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Effect of femtosecond, Er: YAG and Nd: YAG Laser Systems on bond strength resin cement with esthetic post system

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Abstract
Purpose: The aim of this study was to investigate the results and contributions of surface treatments with different laser systems on bond strength of resin cement with aesthetic post system made of different materials.
Material and Methods: 3 different aesthetic post systems (RelyX™ fiber post, C-Post® zirconium oxide post, Easy Post™ zirconia reinforced fiber post), including 40 from each, were used. On these posts, 3 different surface treatments (Er:YAG laser, Nd:YAG laser and Femtosecond (Fs) laser), including 10 pieces from each system, were applied. In the remaining 10 samples, no action was taken, and a control group was created. The obtained posts were cemented into the composite post slots of 12 mm length and 4 mm diameter using self-adhesive resin cement (RelyX™ U200). From the coronal, medial and apical regions of each prepared sample, 2 mm-thick sections were taken to make push-out tests. Afterward, the push-out resistance was measured using a universal testing machine with 0.5 mm/min head speed.
Results: There were statistically significant differences between the glass fiber posts and the zirconium-reinforced glass fiber posts with zirconium posts ($p<0.05$). The zirconium posts had lower bond strength values. Regarding the etching procedures conducted on the zirconium posts, the Fs lasers and Nd: YAG lasers were found to be more effective ($p<0.05$).
Conclusion: Surface treatments may be applied for increasing the bond strength of zirconium oxide posts, which have lower bond strength than glass fiber posts. Surface treatments conducted with Nd:YAG and Fs lasers increase the value of bond strength of zirconium posts.

Keywords: Femtosecond laser, glass fiber post, zirconium oxide post, push-out

Statement of problem: It is very important to know which laser system should be preferred for resin cement bond strength in order to reduce the loss of retention, which is one of the causes of aesthetic post system failure, to the lowest level.

Clinical implications: The highest bond strengths in glass fiber posts and zirconium-reinforced glass fiber posts were found in Fs laser group, and the highest bond strength in zirconium oxide posts was found in Nd:YAG laser group. However, visible color changes were observed in posts during surface applications with Nd:YAG and Fs lasers.

Introduction
Teeth encounter excessive substance loss during situations such as the removal of dentine for abrasions, attrition, decay, fracture or endodontic treatment. No matter how much crown destruction is present, the existing tooth should be utilized as much as possible. When considering biomechanical factors, successful results can be achieved with retention that will not disrupt the strength and integrity of the root. For this purpose, post-core system is one of the techniques used for supporting the weakened teeth [1-12].
Coronal one-third part of the pulp chamber and the canal are critical control sites for translucence and color harmony. In addition to this, it is very difficult to provide tooth transparency, and brightness with using metal materials [3]. For this reason, increasing demand for aesthetic restorations in dentistry has led to the development of metal-free post systems [4, 5].

While fiber-supported posts and zirconium oxide posts among tooth-colored posts are used, metal-free, extremely aesthetic restorations can be achieved. Although long-term clinical studies are absent, it is known that positive results have been gained in short-term studies with zirconium oxide posts [6, 7].
However, various failures have been observed in prefabricated post systems. These would be aligned as the fracture of the post or the root, and the decementation of the post. While the most severe failure related to aesthetic posts is root fracture, the most frequent failure is the loss of retention of post [8-10].
Various surface applications are performedon the post surfaces in order to reduce negative issues to aminimum. There are systems in the market that are specially developed for this purpose by the companies to perform different surface applications [11]. Etching with a laser, sandblasting, etching with acid, roughening with a rotating device, silane application, tribochemical silica coating would be mentioned among these systems. However, in accordance with the material that the post is composed of, studies in which results related to clinical use are obtained by comparing various surface applications with the selection of the cement system to be used in cementation are very limited in the literature [12].
Lasers, introduced in the 1960's, have found a vast usage area. Although there are many studies about the post and resin cement bonding [12-33], there is no study about the effects of utilization of Femtosecond laser on posts. In the last two decades, significant progress has been made in the development of lasers with very short pulse duration. Since the pulse durations of these lasers named 'Ultra-fast' are at Fs levels (1fs=10-15s), they are also called as Femtosecond 'Fs' lasers [34]. Recently, Fs lasers have been widely in use in cataract surgery [35]. In dentistry, they have been in use for enhancing the bonding of zirconium oxide ceramics with resin-cement [36] and of the enamel and ceramic surfaces with orthodontic brackets [37, 38].
The aim of this study was to investigate which type of laser system used in surface application would contribute more to the bonding strength of aesthetic post systems that are produced from different materials with resincement.
The hypothesis of this study was identified as performing surface applications with different laser systems would positively affect bonding between the post and the cement.

Materıal and Method

120 composite cylinders of 4 mm diameter and 12 mm height were obtained for imitating the dental roots. These composite cylinders were obtained with stratification technique and using 2 mm composite (Universal Restorative 200, 3M ESPE, Seefeld, Germany) for each sectionin a transparent plastic mold. Composite with A1 color was preferred for standardization of light transmittance. A draft for post-space preparation was prepared to the center of the obtained composite cylinder and perpendicular to its long axis by flame-tipped diamond burs with a smaller diameter than the post system under water-cooling. Meanwhile, the samples with cracks were excluded from the study. Composite blocks were embedded into autopolymerizing acrylic blocks (Imicryl SC.) for working comfort and provision of support during the push-out test. This procedure was performed by the help of a parallelometer, using transparent molds 12 mm in diameter and 30 mm in height. The obtained 120 samples were randomly divided into 3 main groups in order to apply different post systems (Figure 1). In addition, groups containing 40 samples each were divided into 4 subgroups containing 10 samples each in order to restore by posts subjected to different surface treatments and to create a control group (Figure 2).

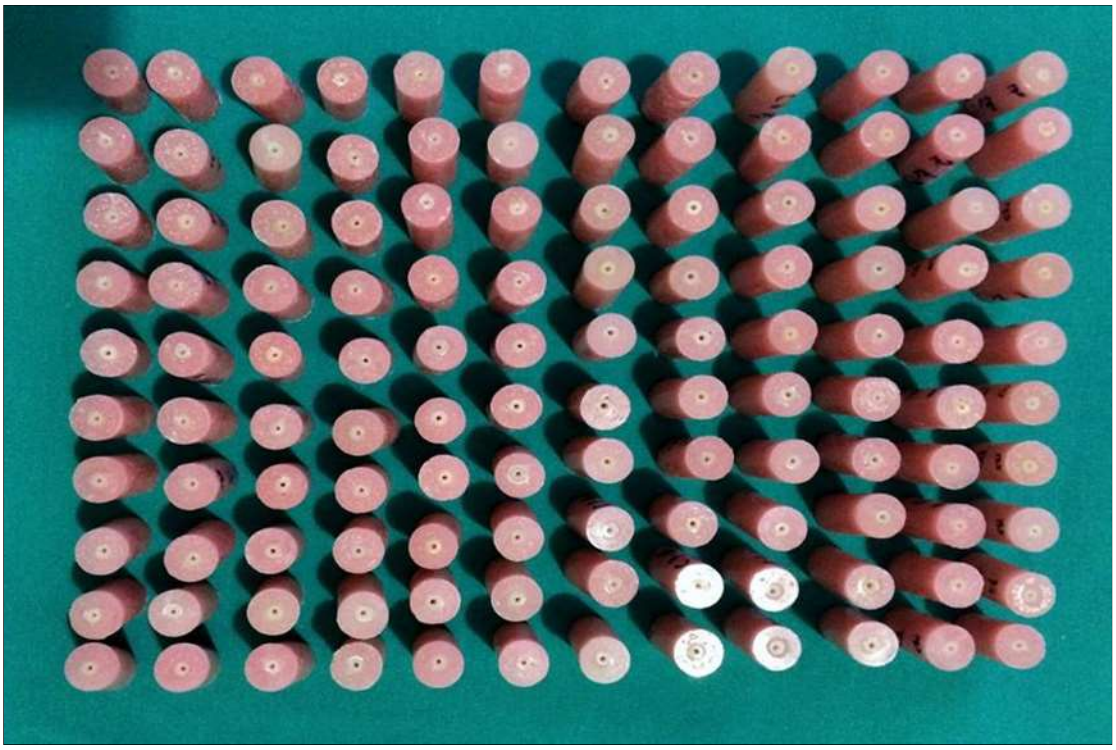

Fig. 1: Prepared acrylic blocks

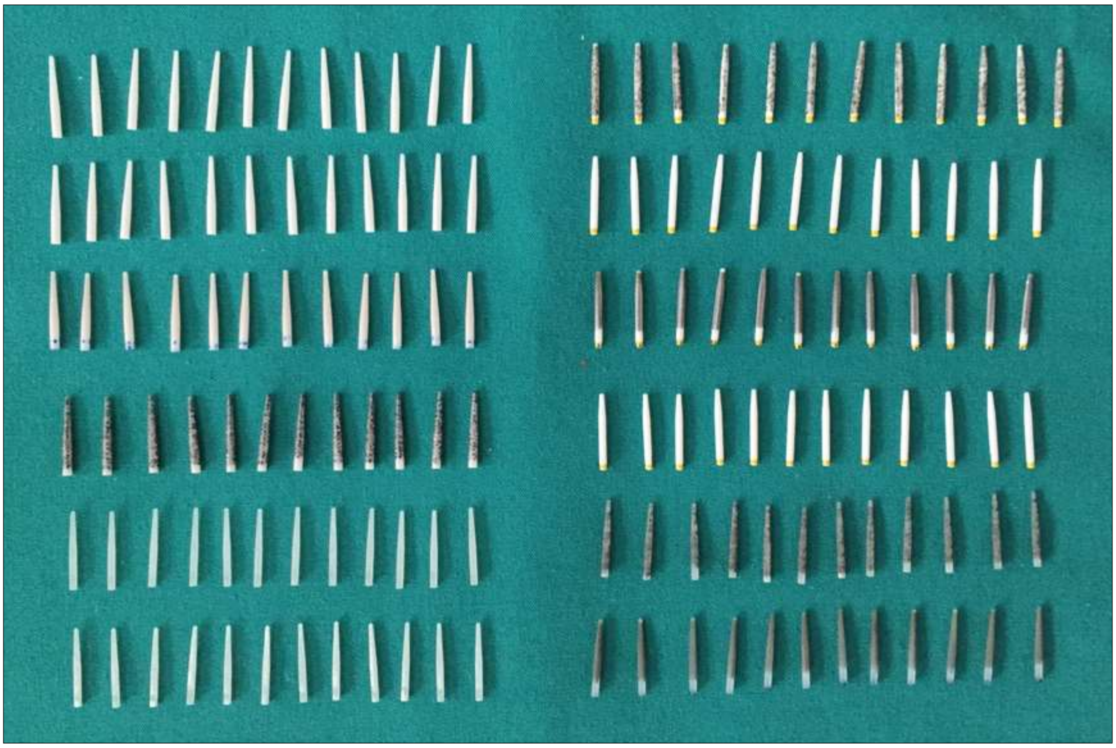

Fig. 2: Prepared posts

It was applied RelyX™ fiber post to the first randomly selected main group containing 40 samples. 9 mm post-space preparation was performed in each composite cylinder using an appropriately sized drill (yellow drill, 3M ESPE).
Then, the first main group was divided into 4 subgroups, each containing 10 samples. The subgroups for restoration were defined as follows:

1) Control Group, with glass fiber posts (CK),
2) Glass fiber posts roughened by Er:YAG laser (CEr)
3) Glass fiber posts roughened by Nd:YAG laser (CNd)
4) Glass fiber posts roughened by Fs laser (CFs)

The Preparations Made for Zirconium Oxide Posts

It was performed C-Post® application in the second randomly selected main group, containing 40 samples. 9 mm post-space preparation was performed in each composite cylinder using an appropriately sized drill (orange drill set, KOMET).
Then, the second main group was divided into 4 subgroups, each containing 10 samples. The subgroups for restoration were defined as follows:

1) Control group with zirconium oxide posts (ZK),
2) Zirconium oxide posts roughened by Er:YAG laser (ZEr)
3) Zirconium oxide posts roughened by Nd:YAG laser (ZNd)
4) Zirconium oxide posts roughened with Fs laser (ZFs)

Preparations for Fiber Post Reinforced with Zirconium

It was performed EasyPost™ fiber post application in the third randomly selected main group, containing 40 samples. 9 mm postspace preparation
preparation was performed in each composite cylinder using an appropriately sized drill (yellow drill, DENTSPLY).

1) Then, the third main group was divided into 4 subgroups, each containing 10 samples. The subgroups for restoration were defined as follows:
1) Control group with glass fiber posts reinforced with zirconium (ZCK),
2) Glass fiber posts reinforced with zirconium roughened with Er:YAG laser (ZCEr)
3) Glass fiber posts reinforced with zirconium roughened with Nd:YAG laser (ZCNd)
4) Glass fiber posts reinforced with zirconium roughened with Fs laser (ZCFs)

Cementation of Posts

RelyX™ U200 self-adhesive cement was mixed at a 1/1 ratio. Part of the cement was moved to the post surface with the help of a spatula. Then, the post was cemented under finger pressure and waited for 20sn. The overflowing cement was removed with a brush, and then, completion of polymerization was performed by applying a LED light with 420-480 nm wavelength and 50-1000mW/cm^2 power (Guilin Woodpecker Medical Instrument Co., Ltd. China.) from the coronal region for 40 seconds. The samples were kept in distilled water for 24 hours at 37 ^{o}C.
Isomet device (Isomet 1000 Buehler, Lake, Bluff, IL) was used for sectioning of the samples 30 mm in height and 12 mm in diameter. A 0.5 mm section of the coronal site of the specimen was removed by cutting with a 0.38 mm thick diamond cutting knife (Norton Diamond Wheel, USA) at 200 RPM-spin under water cooling in order to get rid of the excess post and the over flowing cement residues. Three sections of 2 mm were obtained from each sample using the same diamond cutting knife at 200 RPM-spinunder water cooling.
A universal test device (Instron Ltd. USA) was used for the push-out test (Figure3.30). The diameters of the tips, planned to be forced in the test, were designed in three different sizes considering the diameters of the post sections and covering most of the post surface. A metal plate, having a 2 mm-diameter hole over it, was used for placing the sections. With the help of this prepared equipment and the tip, the push-out test was performed by the universal test devicefrom the apical to thecoronal direction at 0.5mm/min speed (Figure3).

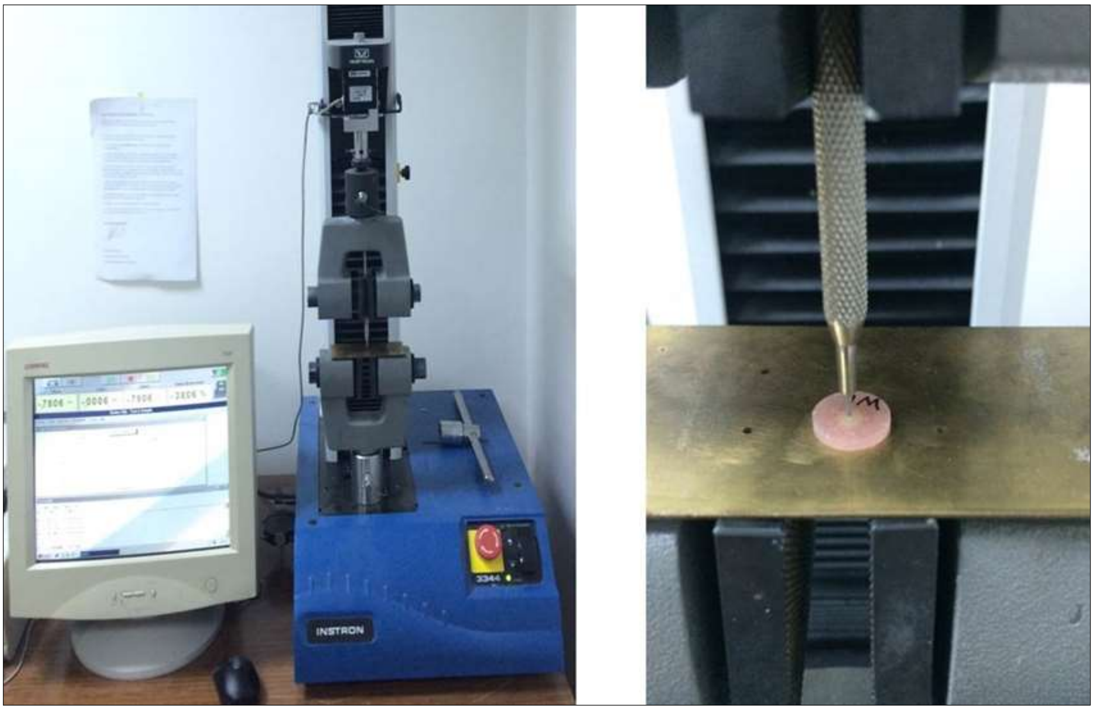

Fig 3: Push-out test system

SPSS 20.0 was used in the analysis of the data. The gathered data were evaluated by the Kolmogorov-Smirnov test for normal distribution, which revealed the normal distribution of all data ($p>0.05$). Then, the data were analyzed statistically by the two-way ANOVA test. In all tests, $p<0.05$ was considered as the presence of significance.

Results

When bond strength values for glass fiber posts, independent from the sections, were analyzed, no statistically significant differences were found between Er, Nd, Fs and control groups ($p>0.05$). However, it was found that while the highest bond strength value was determined in Fs group (11.82 MPa), the lowest bond strength value was in Nd group (10.50 MPa). When the values of the zirconium oxide posts were analyzed, no statistically significant difference was found between Er and control groups ($p>0.05$). However, it was found that Fs group was statistically significantly different from Nd, Er, and control groups ($p<0.05$). Similarly, Nd group was statistically significantly different from Er and control groups ($p<0.05$). In addition to this, while the highest bond strength value was determined in Nd group (9.94 MPa), the lowest bond strength value was in control group (4.86 MPa) (Table 1).

Table 1: Statistical values regarding the posts and surface applications

	Glass Fiber	Zirconium	Glass - Zirconium	Total	
Control	10.64±2.04	4.86±1.66[a]	9.97±1.93	8.49±3.20	p=0.024
Er	11.25±2.05	5.58±1.29[a]	9.14±1.78	8.65±2.91	
Nd	10.5±0.75	9.94±2.93[b]	10.10±1.02	10.18±1.79	
Fs	11.82±1.47	7.38±1.35[c]	10.56±1.46	9.92±2.35	
Tot	11.05±1.69	6.94±2.71	9.94±1.61	9.31±2.69	$p<0.001$
	$p<0.001$				

When the values for glass fiber posts reinforced with zirconium were analyzed, there were no statistically significant differences between Er, Nd, Fs and control groups ($p>0.05$) in these posts. In addition to this, while the highestbond strength value was determined in Fs group (10.55 MPa), the lowest bond strength value was in Er group (9.14 MPa).

When glass fiber posts were assessed regarding the surface treatments, no statistically significant differences were found between the sections in Control Group ($p>0.05$). In addition to this, the highest bond strength value was determined in the apical section (11.56 MPa).

When glass fiber posts were evaluated regarding the surface treatments and the sections, there was no statistically significant difference between the coronal sections and medial sections in the roughening process by Er:YAG laser ($p>0.05$). Similarly, there was no statistically significant difference between the apical and medial sections ($p>0.05$) In addition to this, the difference between the coronal and apical sections was statistically significant ($p<0.05$). Also, the highest bond strength value was determined in the apical section (12.52 MPa).

When glass fiber posts were assessed regarding the surface treatments and the sections, there was a statistically significant difference between the coronal and medial sections regarding the roughening process by Nd:YAG laser($p<0.05$). Similarly, the difference between the apical and medial sections was statistically significant ($p<0.05$). Moreover, the highest bond strength value was determined in the medial section (11.22 MPa).

When analyzed the glass fiber posts regarding the surface treatments and sections, it was determined that a statistically significant difference between the coronal and medial sections regarding the roughening process by Fs laser ($p<0.05$). Similarly, there was a statistically significant difference between the coronal and apical sections ($p<0.05$). However, the difference between the medial and apical sections was not statistically significant ($p>0.05$). In addition, the highest bond strength value was determined in the medial section (12.69 MPa).

When zirconium oxide posts were assessed in terms of surface treatments and sections, there were no statistically significant differences between coronal and medial sections ($p>0.05$). The highest bond strength value was found in the medial section (5.38 MPa).

When zirconium oxide posts were assessed in terms of surface treatments and sections, no significant differences were found between the coronal and medial sections and also between the medial and apical sections in roughening process by Er:YAG laser ($p>0.05$). Moreover, there was a statistically significant difference between the coronal and apical sections ($p<0.05$). Also, the highestbond strength value was determined in the apical section (6.44 MPa).

When zirconium oxide posts were assessed in terms of surface processes and sections, no statistically significant differenceswere found between the sectionsregarding the roughening process by Nd:YAG laser ($p>0.05$). In addition to this, the highest bond strength value was determined in the apical section (10.63 MPa).

When zirconium oxide posts were assessed in terms of surface processes and sections, there were no statistically significant differences between the coronal and medial sections and between the medial and apical sectionsregarding the roughening process by Fs laser ($p>0.05$). However, the difference between the coronal and apical sections was statistically significant ($p<0.05$). Also, the highest bond strength value was determined in the apical section (8.16 MPa).

When glass fiber posts reinforced with zirconium were assessed in terms of surface processes and sections, there were statistically significant differences between the coronal and medial sections and between the coronal and apical sections in Control Group ($p<0.05$). In addition to this, no statistically significant difference was present between the medial and apical sections ($p>0.05$). At the same time, the highest bond strength value was determined in the medial section (10.62 MPa).

When glass fiber posts reinforced with zirconium were evaluated regarding the surface treatments and sections, no statistically significant differences were found between sections in roughening process by Er:YAG laser ($p>0.05$). Also, the highest bond strength value was determined in the medial section (9.58 MPa).

When glass fiber posts reinforced with zirconium were evaluated regarding the surface treatments and sections, there were no statistically significant differences between sections in roughening process by Nd:YAG laser ($p>0.05$). Moreover, the highest bond strength value was determined in the medial section (10.46 MPa).

When glass fiber posts reinforced with zirconium were evaluated regarding surface treatments and sections, there were statistically significant differences between the coronal and medial sections, and between the coronal and apical sections in Control Group ($p<0.05$). Moreover, no statistically significant difference was found to be present between the medial and apical sections ($p>0.05$). Also, the highest bond strength value was determined in the apical section (11.28 MPa) (Table 2).

Table 2: Pairwise intra-group comparison results of the variance analysis in repeated measurements

Glass Fiber															
Control				**Er**				**Nd**				**Fs**			
	C	M	A		C	M	A		C	M	A		C	M	A
C	X			C	X			C	X			C	X		
M	.649	X		M	.110	X		M	.002*	X		M	.000*	X	
A	.052	.111	X	A	.002*	.075	X	A	.013*	.896	X	A	.003*	.855	X
Zirconium															
Control				Er				Nd				Fs			
	C	M	A		C	M	A		C	M	A		C	M	A
C	X			C	X			C	X			C	X		
M	.215	X		M	.113	X		M	.276	X		M	.139	X	
A	.928	.330	X	A	.021*	.317	X	A	.077	.384	X	A	.035*	.377	X
Zirconium - Glass Fiber															
Control				Er				Nd				Fs			
	C	M	A		C	M	A		C	M	A		C	M	A
C	X			C	X			C	X			C	X		
M	.005*	X		M	.238	X		M	.174	X		M	.019*	X	
A	.020*	.948	X	A	.758	.483	X	A	.363	.805	X	A	.018*	.696	X

*Marked sections indicate the presence of a statistically significant difference ($p<0.05$)

Discussion

When all the results of study were reviewed, since the lowest bond strength value among surface treatments was determined in control Group regardless of differences in the post system, the hypothesis was accepted. While the most serious complication related to aesthetic post failure is root fracture, the most common failure is the post retention [8-10-13]. Numerous studies have been conducted to increase the bonding of posts to the root dentine, the adhesive cement, and the core material. Many topics such as the development of materials that the posts are made of [14], the post design [15-17], and post surface treatments [9] have been considered among these studies.

In this study, the dominant failure type was found to be the adhesive failure of post-resin cement with the rates of 79.2% at the coronal section, 75.8% at the medial section, and 78.3% at the apical section in all groups.

Micromechanical locking and various surface treatments that can establish chemical bonding and which are effective on the bonding strength of posts may be applied [39].

In a study with fiber posts, conducted by Graifetal [21]. alcohol application, methyl methacrylate application, and methyl methacrylate application followed by tribochemical covering were preferred as surface applications. In a study with glass fiber posts, conducted by Zicarietal [20]. silane application on the post surface and tribochemical covering were preferred as the methods. Moreover, Alkurt and Yanikoğlu [22] used the NaOCI and Nd:YAG laser applications, together with the treatment of the post surfaces with aluminum particles 50 µm in size.

Post surface application would be performed by using Er:YAG and Nd:YAG laser. Although never been used in post surface applications before, various studies with Fs lasers have revealed positive results,and they have more commonly started to be used in dentistry recently [23-25]. For this reason, in this study, surface applications by Nd:YAG, Er:YAg and Fs lasers were preferred. As a result, the highest bond strength values in glass fiber posts and glass fiber posts reinforced with zirconium were found in Fs laser group, and the highest bond strength in zirconium oxide posts was found in Nd:YAG laser group.

Bitter *et al*. [26], in their study in which they used the push-out bonding test in zirconium oxide posts and fiber posts, found lower bond strengths in zirconium oxide posts in general. Parallel to that, in this study also, bond strengths of the zirconium oxide posts were lower when compared to the glass fiber posts and glass fiber posts reinforced with zirconium.

During evaluation of the bond strength between the post, the cement and the root dentine, push-out, pull-out and microtensile bonding strength tests would be utilized. Since the pull-out tests are performed in larger surface areas, fractures of cohesive type occur when stress is exerted; there are some studies stating that this type of failure reveals no reliable results regarding the bonding between post, cement, and dentine [28, 29]. However, in the microtensile test, bond strength can be calculated by obtaining small sections from a sample without any cohesive failure in dentine. In addition, bond strengths in different sites of the sample can be calculated separately. However, since the samples are prepared in small pieces, technical precision is required, and there would be some losses during the sample preparation phase. During the push-out bonding test, different sites of the sample can be assessed by obtaining tiny sections from the sample. Goracci *et al*. [29] in their study for the comparison of the push-out and microtensile tests, reported that push-out test was the most accurate and reliable method for determining the bond strength of posts to dentine.

D'Arcangelo *et al*. [31] in their study in which they performed push-out bonding test in the sections obtained from coronal, medial and apical regions and used three different fiber posts and adhesive system together with resin and cement, reported the highest bond strength in the coronal triplet. They also reported no statistical difference for medial and apical triplets regarding the bonding strength value. Similarly, in the study by Boff *et al*. [32], the highest bond strength was reported in the coronal triplet, and no statistical differences were found between medial and apical triplets.

In a study by Sahinkesen *et al*. [33] with the fiber posts, the highest bond strength in the group that self-adhesive resin cement was used was found in the medial triplet. There were no statistically significant differences in the coronal and apical triplets.

In this study, when evaluated the sections independent from the type of the post and the surface application, the coronal section was statistically significantly different when compared to the medial and apical sections; however, there was no statistically significant difference between medial and apical sections. In addition to this, the highest bond strength was found in the apical section and the lowest bond strength was found in the coronal section. Polymerization shrinkage of the resin cement, the intensity and the application distance of the light device and variations among companies which produce cement would be the leading causes of these differences among the studies.

In addition, visible color changes were observed in the posts during surface applications with Nd:YAG and Fs lasers in aesthetic post systems. Such a color change might lead to some aesthetic concerns. Since the studies related to this topic in the literature are insufficient, more in-vitro studies are needed.

Conclusıon

1. There were statistically significant differences between the bond strength values of aesthetic post types. ($p<0.05$). The highest bond strength was of the glass fiber posts among all post types (11.05 MPa). The group with lowest bond strength was zirconium oxide posts (6.94MPa)
2. There were statistically significant differences regarding bond strength values of posts related to changes in surface applications. ($p<0.05$). There were statistically significant differences between Er:YAG and Nd:YAG groups, Nd:YAG and control groups, Fs and control groups ($p<0.05$). In addition to this, the highest bond strength was measured in Nd:YAG group (10.18MPa).
3. There were two types of failure regarding the push-out bond strength test, being the adhesive and mixed types. It was found that the dominant type of failure in thepush-out test was the adhesive type (78%).

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