

Restorative Treatment and Marginal Integrity in Patients with Non-Carious Cervical Lesions: Analysis of a Randomized Clinical Trial

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Abstract

Background: Non-carious cervical lesions are difficult to restore because enamel and dentin margins provide different bonding substrates and may deteriorate differently over time. This secondary analysis evaluated whether Er,Cr:YSGG laser preparation, with or without phosphoric-acid conditioning, influenced marginal integrity compared with conventional bur preparation followed by etching.

Methods: Aggregate data from a randomized clinical trial of 75 Class V resin-composite restorations were analyzed at baseline and 6, 12, and 24 months. Marginal integrity was evaluated separately at enamel-composite and dentin-composite interfaces using ordinal C-criteria. Post-baseline distributions were compared using Fisher-Freeman-Halton exact tests. Perfect margins (code 0) were additionally summarized with Wilson 95% confidence intervals, risk ratios, and absolute risk differences. Anatomical form, marginal ledge, and marginal discoloration were exploratory outcomes.

Results: Treatment-group differences were concentrated at the enamel interface. Perfect enamel margins at 12 months occurred in 73.3% of laser-plus-etch, 62.5% of laser-without-etch, and 20.8% of bur-plus-etch restorations (global $p = .007$); at 24 months, the corresponding values were 57.1%, 46.7%, and 14.3% (global $p = .016$). At 12 months, laser plus etching yielded a risk ratio of 3.52 (95% CI 1.60-8.35) for preserving a perfect enamel margin versus conventional treatment. Dentin-margin distributions did not differ significantly at any follow-up. Enamel marginal ledge and discoloration findings were directionally consistent with the primary result.

Conclusion: Laser-based preparation was associated with better preservation of enamel-composite marginal integrity over 24 months, whereas no comparable dentin-margin advantage was demonstrated. Additional acid conditioning may support enamel performance, but the small aggregate dataset warrants cautious interpretation.

Keywords: non-carious cervical lesions; Er,Cr:YSGG laser; resin composite; marginal integrity; acid etching

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Introduction

Non-carious cervical lesions (NCCLs) are defects at or close to the cemento-enamel junction (CEJ) that occur in the absence of a primary bacterial caries process and are generally thought of as the cumulative effects of multiple mechanical, chemical and behavioural influence (Goodacre et al., 2023). They can appear as shallow saucer-shaped depressions or deeper wedge-shaped defects, and may have increasingly sclerotic dentin in the lesion as lesions progress (Goodacre et al., 2023; Hamdi et al., 2025). A systematic review of 14,628 adults found a weighted mean NCCL prevalence of 46.7% (Teixeira et al., 2020); however, there was significant variation in prevalence between different populations and different definitions of NCCL and the prevalence was found to increase with age. Due to the prevalence of these lesions and the fact that many older adults retain their teeth, it is clinically relevant to consider the long-term restorative management of these lesions (Goodacre et al., 2023; Teixeira et al., 2020).

In general, cases of restorative intervention are likely to be ones where the NCCL is progressive and is likely to result in structural failure, persistent sensitivity, esthetic considerations, or where preventive measures are unlikely to be successful (Brckett et al., 2024;

Goodacre et al., 2023). The cervical environment is challenging for adhesive restorations, and although many choose resin composite for its ability to allow for conservative placement and esthetic integration, these restorations can be difficult to manage. Margins can be enamel towards the crown and dentin or cementum towards the apex and factors such as sclerotic dentin, moisture control, functional loading, and access can influence bonding and clinical performance (Goodacre et al., 2023; Hamdi et al., 2025). Retention, marginal adaptation and marginal discoloration have been examined in recent RCTs separately as these outcomes may occur over time without the restoration falling out (Ashour et al., 2024; Haak et al., 2023; Peumans et al., 2023).

Marginal integrity is one of the most important tests to be informative as it represents the overall performance of the surface preparation, conditioning, adhesive application, polymerization, and under-functioning restorative material (Mahn et al., 2015). Long-term evidence has shown that the degradation of marginal integrity will increase over time, even with a clinically retained restoration (Mahn et al., 2015; Peumans et al., 2023). Deterioration in marginal

integrity was observed in around one-third of the restorations after 5 years, highlighting the fact that merely the survival of the restorations can underestimate deterioration of the interface in cervical restorations in a meta-analysis (Mahn et al., 2015). Randomized studies with quantitative and/or clinical margin assessments also indicate that the quality of the margin may change over time without affecting gross retention (Haak et al., 2023; Correia et al., 2026). To assess the quality and durability of cervical restorations, it is therefore important to consider Clinical trials and Systematic reviews separately assess the marginal adaptation or integrity, without worrying about retention (Doshi et al., 2023; Chaple Gil et al., 2026).

The preparation and conditioning approach can influence the surface set as the substrate for the adhesive system (Hamdi et al., 2025; Silva et al., 2019). The laser ablation with Er,Cr:YSGG can create an irregular hard-tissue surface, with reduced conventional smear-layer formation, and exposed dentinal tubules, but bond performance will depend on the laser parameters, adhesive system and surface conditioning used (Silva et al., 2019; Sun et al., 2015). Interestingly, the phosphoric-acid preconditioning showed to affect some of the adhesive combinations, implying that laser roughening cannot replace the consideration of chemical preconditioning (Silva et al., 2019). Recent clinical studies, however, have shown that the outcome of laser effects on dentin and clinical results were not uniformly beneficial, but are protocol and wavelength dependent (Holiel et al., 2026). In all NCCL trials, etching is still a factor regarding marginal adaptation and retention though to varying degrees depending on adhesive and restorative strategies (Chaple Gil et al., 2026; Doshi et al., 2023).

These questions were addressed by Heyder et al., (2022) in a two-year randomized clinical trial of 75 Class V NCCLs. Two groups were prepared with Er,Cr:YSGG laser, one of which was also treated with etch and rinse and the control group was prepared with conventional diamond-bur and treated with etch and rinse (Heyder et al., 2022). It is important to note that the same adhesive system and the same resin composite used in the three groups, so the differences between the treatment groups are mostly due to the preparation/conditioning methods (Heyder et al., 2022). Ordinal C-criteria were used to evaluate the clinical outcomes at baseline, 6, 12, and 24 months, while the marginal integrity was evaluated separately at enamel-composite and dentin-composite interfaces (Heyder et al., 2022).

The current analysis aimed to quantify marginal integrity at each surface using publicly available aggregate outcome distributions. The main aim was to compare the full range of marginal integrity scores among the three randomized treatment groups at 6, 12, and 24 months, separately for enamel and dentin margins. An additional goal was to estimate the relative

and absolute preservation of a perfect margin (code 0) for each laser protocol compared with conventional bur preparation. Other clinical indicators examined were anatomical form, marginal ledge, and marginal discoloration. The main null hypothesis was that there would be no difference in the distribution of the scores for the marginal-integrity measure for the different treatment groups for each of the two interfaces at any time beyond baseline; the alternative hypothesis was that the distribution of at least one treatment group would differ.

Literature Review

NCCLs have a unique adhesive substrate as they may be circumferential through various dental tissues both coronally and apically (Goodacre et al., 2023). The enamel has a high mineral content and after phosphoric-acid etching can form a predictable microretentive pattern; the dentin in the cervical region has a higher water and organic matrix content and can have varying degrees of sclerosis with partial or complete occlusion of the dentinal tubules (Goodacre et al., 2023; Hamdi et al., 2025). Thus, sclerotic dentin might have different response to conditioning and resin infiltration than normal dentin in the cervical region, making it a challenging clinical challenge for adhesive systems (Goodacre et al., 2023; Hamdi et al., 2025). Therefore, it is important to separate the enamel and dentin margins in clinical assessment as a pooled margin score might mask substrate-specific behaviour (Heyder et al., 2022).

In addition, depending on the clinical end point for assessing the success of the restoration, the interpretation of success for an NCCL will differ (Mahn et al., 2015). Retention is not the only failure endpoint that is unambiguous, but it is relatively late in the failure process, and does not account for progressive marginal deterioration that may occur in restorations that are retained (Peumans et al., 2023; Mahn et al., 2015). Marginal staining can be used to determine staining at the interface while the marginal adaptation/integrity involves determining whether a probeable discontinuity or gap has formed along the restoration margin (Mahn et al., 2015; Haak et al., 2023). These findings have been consistently reported in recent RCTs, some of which did not necessarily show a significant difference in overall survival despite differences in measurable marginal adaptation and/or discoloration (Ashour et al., 2024; Peumans et al., 2023).

The restorative material plays a part in the clinical performance, but is not independent of the bonding protocol (Bezerra et al., 2020; Mahn et al., 2015). When comparing the two types of cements (glass-ionomer and composite resin) in NCCLs, no consistent advantage of either material class across all types of outcomes, highlighting the need for outcome-specific interpretation (Bezerra et al., 2020). Randomized clinical trials of newer thermoviscous composites preheated before placement, and S-PRG containing composites, and bulkfilled versus nanofilled composite

materials also demonstrate outcome specific differences in the marginal or esthetic behavior of the materials, although they all exhibit acceptable survival (Correia et al., 2026; Favoreto et al., 2024; Lowenstein et al., 2025). The results of the restorations of the sandwiches also indicate that the inclusion of a glass-ionomer component does not necessarily yield improvements in all the clinical criteria (de Paula et al., 2019). Based on these findings, however, it is more suitable to evaluate at the protocol level and not only at the bulk restorative material level as observed performance (Mahn et al., 2015).

Due to the strong absorption in water and hydroxyapatite containing tissues, the Erbium family of lasers have been suggested as an alternative means of hard-tissue preparation (Silva et al., 2019). However, Er,Cr:YSGG treatment can generate micro irregularities in enamel and dentin surfaces with decreased smear-layer formation and exposed dentinal tubules which depends on power, pulse, water air and the condition of the substrate (Silva et al., 2019; Sun et al., 2015). Laser preparation has not been proven in vitro to be an overwhelmingly better method for adhesion than rotary preparation, and that the effect of laser preparation is dependent on the subsequent surface preparation and adhesion (Silva et al., 2019). The variability has clinical significance as it does not mean that the surface roughness is the criterion for a complete infiltration of resin or a stable bonded interface (Silva et al., 2019).

The phosphoric-acid conditioning treatment is still relevant at the enamel margins since it leads to the formation of microporosities that promote micromechanical interlocking (Chaple Gil et al., 2026). This has implications for the technique sensitivity as the collagen network in dentin is demineralized and must be infiltrated with resin, compared to enamel, where the balance between demineralization and infiltration is different, and aggressive demineralization may result in a sensitivity of the technique (Goodacre et al., 2023). The current evidence to compare adhesive strategies in NCCLs has shown that selective enamel etching and etch-and-rinse methods may have similar properties of retention and marginal-adaptation; however, the strength of evidence and effect size is not the same among the different methods (Chaple Gil et al., 2026; Doshi et al., 2023). Randomized clinical data up to three to four years also indicate that over time, adhesive strategy can impact marginal behavior, and the directions and magnitudes of differences can be dependent on the adhesive system and restorative protocol used (Haak et al., 2023; Omoto et al., 2025; Peumans et al., 2023).

The trial reported by Heyder et al. (2022) would be useful in studying preparation-conditioning effects as the resin composite and adhesive materials were the same in all the groups. Thus, the three methods (laser preparation alone, laser preparation and acid etching, and conventional bur preparation and etching) were

compared in the same study (Heyder et al., 2022). The original report identified a lower number of inadequate enamel margins in the laser groups, and noted good clinical performance of the groups following laser preparation, especially when combining laser preparation with etching (Heyder et al., 2022). However, the cumulative supplementary tables allow also a targeted re-analysis which provides exact distributional comparisons, confidence intervals for the probability of the perfect margin and effect sizes compared to the conventional control. Such estimates can help to better understand the size and patient-level interface specificity of observed differences, but do not necessarily imply patient-level longitudinal modeling that cannot be done in the context of the public data.

The interface-specific analysis is also biologically justified given the differences that can occur when a restorative protocol is used at the enamel and dentin margins (Goodacre et al., 2023). It could be a treatment effect at enamel margins with dentin margins being comparable, and a pooled interpretation would be a general benefit for the whole of the restoration interface. However, if effects are found both in the two substrates, it would be more indicative of a more general, preparation-dependent advantage. Therefore, the score structure is retained, enamel is not combined with dentin, and code 0 is not used to completely substitute the entire distribution of marginal-integrity.

Methodology

Study design and data source

This study was considered a secondary analysis of the publicly available supplementary data of a randomized, clinically-controlled study of Class V resin-composite restorations conducted by Heyder et al. (2022). The comparison between Er,Cr:YSGG laser preparation with and without phosphoric-acid conditioning, and conventional diamond-bur preparation and etch-and-rinse treatment was investigated in the source trial (Heyder et al., 2022). The public data set includes the number and percentages of clinical score categories at baseline and 6, 12 and 24 months. The present analysis was limited to outcome distributions at the group level, and not to individual trajectories, due to lack of individual restoration identifiers and patient-specific longitudinal records.

Participants and randomized groups

The study was conducted on 29 adults in the Department of Conservative Dentistry and Periodontology, Jena University Hospital, Germany (Heyder et al., 2022). The age range of the participants was 22 to 89 years with a mean age of 56.24 years and each participant had at least one non-carious cervical defect with exposed dentin (Heyder et al., 2022). Teeth with caries in the molars and cervical lesions were excluded, as well as the teeth that were supposed to receive prosthetic treatments, inadequate oral hygiene, heavy smoking and high coffee and black tea consumption as described in the source protocol (Heyder et al., 2022).

In the Heyder et al. (2022) study, seventy-five Class V lesions were divided into three groups: laser preparation with etch-and-rinse conditioning, laser preparation without etch-and-rinse conditioning and conventional bur preparation with etch-and-rinse conditioning. The results presented in the supplementary tables are at the restoration level. The follow-up denominators decreased over time due to lost restorations and inability to re-evaluate some of the restorations (Heyder et al., 2022).

Clinical preparation and restorative protocol

The Er,Cr:YSGG laser (Waterlase MD, Biolase, Irvine, CA, USA) was used for cavity preparation for both laser groups at 3 W, 150 mJ, 30 J/cm², 30 Hz, 60% air, and 50% water in H Mode (Heyder et al., 2022). The sapphire tip (MG6, 600 microns) was placed at a distance of around 1-1.5 mm from the surface of the tooth until a roughened surface with a whitish opaque appearance was achieved (Heyder et al., 2022). The preparation of conventional control cavities was performed using diamond burs under water cooling and the coronal enamel was beveled at least 1 mm (Heyder et al., 2022).

Prior to restoration, retraction cord (Heyder et al., 2022) was used to expose the cervical margin. The laser-plus-etch group and conventional control were treated with orthophosphoric acid (37%) for 15 s on dentin and 30 s on enamel, while the laser-without-etch group was not treated with phosphoric acid at all (Heyder et al., 2022). The cavities were filled in 2 mm increments with Venus resin composite as well as the same adhesive components of Gluma Solid Bond adhesive and finished and polished in a standardized manner (Heyder et al., 2022). Hence, the randomisation is the cavity preparation and the acid-conditioning strategy, and not different restorative materials.

Clinical outcomes

The restorations were visually and tactilely evaluated at baseline and at 6, 12 and 24 months by a trained blinded independent examiner (Heyder et al., 2022). The C-criteria of the USPHS-compatible CPM index (code 0 most favorable, code 3 least favorable condition) were used to grade clinical performance (Heyder et al., 2022). Marginal integrity, marginal ledge and marginal discoloration were assessed separately at enamel-composite and dentin-composite margin (Heyder et al., 2022).

The prespecified primary outcome was marginal integrity. Codes 0, 1, 2 and 3 indicated perfect margin, probable defect of up to 1/3 circumference, one third to 2/3 circumference and marginal leakage, respectively (Heyder et al., 2022). Marginal ledge, marginal discoloration, and anatomical form were treated as exploratory outcomes. Original ordinal categories were not converted to a continuous score, but were analyzed as categories.

Data preparation and statistical analysis

For each treatment group, interface, outcome and follow up, counts were transcribed from the supplementary

tables and verified from the denominators provided. Patient level and restoration level observations were not generated and no missing outcomes were imputed. The denominators were used as reported for each criterion and visit, and they were available for the analysis.

Numerous factors affect the integrity of the margins, which were summarized for each code category as n (%). Wilson 95% confidence intervals were also computed for the percentage of restorations that had a perfect margin (code 0). The Fisher-Freeman-Halton exact test for an r x c contingency table was performed with 500,000 Monte Carlo samples to compare the full ordinal distributions between the three treatment groups at each of the post-baseline visits, owing to some sparse cells. Prespecified pairwise exact comparisons were made and adjusted by the Holm procedure if a global comparison was significant.

A complementary code 0 vs. codes 1-3 analysis was done to test effect size. Risk ratios were calculated with score-based 95% confidence intervals for the likelihood of preserving a perfect margin for each laser protocol compared to the conventional control and absolute risk differences were calculated with Newcombe 95% confidence intervals. These binary summaries were not used in lieu of the primary ordinal comparison, but were used for quantifying magnitude.

The same ordinal structure was used to summarize the additional clinical criteria. Multiple exploratory outcomes and interfaces were examined and comparisons were made globally, treating results with p values as exploratory as interpretation was not based on p values but on consistency, directionality and cell counts. However, public aggregate data does not allow the identification of repeated observations in the same restoration or multiple restorations in the same patient so models were not fitted to this data. Two-tailed tests were used for all tests and the significance level was .05. Analyses were conducted in Python 3.13.5 using pandas 2.2.3, SciPy 1.17.0, statsmodels 0.14.6, and Matplotlib 3.10.8.

Ethical considerations

The original trial received approval from the Ethical Committee of Friedrich Schiller University, Jena, Germany (No. 2013-05/07), and written informed consent was obtained before treatment (Heyder et al., 2022). The present analysis used only de-identified, publicly available aggregate data and involved no new participant contact or intervention.

Results

Marginal-integrity data were available for 63 restorations at 6 months (17 laser + etch, 18 laser without etch, and 28 bur + etch), 55 at 12 months (15, 16, and 24, respectively), and 50 at 24 months (14, 15, and 21, respectively). Baseline marginal integrity was code 0 for all evaluated restorations in all groups, so inferential comparisons focused on the three post-baseline visits. The declining denominators were retained as reported, and the analysis therefore reflects

available restorations at each examination rather than a reconstructed complete-case cohort.

At the enamel-composite interface, preservation of a perfect margin favored both laser groups throughout follow-up. At 6 months, code 0 was present in 88.2% of the laser-plus-etch group, 77.8% of the laser-without-etch group, and 50.0% of the conventional control; the full ordinal comparison was close to, but did not reach, the prespecified significance threshold (global exact $p = .055$). By 12 months, the corresponding code 0 proportions were 73.3%, 62.5%, and 20.8%, and the full distribution differed among groups (global exact $p = .007$). The Holm-adjusted pairwise comparison was significant for laser + etch versus bur + etch (adjusted $p = .009$), whereas the other pairwise comparisons did not remain significant after adjustment. At 24 months, perfect enamel margins remained more frequent after laser preparation (57.1% for laser + etch and 46.7% for laser without etch) than after conventional bur preparation (14.3%); the overall ordinal distribution again differed among groups (global exact $p = .016$), although no individual pairwise comparison remained significant after Holm correction. The complete enamel-composite marginal-integrity distributions are presented in Table 1.

Table 1. Enamel-composite marginal integrity by treatment group and follow-up

Time	Group	n	Code 0	Code 1	Code 2	Code 3	Global exact p
6 months	Laser + etch	17	15 (88.2 %)	1 (5.9 %)	1 (5.9 %)	0 (0.0 %)	.055
	Laser without etch	18	14 (77.8 %)	3 (16.7 %)	1 (5.6 %)	0 (0.0 %)	
	Bur + etch	28	14 (50.0 %)	11 (39.3 %)	3 (10.7 %)	0 (0.0 %)	
12 months	Laser + etch	15	11 (73.3 %)	4 (26.7 %)	0 (0.0 %)	0 (0.0 %)	.007
	Laser without etch	16	10 (62.5 %)	4 (25.0 %)	2 (12.5 %)	0 (0.0 %)	
	Bur + etch	24	5 (20.8 %)	13 (54.2 %)	6 (25.0 %)	0 (0.0 %)	

Time	Group	n	Code 0	Code 1	Code 2	Code 3	Global exact p
24 months	Laser + etch	14	8 (57.1 %)	2 (14.3 %)	4 (28.6 %)	0 (0.0 %)	.016
	Laser without etch	15	7 (46.7 %)	7 (46.7 %)	1 (6.7 %)	0 (0.0 %)	
	Bur + etch	21	3 (14.3 %)	10 (47.6 %)	8 (38.1 %)	0 (0.0 %)	

Note. Codes range from 0 (perfect margin) to 3 (marginal leakage). Global p values are Fisher-Freeman-Halton exact tests with Monte Carlo sampling. The distributional separation in Table 1 is also evident when code 0 is considered as a clinically intuitive summary of margin quality. Figure 1 shows that the proportion of perfect enamel margins declined in all groups during follow-up, but the decline was consistently greater in the conventional bur-plus-etch group than in either laser group.

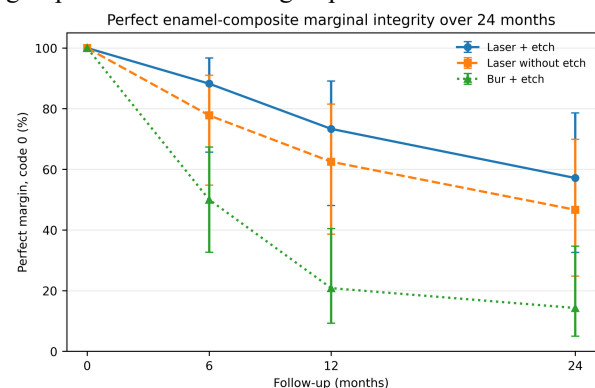


Figure 1. Proportion of restorations with a perfect enamel-composite margin (code 0) across follow-up. Error bars show Wilson 95% confidence intervals. Baseline was 100% in all groups.

The effect-size analysis showed that the enamel finding was not only distributional but clinically large. At 12 months, laser + etch was associated with a 3.52-fold probability of retaining a perfect enamel margin compared with bur + etch (RR 3.52, 95% CI 1.60-8.35), corresponding to an absolute difference of 52.5 percentage points (95% CI 20.5-72.1). At 24 months, the corresponding estimate was RR 4.00 (95% CI 1.38-12.46) with an absolute difference of 42.9 percentage points (95% CI 11.0-66.3). Laser preparation without additional etching also showed higher code 0 proportions than the conventional control at 12 months (RR 3.00, 95% CI 1.31-7.28) and 24 months (RR 3.27, 95% CI 1.08-10.46), although confidence intervals were

wide because of the small available denominators. These relative effect estimates and their 95% confidence intervals are summarized in Figure 2.

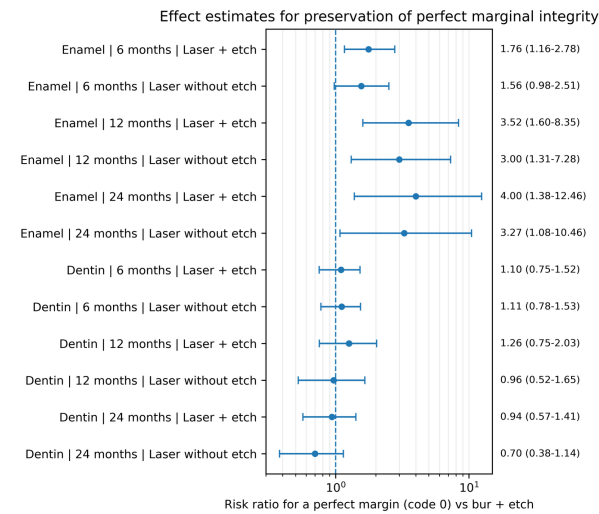


Figure 2. Risk ratios for preservation of a perfect margin (code 0) for each laser protocol versus conventional bur preparation with etching. Points are risk ratios and horizontal lines are score-based 95% confidence intervals. The vertical reference line is $RR = 1$. Baseline is omitted because all groups had perfect margins.

A different pattern was observed at the dentin-composite interface. Code 0 proportions at 6 months were 82.4%, 83.3%, and 75.0% for laser + etch, laser without etch, and bur + etch, respectively; at 12 months they were 73.3%, 56.3%, and 58.3%; and at 24 months they were 71.4%, 53.3%, and 76.2%. None of the full ordinal comparisons was significant (global exact $p = .388$ at 6 months, .864 at 12 months, and .571 at 24 months). Effect estimates were correspondingly compatible with little or no dentin-margin advantage; at 24 months, the RR for a perfect dentin margin was 0.94 (95% CI 0.57-1.41) for laser + etch and 0.70 (95% CI 0.38-1.14) for laser without etch, each compared with bur + etch. The contrast between the enamel and dentin results indicates that the observed treatment-group separation was interface specific rather than uniform across the restoration margin. The full dentin-composite marginal-integrity distributions are reported in Table 2.

Table 2. Dentin-composite marginal integrity by treatment group and follow-up

Time	Group	n	Code 0	Code 1	Code 2	Code 3	Global exact p
6 months	Laser + etch	17	14 (82.4 %)	1 (5.9 %)	2 (11.8 %)	0 (0.0 %)	.388

Time	Group	n	Code 0	Code 1	Code 2	Code 3	Global exact p
	Laser without etch	18	15 (83.3 %)	3 (16.7 %)	0 (0.0 %)	0 (0.0 %)	
	Bur + etch	28	21 (75.0 %)	6 (21.4 %)	1 (3.6 %)	0 (0.0 %)	
12 months	Laser + etch	15	11 (73.3 %)	3 (20.0 %)	1 (6.7 %)	0 (0.0 %)	.864
	Laser without etch	16	9 (56.3 %)	5 (31.3 %)	2 (12.5 %)	0 (0.0 %)	
	Bur + etch	24	14 (58.3 %)	6 (25.0 %)	4 (16.7 %)	0 (0.0 %)	
24 months	Laser + etch	14	10 (71.4 %)	2 (14.3 %)	2 (14.3 %)	0 (0.0 %)	.571
	Laser without etch	15	8 (53.3 %)	5 (33.3 %)	1 (6.7 %)	1 (6.7 %)	
	Bur + etch	21	16 (76.2 %)	3 (14.3 %)	2 (9.5 %)	0 (0.0 %)	

Note. Codes range from 0 (perfect margin) to 3 (marginal leakage). Global p values are Fisher-Freeman-Halton exact tests with Monte Carlo sampling. In contrast to the enamel findings, the dentin code 0 proportions did not show a stable treatment ordering across follow-up. Figure 3 visualizes this overlapping trajectory and the corresponding uncertainty around the proportions of perfect dentin margins.

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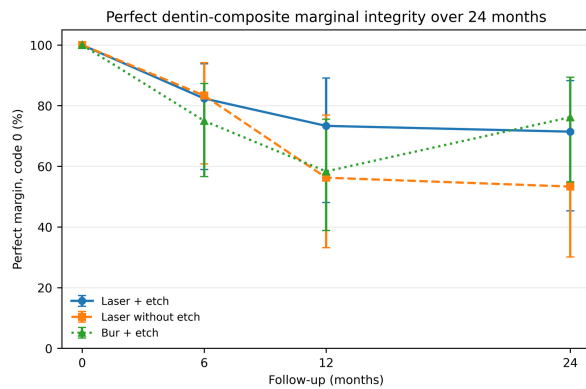


Figure 3. Proportion of restorations with a perfect dentin-composite margin (code 0) across follow-up. Error bars show Wilson 95% confidence intervals. Baseline was 100% in all groups.

Exploratory analyses of the additional clinical criteria were broadly consistent with an interface-specific pattern. For marginal ledge at the enamel interface, the ordinal distribution differed among groups at 6 months (exact $p = .021$) and 12 months (exact $p = .014$), but not at 24 months (exact $p = .111$); dentin-margin ledge distributions did not differ significantly at any follow-up. Enamel marginal discoloration did not differ significantly at 6 or 12 months but did differ at 24 months (exact $p = .010$), when code 0 was recorded in 78.6% of laser + etch, 33.3% of laser without etch, and 50.0% of bur + etch restorations. Dentin marginal discoloration showed no significant group difference at 24 months (exact $p = .282$). Anatomical form showed an isolated global difference at 6 months (exact $p = .024$) that was not present at 12 or 24 months; because these involved multiple exploratory comparisons, they were interpreted as supportive rather than confirmatory findings. The 24-month code 0 summaries for these criteria are presented in Table 3.

Table 3. Exploratory clinical criteria at 24 months

Outcome	Interface	Laser + etch code 0	Laser without etch code 0	Bur + etch code 0	Global exact p
Anatomical form	Overall	13 (86.7%)	15 (100.0%)	21 (91.3%)	.547
Marginal ledge	Enamel	8 (57.1%)	7 (46.7%)	3 (14.3%)	.111
Marginal ledge	Dentin	9 (64.3%)	8 (53.3%)	16 (76.2%)	.277
Marginal discoloration	Enamel	11 (78.6%)	5 (33.3%)	11 (50.0%)	.010

Outcome	Interface	Laser + etch code 0	Laser without etch code 0	Bur + etch code 0	Global exact p
Marginal discoloration	Dentin	12 (85.7%)	12 (80.0%)	21 (95.5%)	.282

Note. Code 0 denotes the most favorable category for each criterion. These exact p values are exploratory and were not multiplicity-adjusted across outcome domains.

Discussion

The main finding was that differences in marginal integrity among groups were concentrated at the enamel-composite interface rather than distributed evenly around the restoration. Both Laser groups had a higher proportion of perfect enamel margins at 12 and 24 months than the conventional bur + etch Control, and the complete series of ordered data distributions differed significantly between groups. This effect size analysis confirmed the clinical significance of this pattern: laser preparation plus etching was more than three times as likely to have a perfect enamel margin at 12 months and four times as likely at 24 months compared to conventional treatment. However, there were no significant differences between the marginal integrity of dentin-composite at any post-baseline evaluation. Thus the main null hypothesis may be accepted for the enamel surface at 12 months, at 24 months and for the dentin surface.

This trend was broadly similar to the original study by Heyder et al. (2022), which also suggested that less inadequate enamel margins occurred with laser preparation, and that the clinical performance was especially good when the laser preparation was combined with acid conditioning. Their study also revealed that there was a statistically significant difference in enamel marginal integrity after 1 year and a better configuration of the enamel ledge in the laser groups (Heyder et al., 2022). This analysis is an extension of that report, in that it retains the full ordinal distributions, uses exact tests appropriate for sparse cells, and allows quantifying the probability of maintaining a perfect margin, along with confidence intervals. These extra estimates do not alter the overall trend of the original estimates, but do clarify the size and anatomical location of the group separation. It is important to note that the benefit is not that of a general superiority of the restorative material since the same adhesive system and Venus resin composite was used in all three randomized groups (Heyder et al., 2022).

Biologically, it is plausible that the separation is greater at enamel margins. Er,Cr:YSGG laser can create an irregular microretentive surface with less smear layer formation, and phosphoric acid can be used to modify enamel surface to further enhance the micromechanical interlocking (Silva et al., 2019; Sun et al., 2015). In a

systematic review of Er,Cr:YSGG-prepared dentin, Silva et al. (2019) found that the bonding performance was highly dependent on the laser parameters, type of adhesive, and preconditioning, which in some cases resulted in higher bond strengths with phosphoric-acid pretreatment. That review was mainly related to studies on the bond-strength of a laser created surface, however it was able to confirm the general principle that a laser created surface does not automatically rule out chemical conditioning (Silva et al., 2019). More recent research also confirms the wavelength dependence of the effects of lasers on adhesion: a 24-month randomized study of diode-laser pretreatment revealed that there were wavelength-dependent changes, but no consistent adhesive improvement (Holiel et al., 2026). Recent NCCL trials have shown similar results with contemporary evidence supporting etch-and-rinse or selective-enamel-etching strategies showing greater marginal adaptation compared to enamel-etch-less strategies; however, the effects of treatment are dependent on the adhesive and restorative system used (Chaple Gil et al., 2026; Doshi et al., 2023). The present enamel findings are in line with this direction of evidence, but limited to the preparation and adhesive protocol of this trial.

The comparison between the two laser groups should be taken with a pinch of salt. Paired comparison of the two laser protocols did not always be statistically significant after multiplicity adjustment and laser plus etching generally showed the best enamel profile, especially for enamel marginal discoloration at 24 months. Heyder et al., (2022) also found that extra acid conditioning following laser preparation was beneficial particularly at the enamel margins. The re-analysis was carried out using the current dataset, and directionally this confirms the interpretation, but with small group sizes and increasing confidence intervals, the incremental contribution of acid etching cannot be precisely estimated. Thus, it is more fitting to conclude that acid conditioning seems to be an adjunct to the laser preparation at the enamel interface rather than a proven superior method of preparation to laser preparation.

The results of the dentin were very different. The prevalence of perfect dentin margins was fairly consistent across all three groups and the risk-ratio estimates were not consistent for the benefit of laser preparation. The dentin of the cervical part of the tooth can be heterogeneous, sclerotic, hypermineralized and partially occluded at the dentinal tubules, which can affect the potential for successful resin infiltration and the response to laser treatment and acid conditioning (Goodacre et al., 2023; Hamdi et al., 2025). Laboratory also indicates that the effects of Er,Cr:YSGG on dentin is highly parameter dependent and do not result in uniform adhesion (Silva et al., 2019; Sun et al., 2015). Recent systematic evidence of the effects on sclerotic cervical dentin also indicates that the results vary depending on the surface pretreatments, cautioning

against extrapolating an effect of a given pretreatment to all substrates of dentin (Hamdi et al., 2025). This could be the reason for the lack of a clear separation of the enamel at the dentin interface. It also helps to show why it is not appropriate to combine enamel and dentin margins into one margin outcome if the substrates are very different.

The lack of dentin advantage can also be explained by the recent clinical data which indicates that the Er,Cr:YSGG preparation is not always superior to the conventional conditioning (Değirmenci & Ünalın Değirmenci, 2026). Değirmenci & Ünalın Değirmenci (2026) reported similarly high clinical acceptability and no difference in the marginal adaptation when Er,Cr:YSGG-prepared NCCL restorations were compared to the conventionally acid-conditioned restorations in a 2026 randomized trial. This is because the materials used for restoration, adhesive technique, criteria for success, and follow-up design are different from that trial. However, this trial suggests that laser preparation is not necessarily a better approach and can be considered an alternative method based on the protocol used (Değirmenci & Ünalın Değirmenci, 2026). The present study is able to shed additional light on that interpretation by proposing that any benefit might be more apparent at enamel margins than at dentin margins.

The exploratory outcomes provide additional context. While the enamel marginal ledge distribution was different between groups at 6 months and 12 months, and enamel marginal discoloration was different at 24 months, the corresponding dentin findings were not as distinct between groups. This is similar to the original trial which revealed less unfavourable ledges in the laser-prepared restorations, with the lowest marginal discoloration at the end of follow-up in the laser plus etch group (Heyder et al., 2022). They also agree with the choice to assess the marginal quality without taking restoration retention into consideration. In a meta-analysis of cervical restorations, Mahn et al. (2015) showed that marginal integrity and marginal discoloration had significantly increased over the years even though many of the restorations were still in place. Clinically acceptable restoration survival with progressive changes in the marginal criteria has been reported in more recent long-term trials, as well, and this is further evidence of the differences between retention and marginal quality (Correia et al., 2026; Lowenstein et al., 2025). The interface deterioration over time that occurred for all groups in the present analysis is consistent with that overall trend of code 0 margins decreasing over time.

The enamel effect is an important clinical parameter, which manifests itself in a large magnitude, but with uncertainty. The absolute difference between the two groups (laser + etching and bur + etching) in the number of perfect enamel margins at 12 months was 52.5 percentage points, and at 24 months was 42.9 percentage

points. These are large differences but the confidence intervals were wide as there were only 50 restorations with marginal-integrity data at 24 months. The denominators in the tables are decreasing due to restoration loss and lost follow-up in the source trial (Heyder et al., 2022) and can therefore affect the composition of the restorations that can be assessed for margins. Therefore, it would be better to consider the effect estimates as measures of the available-case contrast of the intervention rather than a precise estimate of a population-wide causal effect.

Several features strengthen the present analysis. Differences between the groups regarding the treatment selection and the material used are minimized because the treatment allocation was randomized and the materials—adhesive and resin composite—were the same within the groups in the source trial (Heyder et al., 2022). To this end, the assessment of enamel and dentin margins was performed separately and the ordinal data were preserved and not just dichotomized as success/failure. Exact contingency-table methods were suitable for the sparse cells, and risk ratios and absolute differences were complementary clinically interpretable estimates of the effect size. High intraspecific consistency in directionality of the three marginal integrity, marginal ledge and marginal discoloration scores at the emulsion-enamel border also gives some internal consistency, although these scores remain exploratory.

Restrictions are not insignificant either. Firstly, only counts of the number of people in aggregates were made public, so over the years there was no way to identify multiple observations of the same restoration or group multiple restorations from the same participant as clustered data. This does not allow for marginal deterioration, time to event modeling or adjustment for lesion/patient level covariates as some of the data are lost. Second, the sample size was small, and the available denominators decreased over time due to attrition which resulted in imprecise estimates of effects. Third, there were multiple comparisons across the exploratory outcomes and no adjustment was made across the domains of outcomes; therefore, isolated *p* values should not be interpreted as confirmatory. Fourth, the source trial was performed at a single center with one laser setting, one adhesive system, and one resin composite (Heyder et al., 2022); this means that the results cannot be automatically transferred to other laser settings, universal adhesives, and the more recent resin composites. Last, the method of preparation and the acid-conditioning strategy varied between some randomized groups, making it impossible to fully distinguish the separate effects of the laser ablation, and the acid-conditioning.

Clinically, the results lend to a conservative interpretation. Use of Er,Cr:YSGG preparation, especially after phosphoric-acid conditioning, might be beneficial for maintaining the quality of enamel-

composite margins in NCCL restorations for at least two years. There is no evidence of a correlative benefit at the dentin-margin and these data alone are insufficient to warrant using this alternative to conventional bur preparation. This is a well-balanced interpretation of the NCCL performance, which has been documented by recent systematic and clinical evidence that adhesive strategy, substrate, material selection, and procedural details interact to determine NCCL performance, rather than acting independently (Chaple Gil et al., 2026, Doshi et al., 2023, Haak et al., 2023, Omoto et al., 2025). Long-term randomized trials also have demonstrated that acceptable survival rates of the restoration(s) can coexist with a gradual marginal changes, highlighting the importance of longer follow-up periods and reporting the results by interface (Correia et al., 2026; Peumans et al., 2023). Further studies utilizing larger populations with longitudinal data and the same level of reporting enamel and dentin margins as well as longer follow-up are warranted to establish if the enamel advantage is maintained and if it is associated with reduced restoration failure over time.

Conclusion

This analysis of a randomized clinical trial showed that Er,Cr:YSGG laser preparation was superior in maintaining the integrity of the margins of enamel-composite during a 24-month follow-up period. Separation was most pronounced at 12 and 24 months and the separation was substantiated by the presence of large differences in the probability of having a perfect enamel margin both relative to and absolute from the overall rate. This was not the case at the dentin-composite interface where no differences in the treatment advantage were found, indicating that the clinical effect was not uniform around the restoration. Supportive, but exploratory, findings in the same direction were the findings of marginal ledge and marginal discoloration. Laser preparation and conditioning with phosphoric acid resulted in the most favourable enamel profile in a consistent manner, but the incremental effect of phosphoric acid etching is not clear due to the small sample size. The results suggest that careful evaluation of NCCL restorations needs to be performed on a case-by-case basis for each type of interface and that further research with patient-level longitudinal data and longer follow-up in larger clinical trials is warranted.

Data Availability

The aggregate data analyzed in this study are publicly available as supplementary material accompanying the original randomized clinical trial reported by Heyder et al. (2022). Only de-identified, aggregate outcome data were used in the present analysis; no individual participant-level records were accessed or reconstructed.

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