debonding [11]. At the same time, human visual resolution is limited, and discrepancies below approximately 0.2 mm may be difficult to detect consistently without magnification [12]. Loupes typically provide moderate magnification in routine practice, whereas operating microscopes offer higher magnification ranges [13]. Loupe systems vary in optical design (e.g., Galilean vs. prismatic/Keplerian) and magnification level [12, 14]. Their proposed effects

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are frequently discussed in relation to procedural accuracy, quality, and ergonomics [14–16]. Without magnification, clinicians may move closer to improve visibility, which can worsen posture and increase musculoskeletal strain [17]. In addition, magnification may facilitate fine-detail tasks during restorative procedures, including detecting irregularities and refining margins [18]. Magnification has also been discussed as potentially helpful for diagnostic tasks and careful restorative procedures, although some procedure-related effects remain uncertain [19, 20]. Although magnification is widely used, stronger evidence is still needed to confirm its consistent benefits for restorative preparation performance [16, 18]. Importantly, quality assessment also varies by scoring strategy, rater expertise, and measurement tools, ranging from direct inspection to digital/imaging-based approaches [16]. Preclinical simulation settings may facilitate adaptation to magnification devices before clinical use while enabling standardized evaluation of preparation performance under controlled conditions [15, 21]. In this setting, objective and reproducible outcome measures can support feedback and comparison across learners and reduce reliance on subjective assessment [22]. Since proper training and guidance have been recommended for loupe use [23], it is important to evaluate whether immediate loupe introduction affects preparation accuracy under standardized preclinical conditions. This may help guide educational and assessment strategies [23]. More recently, preparation quality has been evaluated objectively using 3D digital assessment in dedicated analysis software [24, 25]. Deviations between a reference and a test model are commonly expressed as RMS values [26]. However, these measurements may vary across software platforms because alignment and distance-calculation methods differ [24, 27]. For this reason, metrology-grade software is generally preferred in dental research, and ISO: 12836 recommends the use of metrology-grade platforms such as Geomagic Control X for 3D analysis after digitization [28]. In this preclinical study, veneer preparations performed with loupe assistance and without magnification were compared using a standardized and reproducible 3D deviation analysis against a semi-digital reference preparation model. The null hypothesis was that loupe magnification would not affect preparation accuracy.

Materials and methods

Study design and participants

This in vitro study used a within-participant repeated-measures design with a fixed condition order. All participants first performed the preparation under unaided vision, followed by the loupe-assisted condition. A randomized or counterbalanced sequence was not used because the study aimed to assess the immediate use effect of loupe introduction rather than the effect of long-term habituated or trained loupe use. Because participants were not routine loupe users and no adaptation period was provided, placing the loupe-assisted condition first could have introduced carryover effects into the subsequent unaided condition.

To reduce short-term practice and fatigue effects, participants received standardized instruction and calibration, completed one non-recorded warm-up preparation, and observed a 15–20-minute rest interval between the two experimental preparations. Nevertheless, because the loupe-assisted condition was always performed second, residual order-related effects, including familiarization or fatigue, could not be completely excluded and should be considered when interpreting the findings.

Twenty-six volunteer prosthodontic specialty residents were included in the study. All participants had completed at least 1 year of specialty training and had previous exposure to fixed prosthodontic tooth preparation procedures during their residency training. Previous exposure to dental loupes was assessed by self-report at enrollment. None of the participants were routine loupe users, defined as loupe use in at least 50% of clinical procedures during the preceding 3 months. An a priori power analysis for the within-participant paired design was performed using G*Power software (version 3.0.10). The analysis indicated that a sample size of 26 participants would provide 80% power to detect a moderate standardized paired effect size ($d = 0.55$) at a two-tailed α level of 0.05.

Specimens and operative protocol

Preparations were performed on standardized maxillary typodont teeth (FRASACO ANA-4; Frasaco GmbH, Tettnang, Germany) mounted in a phantom model under standardized preclinical simulation conditions. The test tooth was the maxillary right central incisor (#11) (Fig. 1A). A new unused tooth was used for each experimental preparation. Before the experimental phase, participants reviewed the target preparation criteria on a prepared exemplar tooth and received standardized visual instructions to standardize the intended preparation geometry. One non-recorded warm-up preparation was then completed on an additional tooth of the same type. Each participant subsequently performed two experimental preparations in the predetermined order (unaided vision followed by loupe magnification), separated by a 15–20-minute rest interval. Preparations were carried out using a high-speed air-turbine handpiece (NSK; Nakanishi Inc., Tokyo, Japan) operated according to the manufacturer's specifications (320,000–400,000 rpm)

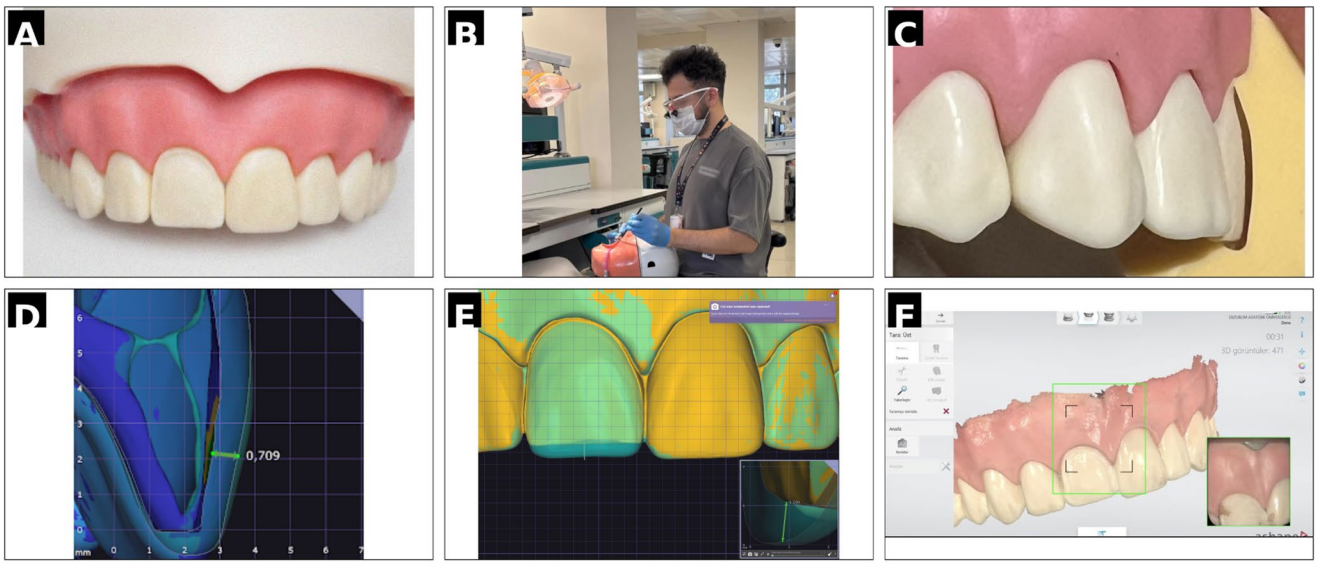

Fig. 1 **A** Maxillary central incisor (#11) typodont tooth after veneer preparation. **B** Participant performing the veneer preparation under standardized preclinical simulation conditions. **C** Preparation depth/contour control using a silicone index. **D**, **E** Digital reference model verification and refinement in exocad. **F** Intraoral scanning of the prepared tooth using 3Shape TRIOS 5

under continuous water spray to simulate clinical cutting conditions, limit heat generation, reduce airborne debris, and maintain a clear cutting field (Fig. 1B).

Magnification and instrumentation

In the magnification condition, 2.5× Galilean loupes (Quick Loupes; Univet, Brescia, Italy) with a fixed working distance of 400 mm were used [23]. Operatory illumination was provided by the phantom-unit light; no loupe-mounted light was used. To minimize bur-wear as a confounder, a new set of diamond burs (Ecoline; D+Z, Kalletal, Germany) was provided before each cutting procedure (i.e., each preparation was started with an unused bur set). The same bur sequence was followed in both conditions. Preparation targets (both conditions) were selected within commonly reported laminate veneer preparation ranges and consistent with in vitro protocols that vary preparation depth [29, 30]. Targets were: regional labial reduction of 0.5 mm (cervical), 0.7 mm (middle), and 1.0 mm (incisal); a 0.5-mm chamfer finish line; 1.0-mm incisal reduction with a standardized butt-joint design; proximal extension without breaking contact; and a smooth, homogeneous surface with mildly convergent and symmetrical axial walls [29, 30].

Reference preparation (criterion standard)

A single standardized reference preparation was created using a dual-expert workflow to reduce single-operator bias. The preparation was performed by an experienced prosthodontist under the real-time supervision of a senior prosthodontist, following a predefined checklist that included regional reduction targets, chamfer form, incisal reduction, and proximal extension. The reference preparation was finalized after operator–supervisor consensus and approval by the supervising faculty member. A silicone index was used throughout to control reduction and finish-line geometry (Fig. 1C).

The approved reference preparation was scanned (TRIOS 5; 3Shape, Copenhagen, Denmark), exported as an STL file, and imported into exocad (exocad GmbH, Darmstadt, Germany) for digital verification and refinement. Cross-sectional analysis and color-map–based distance checks were used to identify deviations from the target reduction, and areas with excessive or insufficient reduction were digitally adjusted before exporting the final reference STL file. (Fig. 1D, E). A single reference was used so that all participant preparations could be compared with the same criterion standard, thereby reducing reference-related variability. This semi-digital approach was preferred because it preserved a clinically oriented preparation while allowing digital verification. The final criterion-compliant STL file was then exported for deviation comparisons.

Finishing/polishing, scanning, and blinding

Before scanning, finishing and polishing were standardized to minimize surface-related scanning variability, because surface finishing has been reported to influence intraoral scanner accuracy [31]. Finishing and polishing were performed using a diamond-impregnated rubber polisher (OptraGloss HP; Ivoclar Vivadent, Schaan, Liechtenstein).

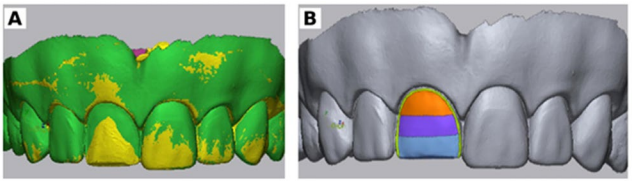

Fig. 2 3D superimposition and ROI definition. **A** Initial alignment and ICP best-fit using the premolar-to-premolar stable region. **B** ROIs: full prepared surface, cervical, middle, and incisal thirds, and a standardized marginal band along the finish line

One calibrated operator polished each specimen with a slow-speed handpiece at 10,000 rpm for 30 s under light pressure in wet conditions.

All specimens were scanned with the same TRIOS 5 unit by a single operator using a standardized scan path (Fig. 1F). To ensure reliable registration on stable anatomy, an additional premolar-to-premolar scan was acquired for each specimen (as shown in Fig. 2A). STL files were anonymized and randomly coded (e.g., 01 A/01B to 26 A/26B) so that filenames did not indicate the condition. The coding list was held by an independent researcher. The examiner performing the metrology steps remained blinded throughout the Geomagic Control X (Hexagon AB, Stockholm, Sweden) procedures.

Alignment, ROI definition, and 3D outcomes

Three-dimensional analysis was performed in Geomagic Control X using a standardized superimposition protocol. The premolar-to-premolar segment was used as the stable alignment region (Fig. 2A), and the prepared surface of tooth #11 was excluded to avoid artificially minimizing preparation differences. Alignment consisted of an initial coarse alignment followed by iterative closest point (ICP) best-fit alignment within the same stable region (convergence tolerance ≤ 0.01 mm; sampling ratio 100%; maximum iterations 100). To reduce operator- and workflow-related variability, all alignment procedures were performed by the same engineer using the same software, devices, and predefined analysis settings throughout the study.

In the present study, 3D accuracy was defined primarily by root mean square (RMS) deviation, which reflects the magnitude of surface deviation between the test and reference preparations. Because RMS does not indicate whether the deviation represents over-reduction or under-reduction, average signed deviation (Avg) was additionally used as a secondary descriptive measure to characterize the direction of preparation errors. RMS values were calculated across five regions of interest (ROIs): the full prepared surface, cervical, middle, and incisal thirds, and a standardized marginal band along the finish line (Fig. 2B). Color deviation maps were generated to support visual interpretation of the deviation patterns. Following alignment, 3D Compare analysis was used to calculate point-to-surface deviations between the test and reference models. The arithmetic mean of signed deviations was recorded as Avg. Negative Avg values indicated over-reduction, whereas positive Avg values indicated under-reduction relative to the reference model.

The labial surface was divided into cervical, middle, and incisal thirds by trisecting the inciso-gingival distance from the most apical finish-line point to the incisal edge and generating two planes perpendicular to the long axis. The finish line was traced for marginal analysis, and a standardized marginal band was evaluated. For each ROI, RMS and Avg values were calculated, and corresponding color deviation maps were generated; representative maps from different specimens are shown in Fig. 3A–D. All ROI definitions and 3D outcome extractions were performed under the same standardized workflow conditions to ensure consistency across specimens.

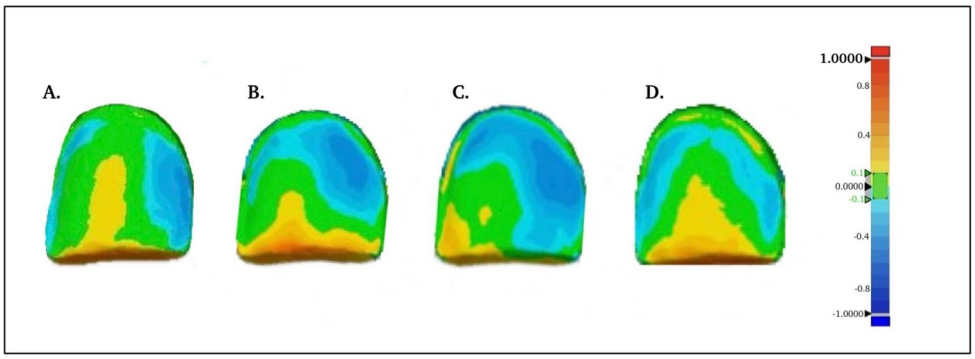

Fig. 3 Representative 3D color deviation maps **A–D** of four specimens after best-fit superimposition to the reference model. The maps show deviation patterns, while RMS values provide quantitative comparison. In the color scale, warm colors (yellow to red) indicate positive deviations, meaning that the test preparation is located outside or above the reference surface, whereas cool colors (light to dark blue) indicate negative deviations, meaning that the test preparation is located inside or below the reference surface. Green indicates values close to zero deviation

Table 1 Results of the paired t-test for differences in RMS deviation values

Outcome	Mean difference	Std. deviation	Std. error mean	95% confidence interval of the difference		t	df	*P* value
				Lower	Upper			
Marginal (unaided - loupe)	−0.0003769	0.0078782	0.0015450	−0.0035590	0.0028051	−0.244	25	0.809
Overall (unaided - loupe)	−0.0074192	0.0576320	0.0113026	−0.0306973	0.0158588	−0.656	25	0.518

Table 2 Results of the Wilcoxon signed-rank test for RMS deviation values

Region	Z	*P* value
Cervical (unaided − loupe)	−0.417	0.677
Middle (unaided − loupe)	−0.292	0.770
Incisal (unaided − loupe)	−1.499	0.134

Table 3 Median, minimum, and maximum RMS deviation values (mm) for each region and condition

Region		Median	Minimum	Maximum	*N*
Cervical area	Unaided	0.026550	0.0008	0.1596	26
	Loupe	0.025850	0.0192	0.0535	26
Middle area	Unaided	0.025300	0.0010	0.0397	26
	Loupe	0.024750	0.0197	0.0359	26
Incisal area	Unaided	0.094750	0.0048	0.1598	26
	Loupe	0.118500	0.0295	0.1596	26
Marginal area	Unaided	0.025000	0.0020	0.0326	26
	Loupe	0.024200	0.0184	0.0390	26
Overall	Unaided	0.141350	0.0263	0.2235	26
	Loupe	0.155700	0.0565	0.2168	26

Table 4 Results of the Kruskal–Wallis test for inter-operator comparison of RMS deviation values

	Unaided	Loupe
Chi-square	27.737	13.797
df	25	25
P value	0.320	0.965

Statistical analysis

The data were statistically analyzed using IBM SPSS Statistics (v20.0; IBM Corp). Normality was assessed using the Kolmogorov–Smirnov test. For paired comparisons, the paired-samples t-test was used for normally distributed variables and the Wilcoxon signed-rank test for non-normally distributed variables. Effect sizes were calculated for all paired comparisons. Inter-operator differences under the loupe and no-loupe conditions were assessed using the Kruskal–Wallis test. The significance level was set at $\alpha = 0.05$.

Results

The paired-samples t-test and Wilcoxon signed-rank test showed no statistically significant differences between the loupe-assisted and unaided conditions for any RMS-based outcome, including the overall, marginal, cervical, middle, and incisal measurements (Tables 1 and 2; $p > 0.05$). Descriptive statistics for all regions and conditions are presented in Table 3. In addition, the Kruskal–Wallis test showed no statistically significant between-operator differences under either the loupe-assisted or unaided condition (Table 4; $p > 0.05$). Overall, immediate loupe introduction did not demonstrate a statistically significant improvement in RMS-based preparation accuracy. To complement the RMS findings, directional deviation was descriptively assessed using average signed deviation (Avg) values (Table 5). Avg values showed a similar pattern under both conditions, with a tendency toward over-reduction in the cervical, middle, and marginal regions and under-reduction in the incisal region. These directional patterns were consistent with the primary RMS-based finding that immediate loupe introduction did not demonstrate improved preparation accuracy compared with unaided vision.

Table 5 Descriptive statistics of average signed deviation (Avg) values (mm) according to region and preparation condition

Region		Mean	Std. deviation	Minimum	Maximum	*N*
Cervical area	Unaided	−0.004296	0.0128093	−0.0662	0.0008	26
	Loupe	−0.001738	0.0017855	−0.0082	−0.0001	26
Middle area	Unaided	−0.000200	0.0016666	−0.0047	0.0029	26
	Loupe	−0.000238	0.0008809	−0.0019	0.0018	26
Incisal area	Unaided	0.010981	0.0160660	−0.0379	0.0459	26
	Loupe	0.02096	0.0166711	−0.0018	0.0544	26
Marginal area	Unaided	−0.000665	0.0014993	−0.0041	0.0020	26
	Loupe	−00.000588	0.0010045	−0.0032	0.0010	26
General	Unaided	−0.029700	0.0246135	−0.0787	0.0050	26
	Loupe	−0.013900	0.0169417	−0.0471	0.0164	26

Negative Avg values indicate over-reduction, whereas positive Avg values indicate under-reduction relative to the reference model

Discussion

Magnification loupes are increasingly used in dental practice. However, their effects on tooth preparation performance remain inconsistent, especially when different outcome measures are applied. This study evaluated whether immediate use of 2.5× magnification affects veneer preparation quality among prosthodontic specialty trainees in a standardized preclinical simulation setting. Based on objective digital RMS deviations relative to a standardized reference tooth, loupe use did not improve veneer preparation quality. Therefore, the null hypothesis was not rejected. Several factors may explain this finding. The participants were prosthodontic specialty trainees who routinely performed tooth preparations under unaided vision, which suggests a high baseline level of hand–eye coordination and three-dimensional perception. When baseline performance is already high, additional measurable differences may be difficult to detect, especially when outcomes are expressed as a single overall metric, even if visibility subjectively changes. Moreover, because loupes were not part of the participants' routine practice and no structured training or meaningful adaptation period was provided, enhanced visual detail may not have translated into more accurate three-dimensional reduction, especially in a procedure such as veneer preparation that requires continuous three-dimensional control. Importantly, the potential order effect should also be considered. Task familiarization may have improved performance in the second condition. In contrast, fatigue from repeated procedures may have reduced performance. These findings are consistent with previous studies [18, 32–35]. Eggmann et al. [18] suggested that 2.5× loupes may improve performance in relatively simple tasks. However, such a potential effect was not demonstrated in the present study and may be less evident when tasks require greater three-dimensional control. Such control is essential in veneer preparation. Murbay et al. [32] also reported no significant improvement with 2.5× loupes in different preparation contexts using quantitative digital evaluation. This suggests that a measurable loupe advantage may remain absent, even when tooth location and preparation type vary. Ge and Liu [33] showed that perceived efficiency or self-rated performance can improve, while objective digital accuracy remains unchanged. This finding highlights the importance of objective metrics when evaluating performance outcomes. Taken together, these findings suggest that any measurable impact of loupes was not demonstrated under the present immediate-use conditions and may depend on structured training, repeated practice, and an adequate adaptation period. Accordingly, the study was powered to detect moderate differences in RMS deviation, and smaller effects cannot be excluded. Thus, the practical implication is not that dental loupes are ineffective, but that measurable accuracy-related improvements may require adaptation and training, which were not evaluated in the present study. In contrast, some studies have reported improvements with loupe use under different conditions. Braga et al. [15] found that, in preclinical students with early instruction and extended practice, loupe use was associated with better performance. This indicates that loupe-related gains are more likely when magnification is introduced as a trained skill rather than a simple visual aid. Similarly, preclinical simulation studies using standardized measurements have reported improved precision among routine magnification users, which suggests that prior experience and adaptation may influence whether measurable effects are observed [36] Overall, these findings suggest that potential loupe-related effects are determined not only by optical factors but also by factors related to the user, training conditions, and assessment methods. These include who uses magnification, for how long, the type of instruction and feedback, and the outcomes used to evaluate performance. Although ergonomic outcomes were not assessed in the present study, loupes have been reported to be associated with improved posture and reduced neck flexion, even without measurable gains in preparation quality [34]. Magnification has been reported to be useful for visually demanding tasks, particularly those that require less training [37]. However, higher levels of magnification may alter visual perception and, in some diagnostic contexts, increase false-positive findings [38]. More broadly, new technologies often involve a learning curve, and loupes are no exception. During initial use, transient discomfort may occur, particularly in trainees with reduced visual acuity, underscoring the need for guided training and an adaptation period [39, 40]. In the loupe-assisted group, median RMS values were consistently low across the cervical, middle, and marginal regions, remaining within approximately 24–26 µm, indicating a stable and controlled preparation pattern in these areas. However, the incisal region demonstrated substantially higher deviation values (≈118 µm) along with a wider range of variation, suggesting greater difficulty in achieving consistent reduction in this area. Notably, similar RMS values were observed when compared with the unaided group across most regions. When interpreted in the context of the literature, mean RMS deviations below 50 µm have been reported to fall within clinically acceptable limits and have also been used as a reference tolerance in previous studies [41, 42]. However, these proposed thresholds are not supported by objective clinical criteria and should therefore be interpreted with caution. In this context, the observed differences in RMS values between loupe-assisted and unaided preparations were minimal, ranging from approximately 0.0005 to 0.023 mm (≈0.5–23 µm), indicating that loupe use did not result

in a meaningful improvement in preparation accuracy under the tested conditions. To complement the RMS findings, directional deviation was descriptively evaluated using Avg values, which reflect the direction of error. A similar pattern was observed under both conditions, with over-reduction in the cervical, middle, and marginal regions and under-reduction in the incisal region. Overall, these descriptive Avg patterns were in agreement with the main RMS-based findings. This suggests that magnification did not influence the directional characteristics of preparation errors. Clinically, over-reduction may lead to unnecessary loss of tooth structure, increased risk of pulpal irritation, potential crack formation, and reduced mechanical resistance of the tooth. In contrast, under-reduction in the incisal region may result in insufficient material thickness, compromised esthetics, and reduced fracture resistance [43, 44]. Limitations should be considered. Preparations were performed in a phantom model under controlled in vitro conditions that do not replicate key clinical variables (e.g., saliva, soft tissues, restricted access, and patient movement); therefore, the findings should not be directly extrapolated to clinical settings. Participants were prosthodontic specialty residents with no routine use of magnification; thus, the results may not be applicable to operators experienced in veneer preparation under magnification. Only a single magnification system (2.5× Galilean loupes with a fixed working distance) was evaluated, and the findings may not generalize to other magnification levels, optical designs, or working distances. The study assessed only the immediate effect of loupe introduction without structured training or adaptation; therefore, the results do not represent long-term use following adequate training. In addition, the fixed sequence may have introduced an order effect despite a 15–20-minute rest interval, and measurement repeatability was not formally assessed. Accordingly, the findings should be interpreted within the context of initial, untrained exposure to 2.5× magnification under controlled preclinical conditions and not generalized beyond these parameters. Further research should also compare different magnification levels and optical designs while incorporating structured training, ergonomic guidance, and defined adaptation periods to reduce first-use effects. In addition, digital workflows for reference-tooth generation and objective evaluation should be optimized, and AI-assisted methods may support greater standardization and efficiency. Finally, video-recorded workflows may help identify procedural differences and error patterns, thereby supporting targeted training and clarifying whether and under which conditions loupes may provide measurable advantages.

Conclusions

Within the limitations of this in vitro, within-participant repeated-measures study, immediate use of 2.5× Galilean dental loupes did not significantly improve RMS-based laminate veneer preparation accuracy under standardized preclinical simulation conditions, based on objective 3D RMS deviation analysis across the predefined regions of interest. Descriptive Avg findings showed a similar directional pattern under both conditions. These findings suggest that initial dental loupe use, without structured training and an adequate adaptation period, may be insufficient to yield measurable improvements in preparation accuracy under similar preclinical conditions.

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Author contributions Qassam Jaghoub: conceptualization, methodology, investigation, data curation, and writing—original draft; Esra Nacar: conceptualization, methodology, investigation, data curation, and writing—original draft; Alper Özdoğan (Corresponding Author): formal analysis (statistical analysis), validation, supervision, and writing—review and editing; Mohammad Kamel: conceptualization, methodology, investigation, data curation, and writing—review and editing.

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Data availability Data will be made available on request.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval This research project was approved by the Ethics Committee of the Faculty of Dentistry, Atatürk University (Decision/Approval No. 73; 14 August 2025). Written informed consent was obtained from all participating residents prior to participation.

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