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The collected data from all groups were imported to Statistical Package for Social Sciences (SPSS) for Windows software, version 16.0 (SPSS Inc., Chicago, IL, USA). The standard descriptive methods such as the mean, standard deviation, median, frequency, minimum and maximum were applied to determine the characteristics of the sample. The chi-square test was used to compare the categorical demographic variables among the groups. Because the distribution of the data did not meet the requirements for normality and homogeneity of variances assumptions, the nonparametric Kruskal-Wallis one way analysis of variance by ranks and Mann-Whitney U tests were used for the multiple and pairwise comparisons, respectively. The correlations between at least two continuous variables were examined using Pearson's correlation coefficient. Stepwise regression analysis was performed to understand the statistical dependence of the DFS and MDAS scores in the general population. Covariance analysis was used to determine whether the difference between the mean DFS and MDAS scores of the groups was statistically significant under a predefined effect. The confidence interval was set to 95% and $p < 0.05$ was considered statistically significant.

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2. McKeage K. Tobramycin inhalation powder: a review of its use in the treatment of chronic pseudomonas aeruginosa infection in patients with cystic fibrosis. Drugs 2013; [Epub ahead of print] Available from: http://link.springer.com/article/10.1007%2 Fs40265-013-0141-0

Book

3. Mueller HJ, Freeman D. FT-IR spectrometry in materiology graphy. 2nd Ed., Ohio: American Society for Metal 1994, p.51-56.

Chapter in a book

4. Alexander RG. Considerations in creating a beautiful smile. In: Romano R, editor. The art of the smile. London: Quintessence Publishing, 2005, p.187-210.
5. Hudson FB, Hawcroft J. Duration of treatment in phenylketonuria. In: Seakins J, Saunders R, editors. Treatment of inborn errors of metabolism. London: Churchill Livingstone, 1973, p.51-56.

Thesis

6. Maden I. Effect Of Nd:YAG Laser Treatment In Addition To Scaling And Root Planning. Doctoral Dissertation, Istanbul University Institute of Health Sciences Periodontology Department, 2009.

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Figure 1. Panoramic radiograph of the patient taken 6 months after surgery, note irregular borders of the lesion.

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	Control group (Mean % ± SD %)	First group (Mean % ± SD %)	Second group (Mean % ± SD %)
CTA	21.41 ± 4.2	2.5 ± 2.4	11.42 ± 4.2
NBA	11.48 ± 0.2	21.41 ± 14.22	11.41 ± 4.2

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Original research

A study on the discoloration of different dental porcelain systems

Mehmet Çağatay Ulucan[1], Melek Kılıç Avşar[2], Giray Bolayır[3]

Purpose

This study aimed to investigate the discoloration of four types of dental porcelain systems (feldspathic, monolithic zirconia, lithium disilicate, and leucite glass-ceramic) with various surface treatments (glazed and mechanically polished) after undergoing chewing simulation against a natural tooth antagonist.

Materials and Methods

Disc-shaped porcelain groups (9x3mm) were produced for the following categories: feldspathic glazed (FG), feldspathic mechanically polished (FM), zirconia glazed (ZG), zirconia mechanically polished (ZM), lithium disilicate glazed (ExG), lithium disilicate mechanically polished (ExM), leucite glass-ceramic glazed (EG), and leucite glass-ceramic (EM). In vitro chewing simulation was conducted on all porcelain groups, and a spectrophotometer was used to compare the color changes between their initial states.

Results

The ΔE values (discoloration) of all porcelain samples were statistically different ($p<0.05$), and the ΔE values of the glazed samples were higher than those of the mechanically polished samples.

Conclusion

All the glazed samples are more likely to show more color change than the mechanically polished sample groups.

Keywords: *Dental ceramics, color stability, discoloration, glaze, mechanical polish*

Introduction

The fundamentals of planning and applying current dental prosthetic treatments are based on restoring the integrity of lost tissue, regulating function and phonation, and meeting the patient's aesthetic preferences to the highest degree (1, 2). In recent decades, with technological advances and patients' preference for fully natural products, polycrystalline ceramic and glass-ceramic monolithic porcelain restorations have gained importance in dentistry due to their edge and biological compliance with tissues, superior aesthetic properties, color stability, chemical durability, and corrosion resistance (3-6). However, ceramic compounds have different chemical-physical and optical characteristics influenced by crystal structures, elemental compounds, and the chemical composition of the matrix and particle positions (7). Some studies have investigated the translucency of ceramics, one of their optical characteristics, and have found that the thickness, chemical structure of crystal particles, and particle sizes in the matrix affect translucency for all ceramics, including glass-ceramics and polycrystalline ceramics (7, 8).

The glaze structure is another factor affecting the optical characteristics of ceramics, as the presence of glaze increases their translucency (9).

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Additionally, the glaze layer increases the surface energy of ceramics, reduces plaque retention, and makes the cleaning process easier (10-12). To maximize the surface characteristics of dental ceramics, mechanical polishing is another surface finishing technique that enhances the material's mechanical and optical features (13-15).

However, it is evident that during most cementation processes, the glaze layer is removed by occlusal adjustment. On the other hand, clinical studies have reported that the glaze layer is removed by daily usage within 6 months (16). Once the glaze layer fades, dental porcelains become rough and less attractive in terms of aesthetics. It has been reported that an increase in surface roughness of restorative materials has negative effects on their discoloration (13-15). Bollen *et al.* (12) reported in their study that when the roughness level exceeds 0.2 µm, the plaque accumulation also increases, in addition to discoloration.

The ΔE values of the CIE L*a*b** system, which is a standard and reliable method, are used in literature and studies to calculate color changes. CIE L* measures the lightness of the material, CIE a* measures the redness (positive value) or greenness (negative value), and CIE b* measures the yellowness (positive value) or blueness (negative value). In this calculation system, ΔE values define the level of color change. It has been reported that a color change can be imperceptible to the human eye when ΔE values are lower than 1; when the values are between 1.0 and 3.3, changing the color is hardly noticeable and is generally considered clinically acceptable. However, when ΔE value is higher than 3.3, the color change can be easily detected and is considered clinically unacceptable (17-19).

The purpose of our study is to evaluate the discoloration of four different dental porcelains, including Feldspathic (Super Porcelain EX-3, Kuraray Noritake Dental Inc.), Zirconia (Katana Zirconia UTML, Kuraray Noritake Dental Inc.), Leucite (IPS Empress CAD, Ivoclar VIVADENT), and Lithium Disilicate (IPS e.max CAD, Ivoclar VIVADENT), in their glazed and mechanically polished versions after undergoing chewing simulator tests. The null hypothesis of this study is that there will be no difference in the optical properties of the dental ceramics between their mechanically polished and glazed versions after undergoing the chewing simulation.

Materials and Methods

Sample characteristics

The present study analyzed the color change patterns of four different dental porcelain systems: Super Porcelain EX-3 (Kuraray Noritake Dental Inc., Tokyo, Japan), Katana Zirconia UTML (Kuraray Noritake Dental Inc., Tokyo, Japan), IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein), and IPS empress CAD (Ivoclar Vivadent, Schaan, Liechtenstein).

Study groups

The porcelain groups were divided into two sub-groups and treated with different surface processes, namely glaze and mechanical polish (Table 1). The total number of porcelain samples was 64. Sixty-four premolar and canine teeth, which were extracted due to orthodontic and periodontal indications, had no tissue loss from mechanical and chemical factors, and had no cavities or fillings, were prepared as antagonists for the porcelain samples. The samples were cleaned of debris using low rev polish, and prior to enamel surface processing, the sample teeth were soaked in a 0.1% thymol solution to prevent possible corrosion of the enamel tissue.

Table 1. *Porcelain samples stratified by the the composition and surface treatment.*

No	Porcelain Material	Manufacturer	Composition	Surface Treatment Method	Code
1	**Super Porcelain EX-3**	Kuraray Noritake Dental Inc.	Feldspathic	Glaze	FG
				Mechanical Polish	FM
2	**KATANA Zirconia UTML**	Kuraray Noritake Dental Inc.	Zirconia	Glaze	ZG
				Mechanical Polish	ZM
3	**IPS e.max CAD**	Ivoclar VIVADENT	Lithium disilicate	Glaze	ExG
				Mechanical Polish	ExM
4	**IPS Empress CAD**	Ivoclar VIVADENT	Leucite	Glaze	EG
				Mechanical Polish	EM

Preparation of porcelain samples

Dental porcelain samples were fabricated in standardized cylindrical forms with a width of 9 mm and a height of 3 mm. The dimensional controls were performed using a digital caliper.

Preparation of feldspathic porcelain samples

Super Porcelain EX-3, a low-temperature feldspathic porcelain system, was prepared using the conventional manual method. As recommended by the manufacturer and due to known material shrinkage during heat treatment, the samples were molded into 10% larger PEEK (Polyether ether ketone) molds. The manually fabricated feldspathic porcelain was heat-treated for 7 minutes at 600°C as per the manufacturer's instructions. Then, the vacuum process was initiated, and the process was stopped at 920°C. The entire heat treatment process was completed at 930°C with a heating rate of 45°C per minute.

A total of 16 feldspathic porcelain samples were prepared. Within the subgroups, 8 samples were glazed and the other 8 were mechanically polished. For glaze treatment of FG samples, a mixture of Super Porcelain External Stain Glaze powder and ES LIQUID was used (Kuraray Noritake Dental Inc., Tokyo, Japan). The process was initiated with 5 minutes of dehumidification, followed by the application of the glaze material to the porcelain surfaces using a porcelain brush. The heat treatment process was then started at 650°C and completed at 910°C with a heating rate of 50°C per minute. The heat treatment and glaze processes were carried out using Ivoclar Vivadent Programat ep 3000 (Ivoclar Vivadent, Schaan, Liechtenstein).

Preparation of monolithic zirconia ceramics

The monolithic zirconia CAD/CAM porcelains were prepared from Katana Zirconia UTML blocks. The zirconia discs were milled using a CAD/CAM machine Yenadent D43 milling machine (Yenadent, Istanbul, Turkey) and then sintered following the manufacturer's guidelines. The sintering process was performed with a heating rate of 10°C per minute, and the temperature in the oven was stabilized at 1550°C for two hours before being decreased to room temperature at a rate of 10°C per minute.

For the zirconia samples, 8 of them were glazed and the other 8 were mechanically polished. For the ZG group, a mix of CERABIEN ZR VC Glaze Powder and liquid porcelain was used (Kuraray Noritake Dental Inc., Tokyo, Japan). The procedure was done according to the guidelines of the manufacturer. After 5 minutes of dehumidification, the glaze heat treatment process was initiated at 600°C under vacuum (72cm/Hg), and the heat was increased to 850°C at a rate of 65°C per minute.

Preparation of lithium disilicate ceramics

The lithium disilicate discs were carved via CAD/CAM device Yenadent D43 milling machine (Yenadent, Istanbul, Turkey) and heat-treated according to the manufacturer's guidelines. After the 6-minute dehumidification process at 403°C, the heat treatment was initiated, and the heat decreased 90°C per minute until the target temperature of 820°C was reached. The first vacuum was applied between 550°C and 820°C during the initial heat treatment. After waiting for 10 seconds at 820°C, the second stage of the heat treatment was started. The temperature was increased up to 840°C at a rate of 30°C per minute during the second heat treatment process. The vacuum was applied at each stage of the process. After the samples were stabilized at 840°C for 7 minutes, they were left to cool down. 8 of the samples were glazed and the other 8 were mechanically polished.

For the ExG group, a mix of IPS Ivocolor Glaze Powder and Liquid material was used (Ivoclar Vivadent, Schaan, Liechtenstein). After the samples were dehumidified at 403°C for 6 minutes, they were heat-treated with an increase of 60°C per minute up to 725°C, and the glazing process was completed by keeping the samples at this temperature for one minute. The vacuum was applied between 450°C and 724°C during the firing process.

Preparation of leucite glass ceramics

Leucite glass-ceramic was prepared via CAD/CAM device Yenadent D43 milling machine. 8 of the samples were glazed and the other 8 were mechanically polished. For the EG group, the IPS Empress Universal Glaze Liquid was applied with a porcelain brush (Ivoclar Vivadent, Schaan, Liechtenstein), and then the dehumidification process was carried out at 403°C for 6 minutes. After the samples were heated at an increased rate of 55°C per minute up to 790°C and kept at this temperature for a maximum of 2 minutes, the glazing process was completed. The vacuum was applied between 450°C and 789°C during the firing process.

Application of glaze and mechanical polish

Under the heading of preparation of samples above, the glaze materials used for each group and the protocols followed are explained. For all samples, the glaze application process was carried out as follows: first, each sample was dehumidified, then a uniform layer of overglaze porcelain liquid was evenly applied on one side of the samples with a porcelain brush by one operator. After this process, the samples were fired as recommended by the manufacturers.

The mechanical polishing was carried out using the EVE Diapol three-stage porcelain polishing kit (EVE Ernst Vetter GmbH, Keltern, Germany) and Renfret Polish All in One polishing paste (Renfrent, Hilzigen, Germany). According to the manufacturers, these polish kits and paste can be used on all porcelain samples in our study (zirconia, feldspathic, lithium disilicate, and leucite porcelains). In addition, a single mechanical polishing system was chosen for standardization for all porcelains in our study.

The mechanical polishing was carried out as follows: All polishing processes were applied by one operator. Each of the mechanical polishing steps included coarse, medium, and fine rubber discs (EVE Diapol Rubber Discs), and polishing paste (Renfret Polish All in One polishing paste) with cotton buff, respectively. In the polishing kit, blue rubber discs were used for coarse polish, then medium polish was applied with pink rubber discs, and finally, a third step was carried out with white rubber discs for a fine finish. Each step was performed with a 10,000-rpm rotary instrument, lasting a minimum of one minute. This polish kit was chosen because, according to its manufacturer, it can be used for all types of porcelain (zirconia, feldspathic, lithium disilicate, and leucite porcelains) as well as for the standardization of mechanical polish kits for all porcelains. After mechanical polishing with rubber discs, polishing paste (Renfert Polish All in One) was applied to all porcelains with a cotton buff for at least 60 seconds with a 7,000-rpm rotary tool for a spotless and high-gloss polish finish.

The chewing simulation

The chewing simulation test on porcelain samples of our study was carried out via the SD Mechatronic Chewing Simulator CS-4.8 Biaxial Fatigue Testing system (SD Mechatronik GMBH, MiesbacherStrasse 34 D-83620 Feldkirchen-Westerham, Germany). For the simulation, the sample porcelains were embedded into acrylic and placed into retainers. The antagonist's teeth were also embedded into acrylic and placed into retainers. Samples and teeth were placed into the simulator and calibrated. The samples were subjected to 600,000 chewing cycles at 50N chewing pressure and a frequency of 1Hz, while thermal cycles were applied to fatigue the dental ceramics. The ceramics underwent 10,000 thermal cycles from 5°C to 55°C.

Color assessment

Color values of each porcelain sample were measured after surface finishing applications and after chewing simulation with thermal cycle using the Vita Easyshade Advance (Vita Zahnfabrik Bad Sackigen Germany) spectrophotometer system. A black background was used to mimic the oral environment, and for the standardization of measurements. The ΔE values of the CIE Lab* system were used to calculate the color changes.

Statistical analysis

The statistical package for Social Sciences (SPSS) software version 22.0 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY, USA) was used for data evaluation. The normality of the dataset was checked with Kolmogorov-Smirnov test. Multiple and pairwise comparisons were made, respectively, with analysis of variance and Tukey's Honestly Significant Difference (HSD) tests. The confidence interval was set to 95% and p values less than 0.05 were considered significant.

Results

After analyzing the color changes of glazed and mechanically polished porcelains with different chemical structures, it was found that porcelains with the same surface finish process exhibited significant differences in ΔE values among samples with different compositions ($p<0.05$, Table 2). Among the glazed porcelains, group EG had the highest ΔE values, while the least color change was observed in group FG ($p<0.05$). For samples treated with mechanical polishing, the highest ΔE values were found in group EM, similar to the glazed porcelains (Figure 1). However, the porcelains that underwent mechanical polishing with the least color change were in group ZM ($p<0.05$).

Table 2. *ΔE and standard deviation values of the porcelain specimens according to surface treatments.*

Porcelain	N	Average	Std. Deviation	Result
FG	8	2,7388	,01246	F=8266,17 P=0,001*
ZG	8	3,0613	,00835	
ExG	8	3,1863	,00518	
EG	8	3,4313	,00835	
FM	8	1,2100	,00756	F=9285,44 P=0,001*
ZM	8	,7663	,01302	
ExM	8	2,0263	,02615	
EM	8	2,4563	,03335	

*p<0,05 significant

As shown in Table 3, the ΔE values of all glazed samples were higher than those of the mechanically polished samples when comparing post-simulation values of samples with the same composition in different surface treatment groups. Mean values in group EG were above the apparent and unacceptable limit of 3.3, while values in glaze groups other than FG were above 3 ($p<0.05$).

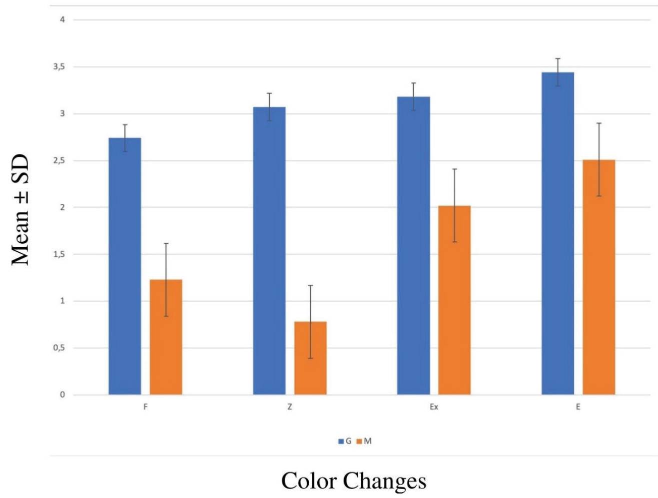

Figure 1. *Color changes of the porcelain samples.*

Table 3. *ΔE and standard deviation value of glaze and mechanical sub-groups of porcelain groups according to their contents.*

Porcelain	N	Average	Std. Deviation	Result
FG	8	2,7388	,01246	F=1,46 P=0,001*
FM	8	1,2100	,00756	
ZG	8	3,0613	,00835	F=1,87 P=0,001*
ZM	8	,7663	,01302	
ExG	8	3,1863	,00518	F=5,57 P=0,001*
ExM	8	2,0263	,02615	
EG	8	3,4313	,00835	F=14,51 P=0,001*
EM	8	2,4563	,03335	

*p<0,001 significant

Discussion

The null hypothesis of the present study was that there would be no difference in optical properties of dental ceramics after the chewing simulation on surfaces that were mechanically polished and glazed, but this hypothesis was rejected. The results of the study indicated that the initial surface treatments, including different surface preparation, mechanical polishing, and glazing methods, affected the color changes after the chewing simulation.

The ceramics used in this study are commonly known and used in routine dental practice. Manufacturers provide various options for color selection, including different hues, chroma, and translucency, such as high translucency (HT) or low translucency (LT). For standardization, A1 color low translucency blocks were selected in this study.

Aesthetic appearance is a critical success criterion for dental materials, which can be described as the compatibility of the materials with natural teeth and their color stability (20). Patients' expectations and the durability of aesthetical success are of great importance in dental restoration processes. Discoloration is usually at the top of the list of reasons for patients' dissatisfaction with dental restoration processes (21).

As mentioned earlier, the surface properties of ceramics, such as the thickness of the material and the chemical composition of the structure, also affect the optical characteristics (22, 23). The porosity of the surface structure or the increase in the roughness of the ceramics can lead to an increase in plaque uptake in the mouth. Furthermore, the rough surface can affect the reflection of light, thereby impacting the optical characteristics of the ceramic, such as gloss (13, 15).

In clinical practice, glazing and mechanical polishing (with or without polish paste) are the generally used procedures for ceramics surface treatment (24, 25). Studies have shown that the glaze layer directly affects the color characteristics of the materials. Glazed surfaces have higher success in reflecting light, and the glazing procedures on surfaces are very successful in achieving the desired surface properties of ceramics (24, 26). However, it has been reported that if the glaze material is not applied uniformly to the surface during the glaze surface treatment, it can affect the surface properties (25, 27).

After the cementation process of fixed restorations, occlusal and proximal adjustment or shape corrections are required. However, after these adjustments, the glaze layer is lost (28-31). It has been reported that faded glaze layers on rough ceramic surfaces reflect light less directly, resulting in a negative effect on the color values of the restorations (32). In the present study, we found that the glazed surface's color-changing parameters are higher than those of mechanically treated surfaces. Our theory is that the occlusal abrasion forces lift the glazed surface, causing more color changes than just mechanically treated surfaces in their initial state after simulation.

Studies suggest that mechanical polish kits with polish pastes are a successful alternative for removed glaze layers (24, 28, 33). Mohammadibassir *et al.* also claim that repeated firing procedures for repairing glazing treatment reduce ceramic surface quality (28). Vichi *et al.* (25) mention that mechanical polishing is a good alternative for glaze-treated surfaces and that the mechanical application duration is essential for surface smoothening. In their study, 60 s of mechanical-polished lithium disilicate and zirconia-reinforced lithium silicate ceramics showed the lowest roughness parameter. Nevertheless, ceramics mechanically polished for just 30 s showed no difference between their initial surface conditions (25). Can *et al.* state that mechanical polishing affects glaze-treated ceramic surfaces (34). In our study, we applied mechanical surface treatment via a polishing kit, and each procedure was applied for at least 60 s.

ΔE values are used to base the discoloration values on numerical values of different samples of the same processes or the same samples of different processes (35, 36). The human eye cannot notice the discoloration ΔE values that are below 1 (36-38). As previously mentioned, ΔE values between 1 and 3.3 are acceptable discoloration levels in clinical work, and these color changes are barely noticeable by the human eye. Change values over 3.3 are easily noticeable and called clinically unacceptable (17-19, 39). Studies regarded 3.3 as the limit to ΔE value (40, 41).

On repeated color measurements, there are studies that report that Vita Easyshade (Vita Zahnfabrik) spectro-photometer, which we used in our study, is a reliable device (42, 43). Moreover, other reports prove that the results are not affected under different types of light sources (42).

According to the data that we gathered from our study, except for the FG group, the ΔE levels of glaze groups are higher than 3. Also, it needs to be added that for those three-group color differences from the initial forms, they can be easily visible. All glazed-porcelain values are also higher than those of mechanically polished groups. We observed that the ΔE values of mechanically polished groups are lower than 3.3, which was previously mentioned to be the highest acceptable value (40, 41). Upon ΔE value evaluation of the porcelain groups exposed to the same surface processes, we found that the samples that were abraded more had higher ΔE values. We can conclude that the glazed group's worse discoloration level results from the removal of the glaze layer upon exposure to external effects, causing more wear on the surfaces of the samples.

In their study on porosity and discoloration of porcelains exposed to different polishing processes, Saraç *et al.* reported that materials with higher porosity levels also had higher ΔE levels (44). Similarly, in their study on the discoloration of porcelain systems containing various chemical compounds, Soygun *et al.* stated that the surface porosity value was directly proportional to the ΔE level (45). Our study's findings are in line with those of the previous work, indicating that the greater the surface structure change, the greater the discoloration. Specifically, we observed the highest levels of discoloration in the leucite and lithium disilicate groups.

Conversely, the feldspathic and zirconia groups showed the least amount of discoloration in our study, potentially due to the smaller scale wear of these materials. Furthermore, the larger average particle sizes of lithium disilicate and leucite ceramics compared to zirconia ceramics may account for the higher amount of wear and discoloration observed on their surfaces (22, 25).

We also noted that the mechanically polished samples showed less discoloration compared to the glazed samples in our study. This difference may be attributed to the removal of the glaze layer over time. However, our study had several limitations, including the lack of fully standardized extracted teeth used as antagonists, the disc-shaped porcelains that do not imitate natural morphological crowns, and the changes in porcelain behavior against abrasive forces and their optical properties in the oral environment, making analysis challenging. As such, future studies could involve simulations with anatomically-shaped crowns and standard antagonists, and even clinical studies.

Conclusion

The glaze layer is removed due to occlusal adjustment and exposure over time. The surfaces then become rough, resulting in heavier wear and abrasion. Additionally, the removal of the glaze layer and the appearance of rough surfaces can cause aesthetic issues and affect patient satisfaction. In light of the aforementioned circumstances, dentists can perform routine mechanical polishing of surfaces to improve the aesthetic and mechanical features of the materials. It can also be argued that zirconia ceramics' applications may be more comfortable, especially for patients with bruxism, due to their corrosion resistance, smaller impact on their antagonists, and lower discoloration levels resulting from stabilized surface characteristics.

***Türkçe özet**: Farklı dental porselen sistemlerinin renk değişimleri üzerine çalışma. Amaç: Bu çalışmada, doğal diş antagonistlerine karşı çiğneme simülasyonu sonrasında çeşitli yüzey işlemlerine tabi tutulan (glaze uygulanmış ve mekanik cila uygulanmış) dört tip dental porselen sisteminin (feldspatik, monolitik zirkonya, lityum disilikat ve lösit cam-seramik) renk değişimleri incelenmiştir. Gereç ve Yöntem: Yüzey bitim işlemleri uygulanan, feldspatik glaze uygulanmış (FG), feldspatik mekanik cila uygulanmış (FM), zirkonya glaze uygulanmış (ZG), zirkonya mekanik cila uygulanmış (ZM), lityum disilikat cam-seramik glaze uygulanmış (EXG), lityum disilikat cam-seramik mekanik cila uygulanmış (ExM), lösit cam-seramik glaze uygulanmış (EG), lösit cam-seramik mekanik cila uygulanmış (EM) porselen grupları 9x3 mm boyutlarında disk formunda hazırlandı. Bütün porselenler in-vitro ortamda çiğneme simülasyonuna tabi tutuldu. Simulasyon sonrası örneklerin başlangıç durumları ile renk değişimlerinin incelenmesi için spektrofotometre kullanıldı. Bulgular: Tüm porselen örneklerin ΔE değerleri (renk değişim değerleri) istatistiksel olarak farklı (p<0,05) ve glaze uygulanmış numunelerin ΔE değerleri mekanik cilalı numunelerin ΔE değerlerinden daha yüksek bulunmuştur. Sonuç: Tüm glaze işlemi uygulanmış örneklerin renk değişim değerleri mekanik cila uygulanmış örnekelere göre yüksek olduğu belirlenmiştir. Anahtar Kelimeler: dental seramik, renk stabilitesi, renk değişimi, glaze, mekanik cila*

Ethics Committee Approval: The study protocol has been reviewed and approved by the Sivas Cumhuriyet University Clinical Research Ethics Committee (Decision no: 2016-05/9).

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: MCU, GB participated in designing the study. MCU, GB participated in generating the data for the study. MCU, GB participated in gathering the data for the study. MCU, GB participated in the analysis of the data. MCU, MKA, GB wrote the majority of the original draft of the paper. MCU, MKA, GB participated in writing the paper. MCU, MKA, GB have had access to all of the raw data of the study. MCU, MKA, GB have reviewed the pertinent raw data on which the results and conclusions of this study are based. MCU, MKA, GB have approved the final version of this paper. MCU, MKA, GB guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Original research

The Effects of Er,Cr:YSGG laser on shear bond strength of orthodontic lingual brackets to CAD/CAM ceramic systems

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Purpose

The aim of this study is to compare the bond strength of lingual brackets bonded to resin-matrix and lithium disilicate based-ceramic crowns following various surface treatments.

Materials and Methods

Sixty ceramic crowns (IPS Emax and Cerasmart) were fabricated by CAD/CAM. Er,Cr:YSGG laser, sandblasting with aluminium oxide and hydrofluoric acid treatment effects on ceramics was tested (n=10/group). A light-cure orthodontic adhesive was used to bond lingual brackets to the ceramic surfaces. Bond strengths of the brackets to ceramics were assessed by shear bond test. The remnant adhesive on bracket and ceramic surfaces was inspected with a light microscope and adhesive remnant index scores were recorded. The data were analyzed statistically using the Kruskal–Wallis test followed by the Mann–Whitney U-test.

Results

Cerasmart ceramic specimens showed lower shear bond strength values than IPS Emax ceramic specimens ($p<0.05$). The statistical analysis of the surface treatment groups regarding bond strength were ranked as follows: Laser ≤ Hydrofluoric acid ≤ Sandblasting ($p=0.058$). While laser-treated Cerasmart ceramic group displayed the lowest SBS (9.39 MPa), hydrofluoric acid-treated IPS Emax group had the highest (16.8 MPa) bond strength value.

Conclusion

The use of Er,Cr:YSGG lasers for etching of CAD-CAM ceramics could be a promising alternative to “conventional techniques”, to improve bond strength of lingual brackets to IPS Emax and Cerasmart ceramics.

Keywords: *Lingual bracket, ceramic, shear bond strength, Er,Cr:YSGG laser*

Introduction

The increasing aesthetic demand of adult patients has contributed to a marked increase for lingual fixed orthodontic treatment in recent years (1-3). While invisible brackets offer higher aesthetic gain than conventional techniques; speech dysfunctions, mastication problems, and oral discomfort are the main adverse effects of this technique (4,5). Besides, adults receiving orthodontic therapy might have various types of ceramic restorations, and bonding of orthodontic appliances to ceramic surfaces could be classified as a challenge compared to bonding to dental structures (1,6).

In adult patients, commonly used tooth-colored materials could be leucite- and lithium disilicate-reinforced glass, zirconia, and hybrid ceramics (7). Lithium disilicate glass-ceramics (IPS Emax, Ivoclar Vivadent AG, Schaan, Liechtenstein) have high mechanical strength, favorable translucency, shade variety, aesthetics, and etchability (8). Moreover, dif-

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ferent microstructure, processing techniques and materials such as resin-matrix ceramics and polymer-infiltrated-ceramic network materials have been developed (9). Amid the diverse spectrum of bond resin ceramics, CAD/CAM nanohybrid-composite (Cerasmart, GC Corp, Tokyo, Japan), a high-density composite material containing inorganic ceramic fillers (silica and barium glass filler by weight), has become popular for its positive features combining ceramics and resin composites (7,9).

Since different microstructure and processing techniques of ceramics might influence the adhesion properties of brackets, preparation of the surfaces is essential for improving bond strength of brackets to ceramics (1,10). Recently, hydrofluoric acid, diamond bur, or sandblasting were used for etching the ceramic surfaces in orthodontics (11). Hydrofluoric acid and chair-side intraoral sandblasting might have possible hazardous effects. Besides, laser etching technology offers an alternative for etching surfaces to reinforce the bond between orthodontic brackets and restorative materials or dental tissues (6,10). The most commonly used lasers in dental applications are Er:YAG and Er,Cr:YSGG lasers. Since Er,Cr:YSGG laser has minor thermal side-effects on vital tissues of the tooth, it is preferred both for soft and hard-tissue applications (11-13).

Recently, studies about lasers have focused on the effectiveness of laser treatments on bonding of labial brackets to surfaces (14,15). There is only one study in the literature evaluating the effects of laser (Nd:YAG) on the shear bond strength (SBS) of lingual brackets (16). Thus, the present study aimed to decide an ideal surface treatment method for bonding of lingual brackets to resin-matrix and lithium disilicate glass ceramic crowns. The null hypotheses were that first, the SBS of brackets to ceramics would not be improved by Er,Cr:YSGG laser treatment of lingual brackets and second, the type of ceramic would have no influence on the bracket bonding success.

Materials and Methods

Specimen preparation

Sixty maxillary right first premolar ceramic crowns (IPS Emax (Ivoclar Vivadent AG, Schaan, Liechtenstein) and Cerasmart (GC Corp, Tokyo, Japan) were fabricated by CAD/CAM (Cerec In Lab MC XL; Sirona Dental Systems, Charlotte, USA) (Table 1). Then, the crowns were grouped according to surface treatment methods randomly as follows:

1. Er,Cr:YSGG laser treatment (n=20) (Waterlase; Biolase Technology, Irvine, CA, USA) was performed with the power output of 3.5 W. The distance of laser tip was approximately 1 mm and perpendicular to the ceramic surface (65% air and 55% water spray) with a pulse duration of 140 µs. In addition, the crowns were irradiated with a wavelength of 2.780 nm. Furthermore, the average exposure time was set at 10 s and 20 Hz repetition rate.

2. Sandblasting with aluminium oxide particles (50 µm diameter) (n=20) was performed at 2.5 bar for 4 s at a distance of 1 cm.

3. Hydrofluoric acid (HF) (n=20) (%9.6, Pulpdent, Watertown, Mass, USA) was applied to the surface for 2 min and rinsed with deionized water for 2 min.

Afterwards, the metal brackets (Protect, Zhejiang Protect Medical Equipment Co, China) were bonded on crowns with a light-cure adhesive (Transbond XT, 3M Unitek, Monrovia, USA). Then, the specimens were polymerized with a LED (Elipar S10, 3M ESPE, St Paul, USA) for 20 s from distal and mesial side of the bracket. A compressive force (300-g) was applied on the brackets (force gauge, Correx Co, Bern, Switzerland) for 10 s and with a sharp scaler all of the visible resins around the brackets was removed. Following storage in distilled water at 37°C for 24 h, the specimens were embedded in an auto polymerizing acrylic resin (Meliodent, Heraus Kulzer, Hanau, Germany) using a cylindrical plastic mold.

Shear bond strength test

Specimens were loaded in shear mode of the universal testing machine (Lloyd Instruments, Fareham Hants, UK) with a cross-head speed of 0.5 mm/min. The bond strength values were recorded in Newtons (N), was divided by the surface area of the bracket base to calculate the SBS in MPa.

Failure mode analysis

The failure modes were evaluated with a stereomicroscope (40X, Leica Microsystems, Milan Italy) and classified according the modified adhesive remnant index (ARI). The ARI scoring index was ranked from 0 to 4 as follows (17):

Score 1. No adhesive was left on the ceramic surface.

Score 2. Less than half of the adhesive remained on the bracket base.

Score 3. More than half of the adhesive remained on the bracket base.

Score 4. All adhesive was left on the ceramic surface with a clear impression of the bracket mesh.

SEM analysis

Representative specimens of the ceramics from each group were exposed to different surface treatment methods and scanning electron microscopy (SEM; Carl Zeiss NTS, Oberkochen, Germany) was carried out to identify the surface variations of the ceramics.

Table 1. *Materials tested in the present study.*

Material	Trade name	Shade	Lot no	Manufacturer	Composition
Lithium disilicate	IPS Emax	A1-HT	V46006	Ivoclar Vivadent AG, Schaan, Liechtenstein	SiO_2 %57 – 80 Li_2O 11.0 – 19.0 K_2O %13 P_2O_5, %11 ZrO_2 %8 ZnO, %8 Al_2O_3 %5 MgO, %5 Color oxides
Nano hybrid ceramic	GC Cerasmart™	A1-HT	008512	GC Corp, Tokyo, Japan	Bis-MEPP, UDMA, DMA, %71 silica (20 nm), barium glass (300 nm) nano particles by weight

Statistical analysis

Since data were not normally distributed according to Shapiro Wilk test, the statistical significance was determined by the Kruskal–Wallis followed by Mann–Whitney U-test (SPSS v11.5, Chicago, USA) with the level of significance set at $p < 0.05$. The chi-square test was used to detect the presence of statistical differences in the ARI results of the tested groups. Pearson's correlation statistical analysis was performed to define the correlation between SBS and ARI ($p < 0.05$).

Results

The means SBS and standard deviations of the tested groups are presented in Figure 1. The results of the statistical analysis indicated no significant differences among the bond strength values of the tested groups ($p<0.05$).

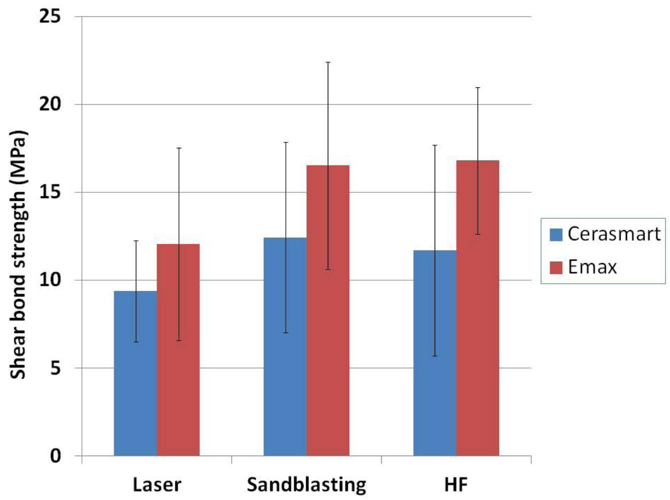

Figure 1. *Shear bond strength and standard deviation values of the tested groups.*

Table 2. *Failure analysis of the tested groups (%).*

Surface Treatment	Groups	Score 1	Score 2	Score 3	Score 4
Laser-treated	IPS Emax	0	20	80	0
	Cerasmart	0	0	75	25
Sandblasted	IPS Emax	20	30	50	0
	Cerasmart	10	20	50	20
HF-treated	IPS Emax	11,1	55,6	33,3	0
	Cerasmart	30	20	50	0

The Cerasmart ceramic specimens exhibited significantly lower bond strength values than IPS Emax ceramic specimens ($p<0.05$). In addition, the statistical ranking of the surface treatment groups was observed as follows: Laser ≤ HF ≤ Sandblasting ($p = 0.058$). While laser-treated Cerasmart ceramic group had the lowest bond strength (9.39 MPa), HF-treated IPS Emax group had the highest (16.8 MPa). Besides, laser-treated Cerasmart ceramic group demonstrated a significantly lower bond strength value than sandblasted and HF–treated IPS Emax groups ($p<0.05$).

ARI analysis revealed that the majority of the specimens presented scores 2 and 3 (%80.65) (Table 2, Figure 2). Furthermore, no significant correlation was observed between bond strength and ARI scores of the groups. SEM analysis demonstrated microstructural variations between the ceramic surfaces (Figure 3).

Discussion

The present study showed that surface treatment of ceramics had no effect on the SBS of lingual brackets, leading to the acceptance of the first null hypothesis. In the present study, SBS test was applied to find a suitable etching method for effectively bonding of lingual brackets to resin-matrix and lithium disilicate glass ceramics. To our knowledge, this is the first report evaluating the effect of Er,Cr:YSGG laser on SBS of lingual brackets. The bond strength values of HF for 2 min, sandblasting with Al_2O_3 for 4 s, and 3.5 W Er,Cr:YSGG laser treatment groups were obtained between 9.39 MPa-16.53 MPa in the present study. As previously reported, in vitro bond strength of 6 MPa to 8 MPa is considered as a gold standard and "clinically acceptable" (18). Therefore, all surface treatments tested in the present study could be considered sufficient etching procedures for clinical applications.

The laser-treated groups also exhibited clinically acceptable SBS values (Cerasmart-laser: 9.39 MPa and IPS Emax-laser: 12.07 MPa). However, laser-treated Cerasmart group showed significantly lower SBS value than HF-treated and sandblasted IPS Emax groups ($p<0.05$). Since there is no study to our knowledge in the literature evaluating the SBS of lingual brackets to lithium disilicate and hybrid ceramics, it is difficult to compare the present results with previous studies. A study by Sfondrini *et al*. investigated the SBS values of different lingual bracket base designs and reported SBS values ranging approximately from 16 to 20 MPa (5). In addition, a previous report evaluated the effect of surface treatment methods on SBS of indirectly bonded lingual appliances and reported values ranging between 13.17 MPa and 16.42 MPa. The difference in the bond strength values between the results of the present study and others may be related to the bonding substrates (19).

The ceramic type affected the bond strength of lingual brackets, necessitating the rejection of the second null hypothesis. This finding could be related to the size of particles and crystalline structure of the ceramics and processing techniques of the ceramic systems. While Cerasmart has barium and glass fillers, IPS Emax ceramic is a glass-ceramic with a 70% crystal volume incorporated in a glass matrix and a fine-grained size of approximately 1.5 µm (9). Therefore, the higher bond strength of IPS Emax ceramic than Cerasmart ceramic could be attributed to the micro-porosities

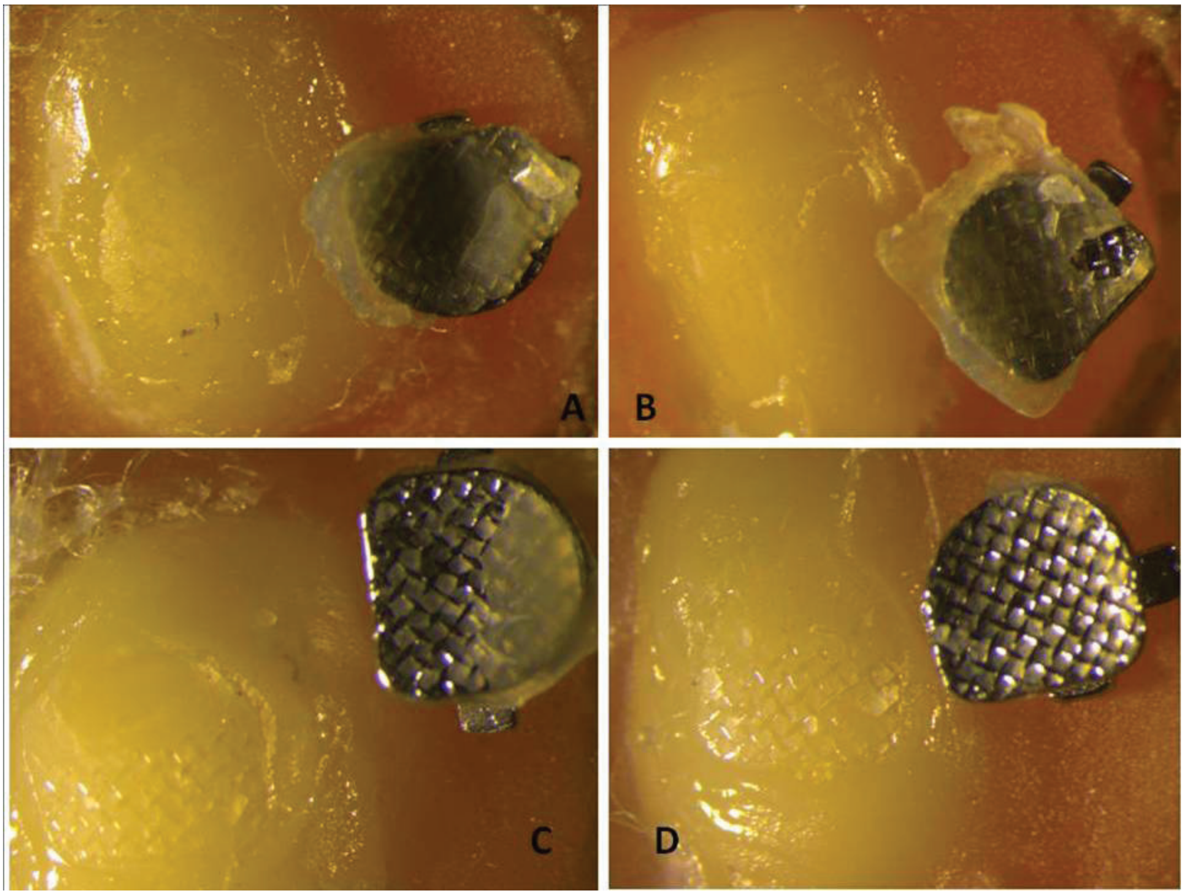

Figure 2. *Stereomicroscopic images showing representative ARI groups; A: All adhesive remained on the bracket base; B: More than half of the adhesive remained on the bracket base; C: Less than 50% of the adhesive remained on the bracket base; D: No adhesive remained on the bracket base. Original magnification x40, bar= 1 mm.*

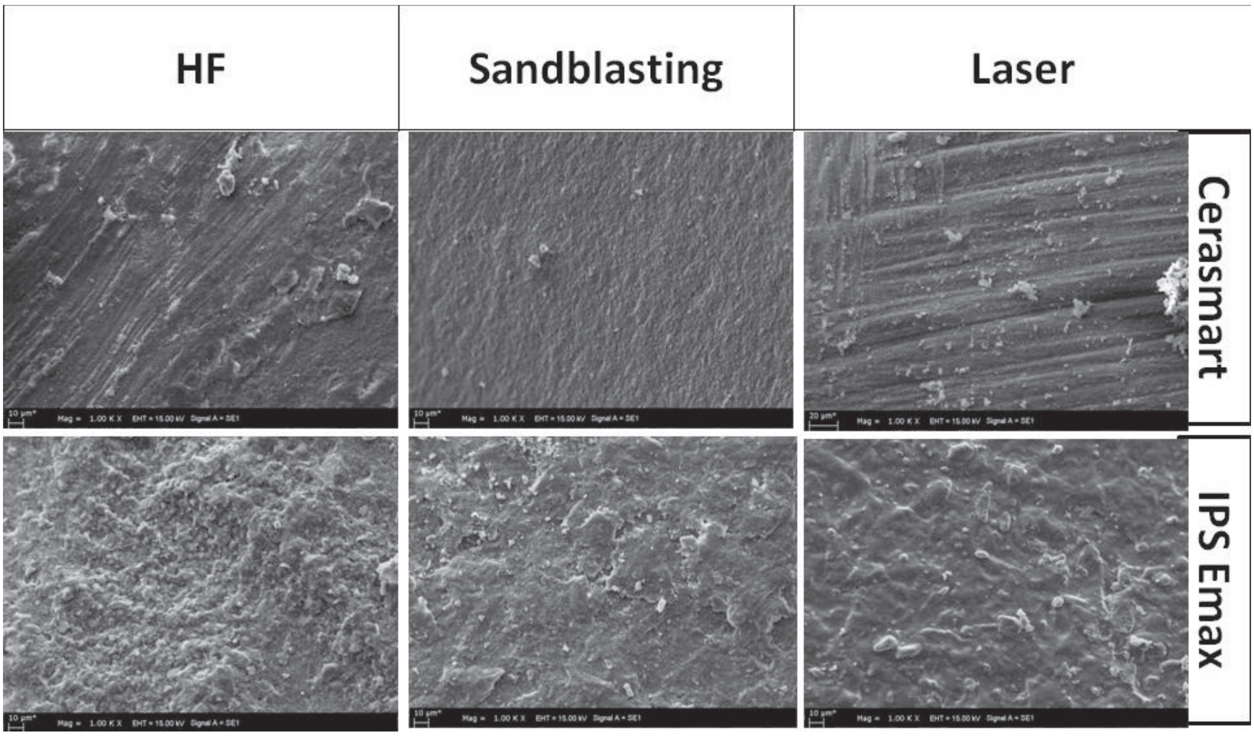

Figure 3. *SEM photomicrographs of HF-treated, sandblasted, and laser-treated ceramic surfaces (Original magnification: 1000x, bar = 10 µm).*

created by the dissolution of the glass phase of this ceramic. Similarly, Abu Alhaija *et al*. compared the bond strength of stainless steel brackets to different ceramics. The researchers also observed significant differences between the SBS values of brackets to feldspathic porcelain, In-Ceram, and IPS-Empress (20). Furthermore, a previous study investigated two surface-conditioning methods' effects on the SBS of metal brackets bonded to three different all-ceramic materials (feldspathic, leucite-reinforced and fluoro-apatite ceramic) (21). In accordance with the present study, that previous study reported significant differences between all ceramics.

Since possible harmful effects could be possible with the use of strong HF acids, different surface treatment methods have been evaluated instead of HF acid previously (22,23). Likewise in the current study, Er,Cr:YSGG laser treatment was performed and its effect on SBS of lingual brackets to ceramics was compared with routine etching procedures. To our knowledge, there are no standard Erbium laser irradiation settings in literature for ceramic etching. Therefore, a previous setting of the Er,Cr:YSGG laser was used in the present study (11). Yassei *et al*. compared the effect of HF acid and Er-YAG laser (1.6, 2, and 3.2 W) on the SBS of orthodontic brackets to porcelain. The authors reported that there was no significant difference between these surface treatments (24). Similarly, another study examined the influence of different lasers (Er:YAG and Er,Cr:YSGG) on bonding of resin composite to labial brackets. They concluded that 3W or 2 W Er,Cr:YSGG laser application can be suggested instead of other etching processes (12). Moreover, a previous study investigated whether the Er:YAG (3W) or Er:CrYSGG (3W) laser affects the SBS of brackets to dental porcelain or not. They concluded that Er:YAG laser is not a suitable substitute to HF etching. Although HF etching performed significantly higher than Er:CrYSGG laser, the bond strength required for orthodontic brackets has been achieved for the laser groups (25).

The optical microscope photographs of the ARI analysis indicated that the ceramic-adhesive interface bond failures were mostly detected (Table 2, Figure 2). The adhesive was bonded to bracket surface better than the ceramic surface (Scores 1 and 3) except HF-treated Emax group (majority of the failures were Score 2). Besides, no destruction of the ceramic surfaces in any group has been observed. Furthermore, this could be a clinical advantage since less adhesive should be removed from the ceramic surface after bracket debonding, as reported previously (26). A previous study reported that the morphology of the base design might have a positive effect on the penetration of the composite material to the bracket (2).

In the current study, the percentage of score 3 in the laser-treated Cerasmart group was % 75 (Figure 2B), indicating the lowest bonding results in all tested groups. In HF-treated IPS Emax groups (Figures 2C and 2D), the percentage of scores 2 increased. This result could be due to higher bond strength results of the lingual brackets to IPS Emax ceramic specimens than Cerasmart specimens. In addition, this result indicated that the adhesive bonded IPS Emax ceramic better than the bracket. However, no correlation was observed between bond strength and ARI scores.

The statistically non-significant bond strength results of the groups were supported by the SEM observations. Besides, there were structural variations in the surfaces of the Cerasmart and IPS Emax restorative materials following surface treatments. In addition, it should be pointed out that IPS Emax specimens displayed distinct surface irregularities, creating a micro-retentive features compared to Cerasmart specimens (Figure 3).

The first limitation of this study was its small sample size. Second limitation is the absence of aging procedures simulating clinical situations. Further investigations are necessary to determine the long-term adhesion of lingual brackets to all ceramics under clinical conditions. Additional trials were also needed to compare these findings with labial orthodontic appliances.

Conclusion

IPS Emax ceramic crowns are more likely to demonstrate higher bond strength than Cerasmart ceramic crowns. Besides, Er,Cr:YSGG laser could be an effective method for etching of resin-matrix and lithium disilicate-ceramic based CAD/CAM crowns before bonding lingual brackets to them.

Türkçe özet: *Ortodontik lingual braketlerin CAD/CAM seramik sistemlere makaslama bağlanma dayanımı üzerine Er,Cr:YSGG lazerin etkisi. Amaç: Çalışmanın amacı, farklı yüzey işlemleri sonrasında rezin matriks ve lityum disilikat bazlı seramik kronlara bağlanan lingual braketlerin, bağlanma dayanımlarını karşılaştırmaktır. Gereç ve Yöntem: 60 adet seramik kron (IPS Emax ve Cerasmart) CAD/CAM ile hazırlandı. Er,Cr:YSGG lazer, alüminyum oksit ile kumlama ve hidroflorik asitlerin seramikler üzerine etkileri test edildi (n=10/grup). Lingual braketleri seramik yüzeylere yapıştırmak için, ışıkla sertleşen ortodontik adeziv kullanıldı. Braketlerin seramiklere bağlanma dayanımı, makaslama bağlanma testi ile değerlendirildi. Braketler ve seramik yüzeyler üzerinde kalan artık adezivler, ışık mikroskobu ile gözlendi ve adeziv artık indeksi kaydedildi. Veriler istatistiksel olarak, Kruskal-Wallis testini takiben, Mann-Whtiney U testi ile analiz edildi. Bulgular: Cerasmart seramik örnekler, IPS Emax seramik örneklerden daha düşük makaslama bağlanma dayanımı gösterdi (p<0.05). Yüzey işlem grupları istatistiksel olarak bağlanma dayanımı değerlerine göre şu şekilde sıralanmaktadır: Lazer ≤ Hidroflorik asit ≤ Kumlama (p=0.058). Lazerle işlem gören Cerasmart seramik grubu en düşük iken (9.39 MPa), hidroflorik asit ile işlem gören IPS Emax (16.8 MPa) en yüksek bağlanma dayanımı değeri göstermiştir. Sonuç: Lingual braketlerin IPS Emax ve Cerasmart seramikler üzerine bağlanma dayanımını geliştirmek için, CAD-CAM seramiklerin pürüzlendirilmesinde Er,Cr:YSGG lazerlerin kullanımı, konvansiyonel tekniklere göre umut verici bir alternatiftir. Anahtar kelimeler: lingual braket, seramik, makaslama bağlanma dayanımı, Er,Cr:YSGG lazer.*

Ethics Committee Approval: Not required.

Informed Consent: Not required.

Peer-review: Externally peer-reviewed.

Author contributions: EK, GE, ICN participated in designing the study. FE participated in generating the data for the study. FE participated in gathering the data for the study. FE participated in the analysis of the data. ICN wrote the majority of the original draft of the paper. EK, GE, SY, ICN participated in writing the paper. FE has had access to all of the raw data of the study. EK, ICN have reviewed the pertinent raw data on which the results and conclusions of this study are based. EK, ICN have approved the final version of this paper. EK, ICN guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

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Original research

Evaluation of submandibular gland and submandibular fossa: A combined cone beam computed tomography and ultrasound study

Esin Akol Görgün[1], Fatma Çağlayan[1]

Purpose
The purpose of this study was to use Cone Beam Computed Tomography (CBCT) to evaluate the submandibular fossa (SF) morphometrically and ultrasonography (USG) to evaluate the submandibular gland (SG).

Materials and Methods
Radiological evaluation was performed on 40 SFs and SGs from 20 patients. The depth and width of the SF were measured on axial CBCT sections, while the antero-posterior, medio-lateral, and supero-inferior lengths and volumes of the SGs were measured by USG. Statistical analysis was performed to evaluate CBCT and USG measurements.

Results
The study found a statistically significant positive correlation between SF depth and SG medio-lateral dimension ($p = 0.023$), SF width and SG antero-posterior dimension ($p = 0.021$), and SF width and SG volume ($p = 0.000$). However, there was no significant correlation between SF depth and SG volume ($p=0.146$).

Conclusion
The SF is an important area in surgical procedures planned in the mandibular posterior region, especially in implant applications. The dimensions of the SF are closely related to the dimensions of the SG. USG can be used to examine the SG without the risk of ionizing radiation.

Keywords: *Submandibular gland, submandibular fossa, ultrasonography, cone beam computed tomography, implant surgery*

Introduction

Submandibular fossa (SF) is a common anatomical variation that occurs because of the pressure of the submandibular salivary gland on the lingual cortex of the mandible body. It starts from the distal of the mental foramen inferior to the mylohyoid line and extends to the mandibular third molars. The submandibular gland is located in this region. Various imaging methods such as panoramic radiography, Cone Beam Computed Tomography (CBCT), and Computed Tomography (CT) have been used to evaluate this region (1-4).

Ultrasonography (USG) is a noninvasive and easy-to-apply imaging method that does not involve the risk of ionizing radiation. It is used to examine muscles, tendons, joints, vessels, and internal organs that are not behind the bone. Due to the superficial location and appropriate homogeneous soft tissue densities of the salivary glands, USG is the preferred imaging technique for their evaluation (5).

CBCT is a convenient imaging method for the three-dimensional evaluation of the bony structures of the maxillofacial region. It provides

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high-quality images with low millimeter resolution and low radiation dose (6-13). Different methods have been used to measure SF depth in CBCT in various studies in the literature (1, 3, 14). For instance, Parnia *et al.* (14) determined the most prominent upper and lower points of the lingual concavity corresponding to the submandibular fossa in paraxial sections and drew a starting line connecting them. They then measured the SF depth by drawing a second line perpendicular to the first line from the deepest point of the fossa. In some studies, SF depth was measured on cross-section CBCT images by drawing a line to the most prominent upper and lower points of the lingual concavity and a second line from the deepest point of the concavity to the first line (1, 3).

Implant treatment has become very popular in the rehabilitation of missing teeth. One of the most important structures to be examined before placing an implant in the mandible is the depth of the SF. Damage to the SF due to lingual plate perforation during surgery can result in severe bleeding and subsequent hematoma with life-threatening consequences due to upper airway obstruction.

Since the SG is located in the SF, the depth of the SF should be related to the dimensions of the submandibular gland. However, there are no studies on this subject in the literature. The aim of this study was to evaluate the SF by CBCT and the SG by USG and to investigate whether there was a relationship between the SG size and SF dimensions measured by USG and CBCT, respectively. The null hypothesis tested in this study is that no correlation could be established among measurements made with either device.

Materials and Methods

Ethical approval

This study was conducted at the Department of Oral and Maxillofacial Radiology, and its compliance with scientific ethical standards was approved by the faculty ethics committee's decision numbered 2021/58. Informed consent forms were obtained from the patients.

Sample size estimation

The sample size for the Pearson correlation test, which was used to test the primary hypothesis of the study, was calculated. As a result of the sample size analysis performed using Cohen's effect size value of 0.50, it was determined that a minimum of 29 individuals should be included in the study ($1 - \beta = 0.80$) to reveal significant differences between the groups with 80% power and $\alpha = 0.05$ error (95% confidence interval). CBCT and USG were used to evaluate 40 SFs and SGs of these patients, respectively.

Study design

The patients were randomly selected among those who applied to the Department of Oral and Maxillofacial Radiology for CBCT scans for various reasons in 2021, and the study took one year to complete. When selecting the patients, the absence of mandibular bone destruction caused by pathology, complete visualization of the mandible, and the patients' voluntary participation were taken into consideration.

CBCT procedures and measurements

In the study, 40 SFs of 20 patients were included, who were examined with a flat panel NewTom 3G Dental Volumetric Tomography device (NewTom FP, Quantitative Radiology, Verona, Italy). The device had a voxel size of 0.16 mm and a typical exposure time of 5.4 seconds, and it operated with the conical beam technique at 110 kVp as standard and a maximum of 15 mA. The device had an automatic exposure control system (AEC), which adjusted the dose and exposure time according to the density of the patient's skull in the guide image obtained at the beginning of the shooting. The study reconstruction was obtained with axial sections at 0.5 mm intervals of the patients whose raw data were obtained, and it was set parallel to the lower border of the mandible.

The depth of the submandibular fossa was measured on the axial section where the fossa was seen the deepest. A line was drawn on the lingual surface of the mandible on the axial section where the fossa was the deepest, connecting the anterior and posterior borders of the fossa. The length of this line was measured and recorded as the SF width. Then, a perpendicular line was drawn from the first line to the deepest point of the fossa to measure and record the SF depth (Figure 1)

USG procedures and measurements

The submandibular salivary glands of individuals who had undergone CBCT imaging for various reasons were examined using USG with their informed consent. The USG evaluation was performed using a Toshiba Aplio 300 ultrasonography device (Toshiba Corporation, Tokyo, Japan) and a 12-MHz linear array transducer probe. During the USG examination, the patient's head was fixed in extension, and the SG was first examined transversely and then the probe was

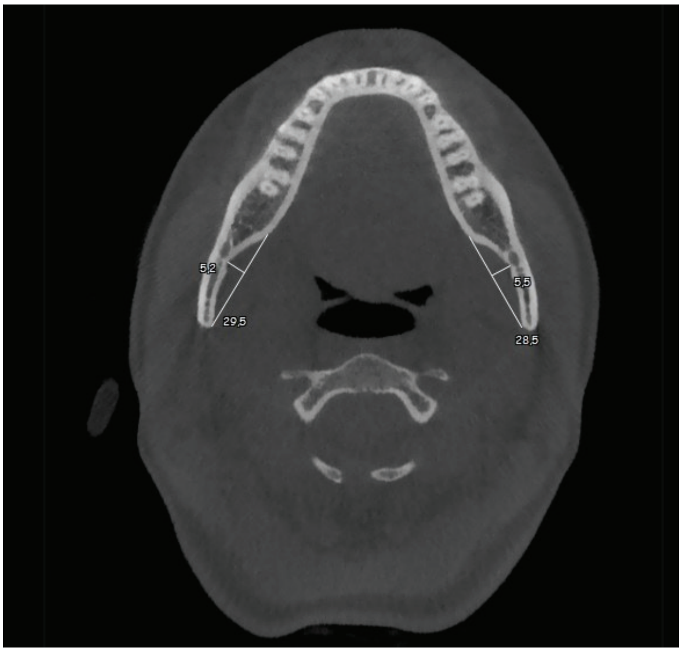

Figure 1. *Measurement of submandibular fossa width and depth on the axial CBCT section. The width of the SF was measured by connecting the anterior and posterior borders of the fossa. The depth of the SF was measured with a perpendicular line to the deepest point of the fossa from the first line.*

rotated longitudinally to calculate the volume of the submandibular salivary gland (Figure 2).

To begin the USG examination, the probe was positioned parallel to the lower edge of the mandible after locating the submandibular salivary gland. The homogeneous echogenic structure of the SG parenchyma could be easily distinguished from the surrounding soft tissues using USG. To make dimensional measurements, the CALIPER option was selected on the USG device. The image was frozen when the SG was displayed in full on the USG screen. Distance 1, which represented the antero-posterior length of the SG, was measured and recorded (Figure 3). Similarly, the supero-inferior measurement was made on the same image and recorded as distance 2 (Figure 4). The probe was then turned perpendicular to the body of the mandible to measure the medio-lateral length of the submandibular gland, which was recorded as distance 3. Finally, the VOLUME icon was clicked on the touch screen of the device to calculate the volume of the SG automatically (Figure 4).

Statistical analysis

The statistical analysis was performed using the IBM SPSS Statistics 20 package program (Armonk, NY: IBM Corp., USA). Descriptive statistics were utilized to determine the distri-

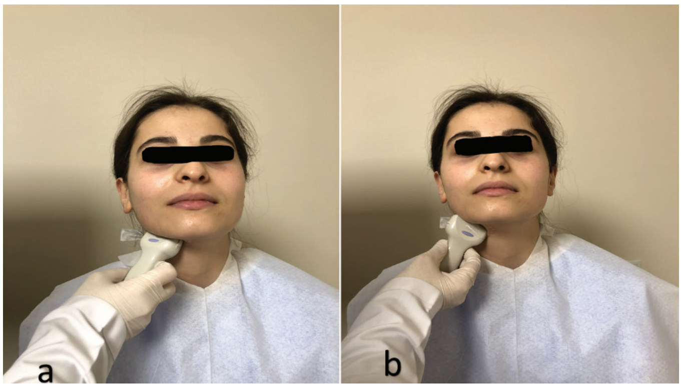

Figure 2. *Examination of submandibular gland by USG. a: Transversal direction, b: Longitidunal direction.*

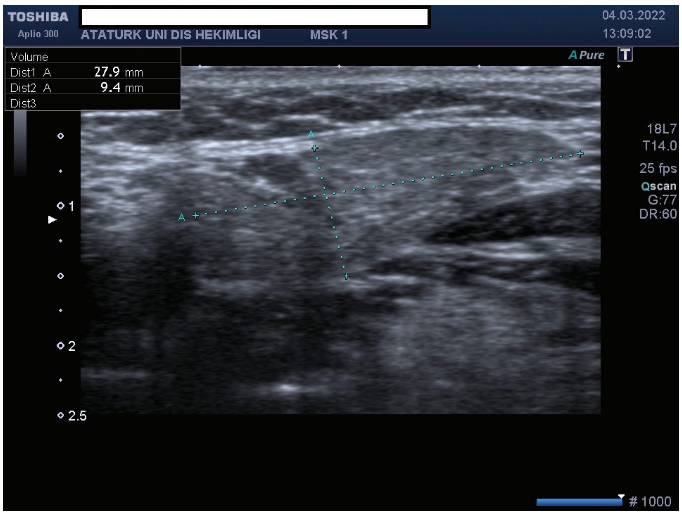

Figure 3. *The anteroposterior length of the submandibular gland was measured and recorded as distance 1. Supero-inferior measurement was also made on the same image and it was recorded as distance 2.*

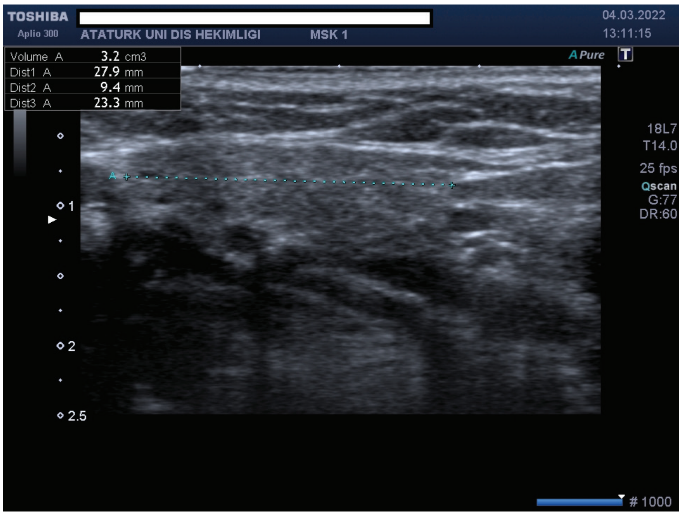

Figure 4. *To measure the third dimension, the probe was turned perpendicular to the body of the mandible and the medio-lateral length of the submandibular gland was measured and recorded as distance 3. After the dimension measurements in these three planes are done, the volume was calculated automatically.*

bution of the data, and the conformity of all values to the normal distribution was assessed. Pearson correlation coefficient was employed to evaluate the relationship between SF depth and medio-lateral length of SG, SF width and superior-inferior length of SG, and SF width and volume of SG. However, it was discovered that the antero-posterior length of SG did not exhibit normal distribution ($p<0.05$), and therefore, Spearman correlation coefficient was utilized to evaluate the relationship between SF width and antero-posterior length of SG. A significance level of $p<0.05$ was used for statistical significance. All measurements were conducted by the same observer with a minimum of 3 years of maxillofacial USG experience, and the reliability of the measurements was assessed using the intra-observer correlation test.

Results

The study included a total of 20 patients (6 men and 14 women) and examined 40 SF and SG. The participants had a mean age of 34.65±15.16. Cronbach's alpha values of 0.941 and 0.997 were obtained for the CBCT and USG measurements, respectively, which were used to assess intra-observer agreement (95% Confidence Interval). Table 1 presents the descriptive analysis of antero-posterior, supero-inferior,

Table 1. *The descriptive analyses of antero-posterior, supero-inferior, medio-lateral lengths, and volume of SG, SF depth and SF width.*

	n	Mean± SD
Antero-posterior length of SG	40	28.272±3.040 mm
Supero-inferior length of SG	40	11.175±2.138 mm
Medio-lateral length of SG	40	26.402±4.059 mm
Volume of SG	40	4.245±0.713 cm^3
SF depth	40	4.467±0.801mm
SF width	40	30.355±4.618 mm

SG: Submandibular Gland, SF: Submandibular Fossa, SD: standard deviation

Table 2. *Correlation coefficients and significance levels between SF depth and SG medio-lateral size, SF width and SG supero-inferior size, SF width and SG volume, and SF width and antero-posterior length of SG.*

	r[a]	p
SF depth and medio-lateral length of SG	0.358	0.023*
SF width and superior-inferior length of SG	0.365	0.021*
SF width and volume of SG	0.678	0.000**
	rho[b]	p
SF width and antero-posterior length of SG	0.414	0.008**

*SG: submandibular gland, SF: submandibular fossa, [a] Pearson correlation coefficient, [b] Spearman correlation coefficient, *p <0.05, **p <0.01).*

medio-lateral lengths, and volumes of the submandibular glands, SF depth, and SF width.

Table 2 shows that there is a positive correlation between the SF depth measured on CBCT and the medio-lateral length of SG measured by USG (p=0.023, r= 0.358), indicating that as the medio-lateral length of the SG increases, the depth of the SF increases. Similarly, a positive correlation was found between the SF width measured on CBCT and the antero-posterior and superior-inferior lengths measured by USG (p=0.021, r=0.365), indicating that as the antero-posterior and supero-inferior lengths of the submandibular gland increase, the SF width increases (p=0.008, rho= 0.414). Moreover, a positive correlation was found between SF width measured on CBCT and submandibular gland volume measured by USG (p=0.000, r=0.678), indicating that as the submandibular gland volume increases, the SF width increases. However, there was no significant relationship between SF depth and volume of SG.

Discussion

The submandibular gland is located in the posterior part of the submandibular triangle, and its size is approximately 30x35x15 mm. The borders of the submandibular triangle are formed by the anterior and posterior belly of the digastric muscle and the body of the mandible (15).

Many studies in the literature have measured SF depth using CBCT sections. Stratemann *et al.* (16) found less than 1% relative error between their CBCT measurements and physical measurements on the skull. Other studies have also emphasized CBCT as the gold standard (17, 18). While cross-sectional images have been used in many studies to measure SF depth on CBCT (1-3), Quirynen *et al.* (13) classified bone morphologies into three types and found that it may be inaccurate to work on cross-section images in individuals with type II and III bone morphologies. Therefore, our measurements were made on axial sections.

In edentulous patients, SF depth measured from cross-sectional sections may not reflect accurate facts, as the top of the fossa may be adjacent to the bone surface. Parnia *et al.* (14) excluded some cases from their retrospective study on CT images of 100 patients due to this issue. In our study, we also excluded edentulous patients. Additionally, no other study in the literature has measured the antero-posterior width of SF.

Gandage *et al.* (19) investigated the sensitivity and specificity of USG in evaluating the salivary glands and found high sensitivity (93.33%) and high specificity (98.07%). In our study, we used USG to measure the size and volume of the submandibular gland in three dimensions. We found statistically significant positive correlations between the medio-lateral length of the submandibular gland and the SF depth measured on the axial images, and between the antero-posterior and supero-inferior lengths of the submandibular gland and the SF width measured on the axial images. These results were expected based on anatomical considerations.

SF depth and width are important structures to consider in surgical procedures of the posterior mandible, particularly in planning implant treatments. Damage to the SF due to lingual plate perforation during surgery can result in severe bleeding followed by life-threatening hematoma due to upper airway obstruction (20, 21). Therefore, USG can be considered as an alternative to CBCT in cases where rapid assessment of SF depth is required, as it is practical, non-invasive, inexpensive, and radiation-free. Furthermore, USG can evaluate any focus of infection and regional lymph nodes in the region (22).

Dental implants have become increasingly popular in the rehabilitation of edentulism. However, incorrect planning before surgery can cause serious damage to anatomical structures and lead to life-threatening injuries. Mandibular lingual concavities are depressions formed on the bone by the submandibular and sublingual salivary glands (23). Imaging of the SG helps prevent cortical lingual plate perforation, allows preservation of vascular structures, and nerves (24). Although CBCT is undisputedly superior to USG in the morphological and morphometric evaluation of bone including SF before implant, it is expensive, takes time, and contains ionizing radiation. Therefore, USG can be considered as an alternative imaging method in the rapid evaluation of SF depth in patients with implant planned.

The most important limitation of the present study is the sample size. In the future, the sample size should be expanded by increasing the number of patients. However, no other study in the literature has investigated SF and SG in combination with USG and CBCT. As this is the first study in the literature to use CBCT and USG in combination, it may pave the way for more comprehensive studies in the future.

Conclusion

This study found a positive correlation between the size and volume of the submandibular gland measured by USG and the SF depth and width measured by CBCT. In cases where SF depth and width need to be examined, such as in implant treatment, it may be recommended to use USG in addition to CBCT imaging.

Türkçe Özet: *Submandibuler bez ve submandibular fossanın değerlendirilmesi: Kombine konik ışınlı bilgisayarlı tomografi ve ultrason çalışması. Amaç: Bu çalışmanın amacı Konik Işınlı Bilgisayarlı Tomografi (KIBT) ile SF'yi morfometrik olarak ve Ultrasonografi (USG) ile SB'yi değerlendirmektir. Gereç ve Yöntem: Çalışma kapsamında 40 SF ve 20 hastanın SB'leri radyolojik olarak değerlendirildi. İskeletsel olarak, SF'nin derinliği ve genişliği aksiyal KIBT kesitlerinde ölçüldü. SB'lerin an-*

tero-posterior, medio-lateral ve süperio-inferior uzunlukları ve hacimleri USG ile ölçüldü. KIBT ve USG ölçümleri istatistiksel olarak değerlendirildi. Bulgular: SF derinliği ile SB medio-lateral boyutu (p = 0.023), SF genişliği ve SB antero-posterior boyutu (p = 0.021), SF genişliği ve SB hacmi (p = 0.000) arasında istatistiksel olarak anlamlı pozitif korelasyonlar bulundu. Ancak SF derinliği ile SB hacmi arasında anlamlı bir ilişki bulunmadı (p=0,146). Sonuç: Alt çene posterior bölgede planlanan cerrahi işlemlerde özellikle implant uygulamalarında SF çok önemli bir alandır. SF derinliği ve genişliği, SB boyutlarıyla yakından ilişkilidir. USG ile iyonize radyasyon riski olmaksızın SB de net olarak incelenebilir. Anahtar Kelimeler: Submandibular Bez, Submandibuler Fossa, Ultrasonografi, Konik Işınlı Bilgisayarlı Tomografi, implant cerrahisi.

Ethics Committee Approval: The study protocol has been approved by the Local Research Ethics Committee's decision numbered 2021/58.

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: FC participated in designing the study. EAG participated in generating the data for the study. FC participated in gathering the data for the study. EAG participated in the analysis of the data. EAG wrote the majority of the original draft of the paper. FC participated in writing the paper. EAG has had access to all of the raw data of the study. EAG has reviewed the pertinent raw data on which the results and conclusions of this study are based. EAG, FC have approved the final version of this paper. EAG, FC guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

Financial Disclosure: The authors declared that this study has not received any financial support.

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Original research

The effects of various scaling instruments on the surface roughness of monolithic zirconia and lithium disilicate

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Purpose

This *in vitro* study aims to evaluate the effects of plastic piezoelectric maintenance tips on the surface roughness of monolithic lithium disilicate and zirconia.

Materials and Methods

Fifty-four lithium disilicate and 54 zirconia disks were prepared with CAD/CAM. On each material, scaling with a stainless-steel curette or with a piezoelectric device using either a steel or plastic tip was conducted. The surface roughness of the materials before and after the instrumentation was measured with a profilometer. The changes in roughness of the materials according to the scaling methods were analyzed with generalized linear models. Mann-Whitney U with Bonferroni correction was used for between-group comparisons.

Results

The instruments caused surface alterations on both materials (p=0.001), while the roughness change of lithium disilicate and zirconia specimens did not demonstrate any statistically significant difference with each other (p=0.274). However, the curette was found to cause significantly more (p=0.019) roughness change (0.259 ±0.405) on the specimens than the piezoelectric plastic tip (0.060 ±0.238).

Conclusion

Piezoelectric scalers with plastic tips cause less deterioration on monolithic zirconia and lithium disilicate surfaces when compared to stainless-steel hand curettes.

Keywords: *Instrumentation, curette, plastic, ultrasonic, piezoelectric*

Introduction

The goals of initial periodontal treatment are to eliminate the primary etiological factor, oral biofilm, and implement a relatively smooth surface to prevent re-colonization (1). Given that favorable outcomes can be achieved both with hand instruments and ultrasonic devices, the surface structure following instrumentation is of significance, particularly regarding prevention of recurrence (2). Rough hard surfaces promote oral biofilm adherence by procuring an increased surface area in favor of initial bacterial attachment and resistance to mechanical plaque control (3). Hence, the characteristics of the restorative material and the scaling instrument are important factors in maintaining long-term success. In recent years, curettes and ultrasonic scaling tips produced of materials such as carbon, plastic or titanium have been developed, which are thought to cause less surface damage, especially on implant components. Concurrently, however, also new materials are being introduced to the market for prosthetic rehabilitation, which show various surface characteristics and possibly get affected to different extents by these new instruments.

In the last decade, the use of computer-aided design and manufacturing (CAD/CAM) technology in dentistry has significantly surged (4). Increasingly more clinicians prefer point-of-care digital dentistry rather

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than sending analog impressions to dental laboratories (5). This gained wide acceptance thanks to inexpensive CAD/CAM equipment and development of new restorative materials, particularly those that can fulfill esthetic requirements (6). Monolithic restorations, such as zirconia and lithium disilicate, provide acceptable results in this regard, also comply with biomechanical needs, do not require additional veneering or glazing, can be used longer when compared to metal-ceramic restorations and display a reduced risk of cohesive fracture when compared to conventional veneers (4,7-9). However, the surface characteristics of these materials following periodontal treatment, particularly with plastic scaling tips, are not fully revealed.

This *in vitro* study was planned to evaluate the deterioration of monolithic zirconia and lithium disilicate surfaces when they are exposed to various scaling instruments: hand instrumentation with a stainless-steel curette, piezoelectric scaling with conventional stainless-steel tips and piezoelectric scaling with plastic maintenance tips. The null hypotheses was that scaling with a hand curette, piezoelectric scaling with steel tips or piezoelectric scaling with plastic tips would create no change in the surface roughness of monolithic zirconia and lithium disilicate, and thus the surface roughness change of the materials would not differ between used instruments.

Materials and Methods

Sample size

The sample size was calculated with G-Power 3: 95% confidence (1-α), 95% test power (1-β) and an effect size of f=6.7 (large). The minimum required size of n=2 for each instrumentation method by material was calculated. Nonetheless, based on prior research, 18 disks were included in each group (10).

Material production and instrumentation

Fifty-four zirconia and 54 lithium disilicate disks (8 × 2 mm) were prepared with CAD/CAM. Zirconia disks were produced from Straumann Zolid SHT (Amann Girrbach Ceramill, Koblach, Austria) using the inLab MC X5 (Dentsply Sirona, York, PA) device. Lithium disilicate was scraped from Amber Mill blocks (HASS, Gangwon, Korea) with inLab MC XL (Dentsply Sirona, York, PA, USA). The materials were mechanically glazed, and assigned to three groups based on the scaling method: hand instrument, piezoelectric stainless-steel tip, and piezoelectric plastic maintenance tip. Scaling was conducted by a single periodontist (MY). The procedure with the hand instrument consisted of fifteen strokes with mild to moderate force at marked zones with a 7/8 Gracey curette (EverEdge, Hu-Friedy, Chicago, IL, USA) keeping the terminal shank parallel to the surface and using the modified pen grip. The instrument was sharpened every time before being applied to a new disk. Stainless-steel tips (G1-S; NSK, Tokyo, Japan) and plastic maintenance tips (V10-S; NSK, Tokyo, Japan) were separately used for ultrasonic scaling with a piezoelectric device (Variosurg, Model NE214; NSK, Tokyo, Japan) in "periodontology" mode at medium power (50%) under saline irrigation. The tips were positioned with an angle of approximately 10-15° on the disks and horizontally moved in the marked zones for 20 seconds with no lateral pressure, and were discarded and replaced with new ones following the procedure on every nine disks.

Surface roughness measurement

The surface roughness was evaluated by a single examiner (ED) with a profilometer (MarSurf PS1, Mahr GmbH, Germany) calibrated and set at a speed of 0.100 mm/s in a range of 600 μm on the marked zone. The average values of the measurements which were repeated five times, were used for statistical analysis. Disks were gold-coated with an ion-coating unit (Polaron SC Sputter Coater, Quorum Technologies, UK) and photographed with a scanning electron microscope (EVO L10, Carl Zeiss, Germany) for demonstrative reasons.

Statistical analysis

Data were analyzed with the Statistical Package for the Social Sciences (SPSS® V23, IBM®, Armonk, NY, USA). The normality of the distribution was examined with the Shapiro-Wilk test. Generalized linear models were used to examine the main effects and two- and three-way interactions in the analyses of the roughness and the roughness change values according to the material and the scaling method. Pairwise comparisons were performed using the Mann Whitney U test with Bonferroni correction. The results are presented as means and standard deviations. $p<0.05$ was considered statistically significant.

Results

The mean effect of scaling on the surface roughness (Ra) was found to be statistically significant (p=0.001), while the average Ra of the specimens before and after instrumentation were 0.708 ±0.354 and 0.867 ±0.428 respectively. Material (p=0.521), instrument (p=0.257), and material-instrument (p=0.395) interactions regarding Ra did not exhibit significant effects (Table 1). Based on the observation that all specimens showed surface alterations, the roughness changes (Rc) according to the material and the scaling instrument were evaluated in detail (Figures 1, Figure 2, Figure 3). No effect of the material and material-instrument interactions on Rc was observed (Table 2). However, significantly different surface alterations were observed according to the used instrument (Table 3). The hand curette group exhibited a larger Rc compared to the piezoelectric plastic maintenance tip (p=0.025). Rc of the piezoelectric stainless-steel tip did not exhibit any significant difference with the hand curette (p=0.500) or the plastic maintenance tip (p=0.595).

Discussion

The present study aimed to evaluate the surface deterioration caused by different oral prophylaxis instruments, particularly piezoelectric plastic tips, on two different monolithic materials, lithium disilicate and zirconia. The null hypothesis was partly rejected, revealing that instrumentation created a change in the surface roughness of both materials, and the instruments caused surface damage in different extents

Table 1. *Descriptive statistics of the initial and post-treatment surface roughness values according to the material and the instrument.*

		Lithium disilicate	Zirconia	Total
Hand curette	Initial	0.756 ±0.376	0.755 ±0.359	0.755 ±0.363
	Post-treatment	1.130 ±0.563	0.899 ±0.309	1,015 ±0.463
Piezoelectric stainless-steel tip	Initial	0.561 ±0.194	0.811 ±0.437	0.686 ±0.356
	Post-treatment	0.748 ±0.341	0.936 ±0.341	0.842 ±0.349
Piezoelectric plastic maintenance tip	Initial	0.555 ±0.230	0.811 ±0.405	0.683 ±0.350
	Post-treatment	0.565 ±0.255	0.921 ±0.497	0.743 ±0.429
Total	Initial	0.624 ±0.288	0.792 ±0.395	0.708 ±0.354*
	Post-treatment	0.814 ±0.465	0.919 ±0.384	±0.428*

* p=0.001

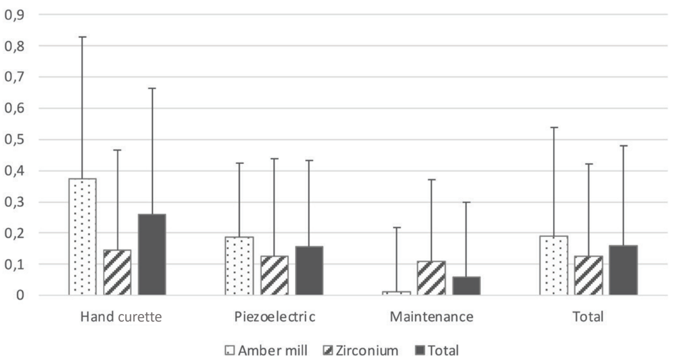

Figure 1. *The roughness changes according to the used instrument and the material.*

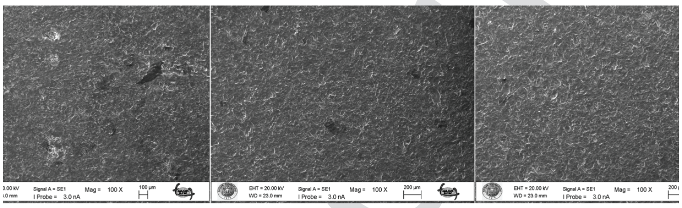

Figure 2. *Scanning electron microscopy images (×100) of lithium disilicate following treatment with hand curette, piezoelectric stainless-steel tip and piezoelectric plastic maintenance tip, respectively.*

when the materials were pooled. However, plastic or conventional steel tips did not exhibit a significant superiority to each other regarding surface damage. Thus, both can be reliable in the proximity of monolithic restorations. On the other hand, stainless-steel curettes caused more surface damage when compared to piezoelectric scaling with a plastic maintenance tip.

Monolithic zirconia restorations have significant advantages such as high flexural strength, minimal preparation

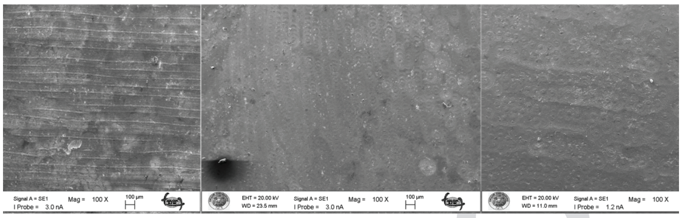

Figure 3. *Scanning electron microscopy images (×100) of zirconia following treatment with hand curette, piezoelectric stainless-steel tip and piezoelectric plastic maintenance tip, respectively.*

Table 2. *Evaluation of the roughness change according to the materials and the instruments.*

	Test statistics (Wald chi-square)	Degree of freedom	p
Material	1.196	1	0.274
Instrument	7.885	2	**0.019**
Material-instrument	5.383	2	0.068

Table 3. *Descriptive statistics of the roughness change.*

	Lithium disilicate	Zirconia	Total
Hand curette	0.374 ± 0.455	0.145 ± 0.322	0.259 ± 0.405[a]
Piezoelectric stainless-steel tip	0.187 ± 0.238	0.126 ± 0.313	0.156 ± 0.276[ab]
Piezoelectric plastic maintenance tip	0.010 ± 0.208	0.110 ± 0.262	0.060 ± 0.238[b]
Total	0.190 ± 0.348	0.127 ± 0.295	0.159 ± 0.322

a-b: Values in the same column with different superscripts represent statistically significant differences

requirement, reduced wear on antagonists, less lab time and fewer dental sessions when compared with conventional materials (11). Until a few years ago, their main disadvantage was poor aesthetic performance due to insufficient translucency (12). However, recent changes in the composition, structure and manufacturing methods have led to monolithic zirconia with better translucency and, concurrently, a significant reduction in strength (13). Lithium disilicate obtained from Amber Mill, on the other hand, is relatively new to dental applications. It is generally used in the anterior zone for inlay and onlay restorations, partial and full crowns, and 3-unit fixed dental bridges (14). Both lithium disilicate and zirconia not only exhibit good biocompatibility and mechanical properties, but also exhibit good esthetic results (15). Thus, especially in periodontally compromised patients with the potential of frequently undergoing oral prophylaxis, exhibiting minimal surface roughness following the treatment can be the main criterion in material selection. According to our results, the materials do not have any significant advantages over each other, and both can be used in periodontitis patients with no reason for preference in regard to initial or post-treatment surface roughness. There are contradictory results in the literature about the extent of deterioration on lithium disilicate and zirconia surfaces following scaling with various instruments. No surface alterations were previously reported on these materials following treatment with stainless-steel curette, ultrasonic scaler or prophylaxis paste (16). Yet, our results are rather in accordance with other prior studies demonstrating an increase in roughness in both (10,17). Hence, effort should be given to decide upon the least harmful scaling instrument for zirconia and lithium disilicate restorations. Interestingly, in our study, the difference between the alterations caused by various instruments was negligible when the materials were evaluated separately. But when the materials were pooled, namely monolithic specimens were assessed in total, the plastic maintenance tip, which induced the lowest surface alteration, was found to be less harmful than the stainless-steel curette.

The efficacies of the materials on biofilm removal and biofilm adherence following treatment were not evaluated in the present study, since there is sufficient information in the available literature (16,18-20). However, our study has the limitation that the applied force during the instrumentation was not measured. Clinically, this force can vary depending on the situation, the instrument and the operator's skills or preferences. Prior research pointed out a drastic force range from 1.01N to 10.35N, while up to 14N was used in studies evaluating surface alterations (21,22). In order to reduce the impact of this limitation on our results, instrumentation was conducted by an experienced periodontist with the modified pen grip and with mild to moderate force, copying the clinical setup and keeping the applied force as standard as possible. Moreover, the hand instruments were sharpened for every new disk to eliminate the effects of blunt instrumentation on the materials.

Both hand and power-driven instruments are effective in biofilm removal. Although similar clinical outcomes can be achieved particularly in single-rooted teeth, the hand instruments take more time and effort when compared to ultrasonic or sonic instruments (18). Therefore, there is a tendency to use power instruments, while the clinical relevance of various tip designs remains unknown (23). Due to the increase in dental implant applications and concurrent peri-implant diseases, developing more efficient and less harmful instruments for implant maintenance became a concern for the dental industry. The plastic tips are recommended particularly for this reason, since they have minimal impact on the titanium surfaces when compared to stainless-steel tips, although a sizable concession in efficiency has to be considered (24). To the best of the authors' knowledge, little is known about how these piezoelectric plastic tips affect monolithic materials. According to our results, if a choice between a stainless-steel curette and a piezoelectric plastic tip is to be made, the latter would be more advisable to reduce potential collateral damage to the material. It should also be considered that ultrasonic scaling with steel tips significantly impacts the optical properties of ceramic materials and may cause cracks and marks in esthetically challenging areas (25).

Conclusion

Within the limitations of our study, there are no drastic differences between stainless steel and plastic tips when conducting piezoelectric scaling in the proximity of monolithic zirconia or lithium disilicate restorations. However, piezoelectric scaling with plastic tips should be encouraged rather than stainless-steel hand curettes, since they create less surface deterioration on these materials.

Türkçe özet: *Çeşitli kazıma aletlerinin monolitik zirkonya ve lityum disilikatın yüzey pürüzlülüğüne etkisi. Amaç: Bu in vitro çalışma, plastik piezoelektrik kazıyıcı uçların monolitik lityum disilikat ve zirkonyanın yüzey pürüzlülüğü üzerindeki etkilerini değerlendirmeyi amaçlamaktadır. Gereç ve yöntem: CAD/CAM ile 54 adet lityum disilikat ve 54 adet zirkonyum disk hazırlandı. Her malzemede, bir paslanmaz çelik küret ile veya çelik veya plastik uç kullanan bir piezoelektrik cihazla kazıma yapıldı. Enstrümantasyondan önce ve sonra bir profilometre yardımıyla malzemelerin yüzey pürüzlülüğü ölçüldü. Kazıma yöntemlerine göre malzemelerin pürüzlülüklerindeki değişimler genelleştirilmiş lineer modeller ile analiz edildi. Gruplar arası karşılaştırmalarda Bonferroni düzeltmeli Mann-Whitney U kullanıldı. Bulgular: Aletler her iki malzemede de yüzey değişikliğine neden olurken (p=0,001), lityum disilikat ve zirkonya örneklerindeki pürüzlülük değişimleri birbirlerine göre istatistiksel anlamlı bir farklılık göstermedi (p=0,274). Ancak küretin (0,060 ±0,238) piezoelektrik plastik uca (0,259 ±0,405) göre malzemelerde anlamlı derecede daha fazla (p=0,019) pürüzlülük değişikliğine neden olduğu bulundu. Sonuç: Plastik uçlu piezoelektrik kazıyıcılar monolitik zirkonya ve lityum disilikat yüzeylerde paslanmaz çelik küretlere göre daha az bozulmaya neden olmaktadır. Anahtar Kelimeler: enstrümantasyon, küret, plastik, ultrasonik, piezoelektrik*

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Original research

Youtube videos as a source of information on digital indirect bonding: A content analysis

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Purpose

The aim of this study was to evaluate YouTube videos as a source of information for digital indirect bonding techniques.

Materials and Methods

The keyword "digital indirect bonding" was first searched on YouTube, resulting in 57 recorded videos. Descriptive parameters, including source, target audience, purpose, duration, upload date, number of likes, dislikes, views, and comments, were then evaluated. After this initial assessment, the interaction index and viewing rate were calculated. Video content quality was determined using a 5-point scale that categorized videos as having poor, moderate, or good content quality. This rating was based on the presence and discussion of various topics related to digital indirect bonding, including digital scan, digital bracket placement, transfer tray production from a 3D-printed model or direct production as a 3D-printed tray, clinical application, and advantages and/or disadvantages. The videos were assessed for quality using the global quality scale (GQS) and video information and quality index (VIQI). Statistical evaluation was conducted using Kruskal-Wallis, Chi-square, and Pearson correlation analysis, and intraclass correlation coefficients were calculated to determine the rating reliability.

Results

The majority of the videos were classified as having poor content quality (41.9%), followed by moderate (38.7%) and good (19.4%) content quality. No significant differences were found between the videos in terms of descriptive parameters. However, videos with good content quality had significantly higher GQS and VIQI scores than moderate and poor content videos. The total content showed significant correlations with GQS and VIQI ($r=0.780$ and $r=0.446$, respectively; $p<0.05$).

Conclusion

In conclusion, while the majority of YouTube videos regarding digital indirect bonding were of poor content quality, those that were of good content quality could be considered a useful source of professional information.

Keywords: *Digital, indirect bonding, information, video, YouTube*

Introduction

Interest in fixed orthodontic treatment has increased due to the growing importance placed on aesthetics and appearance. Since their introduction in the mid-1960s, orthodontic attachments have generally been directly bonded to enamel surfaces in clinical practice (1). The use of light-cured adhesives with direct bonding techniques has provided clinicians with unlimited working time since the early 1980s, allowing for more control over the positioning of brackets and tubes during bonding procedures (2). However, improper positioning of attachments on the posterior teeth can lead to problems due to difficulties in accessibility and visibility. In 1972, Silverman *et al.* (3) introduced the indirect bonding technique, which provides more accurate bracket positioning and shortens clinical

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chair time. The traditional indirect bonding technique involves laboratory and clinical stages. First, each bracket is accurately placed on study models with various adhesive materials, increasing laboratory working time. Then, a transfer tray is produced with different materials before clinical application (4).

Digital technology has been rapidly spreading among orthodontists, offering immense convenience throughout the treatment process, from diagnosis to follow-up (5). In orthodontic practice, digital technology has been integrated with intraoral scanners, computer-aided design and manufacturing systems, and three-dimensional (3D) printers (6). Parallel to this development, the time-consuming steps of the traditional indirect bonding technique have led orthodontists to prefer digital bracket placement, considering advantages such as increased bracket-positioning accuracy, reduced bracket repositioning, and decreased need for wire bending (7).

The digitalized indirect bonding technique requires smart workflows, including virtual bracket placement and production of 3D-printed study models, as well as transfer trays made of different materials (e.g., thermoplastic or silicone) or direct production as a 3D-printed tray (8). This new digital bonding technique provides precise transfer, increased patient comfort, and decreased orthodontic treatment duration (9, 10). However, the digital indirect bonding system provided bracket positioning with maximum linear transfer error in the buccolingual direction and maximum angulation error in the torque (11). Other disadvantages have been reported such as increased total working time based on the digital bracket placement, immediate bracket failures and cost (12). The limits of users by the types of bracket models was another drawback and the lack of working with different bracket types has recently been highlighted by researchers (13).

Most social media users receive health-related information from the Internet (14). YouTube videos are commonly utilized to access information because they provide both visual and audio content and can be accessed without membership fees. Al-Silwadi *et al.* (15) stated that providing audiovisual information to orthodontic patients using the Internet notably raised their awareness of treatment options, risks, and benefits. However, orthodontists should be aware of the impact of possible misinformation (16). Kılınç and Sayar (17) reported that the information contained in YouTube orthodontic videos could cause the spread of misleading information through the absence of an assessment system for qualifying videos before they are uploaded. For this reason, the quality of data obtained from the YouTube video platform has recently gained importance. In this respect, numerous studies have evaluated the quality of orthodontics-related information across YouTube videos in the past five years (17-30).

Nowadays, the conventional indirect bonding method has been replaced by the digital technique with the widespread use of digital workflows in clinical practice. However, no studies are available that evaluate YouTube videos about digital indirect bonding in terms of characteristics, content, and quality. The aim of this study was to evaluate whether YouTube videos could serve as a source of information for digital indirect bonding techniques. The null hypothesis was that there would be no difference among YouTube videos in terms of content quality.

Materials and Methods

Online search protocols

The ethical approval was not obtained for this study because public data was used. The YouTube video database was searched on November 1, 2021, to assess the available information on the digital indirect bonding technique. The possible keywords related to the digitalized indirect bonding technique, including indirect bonding and digital bonding were determined using a GoogleTrends website search. Consequently, the keyword digital indirect bonding was used in the YouTube search. The YouTube parameter was view count sorting, with no additional search filters. In total, it was accessed and recorded 57 videos. Videos were excluded from this study if they were (a) not recorded in English, (b) longer than 30 minutes, (c) shorter than 1 minute, (d) silent, (d) irrelevant to the subject, (e) duplicates, or (f) advertisements. The videos uploaded in parts were combined into a single video. Additionally, the duration of webinar videos with continuing education (CE) was longer than 30 minutes. Based on this, these videos were not evaluated during this study.

Data classification

The videos' sources were classified into three groups: dentists/specialists, dental companies or manufacturers, and other sources. The videos' target audiences were categorized into three groups: laypeople, professionals, and both. The videos' purposes were categorized into three groups: professional information, patient information, and general information. To evaluate the videos' content quality (VCQ), the videos were rated according to their informations about each of five topics: digital scan, digital bracket placement, transfer tray production from a 3D-printed model or direct production as a 3D-printed tray, clinical application, and advantages and/or disadvantages.

Evaluation process

Each topic was awarded 1 point. The total score ranged from 0 to 5. Each video was classified as having poor (0–1 points), moderate (2–3 points), or good (4–5 points) content.

Descriptive information such as video duration, time elapsed since upload, numbers of views, likes, dislikes and comments were recorded and then the interaction index and viewing rate were assessed based on the formulas (31):
* Interaction index = (Number of likes-dislikes)/(Number of views) × 100 * Viewing rate = View number / The time elapsed since its upload × 100

The videos were rated using the global quality scale (GQS), and a 5-point Likert scale was used to evaluate each video's flow, usefulness for patients, and general quality. The overall audiovisual quality was evaluated with the video information and quality index (VIQI), and a 5-point Likert scale was used to assess the following parameters: flow of information, information accuracy, quality, and precision.

Reliability measurements

The reliability assessment of all parameters for intra- and interexaminer was carried out. Two researchers separately evaluated all videos and reassessed these videos two weeks later to determine intra- and interexaminer reliability of rating.

Statistical analysis

The data were analyzed with SPSS (version 25; IBM Corp. Armonk, NY, USA). The Shapiro-Wilk test was used to test normality. For non-normally distributed data, Kruskal-Wallis test was used to evaluate the differences among videos with different content. For categorical variables, the percentages were calculated and the diferences were assessed with Chi-square test. The correlations between total VCQ, GQS, VIQI and other descriptive parameters were calculated using Pearson correlation coefficients. The rating reliability was evaluated using intraclass correlation coefficient (ICC) values. The significance level was determined at $p<0.05$.

Results

After the initial search using "digital indirect bonding" as a keyword, a total of 57 videos were screened, of which 26 were excluded from evaluation. Exclusion criteria were a running time of over 30 minutes or under a minute (n=9), duplicates (n=4), non-English language (n=1), silent videos (n=1), advertising (n=2), videos that were irrelevant to the subject (n=8) or videos in multiple parts (n=1).

The ICC values ranged from 0.932 to 0.967 for intraexaminer reliability and from 0.877 to 0.941 for interexaminer reliability. The descriptive characteristics are shown in Table 1. A majority of videos (61.3%) were uploaded by dental companies or manufacturers and the remaining videos were uploaded by dentists or specialists. About 70% of videos aimed to provide professional information and approximately half of all videos targeted dental professionals. The mean duration of videos about digital indirect bonding was 5.29 minutes. The mean number of days since upload was 1,125.87 days. The mean number of views was 2,463.71. The mean number of likes was 11.42 (ranged from 0 to 73), whereas the mean number of dislikes was 0.84 (ranged from 0 to 7). The mean interaction rate was 0.83 and the mean viewing rate was 267.92. The total video content score was 1.94±1.09 for all included videos.

According to the VCQ assessment, of the 31 videos that were analyzed, 13 (41.9%), 12 (38.7%) and 6 (19.4 %) were respectively categorized as showing low-, moderate- and high-quality content. There were no significant differences between the groups in terms of descriptive parameters (Table 2).

The comparisons of descriptive parameters are shown in Table 3. There were no significant differences in terms of duration, days since upload, numbers of views, likes, dislikes, comments and interaction index, viewing rate, quality and precision parameters under the VIQI assessment. Conversely, there were significant differences in terms of total VCQ and GQS scores between videos with low-quality, moderate-quality and high-quality content ($p=0.001$; $p<0.05$). Pairwise comparisons showed that the low-quality content group had significantly lower mean values of total VCQ and GQS scores than moderate- ($p=0.001$ and $p=0.002$, respectively; $p<0.05$) and high-quality videos ($p=0.001$; $p<0.05$). Moderate-quality videos had significantly lower mean values of total VCQ and GQS scores than the high-quality content group ($p=0.014$ and $p=0.002$, respectively; $p<0.05$).

The results also showed significant differences in flow, accuracy and total VIQI scores between the groups ($p=0.022$, $p=0.014$, and $p=0.025$; respectively; $p<0.05$) as presented in Table 3. Pairwise comparisons demonstrated that the high-quality content group had significantly higher mean scores of flow and accuracy compared to low quality ($p=0.009$ and $p=0.005$, respectively; $p<0.05$) and moderate-quality videos ($p=0.007$ and $p=0.017$, respectively; $p<0.05$). In terms of total VIQI scores, high-quality videos scored significantly higher than low quality and moderate-quality content ($p=0.009$ and $p=0.023$, respectively; $p<0.05$).

The correlations between total VCQ, VIQI and GQS scores and other video parameters are shown in Table 4. A strong correlation was found between VCQ and GQS scores ($r=0.780$; $p=0.001$; $p<0.05$). Moderate correlations were found between VCQ and VIQI ($r=0.446$; $p=0.012$; $p<0.05$), GQS and VIQI ($r=0.412$; $p=0.021$; $p<0.05$), GQS and duration ($r=0.501$; $p=0.004$; $p<0.05$), and VIQI and interactive index ($r=0.387$; $p=0.032$; $p<0.05$). Moreover, moderate negative correlations were found between VCQ and number of dislikes ($r=-0.427$; $p=0.017$; $p<0.05$) and between VIQI and number of dislikes ($r=-0.489$; $p=0.005$; $p<0.05$).

Table 1. *Descriptive characteristics of the YouTube videos about the digital indirect bonding.*

		n	%
Source	**Dentist/specialist**	12	38.7
	Dental company or manufacturer	19	61.3
	Other	0	0.0
Purpose	**Professional information**	22	71.0
	Patient information	0	0.0
	Both	9	29.0
Target audience	**Layperson**	0	0.0
	Professional	16	51.6
	Both	15	48.4
	Mean±SD		**Min-Max**
Duration (minute)	5.29±5.68		1.26-25.51
Days since upload	1125.87±708.83		34-2595
Number of views	2463.71±4183.01		83-20818
Number of likes	11.42±16.35		0-73
Number of dislikes	0.84±1.51		0-7
Number of comments	1.29±2.84		0-15
Interaction index	0.83±1.35		-0.24-5.61
Viewing rate	267.92±370.2		9.58-1436.7
Total video content score	1.94±1.09		1-5
GQS score	2.39±1.09		1-5
VIQI assessment			
Flow	3.52±1		2-5
Accuracy	3.81±0.79		3-5
Quality	3.74±0.73		3-5
Precision	3.9±0.83		3-5
Total VIQI score	14.97±3.01		11-20

Table 2. *Comparison of descriptive categorical features between different video content groups.*

		Poor (n=13)		Moderate (n=12)		Good (n=6)		
		n	*%*	*n*	*%*	*n*	*%*	[a]p
Source	**Dentist/specialist**	4	33.3	5	41.7	3	25.0	0.700
	Dental company/manufacturer	9	47.4	7	36.8	3	15.8	
Target audience	**Professional**	9	56.3	6	37.5	1	6.3	0.102
	Professional and layperson	4	26.7	6	40.0	5	33.3	
Purpose	**Professional information**	11	50.0	8	36.4	3	13.6	0.278
	General information	2	22.2	4	44.4	3	33.3	

[a] Chi-Square Test

Table 3. *Comparison of video parameters between different video content groups.*

	Poor (n=13)		Moderate (n=12)		Good (n=6)		p
	Mean±SD	Min-Max	Mean±SD	Min-Max	Mean±SD	Min-Max	
Duration (minute)	4.96±6.93	1.26-25.51	4.8±4.43	1.32-15.07	7.01±5.52	2.16-14.54	0.281
Days since upload	1075.46±670.09	34-2378	1143±815.69	143-2595	1200.83±677.61	467-2361	0.901
Number of views	2472.46±3473.42	99-11453	2965.92±5771.36	83-20818	1440.33±943	196-2471	0.958
Number of likes	14.77±23.23	0-73	7.42±9.82	0-31	12.17±5.31	5-19	0.225
Number of dislikes	1.46±2.07	0-7	0.5±0.8	0-2	0.17±0.41	0-1	0.126
Number of comments	2.15±4.1	0-15	0.67±1.23	0-4	0.67±1.21	0-3	0.454
Interaction index	0.75±1.35	0-5.05	0.44±0.62	-0.24-1.51	1.77±2.08	0.26-5.61	0.128
Viewing rate	306.27±402.39	9.58-1424.5	300.94±424.64	11.58-1436.7	118.81±62.09	34.27-191.8	0.893
VCQ	1±0	1-1	2.17±0.39	2-3	4.5±1.22	4-5	0.001**
GQS	1.54±0.52	1-2	2.50±0.67	2-4	4±0.63	3-5	0.001**
VIQI assessment							
Flow	3.23±0.93	2-5	3.33±0.98	2-5	4.5±0.55	4-5	0.022*
Accuracy	3.54±0.66	3-5	3.67±0.78	3-5	4.67±0.52	4-5	0.014*
Quality	3.69±0.75	3-5	3.5±0.67	3-5	4.33±0.52	4-5	0.060
Precision	3.77±0.83	3-5	3.75±0.87	3-5	4.5±0.55	4-5	0.137
Total VIQI score	14.23±2.77	11-20	14.25±2.9	11-20	18±1.9	16-20	0.025*

Table 4. *Correlation coefficients for total video content quality (VCQ), global quality scale (GQS), video quality information index (VIQI) and other factors.*

	VCQ	GQS	VIQI	Duration	Days since uploaded	Number of views	Number of likes	Number of dislikes	Number of comments	Interaction index	Viewing rate
VCQ	1	0.780**	0.446*	0.331	-0.027	0.002	0.089	-0.427**	-0.151	0.220	-0.047
GQS		1	0.412*	0.501**	0.010	0.207	0.304	-0.194	-0.016	0.218	0.136
VIQI			1	0.339	-0.147	0.095	0.188	-0.489**	-0.024	0.387*	0.126

**p<0.05, **p<0.01*

Discussion

Recently, increased demands for clinical applications that require less chair time have led orthodontists to use digital workflows during bonding procedures. Using digital indirect bonding technology necessitates the use of intraoral or desktop scanner, digital bracket placement software, and a 3D printer (6). Within this context, various dental products are available for orthodontists. Considering the requirements, commercial suppliers play an important role in the transition from conventional indirect techniques to digital indirect bonding in orthodontic practice.

According to the results, dental companies uploaded most sources of information about digital indirect bonding.

This was an expected result. The need for an operating system that allows virtual transfer tray design resulted in most information originating from dental manufacturers. As the source was dental companies, the videos were prepared to provide educational information for dental professionals. This finding could be associated with the fact that the evaluated title was more technical, as stated in the previous study (30). In this study, dental professionals were observed to be poor at explaining their knowledge on YouTube. Another finding was the limited number of videos created by patients. Based on this, it was considered that digital technique had been applied inadequately to patients in clinical practice. Considering the high cost of equipment (e.g., 3D printers), such a result could be expected.

In this study, a 5-point Likert scale was used to perform the content analysis. Most of the videos (41.9%) were classified as poor, 38.7% as moderate, and 19.4% as good. Likewise, the content of the YouTube videos on different topics, such as orthognathic surgery, lingual orthodontic treatment, impacted canines, clear aligners, surgically assisted rapid palatal expansion, mini screws, craniofacial distraction osteogenesis, orthodontic retention and retainers was generally found to be deficient in previous studies (18, 19, 21, 22, 25-29). On the other hand, conflicting results were reported about the quality of videos on certain subjects (20, 23, 24). Previous videos about orthognathic surgery and cleft lip and palate were rated as moderate (20,23). Yavuz *et al.* (24) demonstrated that good general content was found in most videos related to accelerated orthodontics. A recent study revealed that videos with high-quality content provided reliable and acceptable information about adult orthodontics (30). The differences between content qualities may be associated with audience interest and the popularity of video titles for different topics, whereas adequate content quality may be explained by more detailed information in the same video topics.

According to the video characteristics, the length of the assessed videos was within the range of previous studies in the field of orthodontics (19, 22, 25, 26). The longest video (25.51 minutes) was given an information from a doctor channel. However, videos that were too long (duration ≥ 30 minutes) or too short (duration less than1 minute) were not evaluated in this study. One of them was the webinar videos with CE credits. The high-quality videos were the longest ones, in accordance with earlier findings (22-25, 27, 29, 30).

The digital indirect bonding videos identified as having poor, moderate, and good content had 2,471.46, 2,965.92, and 1,440.33 views, respectively. Longer videos with good content demonstrated lower numbers of views and viewing rates. Similarly, Lena and Dindaroğlu (19) reported that audience interest decreased when the duration of YouTube videos was increased. Regarding the number of likes, videos with poor content received the most positive feedback. This result was surprising. It should be kept in mind that dental companies due to the need for advertisements could manipulate the number of likes or dislikes. Based on the results, videos with good content had higher interaction index values than the other videos. However, viewers had not found more content interesting. The number of views could be related to the duration of the video rather than the video content. Short videos had more viewings, as found in previous studies on different orthodontic topics (16, 19, 24, 27). This finding was supported by the fact that viewers lost interest with the prolonged duration of a video (19).

The general quality of the videos was examined using GQS scores based on the usefulness and general concern of a video to patients. According to the total mean score of GQS (2.39 ± 1.09 out of 5), the videos were generally of poor to moderate quality and had limited usability for patients. Regarding the VIQI assessment, the videos of different content quality did not differ from each other in terms of the use of still images, animation, interviews with individuals in the community, video captions, and a report summary. There were also no differences between poor, moderate, and good content videos on the level of coherence between the video title and the content. However, good content videos had significantly higher scores for information of flow and accuracy. These differences accounted for the increased total VIQI scores of good content videos. Based on these findings, the null hypothesis was rejected.

In this study, the total content quality scores showed significant correlations with the GQS and VIQI scores.The more content, the better the flow, and the greater the accuracy of the information, the better the quality of the videos. A moderate correlation was found between the VIQI and GQS scores. As a result of technological developments, increased fluency, accuracy, quality, and precision attract more viewers. Although the GQS scores and video duration showed a moderately positive correlation, the increased quality and flow of information and its usefulness for patients should be presented in a duration that was acceptable to viewers. On the other hand, a negative correlation was found between the VIQI scores and the number of dislikes, as expected.

One limitation of this study was the lack of real-time data collection. Another limitation was the absence of videos uploaded by patients to explain their experiences. The results of this study found out a need for new videos, particularly those explaining the feelings of patients who experienced a bonding session with the digital indirect bonding technique. Within the limitations of this study, the content analysis showed that the number of good content videos was inadequate (nearly 20%) about the digital indirect bonding technique. New videos with more details and durations that are acceptable for users should be created and uploaded by professionals, in parallel with the trend toward the increased use of the digital indirect bonding technique.

Conclusion

YouTube was deficient as a source of information about the digital indirect bonding technique. Only a small number of YouTube digital indirect bonding-related videos demonstrated good content quality. Although the content quality of most videos was poor, they could be useful for providing professional information. More informative videos on this topic should be uploaded by professionals.

Türkçe özet: *Dijital indirekt bonding tekniği hakkında bilgi kaynağı olarak YouTube videolarının değerlendirilmesi: Bir içerik analizi. Amaç: Çalışmamızın amacı dijital indirekt bonding tekniği hakkında bilgi kaynağı olarak YouTube videolarının değerlendirilmesidir. Gereç ve Yöntem: YouTube'da "dijital indirekt bonding" anahtar kelimesi aranmış ve ilk değerlendirme sonrasında 57 video kaydedilmiştir. Videolar kaynak, amaç, hedef kitle, süre, yükleme tarihi, beğenilme, beğenilmeme, izlenme ve yorum sayıları gibi tanımlayıcı parametreler açısından değerlendirilmiş*

ve ardından etkileşim indeksi ve izlenme oranı hesaplanmıştır. Video içerik kalitesi; dijital tarama, dijital braket yerleştirme, 3D modelden transfer plağı üretimi veya 3D transfer plağın doğrudan üretimi, klinik uygulama, avantajlar ve/veya dezavantajlar konu başlıklarını içeren 5 puanlık Likert ölçeği kullanılarak zayıf, orta ve iyi içerikli olarak belirlenmiştir. Videolar kalite açısından global kalite skoru (GKS) ve video bilgileri ve kalite indeksi (VBKI) ile değerlendirilmiştir. İstatistiksel değerlendirmede Kruskal-Wallis, Ki-kare ve Pearson korelasyon analizleri kullanılmıştır. Güvenilirliği belirlemek için sınıf içi korelasyon katsayıları hesaplanmıştır. Bulgular: Videoların çoğu içerik kalitesine göre zayıf (% 41.9), ardından orta (% 38.7) ve iyi (% 19.4) içerikli olarak sınıflandırılmıştır. Videolar arasında tanımlayıcı parametreler açısından farklılık bulunmamıştır. İyi içerikli videolar, orta ve zayıf içerikli videolara göre anlamlı derecede daha yüksek GKS ve VBKI puanlarına sahiptir. Toplam içerik, GKS (r=0.780; p<0.05) ve VBKI (r=0.446; p<0.05) ile pozitif yönde anlamlı ilişki göstermiştir. Sonuç: Çoğu YouTube videosunun dijital indirekt bonding ile ilgili içerik kalitesi düşük olmasına rağmen iyi içerikli videolar yararlı bir profesyonel bilgi kaynağı olarak kabul edilebilir.
*Anahtar kelimeler***:** *Bilgi, dijital, indirekt bonding, video, YouTube*

Ethics Committee Approval: Not required.

Informed Consent: Not required.

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Author contributions: SC, EC participated in designing the study. SC, EC participated in generating the data for the study. SC, EC participated in gathering the data for the study. SC, EC participated in the analysis of the data. SC, EC wrote the majority of the original draft of the paper. SC, EC participated in writing the paper. SC has had access to all of the raw data of the study. SC has reviewed the pertinent raw data on which the results and conclusions of this study are based. SC, EC have approved the final version of this paper. SC, EC guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Original research

Efficacy of orthoMTA, retroMTA and ferric sulphate as pulpotomy agents in primary molars: A randomized clinical trial

Sıla Yılmaz[1], Sultan Keleş[1]

Purpose
The purpose of this study is to evaluate the clinical and radiographic success rates of RetroMTA, OrthoMTA, and ferric sulfate as pulpotomy agents in primary molars.

Materials and Methods
Ninety-six primary second molars from 32 children aged 5 to 9 years were enrolled in this study. The teeth were randomly divided into three groups based on the pulpotomy agent used: O-MTA, R-MTA, and FS. Clinical and radiographic follow-up examinations were conducted at 3, 6, 9, and 18 months postoperatively.

Results
At the end of the study period, 84 teeth were evaluated. The clinical success rates were 75% for FS, 96.4% for O-MTA, and 92.8% for R-MTA groups. In the radiographic analysis, the success rates at the 18-month follow-up period were 50% for FS, 85.8% for O-MTA, and 82.2% for R-MTA groups. According to the Chi-square test and Kaplan-Meier survival analysis, there was a statistically significant difference among the success rates and survival probabilities of the groups ($p<0.05$).

Conclusion
OrthoMTA and RetroMTA demonstrated better treatment outcomes for pulpotomy of primary second molars than ferric sulfate at the 18-month follow-up period.

Keywords: *Pulpotomy, primary teeth, ferric sulphate, mineral trioxide aggregate, zinc oxide eugenol cement*

Introduction

Pulpotomy is a treatment procedure used in pediatric dentistry for asymptomatic cariously exposed teeth with a healthy radicular pulp. The success of pulpotomy relies on completely removing the infected coronal part and covering the remaining healthy pulp tissue with a suitable agent (1). The choice of material plays a significant role in the success of pulpotomy, along with accurately diagnosing the infected dental pulp. An ideal material for pulpotomy should provide a hermetic seal, antibacterial efficacy, compatibility with physiological exfoliation, and support healing of the radicular pulp (2,3). Various materials have been used in pulpotomy procedures to promote the devitalization, preservation, or regeneration of the pulp tissue. Formocresol, previously a commonly preferred material, has been replaced by ferric sulfate (FS) and Mineral Trioxide Aggregate (MTA) due to its toxic and mutagenic effects (4,5).

Ferric sulphate (FS) has also been used as a pulpotomy agent because of its high survival rates. A ferric ion-protein complex occurs when the FS contact with the blood, and seals the cut vessels and prevent the consti-

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tution of blood clot (6). The success rate of ferric sulphate has been reported from 81% to 97% in the previous studies (4-7). Although, it has high clinical success rate, there are studies that it may create moderate to severe inflammatory responses lead to internal resorption (7).

Mineral trioxide aggregate (MTA) has been widely recommended for various endodontic procedures in humans. Numerous studies have reported its high clinical success rate, making it an ideal material for pulpotomy (8-10). MTA promotes dentin bridge formation and maintains normal pulp histology. Unlike ferric sulfate, calcium hydroxide, or formocresol, MTA does not result in internal resorption, which is commonly observed in teeth treated with those materials. While studies have demonstrated the high clinical and radiographic performance of MTA in endodontic treatment of primary teeth, ongoing research aims to improve its physical, mechanical, and biological properties (11). Consequently, different materials have been introduced for use in primary molar pulpotomies. OrthoMTA, designed specifically for orthograde root canal filling, exhibits excellent sealing ability in root canals and dentinal tubules, low expansion rate, and ease of application (12,13). RetroMTA, a newly developed MTA material free of heavy metals, offers a shorter setting time (11,14). However, limited clinical studies have compared the success rates of OrthoMTA and RetroMTA as pulpotomy agents for primary molars (11). Thus, there is a need for randomized controlled trials to assess the clinical and radiographic success rates, survival times, and time-related failures of these newly developed materials. The null hypothesis tested in this study was that there would be no differences in the clinical and radiographic success and survival rates among the RetroMTA, OrthoMTA and FS in primary molar pulpotomies.

Materials and Methods

Ethical aprroval

This randomized controlled clinical trial was reviewed and approved by the Ethics Committee of Aydin Adnan Menderes University Faculty of Dentistry (Approval reference:2018/047) and conducted in accordance with the guidelines of the Declaration of Helsinki between June 2017 and July 2018. The trial was designed in accordance with the 2010 Consolidated Standards of Reporting Clinical Trials statement and registered (Protocol Registration Receipt NCT03718676) at http:// www.clinicaltrial.gov.

Sample size

The sample size was calculated considering 95% power and a significance level of .05 (effect size=0.40) according to the outcomes of the study by Goyal *et al*. (15). As a result, 96 teeth from 32 patients were included for three goups (n=32).

Participants and study design

The participants referred to the Aydin Adnan Menderes University Faculty of Dentistry between 5-9 years of age were assessed for eligibility. The details are presented in the Consalidated Standards of Reporting Trials Flow diagram (Figure 1). The trial protocol was explained in details and participants/caregivers signed written informed consent. The inclusion criteria were as follows: Systemically healthy children between 5-9 years of age with three second primary molars indicated for pulpotomy. Carious or mechanial exposure of pulp in symtom free vital primary molars. presence of pulp degeneration and (Pulp canal obliteration, periodontal ligament widening, periapical and furcal radiolucency, and internal/external root resorption) physiologic resorption of less than one third of the root.

The exclusion criteria of the study were as follows: having any known systemic chronic diseases, allergy to local anesthetic agents, uncooperative children for routine dental treatment, presence of spontaneous pain and mobility, fistula formation, gingival redness and swelling, sensitivity to percussion test, not eligible for restoration with a preformed metal crown.

Clinical procedure and study outcomes

The same investigator performed the procedures at the Aydin Adnan Menderes University Faculty of Dentistry Department of Pediatric Dentistry. The three second molars of each patient were randomly assigned, using a table of random numbers, either the group as follows: FS (Group FS, n=32), O-MTA (Group O-MTA, n=32) and R-MTA (Group R-MTA, n=32).

After administration of local anesthesia (Ultracain DS, Aventis Pharma, Istanbul, Turkiye), teeth were isolated with the rubber dam. Coronal access was obtained with a high speed bur mounted in an airator with water sprey following caries removal. The coronal pulp removal was performed by low speed instrument and continuous water spray. The cavity was then rinsed with steril serum and a wet cotton

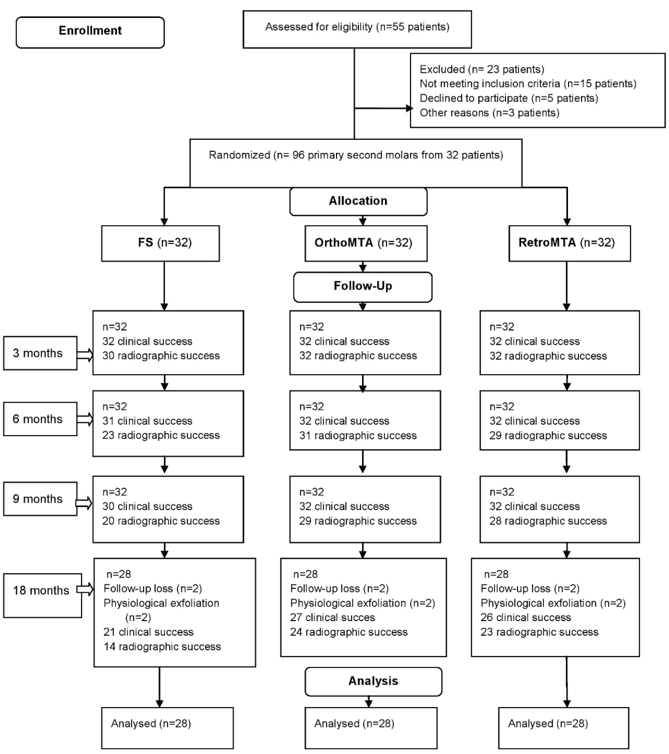

Figure 1. *The CONSORT flow chart of the patients and second primary molars included in this study.*

pellet was placed on pulp stumps for five minutes to achieve hemostasis. If bleeding didn't stop at this stage, the tooth was excluded from study. The teeth included the study were treated as described below depending on the type of pulpotomy agent.

Group Ferric Sulphate (FS)

A 15.5 % ferric sulphate moistened cotton pellet (ViscoStat, Ultradent, South Jordan, USA) was applied to the pulp stumps for 15 seconds. After irrigation, zinc oxide ogenol (Cavex ZoeCem, Cavex,Netherlands) base placed on radicular pulp stumps. The whole cavity was filled up with a glass ionomer cement (Ahfill, AHL, Tonbridge, UK). Final restoration was performed using preformed metal crowns (Kids crown, Shin Heung, Republic of Korea) at the same visit.

Group OrthoMTA (O-MTA) and RetroMTA (R-MTA)

OrthoMTA (OrthoMTA, BioMTA, Daejeon, Korea) and RetroMTA (RetroMTA, BioMTA, Daejeon, Korea) was prepared as recommended by their respective manufacturers' instructions and placed over the pulp stumps. The whole cavities were filled up with a glass ionomer cement. Preformed metal crowns were used for the restorations of pulpotomized teeth (Kids crown®, Shin Heung, Republic of Korea) at the same visit. The crowns were cemented with a glass ionomer based adhesive prepared according to the manufacturer's recommendations.

Follow-up

The teeth were examined clinically and radiographically at 3, 6, 9, and 18 months postoperatively. In case there was no spontaneous pain, pathologic mobility, swelling, fistula, and gingival inflammation such teeth were signed to case report form as clinical success. The postoperative radiographs were evaluated independently by two investigators. The presence of internal/external root resorption, periapical/furcal radiolucency and pulp canal obliteration was recorded as radiographic failure.

Statistical analysis

The data were evaluated using SPSS 20.0 (Statistical Package for the Social Sciences, Inc. Chicago, IL, USA) software. Inter-examiner agreement was calculated for the radiographic assessment using Cohen's Kappa test. Categorical data were analysed by Chi-square test and a multiple comparison post-test, with statistical significance set at $p<0.05$. Log-rank tests were conducted to compare the survival rate of the groups. Graphical representations of survival rates were produced for groups using the Kaplan-Meier method.

Results

A total of 96 teeth were pulpotomized in 32 children (16 girls and 16 boys) in the study. The mean age of the patients was 6.3±1.2 years. Flow chart of this study is presented in Figure 1. All teeth were evaluated without any drop-out at 3-, 6-, and 9-month follow-up periods; whereas, at the 18 month 12 molars could not be evaluated as a result of two patients drop-outs and physiologic exfoliation of molars in two patients. The kappa value was high (0.93) and showed strong inter-examiner agreement.

Clinical findings

After 6 months of follow up, one clinical failure had occured in FS group presenting a fistula. Two molars from FS group showed fistula at the 9-month follow-up. Clinical failure was not observed in O-MTA and R-MTA group during 9-month follow-up period. There were no statistically significant differences between the clinical success rates of the groups in 3, 6, and 9- month follow-up period (Table 2).

After 18-month follow-up period 7, 1 and 2 molars showed clinical failure in FS, O-MTA and R-MTA groups respective-

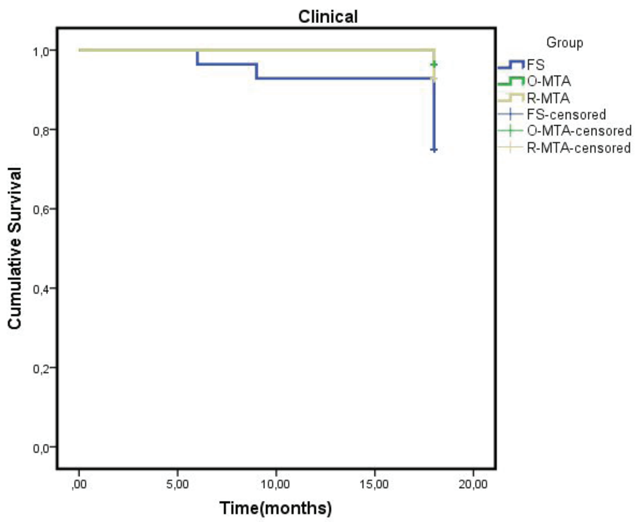

***Figure 2.** Clinical cumulative survival analysis of the groups.*

Table 1. *Clinical success and failure rates for ferric sulphate, OrthoMTA and retroMTA at 3-, 6-, 9-, and 18-month follow-up periods.*

	3 months		6 months		9 months		18 months	
	(+) n (%)	(-) n (%)	(+) n (%)	(-) n (%)	(+) n (%)	(-) n (%)	(+) n (%)	(-) n (%)
FS	32(100)[a]	0(0)	31(96.9)[a]	1(3.1)	30(93.7)[a]	2(6.3)	21(75)[a]	7(25)
O-MTA	32(100)[a]	0(0)	32(100)[a]	0(0)	32(100)[a]	0(0)	27(96.4)[b]	1(0)
R-MTA	32(100)[a]	0(0)	32(100)[a]	0(0)	32(100)[a]	0(0)	26(92.8)[b]	2(7.2)
p value	-		**0.36**		**0.13**		**0.03**	

*(+) = Success, (-) = Failure, *p<0.05=Statistically significant. Different superscript letters mean significant differences between groups at 3-, 6-, 9- and 18-month follow-up periods.*

ly. Four teeth from FS group, one tooth from O-MTA group and one tooth from R-MTA group showed gingival inflammation. 3 teeth from FS group and one tooth from R-MTA group showed fistula formation. The clinical success rates of the groups were 75%, 96.4%, and 92.8% for FS, O-MTA and R-MTA groups, respectively. The differences between the clinical success rates of the groups were statistically significant at the end of 18-month follow-up time (p<0.05) (Table 2). There were significant differences in 18-month clinical survival probabilities of the groups (p<0.05) [Log-rank (Mantel-Cox): x^2=7.30; df=2; p=0.02] (Figure 2).

Radiographic findings

The radiographic success rates were 50%, 85.8 % and 82.2% for the FS, O-MTA and R-MTA groups respectively at the end of 18-month follow-up time. There were statistically significant differences between the radiographic success rates of the groups at 6, 9 and 18 month follow-up periods (p<0.05) (Table 2). In FS group root resorptions were observed in two teeth at 3-month follow-up time. At 6-month follow-up time two additional teeth had root resorptions, five teeth had periapical or furcal radiolucency and four teeth had root resorptions. At 9-month follow-up two additional teeth had root resorptions, one additional tooth had periapical or furcal radiolucency. At 18-month follow-up one additional tooth had periapical or furcal radiolucency (Table 3). In O-MTA group there was pulp canal obliteration in one tooth at 6-month follow-up. At 9-month follow-up one additional tooth had pulp canal obliteration and, one tooth had periapical or furcal radiolucency. At 18-month follow-up one additional tooth had periapical or furcal radiolucency (Table 3). In R-MTA group, one tooth had root resorption, one tooth had furcation radiolucency and one tooth had widening of periodontal ligament at 6-month follow-up period. At 9-month follow-up one tooth had pulp canal obliteration. At 18-month follow-up one additional tooth had pulp canal obliteration (Table 3). There were significant differences in 18-months radiographic survival probabilities of the groups (p<0.05) [Log-rank (Mantel-Cox): x^2=20.3; df=2; p=0.001] (Figure 3).

Discussion

This randomized controlled clinical trial aimed to evaluate the clinical and radiographic success rates of two different mineral trioxide aggregate (MTA) materials, OrthoMTA and RetroMTA, as well as ferric sulfate (FS) in primary second

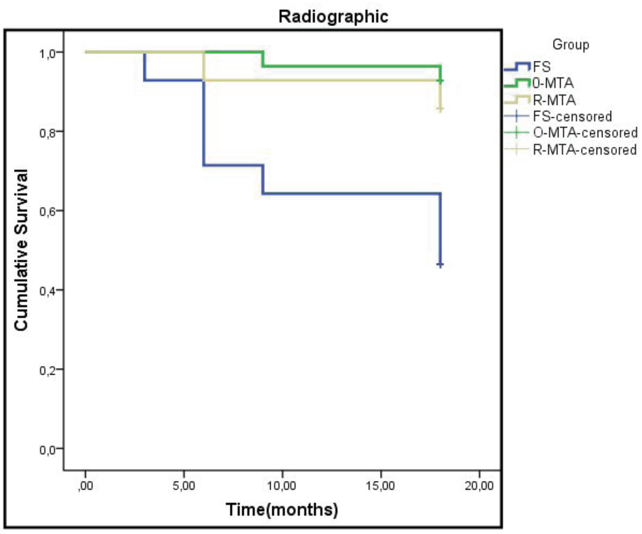

Figure 3. *Radiographic cumulative survival analysis of the groups.*

Table 2. *Radiographic success and failure rates for ferric sulphate, OrthoMTA and RetroMTA pulpotomies at 3-, 6-, 9-, and 18-month follow-up periods.*

	3 months		6 months		9 months		18 months	
	(+) n(%)	(+) n(%)	(+) n(%)	(+) n(%)	(+) n(%)	(+) n(%)	(+) n(%)	(+) n(%)
FS	30(93.7)[a]	2(6.3)	23(71.9)[a]	9(18.1)[a]	20(62.5)[a]	12(37.5)	14(50)[a]	14(50)
O-MTA	32(100)[a]	0(0)	31(96.9)[b]	1(3.1)[b]	29(90.6)[b]	3(9.4)	24(85.8)[b]	4(14.2)
R-MTA	32(100)[a]	0(0)	29(90.6)[b]	3(9.4)[b]	28(87.5)[b]	4(12.5)	23(82.2)[b]	5(17.8)
p value	0,13		**0,02***		**0,00***		**0.002***	

*(+) = Success, (-) = Failure, *p<0.05=Statistically significant. Different superscript letters mean significant differences between groups at 3-, 6-, 9- and 18-months follow-up periods.*

Table 3. *Distribution of the radiographic changes of the groups at 3, 6, 9 and 18 month follow-up periods.*

Groups	FS					O-MTA					R-MTA				
Month	**3**	**6**	**9**	**18**	**Total**	**3**	**6**	**9**	**18**	**Total**	**3**	**6**	**9**	**18**	**Total**
PR or FR	0	5	1	1	7	0	0	1	1	2	0	1	0	0	1
RR	2	2	2	0	6	0	0	0	0	0	0	1	0	0	1
WPL	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
PCO	0	0	0	1	1	0	1	1	0	2	0	0	1	1	2

Abbreviations: PR or FR, periapical radiolucency or furcal radiolucency; RR, root resorption;WPL, widening of periodontal ligament; PCO, pulp canal obliteration.

molars over an 18-month follow-up period. The study findings demonstrated that OrthoMTA and RetroMTA exhibited significantly higher clinical and radiographic success rates compared to FS. FS is commonly used as a hemostatic agent in pulpotomy treatment for primary molars to prevent clot formation, which is known to contribute to treatment failure (16,17). Previous studies have reported that the most common radiographic failure associated with FS is internal root resorption (18,19). The presence of internal resorption is believed to be caused by the irritant effect of zinc oxide eugenol, a base material used with FS, which can trigger chronic inflammation (20,21). Insufficient hemorrhage control, pulpal inflammation, bacterial infiltration, and failed restorations have also been identified as contributing factors to internal resorption (21).

Numerous studies have evaluated the clinical and radiographic success rates of MTA and FS. For example, Peng *et al.* (22) reported clinical success rates for FS ranging from 78% to 100% and radiographic success rates ranging from 42% to 97%. Cordell *et al.* (23) demonstrated an 86.6% clinical success rate for FS, while MTA achieved 100% clinical success. Junqueira *et al.* (24) observed 100% clinical success rates for both MTA and FS pulpotomies at the end of an 18-month follow-up period. In a study by Goyal *et al.* (15), clinical failures in the FS group at the six-month mark included fistula formation in 9.1% of cases and tooth mobility in 27.3% of cases. Similarly, fistula formation was observed in the FS group at the six- and nine-month follow-ups in the present study, with additional cases noted at the nine- and 18-month marks. During the nine-month follow-up period, both the OrthoMTA and RetroMTA groups showed no clinical failures, consistent with existing literature (25-27). However, at the 18-month follow-up, one case of gingival inflammation was observed in each MTA group, while two cases of fistula formation were noted in the RetroMTA group. The clinical success rates at the 18-month follow-up period were 75% for FS, 96.4% for OrthoMTA, and 92.8% for RetroMTA. The similar clinical success rates between the two MTA materials in this study may be attributed to their comparable antibacterial activity against endodontic bacteria (28). The lower success rate observed in the FS group in this study could be related to misdiagnosis of the pulp status, presence of radicular pulp infection, or irritation caused by the zinc oxide eugenol cement used as a base material in the FS group (29).

Studies have reported radiographic success rates of MTA ranging from 94% to 100% over follow-up periods ranging from 12 to 74 months (30). Olatosi *et al.* (26) found a radiographic success rate of 96% for MTA at the 12-month follow-up. Godhi *et al.* (31) followed MTA pulpotomies for 36 months and reported a 100% radiographic success rate. Kang *et al.* (11) evaluated the radiographic success of pulpotomies using ProRoot MTA, OrthoMTA, and RetroMTA in 143 children and reported success rates of 100%, 94.7%, and 94.7% respectively at the 12-month follow-up. Kim *et al.* (32) reported similar success rates for RetroMTA, OrthoMTA, and ProRoot MTA over an 84-month period. Lin and Lin (33) found that the radiographic success rate of FS was lower than that of MTA and NaOCl at the 24-month follow-up. Cordell *et al*. (23) stated that FS had a radiographic success rate of 60%, while MTA showed a 100% radiographic success rate at the 12-month follow-up.

In the present study, when evaluating the radiographic success of pulpotomy materials at the end of 18 months, the success rates were 50% for FS, 92.9% for O-MTA, and 89.3% for R-MTA groups. The lower success rates observed in this study, compared to previous studies, may be mainly due to the assessment criteria used in this study, where pulp canal obliteration was considered a failure. Pulp canal obliteration is a commonly observed radiographic finding in MTA pulpotomies. There are different opinions in the literature regarding the evaluation of pulpal canal obliteration (calcific metamorphosis). Some studies have reported that pulp canal obliteration occurs as a result of odontoblastic activity and is considered a sign of pulp vitality, therefore not indicative of failure (34,35). Waterhouse *et al.* (36) histologically evaluated pulpotomized and extracted primary molars due to clinical failure and found intracanal calcifications in the extracted teeth. Hence, in the present study, pulp canal obliteration was considered a failure. Farsi *et al.* (35) reported an obliteration rate of 5.4% in MTA pulpotomies at the 24-month follow-up. Kusum *et al.* (27) reported pulp canal calcification in 20% of cases after nine months of follow-up. In our study, pulp canal obliteration was observed in one tooth in the FS group, two in the O-MTA group, and two in the R-MTA group at the 18-month follow-up.

Studies have shown that internal root resorption occurs as a result of chronic pulpitis and is commonly found in teeth with necrotic pulp (37). However, there is no consensus in the literature regarding the inclusion of internal resorption as a failure criterion in the radiographic evaluation of pulpotomy therapy. For example, Holan *et al.* (38) did not consider internal resorption as a failure criterion, while other studies have included it (20, 39, 40). In line with the literature, this study considered internal resorption as a radiographic failure criterion. The frequency of internal resorption was higher in the FS group compared to the MTA groups. Despite the absence of clinical symptoms in teeth with internal resorption, they were monitored throughout the study. Additionally, periapical radiolucency or furcation radiolucency was more common in the FS group. It is important to note that this study had limitations, including a small sample size and a short follow-up period.

Conclusion

Within the limitations of this prospective trial, it can be stated that orthoMTA and retroMTA materials used in this study are more likely to demonstrate superior outcomes in terms of clinical and radiographic evaluations compared to FS at the 18-month follow-up period.

Türkçe özet: *Süt azı dişlerinde pulpotomi ajanı olarak OrthoMTA, RetroMTA ve Ferrik sülfatın etkinliği: Randomize klinik çalışma. Amaç: Bu çalışmanın amacı, süt azı dişi pulpotomilerinde OrthoMTA, RetroMTA, ve Ferrik sülfatın klinik ve radyografik başarı oranlarının değerlendirilmesidir. Gereç ve Yöntem: Çalışma için 5-9 yaş arası 32 çocuğun 96 adet süt ikinci azı dişi seçildi. Dişler pulpotomi materyaline göre rastgele üç eşit gruba ayrıldı: O-MTA, R-MTA ve FS. Klinik ve radyografik takip muayeneleri operasyon sonrası 3, 6, 9 ve 18. aylarda yapıldı. Bulgular: Çalışma süresinin sonunda toplam 84 diş değerlendirildi. Bu çalışmada klinik başarı oranı FS, O-MTA ve R-MTA grupları için sırasıyla %75, %96,4 ve %92,8 olarak belirlenmiştir. Takip süresinin sonunda, FS, O-MTA, R-MTA grupları sırasıyla %50, %85,8 ve %82,2 radyografik başarı göster-*

miştir. Ki-kare testi ve Kaplan-Meier sağkalım analizine göre grupların başarı oranları ve sağkalım olasılıkları arasında istatistiksel olarak anlamlı fark bulunmuştur (p<0.05). Sonuç: OrthoMTA ve RetroMTA onsekiz aylık takip süresinin sonunda, süt azı dişlerinin pulpotomilerinde klinik ve radyografik olarak ferrik sülfattan daha başarılı bulunmuştur.
Anahtar Kelimeler: Pulpotomi, süt dişi, ferrik sülfat, mineral trioksit agregat, çinko oksit öjenol siman

Ethics Committee Approval: This randomized controlled clinical trial was reviewed and approved by the Ethics Committee of Aydin Adnan Menderes University Faculty of Dentistry (Approval reference:2018/047).

Informed Consent: Parents provided written informed consent.

Peer-review: Externally peer-reviewed.

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Original research

The effects of dental adhesives total etch; self-etch and selective etch application procedures on microleakage in class II composite restorations

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Purpose

The aim of this study is to evaluate the amount of microleakage resulting from the application of self-etch, selective etch, etch-and-rinse of adhesive systems in class II cavities.

Materials and Methods

Four adhesive systems with etch-and-rinse, selective etch and self etch methods were used on the extracted teeth. All groups were restored with G-aenial A'CHORD (Nanohybrid) (GC, Tokyo, Japan) A2 composite. After 1000 thermal cycles were applied to the teeth after restoration, the samples were kept in 0.5% basic fuchsin for 24 hours. Microleakage values formed after dye penetration with basic fuchsin were determined quantitatively by scoring method on sections taken from each sample in the mesiodistal direction. One-way Analysis of Variance (ANOVA) and Tukey test were used for statistical analysis of the data ($p<0.05$).

Results

While there was no statistically significant difference between the etch-and-rinse and selective etch applications of adhesive systems (G2-Bond Universal, Clearfil Tri-S Bond Universal Prime&Bond Universal and Tokuyama Bond Force II) ($p>0.05$), there was a statistically significant difference in self-etch application ($p<0.05$). As a result of Prime&Bond Universal's self-etch application, it showed statistically more microleakage than the other three adhesive systems ($p<0.05$).

Conclusion

It has been observed that additional etching of enamel and/or dentin with phosphoric acid reduces the amount of microleakage.

Keywords: *Adhesion, multimodal adhesive systems, etch-and-rinse adhesives, self-etch adhesives, selective etch*

Introduction

Due to advancements in adhesive dentistry (1,2), the principle of "Expand to Protect" has been supplanted with the principle of "Minimally Invasive Treatment". The development and regular use of adhesive materials has started to revolutionize many areas of restorative and preventive dentistry. Preparations for mechanical retention of the cavity, which were once necessary through features such as dovetail, groove, undercut, and sharp interior angles to ensure the retention of the filling, are now eliminated (3). As a result, attitudes towards cavity preparation are changing.

Aesthetic restorative materials that are considered ideal should have a smooth surface, maintain color stability, not cause any toxic reactions in the pulp, adhere well to enamel and dentin, and exhibit no microleakage (4). Insufficient marginal adaptation and loss of retention leading to

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microleakage are among the most commonly reported factors causing the failure of adhesive restorations (5). Therefore, in modern dentistry, where adhesives are critical to the success of restorative aesthetic materials, numerous dental adhesives have been developed to achieve adequate bond strengths in enamel and dentin (6,7).

Dental adhesives currently used can be classified into three-stage etch-and-rinse, two-stage etch-and-rinse, two-stage self-etch, and one-stage self-etch adhesive systems. In etch-and-rinse systems, the smear layer is eliminated using orthophosphoric acid at a concentration of 30-40%, which exposes collagens. Subsequently, the applied resin infiltrates the dentinal tubules and intercalates between the collagen fibers, resulting in the formation of a foundation for the hybrid layer upon polymerization (8). Self-etch adhesives incorporate acidic monomers that can demineralize and penetrate dentin without the need for washing. They also modify the smear layer and incorporate it into the hybrid layer (9). However, the bonding efficacy of self-etch adhesives to enamel is still uncertain (10). Therefore, to resolve this issue, it is recommended to roughen the enamel edges of the cavity with orthophosphoric acid before the application of moderately self-etch adhesives (11). To provide clinical ease of use, adhesives known as 'Universal' or 'Multimod' have been developed, which can be used both as self-etch and etch-and-rinse.

Our study aims to assess the impact of total etch, self-etch, and selective etch application techniques using universal adhesives, which are considered novel materials in dentistry, on microleakage observed in class II composite restorations. The null hypothesis of our study is that the application of universal adhesives using total etch, self-etch, and selective etch techniques will not have any effect on the microleakage observed in class II composite restorations.

Materials and Methods

Ethical approval

This study was initiated with the approval of the ethics committee (2021/117).

Sample size estimation

The sample size required for the study was calculated as β=0.80, α=0.05 with the G*Power 3.1 program, and the effect size was determined as 0.40 based on previously published data. The analysis of variance (ANOVA) test was targeted first and a total of 120 sample (n=10) in each group was considered. An additional 10% for non-parametric tests and 10% for cases that could be excluded from the study were also included.

Sample collection and storage

A total of 60 molars selected from caries and non-restorative extracted teeth were used. Care was taken to avoid cracks, hypoplasia or caries among the selected teeth, and these teeth were not included in the study. Extracted teeth were stored in a 0.1% thymol solution at +4 ^{0}C until they were to be used for the study for a maximum of 3 months.

Sample preparation

The tartar and soft tissues were removed from the teeth with a sharp hand tool. Using a cylindrical diamond bur (FG Diamond Burs ISO 110/018, Ra'anana, Israel) and a high-speed rotating water-cooled rotary tool, 60 teeth were prepared, with each tooth's mesial and distal surfaces prepared at the cementum boundary, and two box cavities in the enamel, for a total of 120 cavities (12). The burs were changed every 10 cavities. The mesiodistal width of each cavity was prepared to be 1/3 of the mesiodistal width of the tooth, while the buccolingual width was prepared to be 1/3 of the intercuspal distance. After the preparations were completed, metal matrix bands (PratiCap Matrix no 01063, İDA Dental Product, Turkey) were placed on the samples to reconstruct the lost proximal walls. The samples were then divided into 12 groups, each consisting of five specimens, with 10 box cavities from each group (n=10) (Table 1). Adhesive systems were applied according to the instructions of their manufacturers, using selective etch,

Table 1. *Names, contents and manufacturers of the adhesive systems used in our study.*

Product Name	Manufacturer	Composition	Lot Numbers
G2-Bond Universal	GC Corp., Tokyo, Japan	Primer: 4-MET, MDP ,MDTP , Dimethacrylates, Water, Acetone, Photoinitiators, Fillers Bonding: Bis-GMA, Dimethacrylates, Fillers Photo starters pH=1,5	2011051
Clearfil Tri-S Bond Universal	Kuraray Noritake, Niigata, Japan	MDP, Bis-GMA, HEMA, Hydrophilic Aliphatic dimethacrylate, Colloidal silica, Silane coupling agent Al-camphorquinone, Ethanol, Water pH=2,3	000058
Prime Bond Universal	Dentsply Sirona Pennsylvania, USA	PENTA, 10-MDP, Bis-GMA, UDMA, TEGDMA, Isopropanol, Acetone, Water pH=2,5	210500422
Tokuyama Bond Force II	Tokuyama Dental, Tokyo, Japan	Phosphoric acid, monomer, (new 3D-SR monomer), HEMA, Bis-GMA, TEGDMA, Alcohol, Camphorquinon e, Water pH=2,8	143E41

self-etch, or etch-and-rinse methods based on the group they belonged to. All cavities were restored with the universal composite G-aenial A'CHORD (color A2) using the oblique layering technique, and each composite layer was polymerized with a light device for 20 s in accordance with the manufacturers' recommendations. The LED light source (Woodpecker Led-E Plus) with a wavelength of 420-480 nm and a light power of 850- 1000mW / cm2 was used for polymerization. Finally, all restorations were polished with the Polishing Kit (Super-Snap Rainbo Technique Kit, Shofu, Japan).

Etch-and-rinse application

Enamel and dentin were treated with 35% orthophosphoric acid for 15 seconds. For 15 seconds, the acid-coated tooth surface was rinsed. Excess water was removed with a damp cotton pellet. Adhesive systems were applied in accordance with the manufacturer's instructions.

Selective etch application

Enamel was treated with 35% orthophosphoric acid for 15 seconds. For 15 seconds, the acid-coated tooth surface was rinsed. Excess water was removed with a damp cotton pellet. Adhesive systems were applied in accordance with the manufacturer's instructions.

Self-etch application

Adhesive systems were applied directly without orthophosphoric acid gel application in accordance with the manufacturer's instructions.

Table 2. *Microleakage scores and levels.*

Score	Microleak Level
0	No dye penetration
1	Less than half of the gingival wall has dye penetration.
2	There is dye penetration along the gingival wall.
3	There is paint penetration along the gingival wall and less than half of the axial wall.
4	There is paint penetration along the gingiva and axial wall.

Microleakage test

The dye penetration test was used to determine the amount of microleakage. Before the test, the samples were kept at a temperature range of 5-55±20C for 15 seconds with a transfer time of 10 seconds. A thermal cycle was applied 1000 times using the SD Mechatronic Thermocycler device. After the thermal cycle process, the apexes of the specimens were covered with boxing wax to prevent the transfer of paint from the areas outside the restoration. In addition, the areas outside the 1 mm area around the restorations were covered with three layers of nail varnish (Flormar, Turkey). The samples were then kept in 0.5% basic fuchsin for 24 hours and rinsed thoroughly with water before being implanted in blocks of polymerized acrylic resin.

After autopolymerization, sections were taken from each sample in the mesiodistal direction using a precision cutting device (IsoMet® 1000 Precision Sectioning Saw) under water cooling and 250 rpm. To evaluate the leakage amounts, photographs were taken from each section at 1/100 magnification using a stereomicroscope (Leica, Wetzlar, Germany) and a camera (D-Lux 3, Leica, Germany) for each sample. The amount of microleakage was then evaluated using a scoring method depicted in Table 2.

Statistical analysis

The dataset was analyzed with SPSS software version 22 (Statistical Package for Social Sciences, IBM SPSS, Armonk, NY, USA). The normality assumptions were checked with Shapiro-Wilk test. As the data distibuted normally, one way-ANOVA test was used for multiple comparisons followed by the post-hoc test Tukey's HSD for pairwise comparisons. The confidence interval was set to 95% and p values less than 0.05 was considered significant.

Results

Table 3 shows the leakage values obtained by using microleakage scoring for a total of 120 cavities prepared in our study. When we examined the findings of our study, we did not find any statistically significant difference between the selective etch, self-etch, and etch-and-rinse applications of G2-Bond Universal, which is one of the adhesive systems. However, we did find a statistically significant difference be-

Table 3. *Comparison of the mean (Average) and standard deviations (SD) of the microleakage amounts of the application methods according to the material used in permanent teeth.*

	Selective Etch	Self-Etch	Etch-And-Rinse	
	Mean ± SD	Mean ± SD	Mean ± SD	p
G2-Bond Universal	1,07 ±0,70^{a,A}	1,13 ±0,92 ^{a,A}	0,80 ±0,76 ^{a,A}	0,332
Clearfil Tri-S Bond Universal	1,60 ±1,06 ^{a,A}	2,13 ±0,64 ^{a,BC}	1,07 ±0,80 ^{b,A}	0,000
Prime&Bond Universal	1,40 ±0,99 ^{a,A}	2,47 ±0,74 ^{b,C}	1,27 ±0,96 ^{a,A}	0,000
Tokuyama Bond Force II	1,07 ±0,70 ^{a,A}	1,40 ±1,24 ^{a,AB}	1,20 ±0,68 ^{a,A}	0,332
P	0,322	0,000	0,332	

** A-C shows comparisons between rows, a-b shows comparisons between columns, p<0.05 was considered statistically significant. Oneway Analysis, posthoc Tukey test.*

tween the selective etch, self-etch, and etch-and-rinse applications of Clearfil Tri-S Bond Universal, which is also one of the adhesive systems (p<0.05). Among the adhesive systems used, there was no statistically significant difference between the selective etch and etch-and-rinse applications of Prime Bond Universal, but the self-etch application showed the most microleakage statistically (p<0.05). Finally, we did not find any statistically significant difference between the selective etch, self-etch, and etch-and-rinse applications of Tokuyama Bond Force II (see Figure 1 for details).

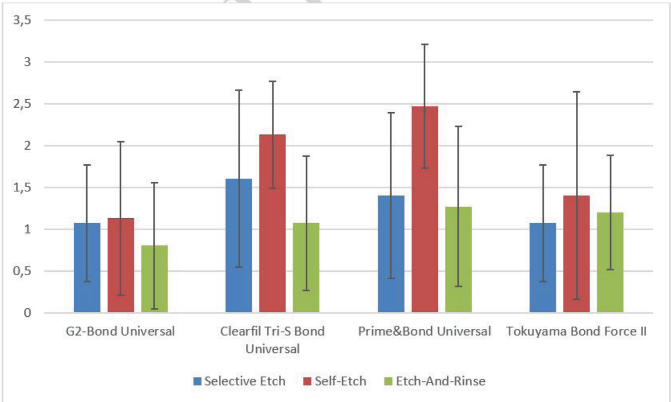

Figure 1. *Microleakage amounts of the application methods of the universal adhesives used are compared in the graphic.*

Discussion

In the identification of microleakage, in vitro investigations are preferred over in vivo research. Although extraoral tests do not completely replicate the oral environment, they are still necessary for the development of restorative materials, as noted by Watanabe *et al.* (13). It has been reported that in vitro studies with good standardization yield results similar to in vivo studies. In this study, we evaluated the microleakage of universal adhesives, which can be considered new among dental materials, on permanent teeth using different application methods (self-etch, selective etch, etch-and-rinse) in vitro.

In a study that examined the depth of polymerization of composite resins with different colors, it was reported that the color and opacity of the composite affected the depth of polymerization (14). Therefore, in our study, all restorations were made with G-aenial A'CHORD brand and A2 color composite.

To minimize the polymerization shrinkage that occurs during the polymerization of composite resins, it has been suggested that the composite layers applied to the cavity should not exceed 2 mm, and the light source should be positioned as close as possible to the surface to be polymerized (15). In our study, we took care to apply the composite layers within 2 mm and to position the light source as close as possible to the samples during polymerization.

Various methods are used in in vitro studies to simulate oral conditions (16). One of these methods is thermal cycling. In dental restoration studies that use thermal cycling, temperatures between 5-55°C are preferred, and a variation of ±5°C is considered normal (17). The holding times in cold and hot water tanks during the thermal cycling procedure can vary between 10, 15, 30, 60, and 120 seconds (18). Although there is no consensus in the literature on the transfer and holding times and the number of cycles used in thermal cycling, it is believed that shorter holding times are more effective in mimicking the intraoral environment (19). While the number of cycles used in microleakage studies varies in the literature, Crim *et al*. and Gale *et al*. reported that the number and duration of cycles did not affect microleakage (20,21). In our study, we applied 1000 cycles of thermal cycling with a waiting time of 15 seconds and a transfer time of 10 seconds at temperatures between 5-55±2 °C.

The dye penetration method is the most frequently used method for detecting microleakage. This method is preferred because it does not damage the dental tissue-restorative material interface, is easy to detect under visible light, provides fast and direct measurement, does not interact with dental hard tissues, is inexpensive, and is non-toxic (22,23). In our study, we used the dye penetration method with 0.5% basic fuchsin solution, which is an easy and widely used method. Although soaking time of the samples in the dye varies between 1 hour and 72 hours, it has been reported that it does not affect microleakage studies. In our study, the samples were kept in the dye solution for 24 hours.

As a result of various studies, it has been reported that at least three sections should be taken from each sample in order to reach true microleakage values (24). In our study, in order to increase the reliability of the measurements, each tooth was examined from 4 surfaces and the average of these measurements was taken to reach the microleakage score for that tooth.

The most frequently used method to evaluate microleakage after the dye penetration method is the scoring method, which is preferred due to its ease of application and low cost (25). However, this method is subjective, and either more than one observer needs to evaluate the samples and calibrate themselves or the same researcher needs to repeat the scoring twice to eliminate any optical illusions (26). In our study, the scores were repeated twice. In our study, stereomicroscopy was used to determine the scores, similar to most of the previous ones (27,28). The cut samples were photographed using a stereomicroscope, and scores were given between 0 and 4 in accordance with the literature (29,30).

A previous study reported that microleakage is more intense at the edges of the samples, and the sections taken from these regions can affect the results of the study (31). Therefore, in our study, the samples were cut in the middle of the mesiodistal direction (27) to avoid this issue. The reason for the different microleakage scores observed in the literature depending on the application of adhesive systems is attributed to the type of monomer and solvent contained in the adhesive system, the way the adhesive system is applied, its sensitivity to dentin moisture, and the pH of the adhesive system (32). Adhesives with a pH exceeding 2.5, also known as "ultra-light self-etch adhesives," do not penetrate the dentin deeply enough. Ultra-light and lightweight self-etch adhesives create minimal porosity on the enamel surface, which may result in the absence of resin tags between the prisms (33). The adhesive systems used in our study were Prime&Bond Universal with a pH of 2.5, Tokuyama Bond Force II with a pH of 2.8, Clearfil Tri-S Bond Universal with a pH of 2.3, and G2-Bond Universal with a pH of 1.5. This may explain why Prime&Bond Universal and Clearfil Tri-S Bond Universal showed more microleakage in self-etch application, while G2-Bond Universal had a moderately acidic primer (pH=1.5) and strong chemical bonding, which led to less microleakage in self-etch application.

In their study comparing the microleakage values of four different adhesive systems (Optibond Solo Plus, Optibond XTR, Optibond All-in-one, Fuji Bond LC), Sadeghi *et al*. (34) reported that the two-stage Optibond XTR applied in self-etch mode had lower microleakage levels than the other single-stage groups. Our study supports these findings, and the reason for G2-Bond Universal showing less microleakage can be attributed to its medium-strong acidic primer (pH=1.5), strong chemical bonding, and two-stage application.

Many universal adhesives contain the monofunctional monomer HEMA to increase wetting of the hydrophilic dentin surface (35) and water to provide self-etch bonding potential (35). Bonding to dentin is more challenging than to enamel because it is a moist tissue. Adhesives are hydrophilic to match moist dentin but become hydrophobic after polymerization (36), and they must maintain a balance between these hydrophilic and hydrophobic characteristics (36). Prime&Bond Universal does not contain HEMA but contains isopropanol as a co-solvent. This chemical ingredient may affect the bond strength of Prime&Bond Universal. The higher bond strength of Prime&Bond Universal may also be related to the fact that it contains isopropanol as an additional solvent, as noted in a previous study (35).

In their 2011 study, Takahashi *et al*. (37) examined the long-term values of water absorption and bond strength of single-stage self-etch adhesive systems with and without HEMA and found that water absorption increased and bond strength decreased over time for HEMA-containing adhesives (37). Our study also supports these findings, and we observed that the microleakage value of Clearfil Tri-S Bond Universal and Tokuyama Bond Force II, HEMA-containing single-stage self-etch adhesive systems, were higher than the HEMA-free two-stage self-etch adhesive G2-Bond Universal.

Takahashi *et al*. (38) evaluated the effectiveness of HEMA and 4-MET co-monomers in MDP-primed adhesive-dentin interfaces in terms of mechanical properties on a submicron scale, while increasing the diffusion of HEMA co-monomer found in MDP-based adhesives into the dentin tissue, reducing inelastic stiffness and adhesiveness. They reported that it reduces the retentive properties of the restorative material with significant viscoelastic deformity at the dentin interface. Additionally, 4-MET produces higher inelastic stiffness compared to HEMA and potential chemical interaction with MDP at the adhesive-dentin interface. Our findings suggest that the use of 4-MET co-monomer is probably a better complement to MDP-based dental adhesives. Therefore, our study supports the above-mentioned findings and explains why G2-Bond Universal contains 4-MET comonomer instead of HEMA and shows less microleakage in self-etch application compared to Clearfil Tri-S Bond Universal, which contains HEMA.

Solvents in adhesives can affect the moisture balance in dentin. Acetone-based systems remain on the surface as a thinner layer after evaporation than ethanol-based systems, resulting in more sensitive joint surfaces. A clinical study reported that after 36 months, an acetone-based adhesive system (One-Step, Bisco) showed lower retention rates than an ethanol-based adhesive system (Single Bond, 3M ESPE) (39). While Clearfil Tri-S Bond Universal used in our study is an ethanol-based adhesive, Prime Bond Universal is an acetone-based adhesive. Therefore, our study supports the above-mentioned findings and explains why Clearfil Tri-S Bond Universal shows less microleakage in self-etch application than Prime Bond Universal.

In their study, Oz *et al.* (40) found that the deterioration of the edge harmony and the edge coloration occurred in the self-etch groups at higher rates compared to the selective etch and etch-and-rinse methods. This is because the bond strength to the enamel with the self-etch application method is lower than that of the selective etch and etch-and-rinse methods (41). However, distortion of edge harmony and edge discoloration is at a level that can be easily removed by polishing, similar to previous studies (42). Lenzi *et al.* (43) restored decidous teeth by using Scotchbond Universal adhesive in self-etch and etch-and-rinse application forms after caries removal and reported that there was no significant difference between the application methods as a result of 18-month clinical follow-up. When the findings of our study are examined, in self-etch application, no statistically significant difference was found in terms of microleakage values in G2-Bond Universal and Tokuyama Bond Force II adhesive systems compared to selective etch and etch-and-rinse applications. However, G2-Bond Universal and Tokuyama Bond Force II showed more microleakage in self-etch application, although there was no statistically significant difference compared to selective etch and etch-and-rinse applications. In the Clearfil Tri-S Bond Universal adhesive system, self-etch application showed statistically significantly more microleakage than the etch-and-rinse application; however, self-etch application did not show a statistically significant difference compared to selective etch application. In Prime&Bond Universal adhesive system, self-etch application showed statistically significantly more microporous than selective etch and etch-and-rinse applications.

In vitro studies have shown that application of phosphoric acid to enamel increases the bond strength of universal adhesives (44). Phosphoric acid increases the infiltration of adhesive resin monomers into the enamel, thereby increasing micromechanical bonding (45). In in vitro studies, it has been reported that there is marginal deterioration of the enamel over time in the Clearfil SE Bond material, which is a two-stage self-etch material, and as a result of this deterioration, the bonding efficiency of the enamel decreases significantly and microleakage is increased (46,47,48,49). The increase in microleakage over time makes selective etch even more important in cases where marginal coverage is critical, such as pulp treatments. Although there are studies reporting that this deterioration in enamel is significantly reduced with selective etch application, some studies have reported that selective etch application does not make a difference (49,50,51,52). At the end of the 5-year evaluation in which they clinically compared the selective etch and self-etch application forms of an adhesive material (AdheSE, Ivoclar Vivadent), no difference was observed between the selective etch and self-etch groups in terms of retention. was found to be high (53). Perdigao *et al.*(54), in their clinical study, concluded that there was only a marginal adaptation difference in their clinical studies, in which they applied 3M Single Bond Universal in etch-and-rinse, self-etch, selective etch mode and followed them for 18 months. It has been stated that since 3M Single Bond Universal has a pH of 2.7, it cannot reach the effect of phosphoric acid on enamel, and therefore selective acidification of enamel is a prerequisite (55).

Souza-Junior *et al*. (52) reported that selective application of phosphoric acid to the enamel prior to the Clearfil Tri-s Plus Bond application increased marginal integrity. At the same time, these data overlap with studies suggesting that selective enamel etching with phosphoric acid increases the bond strength of the composite to enamel (48-50,56,57). Especially in single-stage self-etch adhesives, the application of the selective etch method significantly increases clinical success (58,59). In our study, acid etched applications (selective etch and etch-and-rinse) showed similar microleakage values with G2-Bond Universal and Tokuyama Bond Force II adhesive systems according to self-etch application; Prime&Bond Universal and Clearfil Tri-S Bond self-etch application showed greater microleakage value.

Conclusion

Within the limitations of the this *in-vitro* experiment, the study found that additional roughening of adhesive materials with phosphoric acid (selective etch and etch-and-rinse) reduces microleakage. Therefore, it may be preferred to roughen the enamel and/or dentin with phosphoric acid, as this results in low levels of microleakage. The applications of G-2 Bond Universal and Tokuyama Bond Force II using selective etch, self-etch, and etch-and-rinse methods did not statistically differ from each other. However, treatments of Clearfil Tri-S Bond Universal and Prime&Bond Universal using selective etching and etch-and-rinse methods differed significantly from each other. Based on the results of the study, Clearfil Tri-S Bond Universal exhibited the least tightness in Prime&Bond Universal etch-and-rinse application. Further research and long-term clinical follow-up studies can contribute to simplifying the application technique and achieving good adhesion in clinical success.

Türkçe özet: *Sınıf II kavitelerde adeziv sistemlerin self etch, selektif etch, etch and rinse uygulanması sonucunda oluşan mikrosızıntı miktarının incelenmesi. Amaç: Bu çalışmanın amacı, sınıf II kavitelerde adeziv sistemlerin self etch, selektif etch, etch and rinse uygulanması sonucunda oluşan mikrosızıntı miktarını değerlendirmektir. Gereç ve Yöntem: Çekilmiş 60 adet daimi diş rastgele olarak 12 gruba ayrılmış ve çalışmada kullanılan adeziv materyaller (G2-Bond Universal (GC Corp., Tokyo, Japan), Clearfil Tri-S Bond Universal (Kuraray Noritake, Niigata, Japan), Prime&Bond Universal (Dentsply Sirona Pennsylvania, USA), Tokuyama Bond Force II (Tokuyama Dental, Tokyo, Japan)) uygulandı. Tüm gruplar G-aenial A'CHORD (Nanohibrit) (GC, Tokyo, Japan) A2 kompozit ile restore edildi. Restorasyon sonrası dişlere 1000 kez termal siklus uygulandıktan sonra örnekler %0,5'lik bazik fuksin içerisinde 24 saat bekletildi. Bazik fuksin ile boya penetrasyonu sonrasında oluşan mikrosızıntı değerleri, her örnekten mesiodistal yönde alınan kesitler üzerinde skorlama yöntemiyle kantitatif olarak tespit edildi. Verilerin istatistiksel analizinde tek yönlü Varyans Analizi (ANOVA) ve Tukey testi kullanıldı (p<0.05). Bulgular: Adeziv sistemlerin (G2-Bond Universal, Clearfil Tri-S Bond Universal Prime and Bond Universal ve Tokuyama Bond Force II) etch and rinse ve selektif etch uygulamaları arasında istatiksel anlamlı farklılık bulunmazken (p>0.05), self etch uygulamada istatiksel olarak anlamlı farklılık görüldü (p<0.05). Prime and Bond Universal'in self etch uygulaması sonucunda diğer üç adeziv sisteme göre istatistiksel olarak daha fazla mikrosızıntı gösterdi (p<0,05). Sonuç: Mine ve/veya dentinde ek olarak fosforik asit ile pürüzlendirilmenin mikrosızıntı miktarını azalttığı görülmüş bundan dolayı test edilen adeziv materyallerin ek olarak fosforik asit ile pürüzlendirilmesinin klinik başarıyı arttırabileceği söylenebilir. Anahtar Kelimeler***:*** *Adezyon; multimod adeziv sistemler; etch and rinse adezivler; self etch adezivler; selektif etch*

Ethics Committee Approval: The study protocol has been reviewed and approved by the local ethics board (2021/117).

Informed Consent: Participants provided informed constent.

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Author contributions: MY, SK, EAO participated in designing the study. MY, SK, ETA participated in generating the data for the study. MY, SK, NA participated in gathering the data for the study. MY, SK, NA participated in the analysis of the data. MY, SK, BE wrote the majority of the original draft of the paper. MY, SK, ETA participated in writing the paper. MY, SK, EAO have had access to all of the raw data of the study. MY, SK have reviewed the pertinent raw data on which the results and conclusions of this study are based. MY, SK, ETA, EAO, NA, BE have approved the final version of this paper. MY, SK, ETA guarantee that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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Original research

Efficiency of ProTaper Universal Retreatment, Reciproc Blue and XP-endo Shaper in the removal of a bioceramic-based root canal filling

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Purpose
This *in vitro* study aimed to assess the performance of ProTaper Universal Retreatment (PTUR), Reciproc Blue (RB), and XP-endo Shaper (XPS) system in the removal of bioceramic root canal filling.

Materials and Methods
Forty-five human single-rooted mandibular premolars were prepared up to 30/.04 and filled with Endosequence BC sealer and BC points before being assigned into three groups (n=15). The root canal fillings were removed until reaching pre-determined working length (WL) with PTUR in group 1, RB in group 2, and XPS in group 3. During the removal of the filling material, apically extruded debris was collected in pre-weighed Eppendorf tubes, and operation time was recorded with a digital chronometer. Reaching the WL and maintaining apical patency were evaluated separately. The data were statistically analyzed using Kruskal Wallis and Mann Whitney U tests.

Results
The mean amount of extruded debris was highest in the PTUR group, although all instruments caused apical extrusion of debris. The mean time for reaching WL was longest for RB and shortest for XPS, with significant differences among the groups ($p<0.05$). Although the difference was not significant ($p=0.799$), in the PTUR group the WL was reached in 93.3% of the samples, which was higher than other groups (86.7%).

Conclusion
All tested systems caused a certain amount of debris extrusion. XPS was associated with less extrusion while regaining more rapid access to the periapical area than PTUR and RB.

Keywords: *Debris extrusion, endodontic retreatment, Endosequence BC sealer, Reciproc Blue, XP-endo Shaper*

Introduction

The non-surgical retreatment is the first option after failure of initial root canal treatment (1). Regaining access to the apical foramen by removing preexisting filling materials for facilitating re-cleaning and re-shaping is one of the main goals of retreatment (2). During endodontic retreatment, obturation materials, tissue remnants, microorganisms, and irrigation solutions might extrude from the apical foramen into the periradicular tissues (3). Debris extrusion may result in postoperative pain, flare-up, and delay in recovery (4, 5). In this sense, while removing the filling materials, using an appropriate instrumentation technique to reduce the amount of apically extruded debris would be advantageous in minimizing postop-

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erative reactions (3). Among various methods advocated for removing the filling materials, Ni-Ti instruments have proven to be effective and time-saving (6-8). However, previous *in vitro* studies have shown that almost all Ni-Ti instruments and techniques used for retreatment may cause debris extrusion to some degree (3, 9-12). The amount of extruded debris could be affected by the design, kinematics, and cutting efficiency of the endodontic instruments (13).

ProTaper Universal Retreatment (PTUR; Maillefer, Dentsply Sirona, Ballaigues, Switzerland) is a well-documented NiTi rotary system specially designed for root-filling removal. PTUR system consists of D1 (30/.09), D2 (25/.08), and D3 (20/.07) instruments with a convex cross-section, variable taper, and diameters at the tip. The active tip of the D1 instrument facilitates its initial penetration into the root canal filling (8). The effectiveness, safety, and rapidness of PTUR in retreatment cases have been demonstrated in previous studies (6, 8, 14). Recently, nickel-titanium (Ni-Ti) instruments with different designs, alloying processes, and kinematics have been introduced. Depending on the technological developments, apical extrusion studies have tended to focus on root canal preparation systems with different designs, alloys, and innovative manufacturing features such as surface treatment or phase change (15). The Reciproc Blue (RB; VDW GmbH, Munich, Germany) is a new-generation reciprocating single file system presenting a similar design to Reciproc with an S-shaped cross-section and two cutting edges (16, 17). However, it is manufactured from blue thermomechanical-treated alloy, making the file more flexible and resistant to fracture (17). Although RB was initially developed for primary root canal treatment, its use for retreatment has been promoted (9, 18). XP-endo Shaper (XPS; FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) is another single file system used with continuous rotation. XPS is a minimal tapered instrument with an apical diameter of 0.30 mm and an initial taper of 1%. Through MaxWire alloy technology (FKG Dentaire SA), XPS changes into an austenite phase at body temperature, assuming a snake shape that can reach up to 4% taper (19). It is suggested as an appropriate retreatment tool when used at higher speeds (3000 rpm) (20).

The literature revealed that the type of the obturation material has a direct impact on its re-treatability (14, 18, 21). Endosequence BC sealer (Brasseler, Savannah, GA, USA) is a bioceramic-based sealer with a superior bond strength to root canal dentin (22). A recent study has also revealed that Endosequence BC sealer provides better marginal adaptation and tubular penetration depth compared to epoxy resin sealer (23). Although there are several studies regarding the retreatment of these sealers with various Ni-Ti instruments, no study compared the amount of debris extrusion of Endosequence BC obturation material after removal with PTUR, RB, and XPS files (14, 18, 21). Therefore, the purpose of this *in vitro* study is to assess the performance of Ni-Ti files with different alloys (PTUR, RB, XPS) in the removal of a bioceramic-based root canal filling regarding debris extrusion, success in regaining access to the periapical area, and operation time. The null hypothesis was that there were no differences among the systems for all analyzed variables.

Materials and Methods

Ethical approval

This research was approved by the Research Ethics Committee of the İstanbul Okan University (2021/131).

Sample size estimation

The sample size for this study was calculated using G*Power 3.1 (*Heinrich-Heine-Universität* Düsseldorf, Germany) based on a previous study with an effect size of 0.5, power-beta of 0.80, and 0.05 alpha-type error (10). The minimum sample size for each group was determined as 14 teeth to observe differences among the groups. The sample size was adjusted to 45 teeth (3 groups, n=15) by considering the possible losses.

Sample selection

Forty-five human single-rooted mandibular premolars extracted for periodontal reasons with mature apices and straight roots (less than 10°) were selected. The root canal morphologies were verified by viewing radiographs from buccolingual and mesiodistal directions. The degree of curvature was calculated according to the Schneider method (24). The teeth were examined under x40 magnification by an operating microscope (Leica M320; Leica Microsystems, Wetzlar, Germany). Only teeth with a single root canal and a single foramen were included. The teeth having cracks, previous root canal treatments, internal or external resorptions, root caries, more than one canal, and calcifications were excluded.

Sample preparation

Under the operating microscope, the working length (WL) was established as 1 mm shorter than the length where the tip of the #10 K-file (Maillefer, Dentslpy Sirona) appears at the apical foramen. To standardize the WL at 16 mm, the crowns of the teeth were separated using a diamond disk. The root canals were prepared up to 30/.04 (Endosequence; Brasseler, Germany) and were irrigated with 2 mL of 5.25% NaOCl (Cerkamed, Stalowa Wola, Poland) between each file using a 30 gauge side-vented needle (NOP Dental Needles, Spident, Korea). Apical patency was checked with #10 K-file during the root canal preparation. 5.25% NaOCl and 17% EDTA (Cerkamed) were used as the final irrigant. The root canals were filled with Endosequence BC sealer and 30/.04 BC points (Brasseler, Germany) using a single-cone technique. The quality of the obturation was confirmed by digital radiographs taken from the buccal and proximal directions. The samples were stored in an incubator (EN120, Nüve, Ankara, Türkiye) at 37°C in 100% humidity for 30 days.

A modification of the experimental design described by Myers & Montgomery (25) was used to collect the apically extruded debris and the irrigant. The Eppendorf tubes (2 mL) were labeled for each sample and weighed empty using an electronic balance (ATX 224, Shimadzu Co., Kyoto, Japan) with an accuracy of 10^{-4}. The measurements were repeated three times for each Eppendorf tube, and the average values were taken. Round holes were punched on the plastic caps of the Eppendorf tubes. The roots were inserted into these holes up to the cementoenamel junction and fixed with cyanoacrylate (Zapit, DVA Inc., Corona, CA, USA) (Fig 1a). A 27-gauge open-ended needle was immersed in each plastic cap to balance external and internal pressures. Then, setups were mounted into glass vials (Fig 1b).

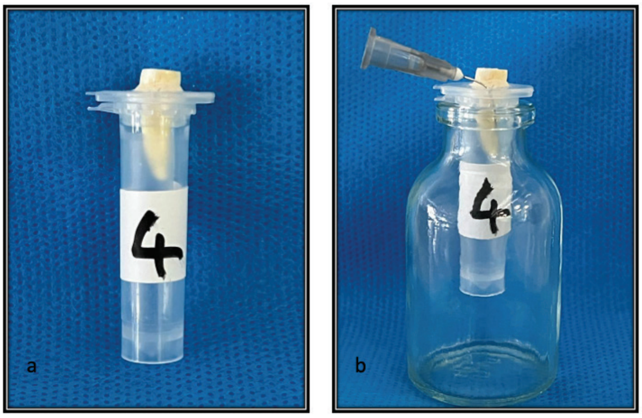

Figure 1. *The representative experimental setup. a) The root canals fixed to Eppendorf tubes b) The setup mounted into a glass vial.*

Removal of the filling material

The teeth were randomly divided into three groups (n=15):

Group 1: The root canal fillings were removed using Protaper Universal Retreatment files D1 for the coronal third, D2 for the middle third, and D3 until the WL was achieved. The instruments were operated with a X-Smart Plus endomotor (Maillefer, Dentsply Sirona), at a speed of 250 rpm with 2 Ncm torque for D1 and D2; 1.5 Ncm for D3 files. The instruments were used in a crown-down manner with a brushing action and lateral pressing movements.

Group 2: The gutta-percha in the coronal thirds (3 mm) were removed using a no. 2 Gates Glidden drill (Mani Inc., Tochigi, Japan) (18). Then, the rest of the root canal filling was removed with RB files (25/.08) operated at "Reciproc All" mode of the X-Smart Plus until the WL was achieved. The instruments were used in the root canal with slight apical pressure in three back and forth movements.

Group 3: The gutta-percha in the coronal thirds (3 mm) were removed using a no. 2 Gates Glidden drill (9). The remaining root canal fillings were removed with the XPS files till the WL was achieved. The instruments were operated on an Elements motor (Kerr-SybronEndo, Glendora, CA, USA) at a speed of 3000 rpm and 1 Ncm torque as suggested for gutta-percha removal with slow pecking motions (9, 20).

After each withdrawal, the flutes of the instruments were cleaned off with a gauze immersed into NaOCl, and the root canals were irrigated with 2 mL distilled water. The removal of root canal filling was terminated after reaching WL smoothly, and no residual filling material was observed on the last instrument or in the irrigation solution. Since this study was not intended to compare reinstrumentation procedures, after reaching WL, no further canal refinement was performed (14).

During the removal process, all glass vials were filled with warm water heated up to 37°C, both to mimic physiological conditions and let the phase change of XPS. The glass vials were covered with aluminum foil to prevent the operator from being affected by the experimental conditions and any contamination. All root canal instrumentations were performed by a single operator experienced in the tested systems, with 15 years of practice in endodontics. Each set of instruments to remove the filling materials was used only once and discarded.

Study variables

Three parameters were evaluated; success in regaining access to the periapical area, the amount of extruded debris, and the operation time.

Success in regaining access to the periapical area: Reaching the working length and maintaining the apical patency were evaluated separately. During the removal of gutta-percha, in case the instruments could not go deeper after three extra strokes, reaching the WL was deemed as not achieved. After confirmed by operating microscope and digital radiographs, the teeth that the WL could be reached and that the patency was maintained were regarded as successful. The cases where the WL cannot be reached, patency could not be maintained, or complications occurred were considered unsuccessful.

Apical debris extrusion: After reaching WL, final irrigation was performed with 2 mL of distilled water. The Eppendorf tubes were separated from the vials, and the caps were removed. The apical root thirds were washed with 1 mL of distilled water to collect the extruded debris around the external root apex. The teeth that WL could not be reached were not included in the debris extrusion evaluation.The Eppendorf tubes were then transferred into the incubator and stored at 70°C for five days to evaporate the distilled water (10). After evaporation, the tubes were weighed three times with the same electronic balance. The average of the measurements was recorded as the final weight value. The net extruded dry debris was calculated by subtracting the initial weight from the final weight of the tubes. All measurements were completed by a second observer who was blind to the operation parameters.

Operation time: For each sample, the time to reach WL was recorded with a digital chronometer (Loyka C809, Akyol Trade Co., İstanbul, Türkiye), excluding the time required for changing the instruments, cleaning the flutes, and irrigation.

Statistical analysis

Statistical analysis was performed with SPSS 23.0 (IBM SPSS Inc., Armonk, NY, USA) software. The conformity of the data to normal distribution was checked by Skewness, Kurtosis, and Shapiro Wilk tests. Kruskal Wallis tests were used to compare multiple groups, and Mann- Whitney U tests were used for paired comparisons. The Chi-square test was used in the evaluation of categorical data. The statistical significance was set at $p < 0.05$.

Results

All instruments were associated with apical extrusion of debris. There was a statistically significant difference be-

Table 1. *The mean and standard deviation (SD) values of the apically extruded debris in grams .*

Instrument type	Apically extruded debris	*p*-value
ProTaper Universal	0.0007±0.0003[b]	**0.013***
Reciproc Blue	0.0005±0.0005[ab]	
XP-endo Shaper	0.0004±0.0005[a]	

**Values with the same letters were not statistically different*

Table 2. *The mean and standard deviation values of the operation time in seconds.*

Instrument type	Operation time	*p*-value
ProTaper Universal	36.26 ± 7.44[a]	**0.000***
Reciproc Blue	115 ± 50.35[b]	
XP-endo Shaper	21.26±7.05[c]	

**Values with different letters were statistically different*

tween the instrument type and the amount of extruded debris (p=0.013) (Table 1). The mean amount of extruded debris was highest in the PTUR group. However, the difference was only significant between PTUR and XPS groups (p=0.005).

There was also a statistically significant difference between the retreatment instrument and the operation time (p=0.000) (Table 2). The mean time required for reaching WL was the longest for RB, while it was the shortest for XPS. The differences were statistically significant among the groups (p=0.000).

WL was reached in 40 out of a total of 45 samples, while it could not be reached in 5 samples. In the PTUR group, the WL was reached 93.3% (n=14). This rate was 86.7% (n=13) for RB and XPS groups. There was no significant difference among the groups regarding reaching WL (p=0.799). Apical patency could not be regained in 60% (n=9), 46.7% (n=7), and 53.3% (n=8) of the samples for PTUR, RB and XPS groups, respectively. However, the difference was not significant (p=0.765).

Discussion

The current *in vitro* study investigated for the first time the performance of PTUR and two heat treatment NiTi instruments RB and XPS, for extruded debris amount, regaining access ability to the periapical area and the operation time during the removal of bioceramic-based root canal filling. The multifile system (PTUR) and one of the single-file systems (XPS) were operated in continuous rotation, whereas the other was used in a reciprocating motion (RB).

The results revealed that all systems led to some degree of debris extrusion, which is consistent with the results of previous studies reporting varying degrees of apical debris extrusion during retreatment with different file systems, operated both in continuous rotation or reciprocation motion (9-11, 18, 20, 26). There was a statistically significant difference in the amount of extruded debris and the time required to reach WL among the currently tested systems (p>0.05). However, the difference was insignificant in regaining the periapical access. Therefore, the null hypothesis was partially accepted. The amount of apically extruded debris is directly related to the instruments' tip size, taper, kinematics, and preparation techniques (27). There are limited studies comparing reciprocating and rotating instruments on the amount of apically extruded debris when used for endodontic retreatment. Lu *et al.* (12) reported that Reciproc resulted in more apical debris extrusion than the Mtwo. However, in most of the studies, Reciproc was associated with less debris extrusion when compared with a conventional rotary retreatment system, PTUR (11, 26, 28). Our results were consistent with the latter studies, although we used RB. Indeed, the only difference between RB and Reciproc instruments, which have the same cross-section design, tip size, and taper, is the manufacturing process (10, 18).

On the other hand, XPS resulted in less debris extrusion than PTUR and RB. Although both are single-file systems, the finding that RB produces more apical debris than XPS complies with the previous study findings, which have tested these systems in shaping and retreatment procedures (9, 29). Although XPS has a bigger final apical diameter (30/.04) at the tip, the greater and variable taper of the RB instrument (25/.08) could be speculated as the possible reason for more debris extrusion. Moreover, the slender design, small mass, and expanding feature of XPS may have contributed less extrusion by providing sufficient space for debris escape (30).

The failure in establishing WL and/or patency may compromise the success of retreatment by impeding proper chemo-mechanical cleaning of the apical root canal that may harbour bacteria (31). Furthermore, apical patency preservation was associated with less postoperative pain (32). The WL was regained in 93.3% of the samples in the PTUR and 86.7% of the samples in the RB and XPS groups. However, regardless of the system used, apical patency could not be maintained in 46.7-60% of the cases. The effect of sealers on the retreatability of the root canals was shown in previous studies (14, 18, 21, 31). Endosequence BC sealer was speculated as difficult to retreat, due to its hardness upon setting and chemical-bond formation with dentin (22, 31). Previous studies have also demonstrated the difference between the regaining WL and patency rates in the root canals filled with Endosequence BC sealer (21, 31). Hess *et al.* (31) reported that WL could be restored in all samples contrary to our results, but patency was only achieved in 80%. In another study evaluating the retreatability of Endosequence BC sealer, Oltra *et al.* (21) established WL in 93% of the samples consistent with our results. However, the patency was regained in only 14%. The numerical differences between the studies may be attributed to the different instruments used for retreatment.

The removal of the filling material in the root canals filled with Endosequence BC sealer was demonstrated to be more time-consuming than those of AH Plus (18, 31). Regardless of the filling technique (lateral condensation or single cone), Endosequence BC sealer has provided better marginal adaptation and penetrated deeper into the dentinal tubules than AH Plus in all root segments (coronal, middle, and apical) (23). The effort required to regain access to the apical area may also affect the mean retreatment time of the Endosequence BC filling (18). According to our results, the mean time required to reach WL was the longest in the RB group (115 ± 50.35 s), followed by the PTUR (36.26 ± 7.44 s) and XPS (21.26 ± 7.05 s). The differences were significant among the groups (p=0.000).

Regarding the duration of retreatment, Özyürek *et al.* (33) found PTUR faster than Reciproc, in alignment with our findings. In the PTUR system, the active tip of the D1 instrument provides better penetration into the root canal filling, which may allow other instruments to reach the WL length more easily and faster (8). Since no previous studies have tested XPS for the retreatment of bioceramic-based filling material, a direct comparison of the results could not be performed. However, in line with our findings, XPS was shown to retreat the root canals obturated with warm vertical compaction faster than other tested Ni-Ti instruments and perform the retreatment in 60% less time than RB (9, 20). The improved efficiency of XPS could be attributed to the interesting tip design with six cutting edges and a booster tip and the plasticization of the gutta-percha at higher speeds (6, 20, 34).

On the other hand, RB files may be unlikely to penetrate bioceramic root canal filling because of the blue thermal treatment, which has been demonstrated to improve the flexibility and reduce the microhardness of the Reciproc instruments (17). Furthermore, a recent study reported that the retreatment of Endosequence BC with RB required 144 seconds, which might be time-consuming (18). The recorded time in that study was more prolonged than ours (115 s), probably due to the time taken for further refinement of the root canals. However, in the current study, the root canals were not re-shaped after reaching WL as it was not intended to compare the re-instrumentation procedures.

The extruded debris was collected with a slight modification of the method proposed by Myers & Montgomery (25). With this modification, the collection apparatus has become more practical and functional to be used as a warm bath required for the phase change of XPS. The main limitation of the present *in vitro* model is the lack of simulating physical back pressure provided by periapical tissues, which may restrict the extruded debris to some extent (3, 25). Regarding the shortcomings of *in vitro* design with no periapical pressure, Myers and Montgomery (25) pointed to reassessing the apical dentinal plug because of the potential benefits of reducing the amount of apically extruded debris. Several methods have been suggested to simulate periapical tissue resistance, including floral foam and agar gel (12, 35). However, these methods also have several disadvantages, such as the absorption of irrigants and debris by the foam and the difficulty in defining a factual agar gel thickness to mimic the size of the apical lesion (12, 35).

Furthermore, no valid method is still known for reproducing an optimal simulation of periapical tissues (18). Therefore, no additional modifications have been made to simulate periapical resistance in the present experimental setup (11, 13). During the removal of gutta-percha, irrigation was performed with distilled water as the crystals of sodium hypochlorite cannot be separated from debris and compromise the reliability of the results (36).

Notably, this study only examined the quantitative debris extrusion. As the weight of the debris increases, the severity of the inflammatory reaction of periapical tissues is expected to increase. However, the severity of the reaction has been reported to be related to not only the amount of debris but also the type and virulence of the bacteria and the host tissue resistance (37). It may not be meaningful to report only the quantity without taking into account the composition of the extruded material and other biologic aspects of the periapical irritation (15). Therefore, from a clinical perspective, further research including the biological factors is needed to better understand whether the differences among the tested systems are clinically relevant.

Conclusion

Within the limitations of this study, it can be concluded that all tested systems caused a certain amount of debris extrusion. XPS was associated with less extrusion than PTUR and RB, while regaining more rapid access to the periapical area.

Türkçe özet: *ProTaper Universal Retretament, Reciproc Blue ve XP-endo Shaper Sistemlerin Biyoseramik Esaslı Kök Kanalı Dolgusunun Uzaklaştırılmasındaki Etkinliği. Amaç: Bu in vitro çalışmada, biyoseramik kök kanalı dolgusunun uzaklaştırılması sırasında Protaper Universal Retreatment (PTUR), Reciproc Blue (RB) ve XP-endo Shaper (XPS) sistemlerinin apikal debris çıkışı, periapikal alana erişmedeki başarı ve operasyon süresi açısından performanslarının değerlendirilmesi amaçlanmıştır. Gereç ve yöntem: 45 adet tek köklü alt küçük azı dişi 30/.04'e kadar şekillendirildikten sonra Endosequence BC sealer ve BC güta-perkalar ile doldurularak 3 gruba ayrıldı (n=15). Kök kanalı dolguları, 1. grupta PTUR, 2. grupta RB ve 3. grupta XPS kullanılarak çalışma uzunluğuna (ÇU) ulaşana kadar çıkarıldı. Operasyon süresi dijital kronometre ile kaydedildi. ÇU'na ulaşma ve apikal açıklığın korunması ayrı ayrı değerlendirildi. Veriler, Kruskal Wallis ve Mann Whitney U testleri kullanılarak istatistiksel olarak analiz edildi. Bulgular: Tüm aletler apikal debris çıkışına neden olmasına rağmen, en yüksek ortalama debris çıkışı PTUR grubundaydı. ÇU'na ulaşmak için gereken ortalama süre en uzun RB grubunda, en kısa XPS grubunda kaydedildi ve gruplar arasındaki fark istatistiksel olarak anlamlıydı (p=0,000). Diğer gruplar (%86,7) ile arasındaki fark anlamlı olmasa da (p=0,799), PTUR grubunda ÇU'na ulaşma oranı daha yüksekti (%93,3). Sonuç: Test edilen tüm sistemler belirli miktarlarda debris çıkışına neden oldu. XPS; PTUR ve RB'ye kıyasla periapikal alana anlamlı derecede daha hızlı erişim sağlarken daha az debris çıkardı. Anahtar Kelimeler: Debris çıkışı, endodontik tedavi tekrarı, Endosequence BC sealer, Reciproc Blue, XP-endo Shaper*

Ethics Committee Approval: The study protocol has been approved by the İstanbul Okan University Research Ethics Committee (Protocol: 2021/131).

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: EC, RSG, GAD, GK, ESK participated in designing the study. EC, RSG, GAD participated in generating the data for the study. EC, RSG, GK participated in gathering the data for the study. EC, RSG, GAD, GK, ESK participated in the analysis of the data. EC, RSG wrote the majority of the original draft of the paper. EC, RSG participated in writing the paper. EC, RSG, ESK have had access to all of the raw data of the study. EC, RSG have reviewed the pertinent raw data on which the results and conclusions of this study are based. EC, RSG, GAD, GK, ESK have approved the final version of this paper. EC guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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