

In Vitro Evaluation of 450 Nm Diode Laser in Gingival Retraction: Comparative Study With Double-cord and Nano: Yag Laser Techniques

Manuela Mucedero

Policlinico Tor Vergata

Michele Benegiamo

University of Salento

Matteo Rozzi

Policlinico Tor Vergata

Silvia Fanelli

Policlinico Tor Vergata

Andrea Francesco Palermo

andrea.palermo@unisalento.it

University of Salento

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IN VITRO EVALUATION OF 450 NM DIODE LASER IN GINGIVAL RETRACTION: COMPARATIVE STUDY WITH DOUBLE-CORD AND NANO: YAG LASER TECHNIQUES

ABSTRACT

Purpose: To evaluate *in vitro* the effectiveness of three gingival retraction techniques—double cord impregnated with aluminum sulfate, 450 nm diode laser, and Nano:YAG laser—through three-dimensional analysis of vertical (VD) and lateral (LD) variations of the gingival margin, and to compare the operative times of the different methods.

Methods: Eight fresh porcine hemi-arches (four mandibular and four maxillary), including 44 teeth and 264 measurement sites, were analyzed. Baseline and post-retraction scans were acquired using the TRIOS 3® intraoral scanner and superimposed through CAD software to measure vertical (VD) and lateral (LD) displacements. Data were analyzed using the Kruskal–Wallis and Mann–Whitney tests with Bonferroni correction ($p < 0.05$).

Results: All techniques achieved clinically acceptable gingival retraction ($VD \geq 200 \mu m$). The double-cord method produced the highest mean values but with greater variability; the 450 nm diode laser provided more uniform and repeatable retractions; and the Nano: YAG laser yielded intermediate values, with a few subcritical cases. Both laser techniques reduced the mean operative time by more than 160 seconds per tooth compared with the double-cord technique.

Conclusions: The 450 nm diode laser proved to be effective, repeatable, and time-efficient representing a valid alternative to the traditional method, offering superior compatibility with digital workflows. Further *in vivo* studies are required to confirm the clinical translatability of these results.

Keywords: gingival retraction; double-cord technique; 450 nm diode laser; Nano:YAG laser; fixed prosthodontics; digital impression.

INTRODUCTION

Gingival retraction is essential in indirect prosthetic procedures to properly expose the subgingival finish line and ensure an accurate impression [1–3]. The double-cord technique impregnated with an astringent solution is the most widely used method, as it provides effective tissue separation and hemostatic control [4,5]. However, it presents certain limitations, including operator dependence, risk of microtrauma, and extended clinical time [6–8].

In recent years, alternative and minimally invasive approaches have emerged, including retraction pastes, electrosurgery, and laser systems, offering controlled tissue displacement combined with a hemostatic effect [9–11]. Diode lasers (810–980 nm) selectively act on the superficial epithelial tissue, creating a dry and stable sulcus [12,13], while the Nano:YAG laser penetrates deeper into the tissues, producing greater retraction but with an increased risk of thermal damage [14,15].

The available literature remains heterogeneous regarding protocols and measurement methods, often limited to two-dimensional evaluations [16–18]. Therefore, the present study compares three gingival retraction techniques through three-dimensional analysis to objectively quantify vertical and lateral changes of the gingival margin and to assess the time efficiency of the different methods.

MATERIALS AND METHODS

The study was conducted on eight fresh porcine hemi-arches (four maxillary and four mandibular) obtained from adult specimens intended for food use. This model was selected due to its anatomical and histological similarities to human periodontal tissues [19–21].

Considering the provisions of Legislative Decree No. 26/2014 (2010/63/UE), particularly Article 31, it is highlighted that the establishment of an ethical committee is not necessary for the present study, as it does not involve the use of animals for scientific purposes, nor procedures that require such approval.

The samples exhibited permanent dentition with at least five intact teeth, including molars and premolars, free from lesions, mobility, or gingival margin alterations. Canines and incisors, often missing or worn, were excluded to ensure sample homogeneity. The specimens, purchased on the

same morning of the experiment, were stored at 4 °C until use to preserve the integrity of both hard and soft tissues.

Experimental Design and Randomization

The experimental procedure consisted of five sequential phases:

1. coding and randomization of samples;
2. preliminary digital scanning (baseline);
3. application of the retraction technique;
4. post-retraction scanning;
5. digital superimposition and morphometric analysis.

The eight hemi-arches, identified by numerical codes, were assigned to three experimental groups through simple randomization using an electronic generator (random.org) to minimize bias and balance anatomical variability (Table 1).

All samples were treated according to standardized operative protocols to reduce intra-operator variability:

- Group A: double cord impregnated (Ultrapak® 000 and 1, Ultradent Products Inc.);
- Group B: 450 nm diode laser (Wiser 3®, Doctor Smile, Lambda S.p.A.);
- Group C: Nano:YAG laser (Nano:YAG®, DMT S.r.l.).

DISTRIBUTION AND ALLOCATION OF SAMPLES PER GROUP			
GROUP	SAMPLE CODE	MOLARS	PREMOLARS
A (Double cords)	M1	3	3
A (Double cords)	S1	3	2
B (Diode 450nm)	S2	3	3
B (Diode 450nm)	S3	3	3
B (Diode 450nm)	M2	3	2
C (Nano:YAG)	M3	3	2
C (Nano:YAG)	M4	2	3
C (Nano:YAG)	S4	3	3

Table 1: Distribution and allocation of samples among the three study groups

A total of 44 teeth (molars and premolars) were analyzed, corresponding to 264 measurement points. All procedures were performed in a controlled environment under constant lighting conditions to prevent optical variations during the scanning process.

Preliminary Digital Scanning

Each sample underwent a baseline digital scan using an intraoral scanner (TRIOS 3®, 3Shape) capable of acquiring high-resolution three-dimensional models in STL and PLY formats [23]. The samples, fixed on a stable support and oriented according to the occlusal plane, were scanned while maintaining a constant distance ≤ 2 cm from the surface of interest. The scanning path followed a continuous trajectory from the occlusal surface of the most distal molar to the last premolar, continuing along the lingual/palatal and buccal aspects [24]. Images were verified in real time using 3Shape software, and any missing areas were immediately rescanned. The digital files, identified by a unique code, served as baseline reference models for subsequent scans.

Gingival Retraction Techniques

After baseline scanning, each sample was treated using one of the three planned retraction methods (Figure 1). All procedures were performed by the same operator to ensure consistency in clinical handling. The operative time per tooth was recorded using a digital stopwatch from the beginning to the end of each procedure [25].

Group A – Double impregnated cord: Retraction was performed using the traditional mechanical–chemical double-cord technique [26–29]. Ultrapak® cords (sizes 000 and 1, Ultradent Products Inc.) were impregnated with 25% aluminum sulfate solution (Gengistal®, OGNA LAS S.r.l.). The first cord was inserted into the gingival sulcus, and the second was placed on top; after five minutes, the upper cord was carefully removed [30–32].

Group B – 450 nm diode laser: Retraction was performed using the Wiser 3® diode laser (Doctor Smile, Lambda S.p.A.) in continuous mode with a 300 µm optical fiber held tangentially to the gingival margin to prevent overheating. Power and exposure settings were adjusted according to the manufacturer’s recommendations, allowing controlled epithelial vaporization and coagulation of marginal capillaries

Group C – Nano:YAG laser: Retraction was carried out with the Nano:YAG® device (DMT S.r.l.), operating at a 1064 nm wavelength with a 300 µm optical fiber in continuous emission mode, using the “Periodontology/Impression Taking” program. As described by Tao et al. [33], this protocol enables controlled sulcular epithelial vaporization with a deep photothermal effect while minimizing the risk of thermal damage.

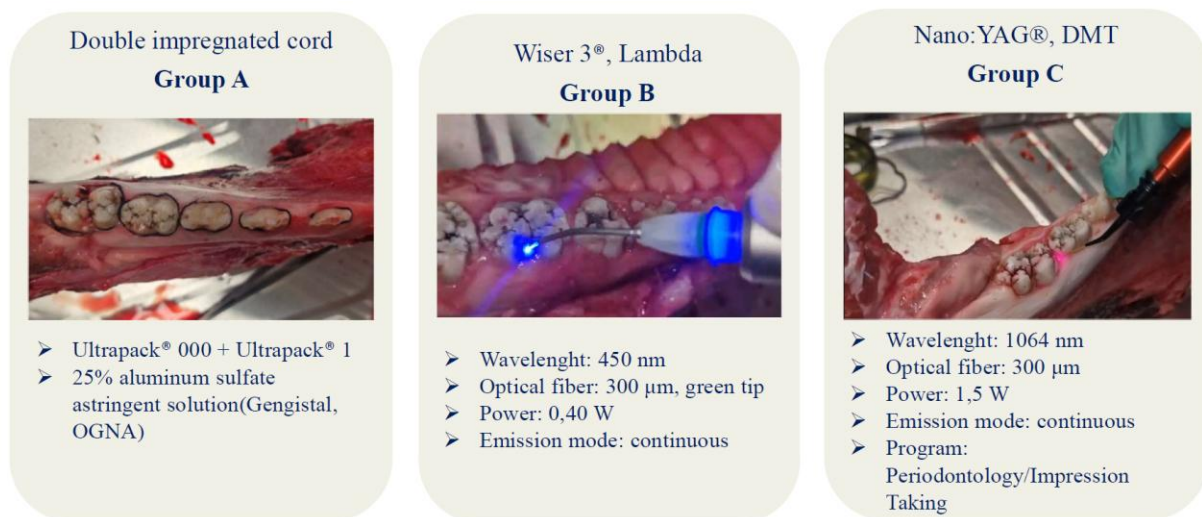


Figure 1: Operative sequences of gingival retraction using the double-cord technique, 450 nm diode laser, and Nano:YAG laser.

Post-Retraction Scanning and Digital Analysis

After completing the retraction procedure, each sample was rescanned using the same baseline protocol. The post-retraction models were exported in STL and PLY formats and labeled with the sample code followed by the suffix “post” [34].

Three-dimensional analyses were performed using Rhinoceros 8® (McNeel & Associates) by superimposing the pre- and post-retraction models through the alignment of fixed reference points not involved in the procedures (Figure 2).

For each tooth, three orthogonal sections (distal, central, and mesial) were traced, and six measurement points per tooth were analyzed to calculate:

- the vertical distance (VD), corresponding to the apico-coronal displacement of the gingival margin;
- the lateral distance (LD), representing the width of the gingival sulcus (Figure 3).

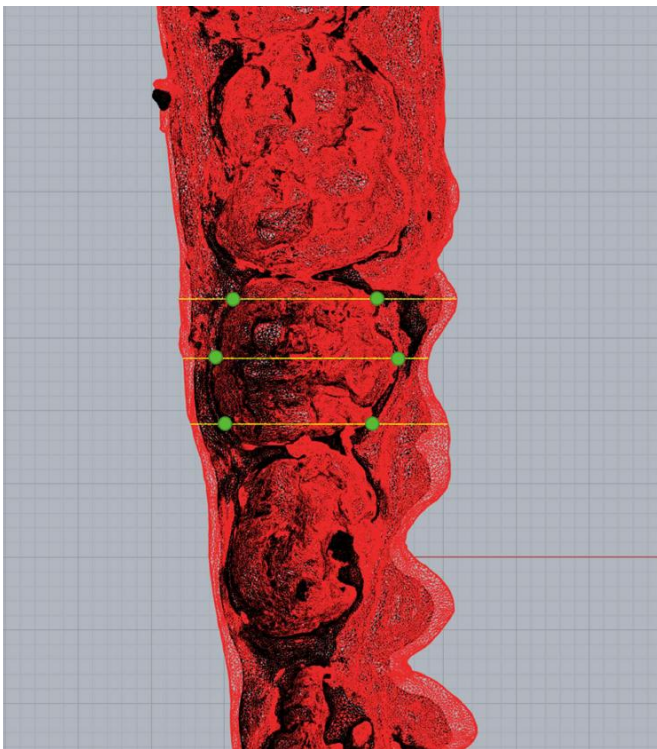


Figure 2: Superimposition of pre-retraction (black) and post-retraction (red) scans of sample M4; green indicates the reference points, and yellow represents the sectional planes passing through those points.

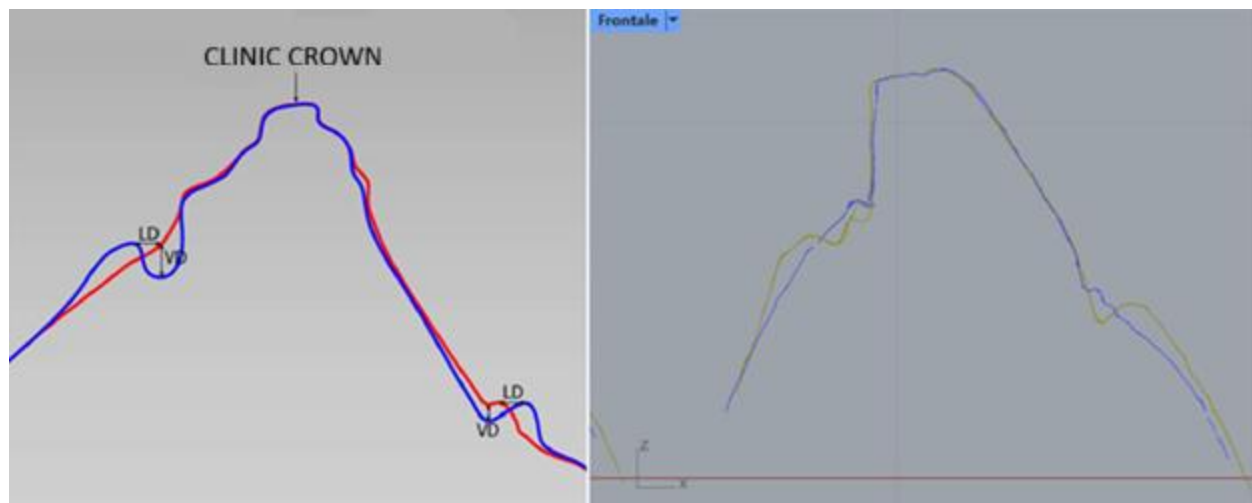


Figure 3: On the left, graphical representation of the vertical (VD) and lateral (LD) distances. On the right, image extracted from the superimposition software (baseline scan in blue and post-treatment scan in yellow).

Measurements and Statistical Analysis

Measurements, expressed in micrometers (μm), were recorded in a dedicated spreadsheet (Microsoft Excel) and categorized by group, tooth, and reference point, allowing for an objective and reproducible assessment of three-dimensional changes [36].

Statistical Analysis

Data processing was performed using dedicated analytical software, starting from the Excel database. The objective was to determine whether significant differences existed among the three gingival retraction techniques (double impregnated cord, 450 nm diode laser, and Nano:YAG laser).

Since the data did not meet normality assumptions and showed heterogeneous variances, a non-parametric approach was applied.

Vertical (VD) and lateral (LD) variations of the gingival margin, together with retraction time per tooth, were analyzed using the Kruskal–Wallis H test for overall comparison among the three independent groups.

When global differences were significant, post-hoc pairwise comparisons were performed using the Mann–Whitney U test with Bonferroni correction to control Type I error.

Results were expressed as median and interquartile range (IQR), and the level of statistical significance was set at $p < 0.05$.

RESULTS

The three-dimensional morphometric analysis revealed significant differences among the three gingival retraction techniques in both vertical (VD) and lateral (LD) directions. A total of 264 measurement points were obtained from 44 teeth, with retraction values exceeding 200 μm in nearly all cases—a threshold considered clinically acceptable for proper registration of prosthetic margins [35,33].

Vertical Retraction (VD)

The Kruskal–Wallis test identified globally significant differences among the three techniques ($p = 2.62 \times 10^{-33}$).

Group A (double impregnated cord) showed the highest median vertical retraction values but also exhibited the greatest intra-group variability. Group B (450 nm diode laser) produced lower absolute retraction values but with a more homogeneous and symmetric distribution, indicating greater reproducibility. Group C (Nano:YAG laser) presented intermediate values; eight measurement points recorded subcritical retractions below 200 μm , mainly localized in two samples (Figure 4, Table 2).

Post-hoc analysis with the Mann–Whitney U test (Bonferroni correction) confirmed significant differences between the double-cord group and both laser groups ($p < 0.001$), while no statistically significant difference was found between the diode and Nano:YAG lasers ($p > 0.05$).

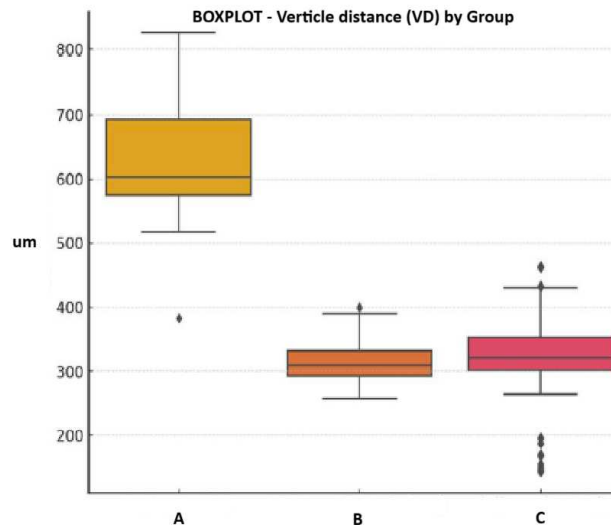


Figure 4: Box plot of vertical retraction (VD) values in the three experimental groups.

GROUP	MEAN (μm)	MEDIAN (μm)	DEV STD (μm)	MIN (μm)	MAX (μm)	Q1 (μm)	MODE (μm)
A	634,1	603,5	88,2	383	825	575	530
B	315,9	309,5	32,7	258	400	293,25	300
C	321,8	321,5	63	144	464	301	318

Table 2: Median values and interquartile ranges (IQR) of vertical retraction for each group.

Lateral Retraction (LD)

For the LD variable, the Kruskal–Wallis test revealed highly significant differences among the three techniques ($p = 1.84 \times 10^{-43}$).

Group A achieved the greatest mean lateral displacement, though with considerable data dispersion (Figure 5).

Group B (450 nm diode laser) demonstrated lower values but with a more regular and homogeneous distribution, whereas Group C (Nano:YAG laser) occupied an intermediate position, with some minimum values below 100 μm . Pairwise comparisons showed statistically significant differences among all combinations ($p < 0.05$), with the 450 nm diode laser exhibiting a more stable and predictable performance than the Nano:YAG, consistent with the findings of Solimei et al. (2024) and Tao et al. (2018) [35,33] (Table 3).

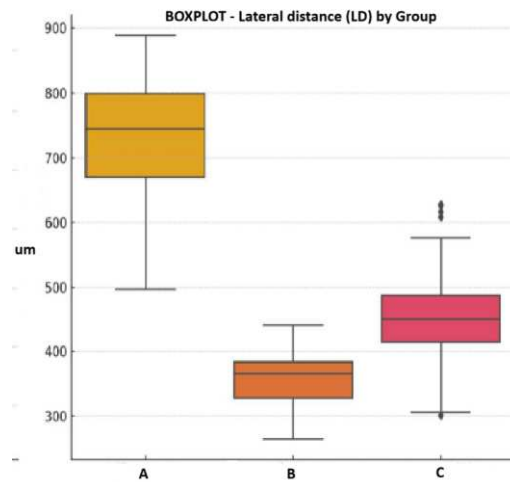


Figure 5: Box plot of lateral retraction (LD) values in the three experimental groups.

GROUP	MEAN (μm)	MEDIAN (μm)	DEV STD (μm)	MIN (μm)	MAX (μm)	Q1 (μm)	MODE (μm)
A	737,5	746	86,9	497	888	669,5	706
B	359,3	366	40,9	264	440	328,8	366
C	451,7	450	66,4	301	628	413,8	450

Table 3: Median values, IQRs, and *p*-values for lateral distance comparisons.

Operative Retraction Times

The analysis of mean retraction time per tooth revealed statistically significant differences among the three techniques (Kruskal–Wallis $H = 27.08$; $p = 1.31 \times 10^{-6}$).

Both laser techniques were significantly faster than the double-cord method, with an average reduction of more than 160 seconds per tooth. The 450 nm diode laser recorded the shortest operative time and the lowest variability, followed by the Nano:YAG, while the double-cord technique was noticeably slower. Although the differences between the two laser systems showed a trend favoring the diode laser, they did not reach statistical significance ($p > 0.05$) (Figure 6, Table 4).

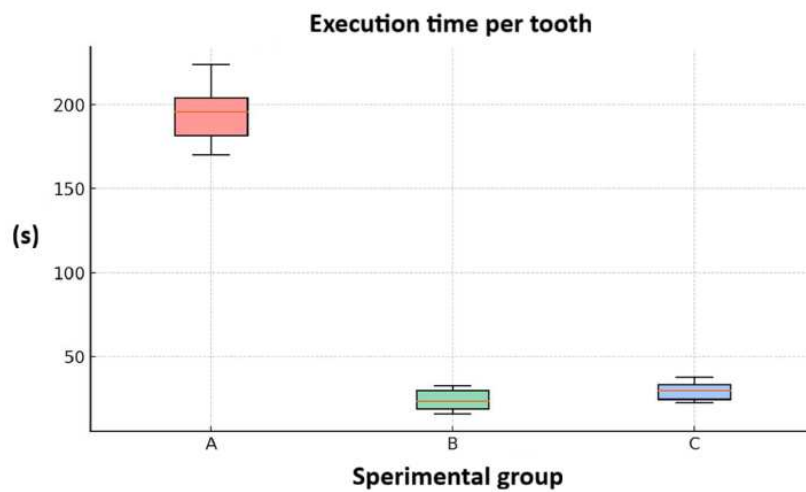


Figure 6: Comparison of mean retraction times (in seconds) among the three techniques.

GROUP	N° OF TEETH	MEAN (s)	MEDIANA (s)	DEV STD (s)	Min–Max (s)	Q1–Q3 (s)
A	11	193,9	196	16,2	170–224	181,5–204,0
B	17	24,8	24	5,9	16–33	19,0–30,0
C	16	29,7	30	4,9	23–38	24,8–33,5

Table 4: Median values, IQRs, and *p*-values for retraction time per tooth.

Overall, the 450 nm diode laser combined clinically adequate retraction, greater data consistency, and a significant reduction in operative time.

DISCUSSION

The objective of this study was to compare three different gingival retraction techniques—double impregnated cord, 450 nm diode laser, and Nano:YAG laser—through three-dimensional morphometric analysis of vertical and lateral changes in the gingival margin. All methods provided clinically effective retraction ($>200\ \mu\text{m}$), confirming their suitability for exposing the prosthetic finish line [37,33].

The double impregnated cord produced the greatest retraction, reaffirming its role as the gold standard technique reported in the literature [26–29,31,32]. However, the substantial intra-group variability observed reflects its operator dependence and limited predictability [30,38]. In addition, the mechanical–chemical component, while effective, can induce microtrauma, bleeding, and longer operative times [6–8].

The 450 nm diode laser produced slightly smaller but more uniform and repeatable retraction values. The consistency of the results suggests a controlled, superficial thermal effect on the sulcular epithelium, providing effective displacement along with simultaneous hemostasis. These findings align with those of Solimei et al. (2024) [35], who demonstrated the predictability and efficiency of short-wavelength diode lasers, and Melilli et al. (2018) [39], who confirmed their compatibility with digital workflows.

The Nano:YAG laser yielded intermediate outcomes, achieving effective retraction in most cases but with less consistency and some subcritical values ($<200\text{ }\mu\text{m}$). This behavior can be attributed to the greater tissue penetration of the 1064 nm wavelength, producing a more diffuse and less controllable photothermal effect, as previously reported by Tao et al. (2018) [33,40,41].

From a procedural standpoint, both laser techniques significantly reduced operative time compared with the conventional double-cord method, with an average saving of more than two minutes per tooth. This finding, consistent with the results of Marsch (2013), Van As (2012), and Tamim et al. (2023) [34,41,43], is clinically relevant for improving workflow efficiency and patient comfort.

Overall, the 450 nm diode laser represents an optimal balance between efficacy, predictability, and biological safety, while the Nano:YAG laser provides intermediate performance but requires more precise calibration of emission parameters [40,41].

Among the limitations of this study, it must be noted that the *in vitro* porcine tissue model, although a valid anatomical analogue of human periodontal tissues [19,21], does not reproduce the biological response of vital gingiva, including healing and post-operative inflammatory processes. Therefore, further *in vivo* clinical studies with larger samples and standardized laser protocols are needed to confirm the translatability of these results to clinical practice [39,34].

In summary, gingival retraction performed with the 450 nm diode laser emerges as a modern, effective, and digitally compatible technique that combines precision, speed, and biological safety—key features in contemporary fixed prosthodontics.

CONCLUSIONS

All techniques tested achieved clinically effective gingival retraction. The double impregnated cord remains the most effective in terms of retraction amplitude but shows higher variability and longer operative times.

The 450 nm diode laser demonstrated consistent, reproducible, and time-efficient performance, making it a valid alternative in digital prosthodontic workflows.

The Nano:YAG laser produced intermediate results with good efficacy but lower stability, indicating the need for optimization of emission parameters. Further *in vivo* studies are required to confirm the clinical translatability of these findings and to evaluate the biological response of gingival tissues following laser irradiation. In the future, the 450 nm diode laser may represent a new clinical standard for gingival retraction in digital fixed prosthodontics.

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Ethics approval: the study not involved human participants, their data or biological material. No ethical approval is required. Considering the provisions of Legislative Decree No. 26/2014 (2010/63/UE), particularly Article 31, it is highlighted that the establishment of an ethical committee is not necessary for the present study, as it does not involve the use of animals for scientific purposes, nor procedures that require such approval.

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