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Original Research Article

Evaluation of Surface Roughness Produced By Orthophosphoric Acid And Er:Yag Laser

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ABSTRACT

Aim: The aim of this study was to comparatively evaluate the changes in surface roughness of primary and permanent teeth following acid and laser application.

Materials and Methods: A total of 80 teeth—40 permanent molars and 40 primary molars—were used in this study. The dentin surfaces were exposed using a separating disc. Primary teeth (Group I, Group II) and permanent teeth (Group III, Group IV) were each divided into two subgroups. Ortho-phosphoric acid was applied to Groups II and IV, while Er:YAG laser was applied to Groups I and III. The initial (Ra0) and post-treatment (Ra1) surface roughness values of each specimen were measured using a profilometer.

Results: The Ra1 values of all groups (Group I: 7.63 ± 2.01 [7.31]; Group II: 3.17 ± 1.81 [2.89]; Group III: 6.37 ± 1.24 [6.14]; Group IV: 3.52 ± 1.98 [3.08]) were higher than their respective Ra0 values (Group I: 1.57 ± 1.16 [1.23]; Group II: 1.77 ± 1.24 [1.52]; Group III: 2.49 ± 2.14 [1.50]; Group IV: 2.01 ± 1.44 [1.40]). The change in surface roughness was greater in Group I (6.06 ± 1.91 [5.70]) compared to Group II (1.40 ± 1.47 [0.81]), and greater in Group III (3.88 ± 1.70 [4.11]) compared to Group IV (1.52 ± 1.52 [0.96]).

Conclusion: In both primary and permanent teeth, laser application resulted in greater changes in surface roughness compared with acid application.

Keywords: Permanent Dentition; Er:YAG Laser; Phosphoric Acid; Primary Dentition

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INTRODUCTION

To successfully perform restorative treatments in dentistry, it is imperative to enhance the physical and aesthetic properties of the materials used while concomitantly augmenting their bonding strength to dental hard tissues. In the context of dentistry, adhesion describes the force of attraction between different molecules or the connection between two different surfaces, while cohesion describes the bond between the same molecules.[1] Mechanical adhesion is a type of adhesion that occurs by locking the adhesive to the recessed and protruding areas on the adherent. Surface roughness is an important factor in ensuring adhesion because it affects the flow of the adhesive material towards the recesses and protrusions and the adhesive's bonding by shrinking.

It is widely accepted that the removal, modification, or dissolution of the smear layer is necessary for optimal adhesion.[2] The objective of acid application is threefold: first to remove the smear layer, second to open the dentin tubules, and third to expose collagen fibrils by demineralisation. The result of these processes is the creation of a hybrid layer for the primer and bonding agent to be later applied.[3] Pre-treatment with different concentrations of phosphoric acid is a conventional method for creating micro-porosities, which facilitate the adhesion of various restorative materials.[4]

Phosphoric acid, at a concentration of 30–40%, has been shown to demineralise dentin tissue to a depth of several micrometres, thus exposing the collagen-rich hydroxyapatite structure. Consequently, collagen fibres that are susceptible to infiltration by hydrophilic monomers, become exposed.[5] However, due to the technical sensitivity and isolation problems associated with acid roughening, alternative methods, such as air-abrasion and laser applications, have been the focus of recent research to roughen dental hard tissues.

In the field of dentistry, lasers operating at low energy levels have been the focus of numerous studies as part of adhesive systems, serving as a substitute for conventional acid roughening techniques for the preparation of enamel and dentin surfaces.[6] It has been reported that Er:YAG lasers can be used safely in dental hard tissues without causing damage to the surrounding tissues.[7] Erbium lasers are particularly well suited to minimally invasive dentistry applications due to their effectiveness in preparing enamel and dentin, which is because they are highly water and hydroxyapatite-absorbable.[8] Er:YAG laser has a wavelength of 2940 nm and is used in various hard tissue applications. A notable advantage of the Er:YAG laser is that it does not cause thermal damage during its use in the cavity. The laser creates superficial micro roughness without forming a smear layer on the applied tooth surface and the dentinal tubule mouths remain open.[9] The fact that laser surface roughening is an essentially painless process, does not generate vibration or heat, and most importantly, does not require isolation, renders it a routine procedure.

Although various studies have investigated the use of lasers, research directly comparing Er:YAG laser and phosphoric acid etching on both primary and permanent dentin remains limited. Structural differences between the dentin of primary and permanent teeth are well documented. In a study comparing the tubule density and diameters of coronal dentin in primary and permanent teeth using SEM, the dentin of primary teeth was reported to have a significantly higher tubule density than that of permanent teeth.[10] A micro-CT study evaluating the mineral density of the enamel and dentin of primary and permanent teeth also reported that permanent teeth exhibit higher mineral density.[11] Additionally, another investigation comparing structural parameters such as dentinal tubule orientation, the presence of interglobular dentin, and incremental lines between primary and permanent molars demonstrated clear biological differences between the two dentin types.[12] Due to these structural variations, the dentin of primary and permanent teeth does not respond in the same way to laser or acid conditioning. For this reason, in the present study, both Er:YAG laser and phosphoric acid were applied to primary and permanent dentin. The aim of this study was to evaluate the changes in dentin surface roughness caused by acid and laser application in primary and permanent teeth.

The null hypothesis tested in this study was that there would be no statistically significant difference in the surface roughness values of dentin from primary and permanent teeth following surface preparation with 37% phosphoric acid or Er:YAG laser. It was assumed that the change in surface roughness would be similar regardless of the surface preparation method applied.

MATERIALS AND METHODS

In this study, a total of 80 teeth (40 permanent molars and 40 primary molars) that were extracted due to orthodontic, traumatic, periodontal problems, or infection at the Zonguldak Bülent Ecevit University Faculty of Dentistry were used. The teeth were randomly divided into four groups, each consisting of 20 samples. (Table 1). A review of the literature shows that the application times used for dentin surface preparation with Er:YAG lasers vary widely.

Table 1. Distribution of samples in the study groups

Group	Number of samples	Tooth type	Method used	Application parameter
Group I	20	Primary molar	Er:YAG laser	20 sec/100 mJ
Group II	20	Primary molar	Orthophosphoric acid	15 sec/37%
Group III	20	Permanent molar	Er:YAG laser	20 sec/100 mJ
Group IV	20	Permanent molar	Orthophosphoric acid	15 sec/37%

While some studies have employed short durations such as 10 seconds, both clinical and experimental research has reported application times ranging from 15–30 seconds and even up to 60 seconds. When considered alongside variations in laser parameters (energy, frequency, water/air ratio, and application mode), this indicates that no standardized protocol exists regarding exposure time. Therefore, the 20-second / 100-mJ combination used in our study falls within the range of durations reported in the literature and is meaningful in terms of evaluating this existing heterogeneity. [13-17]

Group 1 included 20 primary molars treated with Er:YAG laser for 20 seconds at 100 mJ energy. Group 2 consisted of 20 primary molars etched with 37% orthophosphoric acid for 15 seconds. Group 3 comprised 20 permanent molars treated with Er:YAG laser under the same parameters as Group 1 (20 seconds, 100 mJ). Group 4 included 20 permanent molars treated with 37% orthophosphoric acid for 15 seconds. Ethical approval for the study was obtained from the Non-Interventional Clinical Research Ethics Committee of Zonguldak Bülent Ecevit University (approved by decision number 2024/10, decision date 29/05/2024).

Soft tissue residues and debris on all teeth were removed with the aid of a cretin. The extracted teeth were then stored in a sterile saline solution until the start of the study. The teeth were washed under running water after which they were embedded in blocks up to the enamel–cementum boundary. The roots were embedded in autopolymerising acrylic resin. For the experiment, a low-speed diamond separator (Isomet Low-Speed, Buehler, Düsseldorf, Germany) was used to meticulously separate the occlusal third of the teeth perpendicular to their long axes, while being cooled underwater, to expose the dentin surfaces. The exposed dentin surfaces were then prepared with polishing discs (Sof Lex, 3M ESPE, St Paul, MN, USA) from burgundy to yellow colour in all teeth, in accordance with the manufacturer's recommendations. To minimize variability caused by disc wear during the cutting procedure, a new disc was used for each tooth. Primary and permanent teeth were randomly assigned into two groups of 20 specimens per group. To minimize measurement bias, the samples were assigned to groups using a randomly prepared sealed-envelope method. All surface roughness measurements were performed by a blinded investigator who was unaware of the group allocation of the specimens.The roughness value of each specimen was measured from three different areas on the exposed dentin surface with a profilometer (TIME 3221,TESKON, Bursa, Turkey) and calculated by averaging the obtained values (Ra0). In the Group I, a 100 mJ Er:YAG laser was applied to the primary teeth for 20 seconds. The roughness values of the samples were measured from three distinct regions on the surface using a profilometer. The values were averaged to calculate the roughness parameters, denoted as Ra1. Group III followed the same protocol, but with permanent teeth. For Group II, 37% orthophosphoric acid was added to the primary teeth for 15 seconds after which the teeth were thoroughly rinsed with water for a further 15 seconds and then allowed to dry in ambient atmosphere for 10 seconds. Subsequently, measurements were taken from three distinct regions on the surface of the teeth using a profilometer device and the mean values were then calculated (Ra1). Group IV followed the same acid protocol, but with permanent teeth. The mean roughness and changes in these values were recorded.

Data analysis

Statistical analyses were performed with IBM SPSS 25 software and the significance level was set at $p<0.05$. The normality assumption was assessed by the Shapiro–Wilk test. The non-parametric Mann–Whitney U test was used to compare two independent groups as the data were not in normal distribution.

RESULTS

It was observed that the Ra1 values of all groups (Group I: 7.63 ± 2.01 [7.31]; Group II: 3.17 ± 1.81 [2.89]; Group III: 6.37 ± 1.24 [6.14]; Group IV: 3.52 ± 1.98 [3.08]) were higher than their corresponding Ra0 values (Group I: 1.57 ± 1.16 [1.23]; Group II: 1.77 ± 1.24 [1.52]; Group III: 2.49 ± 2.14 [1.50]; Group IV: 2.01 ± 1.44 [1.40]) (Table 2). A statistically significant difference was found between the surface roughness changes of Group I and Group II ($p<0.05$). The surface roughness change in Group I (6.06 ± 1.91 [5.70]) was significantly greater than that of Group II (1.40 ± 1.47 [0.81]). A statistically significant difference was also found between the surface

Table 2. Roughness values of samples according to tooth type and treatment

	Ra0 (min–max)	Ra1 (min–max)	Ra0 (mean±SD [median])	Ra1 (mean±SD [median])
Group I (primary tooth laser group)	0.40 – 4.90	4.64–13.01	1.57±1.16 [1.23]	7.63±2.01 [7.31]
Group II (primary tooth acid group)	0.47–5.57	1.02–6.63	1.77±1.24 [1.52]	3.17±1.81 [2.89]
Group III (permanent tooth laser group)	0.33–7.12	4.88–9.61	2.49±2.14 [1.50]	6.37±1.24 [6.14]
Group IV (permanent tooth acid group)	0.47–5.34	1.08–7.74	2.01±1.44 [1.40]	3.52±1.98 [3.08]

Table 3: Surface roughness change values of samples according to tooth types and treatments applied

	Ra1–Ra0 (min–max)	Ra1–Ra0 (mean±SD [median])	Test statistic	P value
Group I (primary tooth laser group)	3.15–11.82	6.06±1.91 [5.70]	–3.95	<0.001*
Group II (primary tooth acid group)	0.17–5.08	1.40±1.47 [0.81]	–	–
Group III (permanent tooth laser group)	0.87–6.73	3.88±1.70 [4.11]	–3.95	<0.001*
Group IV (permanent tooth acid group)	0.13–5.60	1.52±1.52 [0.96]	–	–

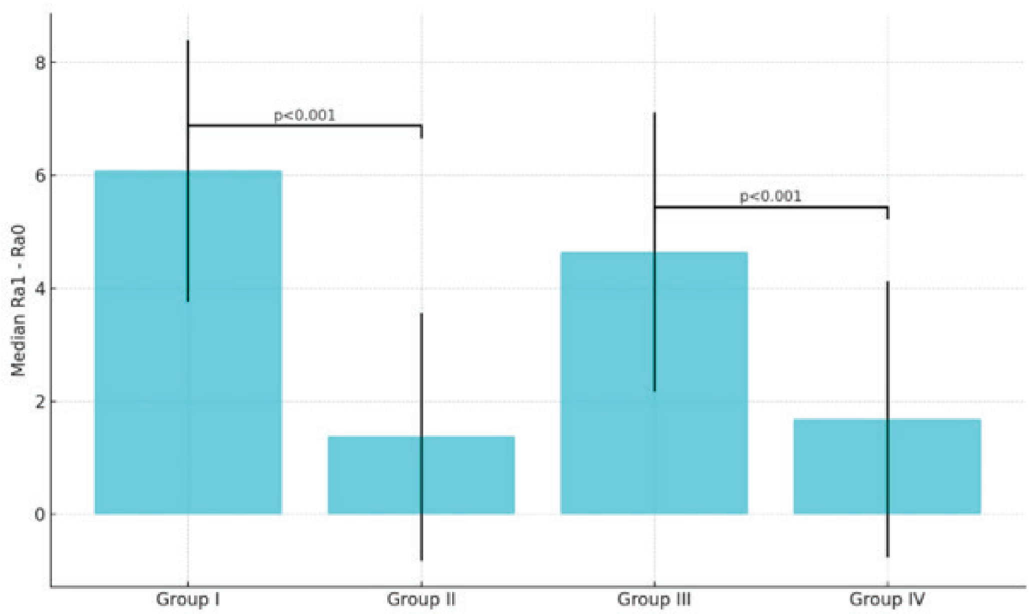

Figure 1. Amounts of surface roughness change according to tooth types and treatments applied

roughness changes of Group III and Group IV ($p < 0.05$). The surface roughness change in Group III (3.88 ± 1.70 [4.11]) was significantly greater than that of Group IV (1.52 ± 1.52 [0.96]) (Table 3, Figure 1).

DISCUSSION

The null hypothesis tested in this study stated that there would be no statistically significant difference in the surface roughness values of dentin from primary and permanent teeth following surface preparation with 37% phosphoric acid or Er:YAG laser. However, the findings demonstrated that the surface preparation method had significant effects on surface roughness, leading to the rejection of the null hypothesis.

To optimise the adhesion of restorative materials to the dentin surface, it is essential to prepare the surface before the procedure. The objective of this preparation is to enhance the surface energy of dentin. The efficacy of bonding can be influenced by various surface preparation techniques and the adhesive system used.[18] It has been documented that the process of acid roughening is subject to variation in relation to the type of acid used (phosphoric acid, hydrochloric acid, or ethylenediaminetetraacetic acid). This variation arises from a range of factors, including the concentration of the acid, the duration of its application, its physical state (ie, gel, semi-gel, or liquid), the manner of washing and rinsing, the time allotted for these processes, the instrument used for application (eg, cotton pellet, brush, special applicator, or syringe), and the chemical structure of the dentin. Acids, such as citric, phosphoric, hydrochloric, and pyruvic acid have been trialled in laboratory conditions. The findings of these studies have led to the conclusion that the use of phosphoric acid is the most favoured, accepted, and standardised method for the roughening process.[19] Despite the existence of a plethora of procedures recommended for the pickling process, the most common method involves the application of phosphoric acid in semi-gel form at a concentration of 37%. The recommended roughening time is subject to variation according to the studies, but is typically in the range of 15–30 seconds.[20,21] The 37% orthophosphoric acid used in this study was in gel form and was applied to the dentin surface for 15 seconds, followed by a wash for 15 seconds and a drying period of 10 seconds according to the manufacturer's instructions.

Among the various laser technologies used for surface preparation, Nd:YAG, CO_2, and Er:YAG lasers are particularly favoured. The Er:YAG laser, with a wavelength of 2940 nm, exhibits a significantly higher level of absorption of OH groups in water and hydroxyapatite structures by water molecules when compared with the CO_2 laser (10 times) and the Nd:YAG laser (20,000 times). To achieve the same level of effectiveness as Er:YAG lasers in hard tissues, it is necessary to use CO_2 and Nd:YAG lasers at high energy levels.[22] For this study, the Er:YAG laser was selected due to its advantageous properties, which include its minimal adverse effects on tissue compared with alternative laser types and its high rate of absorption by dental hard tissues.

This study demonstrates that laser application produces a higher level of surface roughness in both primary and permanent teeth compared with acid etching. This finding can be explained by the micro-explosions, thermal effects, and mineral–matrix separation caused by laser irradiation on the dentin surface. Due to its higher organic content, dentin absorbs laser energy to a greater extent, resulting in a more irregular surface morphology in both primary and permanent teeth compared with acid treatment.

In contrast, phosphoric acid primarily induces selective dissolution of the mineral phase. Acid etching removes the smear layer, partially demineralizes the peritubular dentin, and exposes the collagen fibrils, creating a more homogeneous and controlled micro-retentive surface.[23] Although acid treatment increases surface roughness, it does not produce the same degree of topographic alteration as the irregular ablative effect of laser irradiation; in fact, several studies have reported that Ra values of acid-etched surfaces remain lower than those of laser-prepared ones.[24-27]

Hossain *et al*.[28] compared surface roughness of enamel and dentin after Er:YAG laser and acid treatment and reported that the laser was more effective in creating the desired roughness. Moshonov *et al*.[29] reported that both roughening methods produced similarly successful outcomes in their study using the Er:YAG laser and concluded that laser roughening could be an alternative to acid etching. Conversely, another study comparing micro-shear bond strength values of dentin reported that the highest bond strength was obtained in the acid-etched group.[30]

Firat *et al*.,[31] attribute this result to the effect of the Er:YAG laser on the tissue being predominantly ablative and that prolonged pulse durations cause thermal damage even under water cooling, which has a negative effect on the bonding process.

The findings of this study demonstrate that phosphoric acid application produces similar levels of surface roughness on primary and permanent dentin. This outcome can be explained by the direct demineralization effect of acid on the mineral components of dentin, which occurs in a comparable manner regardless of tooth type.[32,33] Although acid etching creates a similar effect on both primary and permanent teeth, laser application resulted in a greater impact on primary teeth compared with permanent teeth.

Lizarelli *et al*.[34] examined the micromorphological alterations in the dentin of primary and permanent teeth following Er:YAG laser application and reported that, due to differences in mineralization, primary teeth exhibited a rougher surface, whereas permanent teeth showed a smoother surface. This finding can be attributed to the histological and structural differences described in the literature. The dentinal tubule density of primary teeth has been reported to be 2–5 times higher than that of permanent teeth. Additionally, primary dentin contains lower levels of calcium and phosphorus but higher levels of organic material and water compared with permanent dentin.[35,36]

The higher organic matrix content, lower degree of mineralization, and wider and more densely packed dentinal tubules of primary dentin result in greater absorption of laser energy by primary dentin, leading to more pronounced ablation, disruption of collagen structure, and an increase in surface roughness.[37]

In this study, the differing degrees of roughness increase observed between primary and permanent dentin after laser application are consistent with variations in energy absorption linked to the microstructural characteristics of the dentin. Previous studies have reported that due to its higher water content, wider tubules, and lower mineralization, primary dentin is more sensitive to Er:YAG laser energy, resulting in faster ablation and the formation of more pronounced micro-retentive patterns on the surface.[38-40] In contrast, permanent dentin, with its denser mineral matrix and lower organic content, distributes energy differently and exhibits lower ablation efficiency.

The higher roughness values observed in primary dentin in our findings align with these biophysical characteristics. Therefore, the results should be interpreted not merely as superficial morphological differences but as reflections of how the unique structural properties of dentin influence laser–tissue interaction. A limitation of the study is that only surface roughness is considered. Although surface roughness is a concept that affects adhesion, further research is required to evaluate the micro-mechanical structure, exposed collagens, and the hybrid layer in greater detail.

CONCLUSION

The findings of this study indicate that both phosphoric acid and Er:YAG laser applications increase dentin surface roughness in primary and permanent teeth. The Er:YAG laser produced particularly higher roughness values in primary teeth. This difference is consistent with the lower degree of mineralization, higher organic and water content, and greater dentinal tubule density characteristic of primary dentin. The results demonstrate that laser application creates a significant morphological alteration on the dentin surface and provides an effect on surface roughness that is comparable to that of conventional acid etching.

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CONFLICT OF INTEREST

The authors report no competing interests.

Ortofosforik Asit ve Er:Yag Lazerle Oluşturulan Yüzey Pürüzlülüklerinin Değerlendirilmesi

ÖZET

Amaç: Bu çalışmanın amacı asit ve lazer uygulamasının süt ve daimi dişlerde oluşturduğu yüzey pürüzlülüğündeki değişimlerin karşılaştırmalı olarak değerlendirilmesidir.

Gereç ve Yöntem: Çalışmaya 40 adet daimi molar, 40 adet süt molar olmak üzere toplamda 80 adet diş kullanılmıştır. Dişler bir separe yardımıyla dentin yüzeyi ortaya çıkarılmıştır. Süt dişleri (Grup I, Grup II) ve daimi dişler (Grup III, Grup IV) kendi içlerinde ikiye ayrılmıştır. Kendi içerisinde ikiye ayrılan süt dişleri ve daimi dişlere ortofosforik asit (Grup II, Grup IV) ve Er:YAG lazer (Grup I, Grup III) uygulanmıştır. Her bir örneğin başlangıç (Ra0) ve işlem gördükten sonra (Ra1) pürüzlülük değeri profilometre cihazı ile ölçülmüştür.

Bulgular: Tüm grupların Ra1 değerlerinin (Grup I: 7.63±2.01 [7.31]; Grup II: 3.17±1.81 [2.89]; Grup III: 6.37±1.24 [6.14]; Grup IV: 3.52±1.98 [3.08]) Ra0 değerlerinden (Grup I:1.57±1.16 [1.23]; Grup II:1.77±1.24 [1.52]; Grup III:2.49±2.14 [1.50]; Grup IV: 2.01±1.44 [1.40]) daha yüksek olduğu görülmüştür. Grup I'in yüzey pürüzlülük değişim miktarının (6.06±1.91 [5.70]) Grup II'den (1.40±1.47 [0.81]), Grup III'ün yüzey pürüzlülük değişim miktarının (3.88±1.70 [4.11]) Grup IV'ten (1.52±1.52 [0.96]) daha yüksek olduğu bulunmuştur.

Sonuç: Süt ve daimi dişlerde lazer uygulamasının yüzey pürüzlülüğünde oluşturduğu değişim, asit uygulamasından daha fazladır.

Anahtar Kelimeler: Daimi Dişlenme; Er: YAG Lazer; Fosforik Asit; Süt Dişlenme

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