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Influence of blenching agents on the mechanical properties and colour of dental restorative nanocomposite

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ABSTRACT

Purpose: Bleaching agents are commonly used to make the natural dentition look more attractive. Currently, in addition to products from reputable manufacturers, products of not fully known origin are available for purchase. The aim of the study was to investigate whether products of this type have a destructive influence on the mechanical and aesthetic properties of the dental restorative nanocomposite.

Design/methodology/approach: Four bleaching agents were used, two recognized brands, and two products were purchased from Chinese websites (their manufacturer is unknown). Two gels and two types of whitening strips were used. One composite nanomaterial was used. Microhardness, diametral tensile strength,, compressive strength and colour measurements were tested.

Findings: For some bleaching agents, studies have shown a relatively small effect on mechanical properties and an acceptable effect on colour changes. Regardless of the observed changes, the use of bleaching agents qualified for the experiment should be considered safe for composites.

Research limitations/implications: The number of blenching agents used as well as dental composites in this study was limited. In future studies, increasing the number of cycles in the bleaching process should be considered.

Practical implications: A popular method of improving the aesthetic properties of teeth is the use of a wide range of blenching agents. Most patients who use teeth whitening procedures are also users of composite fillings. The use of bleaching agents may have a different effect on the mechanical and aesthetic restorative composites. For economic reasons, many people decide to import cheap bleaching agents of unknown or dubious origin via Internet services to perform the bleaching process on their own. In this study, it was investigated whether products of this type have an influence on the mechanical and aesthetic properties of the dental restorative nanocomposite.

Originality/value: Until now, no comparison of the safety of the use of bleaching agents of recognized manufacturers and of unknown origin in terms of the effect on composite materials has been presented, despite their high social importance.

Keywords: Blenching agents, Dental restorative composite, Mechanical properties, Colour measurements

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BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

1. Introduction

Dental resin-based composites for direct fillings were introduced into clinical practice decades ago. Currently, photopolymerizable composites due to their aesthetic properties are the most popular restorative materials in clinical practice [1-3], regardless of their higher failure rates than dental amalgams [4-5]. Modern composites with very good translucency, shades, colour stability, and polishability are relatively easy to manipulate, need less invasive preparation techniques [6-7] but also show appropriate mechanical and physicochemical properties with very good biocompatibility [8-9].

The possibility of ensuring a relatively high level of aesthetics over many years of operation is considered one of the main advantages of this type of material. At the same time, composite materials, but also the teeth themselves, are affected by many environmental factors, such as food liquids, thermal changes, or even mouth rinses [10-14], which can alter the original properties, including the aesthetic properties of dental materials and teeth [15-20]. A popular method to improve the aesthetic properties of teeth is the use of a wide range of blenching agents [21-25]. Unfortunately, most patients who use teeth whitening procedures are also users of composite fillings. The use of peroxide bleaching agents may have a different effect on the surface of microhybrid or nanocomposites [26], but also on the mechanical properties and color changes [27-34]. To improve the aesthetics of their teeth in these times of globalization, for economic reasons, many people decide to import cheap bleaching agents of unknown or dubious origin via Internet services in order to conduct the bleaching process on their own. The aim of the presented study was to investigate whether products of this type have a destructive influence on the mechanical and aesthetic properties of the dental restorative nanocomposite.

2. Methods

The materials used in the presented study are listed in Table 1. Two different whitening strips and gels were used.

Samples for microhardness, diametral tensile strength, compressive strength and colour measurements were prepared according to the method described previously [35-36]. The composite samples materials were polymerized with a DY400-4 LED lamp (Denjoy Dental, Changsha, China), power 5 W, intensity 1400 to 2000 mW/cm^2, optical wavelength 450 to 470 nm in a Teflon mould.

In the preparatory phase of the experiment, first composite samples models were made in Teflon moulds, painted with spacer varnish, and glued to a steel base. The moulds were then made of thermoformable discs (BioBleach hard, 0.5 mm, Drufomat Scan device), which served as models of whitening splints. Subsequently, samples of composite materials were exposed to bleaching agents.

The whitening time for all four methods was 5.5 hours (7 × 30 min). The gels were applied to the models of the splints (they were changed every 30 min), and then the composite samples were inserted into the model of the splint. The strips in the composite samples were replaced every 30 minutes. When the blenching agents were changed, the samples were rinsed in distilled water and dried with compressed air from visible moisture. During exposure, the samples were placed in a desiccator containing 100 ml of water to ensure adequate humidity. The desiccator was placed in a laboratory dryer at 37°C and the samples with the bleaching agents were placed in an already heated desiccator on a porcelain shelf. After 5.5 hours of exposure, the samples were removed, thoroughly rinsed in distilled water, and dried with compressed air from visible moisture.

Compressive strength (CS) was examined according to the method presented by Mota et al. [37], with some necessary specifications [35]. The samples measured 3 mm in diameter / 6 mm in height. Ten samples were prepared for each group. The tests were carried out using a universal testing machine (Zwick Z020, Germany). A cross-head speed was 0.5 mm/min. Compressive strength value for each sample was calculated according to the equation:

$$\sigma_C = F/S \qquad (1)$$

where: σ_C – compressive strength, MPa; F – force at fracture, N; S – initial cross-sectional area, mm^2.

Table 1.
Materials used in the experiment and their essential components according to the manufacturer's information

Material/storing medium name	Symbol	Declared composition / active ingredients according to the manufacturer's informations	Manufacturer
EasyFill Nanocomposite	EFN	diurethane dimethacrylate, butanediol dimethacrylate, bis-GMA, 83 % by weight of inorganic fillers (28 nm-15 μm)	GDF Gesellschaft für Dentale Forschung und Innovationen GmbH, Germany
Distilled water (control)	C	-	-
3D White Whitening Strips	3DWS	Unknown	Unknown, China
Bright White Whiteening Set Supreme (whitening strips)	BW	Glycerin, carboxymethylcellulose, D L-Menthol, carbomer, EDTA, Sodium Hydroxide, Mint fragrance	Onuge Personal Care, China
Whitening Gel	WG	35% of Urea (Carbamide) Peroxide, the rest unknown	Unknown, China
Opalescence PF Teeth Whitening (gel)	OP	Glycerin, Water (Aqua), 35% Urea (Carbamide) peroxide, Carbomer, PEG6, Hydrogen peroxide, Xylitol, Sodium Hydroxide, EDTA, Peppermint Oil (Aroma), Potassium Nitrate, Sodium Fluoride, Sucralose	Opalescence, USA

Samples for diametral tensile strength (DTS) measured 6 mm in diameter / 3 mm in height. Ten samples were prepared for each group. The compressive load was applied on the lateral surface of the samples at a cross head speed of 0.5 mm/min [38]. The DTS values were calculated with equation:

$$DTS=2F/\pi dh \qquad (2)$$

where: DTS, diametral tensile strength, MPa; F, force at fracture, N; d, diameter of the samples, mm; h, thickness of the samples, mm.

Vickers microhardness (HV) was measured on samples like for DTS, however, samples surface were polished with 6 μm and 3 μm diamond suspensions (Struers GmbH, Willich, Germany) according to the method described previously [35]. Five samples were made from each condition. The hardness was measured five times for each specimen, and the average value was recognized as the value for the sample. Measurements were made using the Future-Tech FM-700 microhardness tester (Future-Tech Corp, Japan) at a load of 100 g / loading time of 15 s [39].

To evaluate colour changes, 12 mm diameter and 3 mm thick samples were prepared as reported in [35]. Five samples were prepared for each experiment condition. A spectrophotometer (CM2600d, Konica Minolta, Japan) was used to record the CIE L**a***b** parameters. A D65 illuminant on a white ceramic tile was used. The L* is the lightness, *a** represents the red—green colour parameter and *b** is blue—yellow axis [35]. The colour change (ΔE*) was calculated as:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2(\Delta b^*)^2}^{*} \qquad (3)$$

where $\Delta L^* = L_{(after\ exposure)} - L_{(baseline)}$; $\Delta a^* = a_{(after\ exposure)} - a_{(baseline)}$; and $\Delta b^* = b_{(after\ exposure)} - b_{(baseline)}$.

Statistical analysis was performed with Statistica 13.1 software (TIBCO Software Inc., USA). The Shapiro-Wilk test was used to check distributions of the residuals, and the Levene test to check equality of variances. Finally one-way ANOVA with Tukey HSD post hoc tests were used ($\alpha=0.05$).

3. Results

The results of compressive strength and DTS were presented in Figures 1 and 2. There was no statistically significant influence of blenching agents on these properties ($p>0.05$).

The type of blenching agent has a statistically significant influence on the microhardness values (Fig. 3) values ($p<0.05$). However, all mean values did not differ statistically significantly from the control group. The differences between groups after exposition to bleaching agents were recorded. Storing of samples with WG gel leads to the decrease in microhardness, but for other blenching agent increase in hardness values was noted.

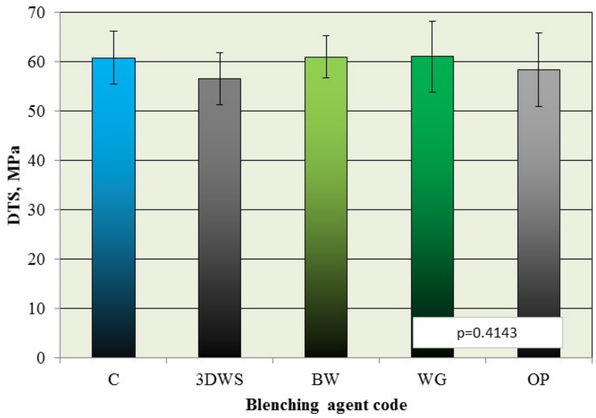

Fig. 1. Mean DTS values after exposure to different blanching agents

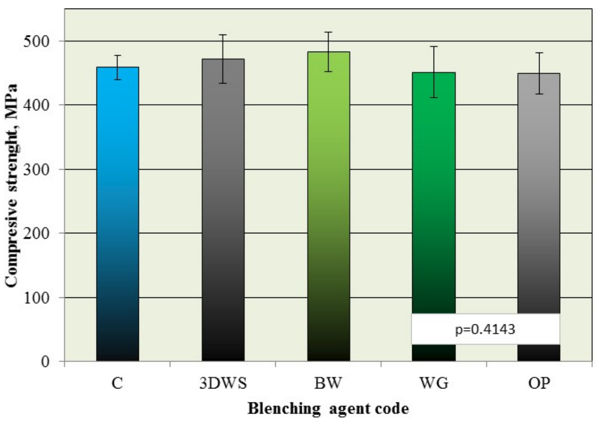

Fig. 2. Mean compressive strength values after exposure to different blanching agents

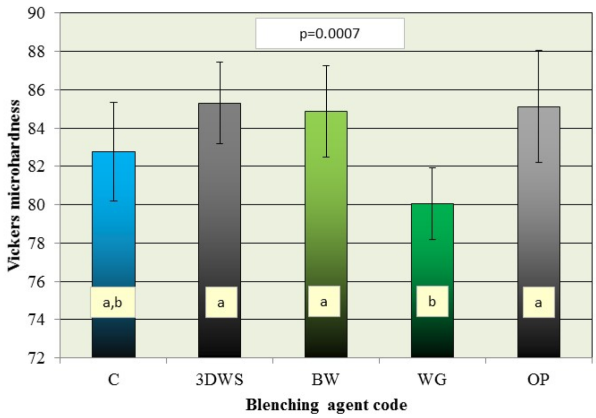

Fig. 3. Mean microhardness values after exposure to different blanching agents, different lowercase letters show significantly different results at the level of $p < 0.05$ level

The ΔE values (Fig. 4) were statistically significant different only for WG and 3DWS. The lowest mean ΔE value was registered for 3DWS (0.68), the highest for WG (1.1).

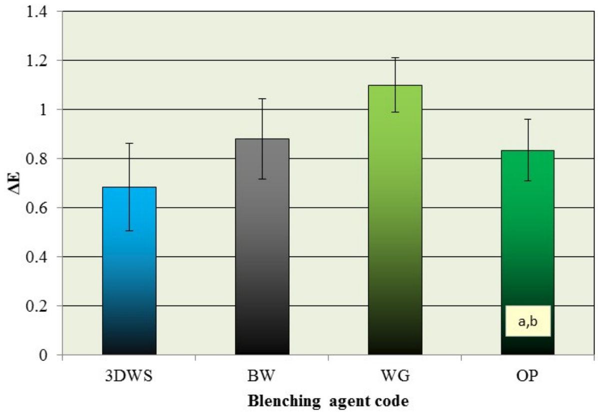

Fig. 4. Mean ΔE values after exposure to different blanching agents, different lowercase letters show significantly different results at the level of $p < 0.05$ level

The ΔL* value (Fig. 5) for 3DWS was -0.51 and was significantly different from for other blenching agents, for which the values were positive. The mean value for OP was also significantly different than for WG (0.94) – the difference between the OP and the 3DWS was 1.45.

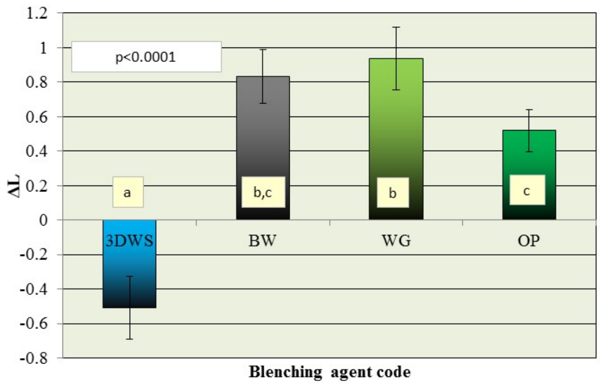

Fig. 5. Mean ΔL values after exposure to different blanching agents, different lowercase letters show significantly different results at the level of $p < 0.05$ level

The Δa* values of a * (Fig. 6) ranged from -0.04 (3DWS) to 0.26 (OP) and the results for 3DWS and WG were statistically significant different from for OP.

The Δb* values of b * (Fig. 7) ranged from -0.18 (BW) to -0.59 (OP) and the result BW was statistically significant different than after exposition for other agents.

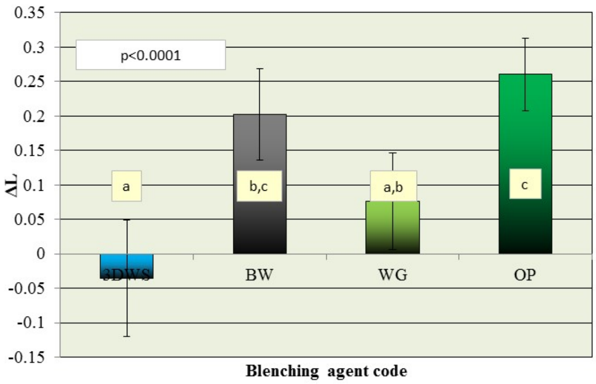

Fig. 6. Mean Δa values of a after exposure to different blanching agents, different lowercase letters show significantly different results at the level of $p < 0.05$ level

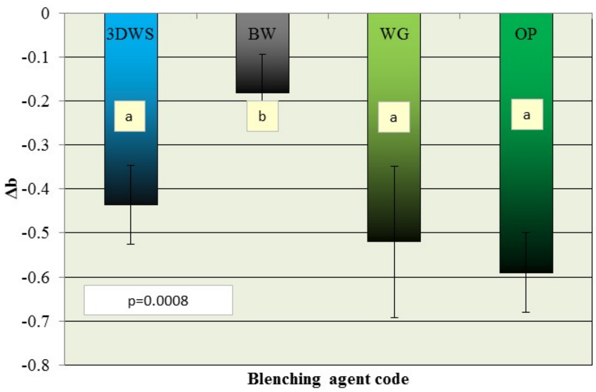

Fig. 7. Mean Δb values of b after exposure to different blanching agents, different lowercase letters show significantly different results at the level of the $p < 0.05$ level

4. Discussion

Dental composites are typically subjected to compressive forces generated during mastication [40] and tension in areas near the interface between teeth and composites [41], so for the functioning of these materials, it is important to show stable values of compressive strength and DTS, which represent the basic mechanical properties of composites on the macroscale. Our research has shown that none of the whitening methods used resulted in statistically significant changes in these properties, so they should all be considered safe for composites in this respect.

Vickers microhardness is a popular method used as an indicator of potential changes in surface hardness of dental restorative composites and is also correlated with wear resistance [42]. In our study statistically significant differences in microhardness were recorded after the use of bleaching agent, but no differences compared to the control group.

For three materials, an increase in mean hardness of up to ~2 kgf/mm^2 was recorded and for one reduction ~3 kgf/mm^2 so the changes were minimal. Similar values of changes were restored for whitening strips and gels by Al-Angari et al. [29] for other nanocomposites and for a much longer time. AlQahtani et al. [28] did not register significant differences between groups or minimal reduction in the hardness of dental composite resins after using in-office bleaching agents. Kamangar et al. [34] reported a greater decrease in hardness for most materials, but the whitening period was much longer, which may have been of importance, as the use of longer times increases the risk of degradation and plasticization of the matrix. Our results confirm the results of other studies that show that the changes in hardness are small. At the same time, they show that the use of a single seven-day bleaching cycle with the applied agents does not cause significant changes in hardness from a practical point of view.

The use of bleaching changed the colour, which is consistent with the findings of other works; however, the changes values were lower than those registered in work where a much longer exposure time was used [29,31,34]. In our work, the ΔE values above 1, which may be discernible only for an experienced person, were recorded for a single material, a gel from an unknown manufacturer (WG) [43]. This change value is considered acceptable because more observers would indicate that the colour matching was very good [44,45].At the same time, the direction of the changes in ΔL, Δa and Δb was consistent with those observed in other studies [34], but the exception was WG for which darkening of the composite was observed.

5. Conclusions

In conclusion, the use of a seven-day cycle of bleaching with strips and gels, including those from unknown sources, does not pose the risk of unfavourable changes in mechanical and aesthetic properties of investigated dental resin-nanocomposite. At the same time, some properties of composites of unknown origin have changed to a greater extent or in a different direction than after the use from products of well-known brands. This indicates that longer use of these types of agents may produce larger changes.

References

[1] N. Jayanthi, V. Vinod, Comparative evaluation of compressive strength and flexural strength of

conventional core materials with nanohybrid composite resin core material an in vitro study, Journal of Indian Prosthodontic Society 13 (2013) 281-289. DOI: https://doi.org/10.1007/s13191-012-0236-4

[2] K. Drzewiecka, J. Kleczewska, M. Krasowski, J. Sokołowski, B. Łapińska, Mechanical properties of composite material modified with amorphous calcium phosphate, Journal of Achievements in Materials and Manufacturing Engineering 74/1 (2016) 22-28. DOI: https://doi.org/10.5604/17348412.1225754

[3] B. Łapińska, M. Łukomska-Szymańska, J. Sokołowski, J. Nowak, Experimental composite material modified with calcium fluoride – three-point bending flexural test, Journal of Achievements in Materials and Manufacturing Engineering 74/2 (2016) 72-77. DOI: https://doi.org/10.5604/17348412.1225912

[4] D. Hurst, Amalgam or composite fillings-which material lasts longer?, Evidence-Based Dentistry 15 (2014) 50-51. DOI: https://doi.org/10.1038/sj.ebd.6401026

[5] M.G. Rasines Alcaraz, A. Veitz-Keenan, P. Sahrmann, P. R. Schmidlin, D. Davis, Z. Iheozor-Ejiofor, Direct composite resin fillings versus amalgam fillings for permanent or adult posterior teeth, Cochrane Database of Systematic Reviews 2014/3 (2014) CD005620. DOI: https://doi.org/10.1002/14651858.CD005620.pub2

[6] Á. Ástvaldsdóttir, J. Dagerhamn, J. W. V. van Dijken, A. Naimi-Akbar, G. Sandborgh-Englund, S. Tranæus, M. Nilsson, Longevity of posterior resin composite restorations in adults – A systematic review, Journal of Dentistry 43/8 (2015) 934-954. DOI: https://doi.org/10.1016/j.jdent.2015.05.001

[7] N. Ilie, R. Hickel, Resin composite restorative materials, Australian Dental Journal 56/s1 (2011) 59-66. DOI: https://doi.org/10.1111/j.1834-7819.2010.01296.x

[8] H. Alzraikat, M. Burrow, G. Maghaireh, N. Taha, Nanofilled Resin Composite Properties and Clinical Performance: A Review, Operative Dentistry 43/4 (2018) E173-E190. DOI: https://doi.org/10.2341/17-208-T

[9] A. Cândea Ciurea, P. Şurlin, Ş.-I. Stratul, A. Soancă, A. Roman, M. Moldovan, L. Tudoran B., E. Pall, Evaluation of the biocompatibility of resin composite-based dental materials with gingival mesenchymal stromal cells, Microscopy Research and Technique 82/10 (2019) 1768-1778. DOI: https://doi.org/10.1002/jemt.23343

[10] W.-Y. Shih, Microleakage in different primary tooth restorations, Journal of the Chinese Medical Association 79/4 (2016) 228-234. DOI: https://doi.org/10.1016/j.jcma.2015.10.007

[11] P. Gürdal, B.G. Akdeniz, B. Hakan Sen, The effects of mouthrinses on microhardness and colour stability of aesthetic restorative materials, Journal of Oral Rehabilitation 29/9 (2002) 895-901. DOI: https://doi.org/10.1046/j.1365-2842.2002.00924.x

[12] J.P. Leal, D. Silva, J. Damasceno, R.F.M. Leal, C. da C. Oliveira-Júnior, V.L.G. Prado, G.C. Vale, Effect of Mouthwashes on Solubility and Sorption of Restorative Composites, International Journal of Dentistry 2017 (2017) 5865691. DOI: https://doi.org/10.1155/2017/5865691

[13] J. Krüger, R. Maletz, P. Ottl, M. Warkentin, In vitro aging behavior of dental composites considering the influence of filler content, storage media and incubation time, PloS One 13/4 (2018) e0195160. DOI: https://doi.org/10.1371/journal.pone.0195160

[14] M. Nowak, I. Kalamarz, G. Chladek, Mechanical properties of Easy Fill composites after storage in mouthwashes, Journal of Achievements in Materials and Manufacturing Engineering 88/1 (2018) 25-34. DOI: https://doi.org/10.5604/01.3001.0012.5868

[15] A. Joiner, Tooth colour: a review of the literature, Journal of Dentistry 32/Suppl. (2004) 3-12. DOI: https://doi.org/10.1016/j.jdent.2003.10.013

[16] F. Banu, K. Jeyapalan, A. Kumar V, K. Modi, Comparison of Colour Stability Between Various Denture Base Resins on Staining and Denture Cleansing Using Commercially Available Denture Cleansers, Cureus 12/1 (2020) e6698. DOI: https://doi.org/10.7759/cureus.6698

[17] D. Manojlovic, L. Lenhardt, B. Milićević, M. Antonov, V. Miletic, M.D. Dramićanin, Evaluation of Staining-Dependent Colour Changes in Resin Composites Using Principal Component Analysis, Scientific Reports 5 (2015) 14638. DOI: https://doi.org/10.1038/srep14638

[18] N.B. Ulusoy, V. Arikan, A. Akbay Oba, Effect of mouthwashes on the discolouration of restorative materials commonly used in paediatric dentistry, European Archives of Paediatric Dentistry 19 (2018) 147-153. DOI: https://doi.org/10.1007/s40368-018-0341-0

[19] S.-H. Kang, Y.-S. Shin, H.-S. Lee, S.-O. Kim, Y. Shin, I.-Y. Jung, J. S. Song, Color changes of teeth after treatment with various mineral trioxide aggregate-based materials: an ex vivo study, Journal of Endodontics, 41/5 (2015) 737-741. DOI: https://doi.org/10.1016/j.joen.2015.01.019

[20] K. Rebelo de Sousa, M. J. Batista, J. Rocha Gonçalves, M. da L. R. de Sousa, Extrinsic tooth enamel color changes and their relationship with the quality of water consumed, International Journal of Environmental

Research and Public Health 9/10 (2012) 3530-3539. DOI: https://doi.org/10.3390/ijerph9103530

[21] B.M. Maran, L. Vochikovski, D.R. de Andrade Hortkoff, R. Stanislawczuk, A.D. Loguercio, A. Reis, Tooth sensitivity with a desensitizing-containing at-home bleaching gel-a randomized triple-blind clinical trial, Journal of Dentistry 72 (2018) 64-70. DOI: https://doi.org/10.1016/j.jdent.2018.03.006

[22] J.L. de Geus, L.M. Wambier, S. Kossatz, A.D. Loguercio, A. Reis, At-home vs In-office Bleaching: A Systematic Review and Meta-analysis, Operative Dentistry 41/4 (2016) 341-356. DOI: https://doi.org/10.2341/15-287-LIT

[23] A. Mounika, J. Mandava, B. Roopesh, G. Karri, Clinical evaluation of color change and tooth sensitivity with in-office and home bleaching treatments, Indian Journal of Dental Research 29/4 (2018) 423-427. DOI: https://doi.org/10.4103/ijdr.IJDR_688_16

[24] Z.B. Kutuk, E. Ergin, F.Y. Cakir, S. Gurgan, Effects of in-office bleaching agent combined with different desensitizing agents on enamel, Journal of Applied Oral Science 27 (2018) e20180233. DOI: https://doi.org/10.1590/1678-7757-2018-0233.

[25] F.A.L. Farawati, S.-M. Hsu, E. O'Neill, D. Neal, A. Clark, J. Esquivel-Upshaw, Effect of carbamide peroxide bleaching on enamel characteristics and susceptibility to further discoloration, The Journal of Prosthetic Dentistry 121/2 (2019) 340-346. DOI: https://doi.org/10.1016/j.prosdent.2018.03.006

[26] E. Varanda, M. Do Prado, R.A. Simão, K.R.H.C. Dias, Effect of in-office bleaching agents on the surface roughness and morphology of different dental composites: an AFM study, Microscopy Research and Technique 76/5 (2013) 481-485. DOI: https://doi.org/10.1002/jemt.22190

[27] P. Mourouzis, E.A. Koulaouzidou, M. Helvatjoglu-Antoniades, Effect of in-office bleaching agents on physical properties of dental composite resins, Quintessence International 44 (2013) 295-302. DOI: https://doi.org/10.3290/j.qi.a29154

[28] M. Q. AlQahtani, The effect of a 10% carbamide peroxide bleaching agent on the microhardness of four types of direct resin-based restorative materials, Operative Dentistry 38/3 (2013) 316-323. DOI: https://doi.org/10.2341/12-224-L

[29] S.S. Al-Angari, G.J. Eckert, A.H.A. Sabrah, Color stability, Roughness, and Microhardness of Enamel and Composites Submitted to Staining/Bleaching Cycles, The Saudi Dental Journal 33/4 (2021) 215-221. DOI: https://doi.org/10.1016/j.sdentj.2020.08.003

[30] L. Markovic, R.A. Jordan, M.-C. Glasser, W.H. Arnold, J. Nebel, W. Tillmann, T. Ostermann, S. Zimmer, Effects of bleaching agents on surface roughness of filling materials, Dental Materials Journal 33/1 (2014) 59-63. DOI: https://doi.org/10.4012/dmj.2012-217

[31] M. Lago, L.R. Mozzaquatro, C. Rodrigues, M.R. Kaizer, A. Mallmann, L.B. Jacques, Influence of Bleaching Agents on Color and Translucency of Aged Resin Composites, Journal of Esthetic and Restorative Dentistry 29/5 (2017) 368-377. DOI: https://doi.org/10.1111/jerd.12261

[32] F. Zakavi, N. Johar, M. Moalemnia, V. Rakhshan, Effects of at-home and in-office bleaching and three composite types (hybrid, microhybrid, and nanofilled) on repair shear bond strength of aged composites: A preliminary study, Dental Research Journal 18 (2021) 61.

[33] M. Bahari, S. Savadi Oskoee, N. Mohammadi, M.E. Ebrahimi Chaharom, M. Godrati, A. Savadi Oskoee, Effect of different bleaching strategies on micro-hardness of a silorane-based composite resin, Journal of Dental Research, Dental Clinics, Dental Prospects 10 (2016) 213-219. DOI: https://doi.org/10.15171/joddd.2016.034

[34] S.S.H. Kamangar, K. Kiakojoori, M. Mirzaii, M.J.K. Fard, Effects of 15% carbamide peroxide and 40% hydrogen peroxide on the microhardness and color change of composite resins, Journal of Dentistry, Tehran University of Medical Sciences 11/2 (2014) 196-209.

[35] R. Stencel, J. Kasperski, W. Pakieła, A. Mertas, E. Bobela, I. Barszczewska-Rybarek, G. Chladek, Properties of experimental dental composites containing antibacterial silver-releasing filler, Materials 11/6 (2018) 1031. DOI: https://doi.org/10.3390/ma11061031

[36] R. Stencel, W. Pakieła, I. Barszczewska-Rybarek, J. Żmudzki, J. Kasperski, G. Chladek, Effects of Different Inorganic Fillers on Mechanical Properties and Degree of Conversion of Dental Resin Composites, Archives of Metallurgy and Materials 63/3 (2018) 1361-1369. DOI: https://doi.org/10.24425/123813

[37] E.G. Mota, A. Weiss, A.M. Spohr, H.M.S. Oshima, L.M.N. de Carvalho, Relationship between filler content and selected mechanical properties of six microhybrid composites, Revista Odonto Ciência 26/2 (2011) 151-155. DOI: https://doi.org/10.1590/S1980-65232011000200010

[38] M. Łukomska-Szymańska, B. Zarzycka, J. Grzegorczyk, K. Sokołowski, K. Półtorak, J. Sokołowski, B. Łapińska, Antibacterial Properties of Calcium

Fluoride-Based Composite Materials: In Vitro Study, BioMed Research International 2016 (2016) 1048320. DOI: https://doi.org/10.1155/2016/1048320

[39] G. Chladek, K. Basa, J. Żmudzki, P. Malara, A.J. Nowak, J. Kasperski, Influence of aging solutions on wear resistance and hardness of selected resin-based dental composites, Acta of Bioengineering and Biomechanics 18/3 (2016) 43-52. DOI: https://doi.org/10.5277/ABB-00434-2015-03

[40] E. Korkut, E. Torlak, M. Altunsoy, Antimicrobial and mechanical properties of dental resin composite containing bioactive glass, Journal of Applied Biomaterials and Functional Materials 14/3 (2016) e296-301. DOI: https://doi.org/10.5301/jabfm.5000271

[41] B. Dejak, A. Młotkowski, A comparison of stresses in molar teeth restored with inlays and direct restorations, including polymerization shrinkage of composite resin and tooth loading during mastication, Dental Materials: Official Publication of the Academy of Dental Materials 31/3 (2015) e77-87. DOI: https://doi.org/10.1016/j.dental.2014.11.016

[42] C. Poggio, M. Lombardini, S. Gaviati, M. Chiesa, Evaluation of Vickers hardness and depth of cure of six composite resins photo-activated with different polymerization modes, Journal of Conservative Dentistry : JCD 15/3 (2012) 237-241. DOI: https://doi.org/10.4103/0972-0707.97946

[43] W.S. Mokrzycki, M. Tatol, Color difference ΔE : a survey, Machine Graphics and Vision 20/4 (2011) 383-411.

[44] G.A. de Morais Sampaio, L. Rangel Peixoto, G. de Vasconcelos Neves, D. do Nascimento Barbosa, Effect of mouthwashes on color stability of composite resins: A systematic review, The Journal of Prosthetic Dentistry 126/3 (2021) 386-392. DOI: https://doi.org/10.1016/j.prosdent.2020.08.001

[45] R.D. Paravina, M.M. Pérez, R. Ghinea, Acceptability and perceptibility thresholds in dentistry: A comprehensive review of clinical and research applications, Journal of Esthetic and Restorative Dentistry 31/2 (2019) 103-112. DOI: https://doi.org/10.1111/jerd.12465