ARTICLE IN PRESS

+ MODEL

Journal of Dental Sciences (2015) xx, 1–7

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Journal of Dental Sciences

REVIEW ARTICLE

Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers

Hao Yu [a], Chang-Yuan Zhang [a], Shao-Long Cheng [b], Hui Cheng [a,b*]

[a] *Department of Prosthodontics, School and Hospital of Stomatology, Fujian Medical University, Fuzhou, China*
[b] *Key Laboratory of Stomatology (Fujian Medical University), Fujian Province University, Fuzhou, China*

Received 18 June 2014; Final revision received 31 July 2014
Available online ■ ■ ■

KEYWORDS
bleaching;
carbamide peroxide;
hydrogen peroxide;
restorative material

Abstract In recent years, there has been an increased demand for improvement in the appearance of natural teeth. The conservative technique of tooth bleaching has gained attention and acceptance from both patients and clinicians. Despite increased popularity, there is controversy surrounding the adverse effects of bleaching on dental restorative materials. This article reviews the effects of bleaching agents on major categories of dental restorative materials and provides evidence-based recommendations to the clinicians and researchers. Current literature reveal that bleaching might have a detrimental effect on restorative materials. However, because of the variability in experimental design, there is a lack of consensus concerning the bleaching effects on restorative materials. A standardized and reproducible guideline for assessment of bleaching effects on restorative materials needs to be established and verified by future studies.

Introduction

Tooth bleaching has become one of the most successful and well-accepted aesthetic dental treatments over the past decades. Although there are several methods available to manage discolored teeth, tooth bleaching has been

* Corresponding author. Department of Prosthodontics, School and Hospital of Stomatology, Fujian Medical University, 246 Yangqiao Zhong Road, Fuzhou 350002, China.
E-mail addresses: Haoyu-cn@hotmail.com (H. Yu), Huicheng.fjmu@yahoo.com (H. Cheng).

http://dx.doi.org/10.1016/j.jds.2014.08.005

Please cite this article in press as: Yu H, et al., Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers, Journal of Dental Sciences (2015), http://dx.doi.org/10.1016/j.jds.2014.08.005

reported to be the choice most desired by the patients seeking for dental aesthetic improvement.[1] Moreover, a survey conducted by the Clinical Research Associates reported that 91% of the dentists provided tooth bleaching in their dental practices and tooth bleaching treatment resulted in a success rate of 79%.[2]

Tooth bleaching was reported in the literature as an aesthetic treatment option as early as 1877.[3] Contemporary tooth bleaching products have evolved into three major categories: in-office bleaching (also known as power bleaching), at-home bleaching (also known as night guard vital bleaching), and over-the-counter (OTC) bleaching agents. In general, most in-office and at-home bleaching techniques have been shown to be effective, although results may vary depending on the factors including type of stain, bleaching agent, and treatment protocol.[4–6] In addition, OTC bleaching products are widely accessible all over the world as a potential low cost alternative to traditional bleaching agents. However, little clinical evidence is available on the safety and effectiveness of the OTC products.[7]

Contemporary tooth bleaching materials are based primarily on either hydrogen peroxide (HP) or carbamide peroxide (CP). CP is very unstable and will immediately degrade into about one-third HP and two-thirds urea on contact with tissues and saliva. HP acts as a strong oxidizing agent through the formation of free radicals, reactive oxygen molecules, and anions.[8] The fact that the bleaching agent is held in intimate contact with the teeth and potentially any associated restorations raises the possibility that the agent may cause undesirable changes, such as softening and degradation of the teeth and restorative materials. Therefore, concerns have been raised about the bleaching effects on dental restorative materials.[9–11] It has been reported that bleaching agents might change the properties of restorative materials, such as color, surface and subsurface microhardness, surface roughness, and surface topography. In stark contrast, other studies suggest that bleaching effects on restorative materials are clinically insignificant.[10,12]

Given the discrepancy in findings, the purpose of the present article is to review the effects of bleaching agents on dental restorative materials and to provide evidence-based recommendations to dental practitioners and researchers. To identify all original articles and reviews reporting the bleaching effects on restorative materials, a systematic search of the literature to January 2014 was conducted using PubMed, ISI Web of Science, and EMBASE. The main search terms were: (bleaching OR whitening) AND (restorative material OR amalgam OR alloy OR ceramic OR glass ionomer OR compomer OR composite resin). The studies were also hand-searched for additional relevant publications.

Effects of bleaching agents on properties of restorative materials

Amalgam

Different studies have reported widely discrepant results for the amount of metal ion leaching from amalgam. While Al-Salehi et al[13] found no significant change in the release of metal ions from bleached amalgam (10% CP for 24 hours), a number of studies reported a significant increase in the release of amalgam components (mercury and silver) after being exposed to CP (10–16%)[14,15] and HP (3.6%, 6%, and 30%)[16] for a longer treatment period. This controversy might be related to the variation in peroxide concentration and time period of application. An alternative hypothesis is that there is a positive correlation between the mercury release and peroxide concentration and the increased release of mercury is attribute to the age of the dental amalgam, the surface roughness of the amalgam surface and the acidity of the bleaching agent.[17,18] Importantly, the reported concentration of mercury leaching from amalgam is still below a level associated with possible health concerns.[10,19] Furthermore, no significant changes in the surface morphology and surface microhardness of amalgam were found after application of 10% CP and HP for 70–84 hours.[20,21]

Concerns regarding greening of the tooth–amalgam margin during extended 10% CP bleaching (7–10 months) has been raised by Haywood.[22] In this case report, carious lesions were noted in all areas of the tooth that contained the green discoloration after removal of the amalgam restoration. For the same patient, when other amalgam restoration that had no greening was removed, no decay was found. Therefore, the cause of this discoloration could be due to marginal discrepancies of the amalgam restoration.

Dental alloy

Microstructural evaluation and corrosion properties of dental alloys subjected to bleaching have been investigated in the literature. Surface microhardness and scanning electron microscope observations revealed no significant deleterious effects of HP bleaching on gold alloy surfaces.[21,23] Besides those studies revealing no alteration of gold alloys, a recent study showed that whitening toothpaste had different effects on surface roughness and microhardness of commercially pure titanium and titanium–tantalum alloys compared to toothpaste without peroxide. However, the observed bleaching effects were not statistically significant.[24] In another study, surface topographic alterations of gold, Ni–Cr, and Co–Cr alloys occurred as a result of the application of 10% and 35% CP simulating at-home bleaching and in-office bleaching during 14 days, respectively.[25] Moreover, the elemental release from a Ni–Cr alloy was found to be increased due to 10% HP or 10% CP treatment for 30 days.[26] Similarly, another study also showed that the HP bleaching agents (3%, 10%, and 30%) caused increased corrosion potential of Ni–Cr and Pd–Cu–Ga alloys. As a result, exposure of Ni–Cr and Pd–Cu–Ga alloys to HP solutions for 24 hours increased metal ion release of all the elements except gold alloy.[27]

Dental ceramic

Although conventional dental ceramics are considered the most inert among dental restorative materials, feldspathic porcelain exhibited surface deterioration in contact with 10% and 35% CP for 21 days.[28] After highly concentrated HP

Please cite this article in press as: Yu H, et al., Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers, Journal of Dental Sciences (2015), http://dx.doi.org/10.1016/j.jds.2014.08.005

application (30%, 35%, 38%), the surface roughness of alumina-reinforced dental ceramic increased significantly with time of immersion as well as with the increase in concentration of HP.[29] The other investigation into the effects of 15% and 35% CP on the surface roughness and whiteness of overglazed and autoglazed low-fusing ceramic, reported that 1-week CP bleaching significantly affected the overglazed ceramic surface.[30] The increased roughness and whiteness of bleached ceramic were possibly due to the reduction of surface SiO_2 content.[31,32] Malkondu et al[33] reported that 35% CP induced a reduction in surface microhardness of both leucite-reinforced and conventional glass ceramic. However, several studies also showed contradicting results. In those studies, no detrimental effects of bleaching agents were found on the surface roughness, surface microhardness, and flexural strength of dental ceramics.[11,34,35]

Glass—ionomer cement

Most of the reviewed studies confirmed the poor resistance of glass—ionomer cement to bleaching agents. In our *in situ* studies, surface morphology and microhardness of conventional glass—ionomer cement were altered after 28-day 15% CP bleaching.[36,37] Severe matrix dissolution was evident on the surface of conventional glass-ionomer cement subjected to 15% CP.[38] Silica core localization, possibly caused by matrix dissolution after bleaching, was thought to be the explanation of increased surface microhardness of conventional glass—ionomer cement subjected to bleaching treatment.[37] However, there was no significant difference in the surface microhardness of conventional glass—ionomer cement between the bleaching groups and the control groups.[39] The less intensive bleaching regime (10% CP for 7 days) seems to be the cause of this controversy. In another laboratory investigation, we found an increased staining susceptibility of conventional glass—ionomer cement after 15% CP bleaching.[38] The severe cracks and pits on the surface of bleached glass—ionomer cement were thought to be responsible for the significant increase in staining susceptibility. Despite the reported alteration in surface morphology, a significant decrease in the flexural properties of conventional glass—ionomer cement was found after bleaching with 10% CP.[35] Additionally, it has been shown that 6% HP did not cause changes in surface dissolution and wear rate of glass-ionomer cements.[40] However, the glass—ionomer cements were bleached for only 30 minutes in that study.

With resin-modified glass—ionomer cement, the surface microhardness increased[31] or remained stable[41] after treatment with 10% CP. The elevated surface microhardness of resin-modified glass—ionomer cement was thought to be related to erosion of bleaching agents. By contrast, when utilizing a higher concentrated bleaching regimes (15% CP and 35% HP), a significant decrease in the surface microhardness of resin-modified glass—ionomer cement was reported.[42]

Polyacid-modified composite resin

There have been a limited number of studies conducted to examine bleaching effects on polyacid-modified composite resin (compomer). Bleaching agents were previously found to soften the subsurface layers of compomer up to 2 mm.[43] Similarly, for bleached compomer, we observed a significant reduction in microhardness at different subsurface levels ranging from 0.1 mm to 0.3 mm.[44] Surface and subsurface alteration, such as surface cracks and dissolution, were also found on the compomer subjected to CP, which might be responsible for the reduction in flexural strength and the increase in staining susceptibility after bleaching.[36,38,45] Wattanapayungkul et al[45] attributed the surface alteration of compomer to filler—matrix debonding caused by oxidation effects of the bleaching agents. Clinically perceptible color difference was observed for compomer subjected to 15% CP bleaching for 2 weeks.[38] However, another study showed that compomer stored in 30% HP for 120 hours did not exhibit much color difference compared with the one stored in distilled water.[46]

Composite resin

Most of the studies into the bleaching effects on dental restorative materials included composite resins as their testing subjects. Therefore, this category of restorative materials has been extensively investigated in the literature. In a laboratory study, 10% CP application for 3 weeks was able to change the surface roughness of packable composite resin. But the surface microhardness remained unchanged.[47] In our *in situ* studies, surface microhardness and texture of composite resin (nanohybrid and packable) remained stable after 15% CP treatment for 28 days.[36,37] Furthermore, under the same experimental setting, significant color changes of composite resin were observed.[36] The possible explanation of bleaching-induced color changes of composite resin could be surface alteration and oxidation of the pigment. In a laboratory study, significant surface softening was found on the composite resin when bleaching treatment (10% CP for 14 days) was performed at body temperature (37°C) while the surface microhardness remained unchanged when bleaching was performed at room temperature (25°C).[44] However, an increase in the surface microhardness was found on the composite resin subjected to highly concentrated CP gels.[33] A silorane-based resin system was recently developed based on the ring-opening polymerization of silorane molecules containing siloxane and oxirane, rather than the free radical polymerization of dimethacrylate monomers.[48] In a laboratory study, similar bleaching-induced surface softening was reported on the silorane-based and traditional types of composite resins (nano-filled and hybrid).[49] Furthermore, the silorane-based composite resin showed significantly more color alteration compared with traditional composite resins after in-office bleaching treatment (30% CP and 35% HP).[50] Despite the color changes, significant fluorescence changes of composite resins, induced by 20% and 35% HP, were found to be dependent on the material tested and bleaching therapy, regardless of the peroxide concentration.[51] It has been found that the staining susceptibility of composite resins significantly increases after application of 15% CP.[38] Surface alteration was held responsible for the elevated staining susceptibility. Moreover, 10% CP was able to remove extrinsic stains from composite resin exposed to juice, tea, and chlorhexidine.[52]

Please cite this article in press as: Yu H, et al., Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers, Journal of Dental Sciences (2015), http://dx.doi.org/10.1016/j.jds.2014.08.005

There has been controversy about the impact of bleaching agents on the subsurface microhardness of composite resin. Hannig et al[43] observed a significant decrease in the microhardness of bleached composite resins, not only on the surface, but also in the deeper layers up to 2 mm. However, in our laboratory study, subsurface microhardness of bleached composite resins remained stable at different environmental temperatures (25°C and 37°C).[44] The discrepancy might be related to the differences between the bleaching regimes and restorative materials tested.

It has been verified that CP with various concentration did not produce a detrimental effect on the fracture toughness and flexural strength of composite resin.[35,53,54] Moreover, in-office bleaching agents (35% CP and HP or even higher concentration) did not affect the tensile strength of composite resin.[55,56]

Other restorative materials

A number of studies have been conducted to investigate the bleaching effects on dental materials that were not mentioned above. Boston and Jefferies[57] reported that 36% HP bleaching for 24 hours increased the surface microhardness and caused limited changes in surface morphology of zinc phosphate cement. Two laboratory studies utilizing 10% CP and 35% HP demonstrated a significant color change of organically modified ceramic (ormocer) subjected to bleaching.[58,59] More recently, significant color changes were reported in ceramic optimized polymer (ceromer) after exposure to both 10% CP and 10% HP.[60]

Effect of bleaching agents on bond strength of restorative materials to tooth structure and brackets

It has been proposed that HP can penetrate enamel and dentin to reach the pulp cavity and the residual oxygen from bleaching agents inhibits resin polymerization.[61,62] The majority of the studies show that both shear bond strength and tensile bond strength of composite resin to enamel significantly reduced when bonding application was performed immediately after completion of bleaching treatment.[63–66] Similar findings were also reported for the newly introduced silorane-based composite resin.[67] Unlu et al[61] suggested that composite resin application onto bleached enamel surfaces should be delayed at least 24 hours after termination of 10% CP application and 1 week after completion of 35% HP application. However, other studies also showed that a delay of 1 week was not long enough to allow for optimal bonding.[68–70] Therefore, a 2-week delay is advised before performing any adhesive restorative procedure after termination of bleaching treatment.[12] It has been reported that treatment of the bleached enamel surface with antioxidizing agents, such as green tea and sodium ascorbate, was able to reverse the reduced bond strength and might be an alternative to delayed bonding.[71–73]

Similar to the bleaching effects on enamel, reduction in bond strength of composite resin and glass–ionomer cement to dentin were also reported after application of CP and HP.[74,75] Souza-Gabriel et al[76] concluded that the restorative procedure of intracoronary dentin bleached with 38% HP with or without LED-laser activation should be performed at least 10 days after the completion of bleaching treatment. Additionally, it has been shown that the bond strength of the composite resin to CP bleached enamel and dentin was dependent on the CP concentration.[77]

Moreover, an investigation using bovine incisor revealed that bleaching on enamel did not affect the bond strength of composite resin to the subjacent dentin.[78] Lima et al[79] prepared enamel–dentin cavities in the bleached tooth and evaluated the push-out bond strength of restoration made with silorane-based and DMA-based composite resins. The reported data indicated that the bleaching treatments did not significantly affect the bond strengths of composite resins to bovine enamel–dentin.

Some studies also evaluated the effects of bleaching agents on bond strength of brackets to enamel. HP bleaching reduced the shear bond strength of brackets bonded to enamel subjected to 35% HP bleaching activated by a Nd:YAG laser. Treatment of the bleached enamel surface with 10% sodium ascorbate prior to bonding was able to reverse this effect.[72] Do Rego et al[80] showed that a delay of 7 days is enough to achieve an optimal bonding strength of metal brackets bonded to previously bleached enamel. However, a laboratory study using bovine teeth concluded that external bleaching significantly influenced the shear bond strength of ceramic brackets on enamel even after 14-day saliva storage.[81]

Concluding remarks

Bleaching has become an attractive treatment modality for both patients and clinicians due to its excellent clinical effectiveness, easy application, lower cost, and safety. Based on the current evidence, bleaching agents may cause structural changes on restorative materials that may compromise their physical properties and lead to premature failure. Furthermore, if the bleaching process weakens any of the material surfaces, wear caused by subsequent tooth brushing may be increased.

Current literature reveals that the effects of bleaching on restorative materials might be material dependent. Gold alloy, dental ceramic, and composite resin exhibit the best resistance to bleaching treatment. Since only minor bleaching effects were reported, polishing of the above-mentioned restorative materials after bleaching treatment would be optimum. As for amalgam, glass–ionomer cement, and compomer, the physical properties of the bleached restorative materials might be significantly altered beyond a clinically acceptable range. Therefore, those restorations might need to be replaced after completion of bleaching. Furthermore, the bleaching effects on restorative materials might be peroxide concentration and period of application related. Increasing peroxide concentration and extending treatment time might lead to an increase in bleaching-induced negative effects. Thus, clinicians should complete the dental bleaching treatment in as short of a time as possible in order to minimize the potential adverse bleaching effects.

Please cite this article in press as: Yu H, et al., Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers, Journal of Dental Sciences (2015), http://dx.doi.org/10.1016/j.jds.2014.08.005

It is also advisable to utilize lower concentration of bleaching agents as suggested by American Dental Association (ADA) and European Scientific Committee on Consumer Products (SCCP). Bleaching effects on restorative materials might also be temperature related.[11,35,44] Elevated environmental temperature may enhance the adverse effects of the bleaching agents on restorative materials. Researchers should consider the impact of environmental temperature on the results as well as the study design when analyzing the bleaching effects on dental materials. Lastly, most of the reviewed studies were performed in laboratory setting. It remains speculative whether the reported changes of restorative materials are relevant under clinical conditions.

Based on the current evidence, clinicians should be cautious in prescribing the bleaching regimen, and should inform their patients that their existing restorations may be affected by bleaching agents and due to color difference and surface or subsurface alteration, restoration may need to be replaced. It is necessary to wait at least 2 weeks after completion of tooth bleaching before performing any adhesive procedure. If adhesive restoration has to be placed immediately after bleaching, application of antioxidizing agents might be able to reverse the negative effects of bleaching on bond strength. Moreover, application of a protective varnish on restoration surface seems to be beneficial to reduce the adverse bleaching effects on restorations.[82]

Unfortunately, none of the reviewed studies clarified the mechanism for the detrimental impact of bleaching agents on the restorative materials. Surface alterations, such as changes in the surface microhardness and morphology, have been attributed to the deleterious impact of the oxidizing bleaching agents on the polymer–matrix of resin-based materials.[44] The oxidizing effect of the bleaching agents might also be held responsible for the observed higher rate of component release from amalgam and dental alloys.[12] Alteration of enamel and dentin organic matrix and residual oxygen present in enamel and dentin after bleaching may be responsible for the reduced bond strength of restorative materials bonded to enamel and dentin. Additionally, chemical softening of the restorative materials might also occur if the bleaching products have solubility parameters similar to that of the resin matrix.[55]

Different bleaching protocols with various experimental setting are used in the current literature with the aim of simulating the clinical situation as closely as possible. Therefore, the lack of consensus about the effects of bleaching agents on restorative materials is not surprising. Taken together, it remains unclear whether the effect of bleaching agents on restorative materials is a significant concern. Further investigations with standardized and reproducible guideline are necessary to provide sufficient scientific evidence regarding bleaching effects on restorative materials.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This work was partially supported by grants from National Natural Science Foundation of China (No. 81200824), Natural Science Foundation of Fujian Province (No. 2012J05145), Funds for Young Scholar of Fujian Public Health Department (No.2012-1-28), and Science Foundation for Outstanding Scholars of Fujian Universities (No. JA12134).

References

1. Tin-Oo MM, Saddki N, Hassan N. Factors influencing patient satisfaction with dental appearance and treatments they desire to improve aesthetics. *BMC Oral Health* 2011;11:6.
2. Christensen GJ, Christensen RP. Home use bleaching survey. *CRA Newsletter* 1995;19:1.
3. Freinman RA, Goldstein RE, Garber DA. *Bleaching Teeth*. Chicago: Quintessence Books, 1987:10.
4. Burrows S. A review of the efficacy of tooth bleaching. *Dent Update* 2009;36. 537–8, 541–4, 547–8 passim.
5. Matis BA, Cochran MA, Eckert G. Review of the effectiveness of various tooth whitening systems. *Oper Dent* 2009;34: 230–5.
6. Sulieman MA. An overview of tooth–bleaching techniques: chemistry, safety and efficacy. *Periodontol 2000* 2008;48: 148–69.
7. Demarco FF, Meireles SS, Masotti AS. Over-the-counter whitening agents: a concise review. *Braz Oral Res* 2009;23(Suppl. 1):64–70.
8. Joiner A. The bleaching of teeth: a review of the literature. *J Dent* 2006;34:412–9.
9. Li Y. Safety controversies in tooth bleaching. *Dent Clin North Am* 2011;55:255–63. viii.
10. El-Murr J, Ruel D, St-Georges AJ. Effects of external bleaching on restorative materials: a review. *J Can Dent Assoc* 2011;77: b59.
11. Yu H, Li Q, Wang YN, Cheng H. Effects of temperature and in-office bleaching agents on surface and subsurface properties of aesthetic restorative materials. *J Dent* 2013;41:1290–6.
12. Attin T, Hannig C, Wiegand A, Attin R. Effect of bleaching on restorative materials and restorations—a systematic review. *Dent Mater* 2004;20:852–61.
13. Al-Salehi SK, Hatton PV, Miller CA, McLeod C, Joiner A. The effect of carbamide peroxide treatment on metal ion release from dental amalgam. *Dent Mater* 2006;22:948–53.
14. Salomone P, Bueno RP, Trinidade RF, Nascimento PC, Pozzobon RT. Assessment of the release of mercury from silver amalgam alloys exposed to different 10% carbamide peroxide bleaching agents. *Gen Dent* 2013;61:33–5.
15. Kasraei S, Rezaei-Soufi L, Azarsina M. The effect of a 16% carbamide peroxide gel on mercury and silver ion release from admixed and spherical dental amalgams. *J Contemp Dent Pract* 2010;11:E009–16.
16. Al-Salehi SK. Effects of bleaching on mercury ion release from dental amalgam. *J Dent Res* 2009;88:239–43.
17. Rotstein I, Mor C, Arwaz JR. Changes in surface levels of mercury, silver, tin, and copper of dental amalgam treated with carbamide peroxide and hydrogen peroxide *in vitro*. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1997;83:506–9.
18. Robertello FJ, Dishman MV, Sarrett DC, Epperly AC. Effect of home bleaching products on mercury release from an admixed amalgam. *Am J Dent* 1999;12:227–30.
19. Al-Salehi SK, Hatton PV, McLeod CW, Cox AG. The effect of hydrogen peroxide concentration on metal ion release from dental amalgam. *J Dent* 2007;35:172–6.

20. Ahn HJ, Song KB, Lee YE, Lee JT, Cho SA, Kim KH. Surface change of dental amalgam after treatment with 10% carbamide peroxide. *Dent Mater J* 2006;25:303—8.
21. Duschner H, Götz H, White DJ, Kozak KM, Zoladz JR. Effects of hydrogen peroxide bleaching strip gels on dental restorative materials in vitro: surface microhardness and surface morphology. *J Clin Dent* 2004;15:105—11.
22. Haywood VB. Greening of the tooth-amalgam interface during extended 10% carbamide peroxide bleaching of tetracycline-stained teeth: a case report. *J Esthet Restor Dent* 2002;14:12—7.
23. Schemehorn B, González-Cabezas C, Joiner A. A SEM evaluation of a 6% hydrogen peroxide tooth whitening gel on dental materials *in vitro*. *J Dent* 2004;32(Suppl. 1):35—9.
24. Faria AC, Bordin AR, Pedrazzi V, Rodrigues RC, Ribeiro RF. Effect of whitening toothpaste on titanium and titanium alloy surfaces. *Braz Oral Res* 2012;26:498—504.
25. Mohsen CA. The effect of bleaching agents on the surface topography of ceramometal dental alloys. *J Prosthodont* 2010;19:33—41.
26. Tamam E, Aydin AK. Surface characterization of passive film and elemental release analysis of a Ni-Cr alloy during bleaching, part I: effects of different bleaching agents. *Clin Oral Investig* 2011;15:375—82.
27. Al-Salehi SK, Hatton PV, Johnson A, Cox AG, McLeod C. The effect of hydrogen peroxide concentration on metal ion release from dental casting alloys. *J Oral Rehabil* 2008;35:276—82.
28. Moraes RR, Marimon JL, Schneider LF, Correr Sobrinho L, Camacho GB, Bueno M. Carbamide peroxide bleaching agents: effects on surface roughness of enamel, composite and porcelain. *Clin Oral Investig* 2006;10:23—8.
29. Abu-Eittah MR, Mandour MH. *In vitro* study of the effect of three hydrogen peroxide concentrations on the corrosion behavior and surface topography of alumina-reinforced dental ceramic. *J Prosthodont* 2011;20:541—52.
30. Zaki AA, Fahmy NZ. The effect of a bleaching system on properties related to different ceramic surface textures. *J Prosthodont* 2009;18:223—9.
31. Türker SB, Biskin T. The effect of bleaching agents on the microhardness of dental aesthetic restorative materials. *J Oral Rehabil* 2002;29:657—61.
32. Türker SB, Biskin T. Effect of three bleaching agents on the surface properties of three different esthetic restorative materials. *J Prosthet Dent* 2003;89:466—73.
33. Malkondu Ö, Yurdagüven H, Say EC, Kazazoğlu E, Soyman M. Effect of bleaching on microhardness of esthetic restorative materials. *Oper Dent* 2011;36:177—86.
34. Ourique SA, Arrais CA, Cassoni A, Ota-Tsuzuki C, Rodrigues JA. Effects of different concentrations of carbamide peroxide and bleaching periods on the roughness of dental ceramics. *Braz Oral Res* 2011;25:453—8.
35. Yu H, Li Q, Lin Y, Buchalla W, Wang Y. Influence of carbamide peroxide on the flexural strength of tooth-colored restorative materials: an *in vitro* study at different environmental temperatures. *Oper Dent* 2010;35:300—7.
36. Li Q, Yu H, Wang Y. Colour and surface analysis of carbamide peroxide bleaching effects on the dental restorative materials *in situ*. *J Dent* 2009;37:348—56.
37. Yu H, Li Q, Hussain M, Wang Y. Effects of bleaching gels on the surface microhardness of tooth-colored restorative materials *in situ*. *J Dent* 2008;36:261—7.
38. Yu H, Pan X, Lin Y, Li Q, Hussain M, Wang Y. Effects of carbamide peroxide on the staining susceptibility of tooth-colored restorative materials. *Oper Dent* 2009;34:72—82.
39. Mujdeci A, Gokay O. Effect of bleaching agents on the microhardness of tooth-colored restorative materials. *J Prosthet Dent* 2006;95:286—9.
40. Mair L, Joiner A. The measurement of degradation and wear of three glass ionomers following peroxide bleaching. *J Dent* 2004;32(Suppl. 1):41—5.
41. Campos I, Briso AL, Pimenta LA, Ambrosano G. Effects of bleaching with carbamide peroxide gels on microhardness of restoration materials. *J Esthet Restor Dent* 2003;15:175—82. discussion 83.
42. Taher NM. The effect of bleaching agents on the surface hardness of tooth colored restorative materials. *J Contemp Dent Pract* 2005;6:18—26.
43. Hannig C, Duong S, Becker K, Brunner E, Kahler E, Attin T. Effect of bleaching on subsurface micro-hardness of composite and a polyacid modified composite. *Dent Mater* 2007;23:198—203.
44. Yu H, Li Q, Cheng H, Wang Y. The effects of temperature and bleaching gels on the properties of tooth-colored restorative materials. *J Prosthet Dent* 2011;105:100—7.
45. Wattanapayungkul P, Yap AU, Chooi KW, Lee MF, Selamat RS, Zhou RD. The effect of home bleaching agents on the surface roughness of tooth-colored restoratives with time. *Oper Dent* 2004;29:398—403.
46. Kwon YH, Kwon TY, Kim HI, Kim KH. The effect of 30% hydrogen peroxide on the color of compomers. *J Biomed Mater Res B Appl Biomater* 2003;66:306—10.
47. Basting RT, Fernandéz YFC, Ambrosano GM, de Campos IT. Effects of a 10% carbamide peroxide bleaching agent on roughness and microhardness of packable composite resins. *J Esthet Restor Dent* 2005;17:256—62. discussion 63.
48. Yu H, Wegehaupt FJ, Wiegand A, Roos M, Attin T, Buchalla W. Erosion and abrasion of tooth-colored restorative materials and human enamel. *J Dent* 2009;37:913—22.
49. AlQahtani MQ. The effect of a 10% carbamide peroxide bleaching agent on the microhardness of four types of direct resin-based restorative materials. *Oper Dent* 2013;38:316—23.
50. Mourouzis P, Koulaouzidou EA, Helvatjoglu-Antoniades M. Effect of in-office bleaching agents on physical properties of dental composite resins. *Quintessence Int* 2013;44:295—302.
51. Torres CR, Ribeiro CF, Bresciani E, Borges AB. Influence of hydrogen peroxide bleaching gels on color, opacity, and fluorescence of composite resins. *Oper Dent* 2012;37:526—31.
52. Fay RM, Servos T, Powers JM. Color of restorative materials after staining and bleaching. *Oper Dent* 1999;24:292—6.
53. Cho SD, Bulpakdi P, Matis BA, Platt JA. Effect of bleaching on fracture toughness of resin composites. *Oper Dent* 2009;34:703—8.
54. Hatanaka GR, Abi-Rached Fde O, Almeida-Júnior AA, Cruz CA. Effect of carbamide peroxide bleaching gel on composite resin flexural strength and microhardness. *Braz Dent J* 2013;24:263—6.
55. Yap AU, Wattanapayungkul P. Effects of in-office tooth whiteners on hardness of tooth-colored restoratives. *Oper Dent* 2002;27:137—41.
56. Cullen DR, Nelson JA, Sandrik JL. Peroxide bleaches: effect on tensile strength of composite resins. *J Prosthet Dent* 1993;69:247—9.
57. Boston DW, Jefferies SR. Effects of a 36% tooth bleaching gel on zinc phosphate cement. *J Biomed Mater Res B Appl Biomater* 2010;92:456—61.
58. Yalcin F, Gurgan S. Bleaching-induced colour change in plastic filling materials. *J Biomater Appl* 2005;19:187—95.
59. Hubbezoglu I, Akaoğlu B, Dogan A, et al. Effect of bleaching on color change and refractive index of dental composite resins. *Dent Mater J* 2008;27:105—16.
60. Kara HB, Aykent F, Ozturk B. The effect of bleaching agents on the color stability of ceromer and porcelain restorative materials *in vitro*. *Oper Dent* 2013;38:E1—8.

Please cite this article in press as: Yu H, et al., Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers, Journal of Dental Sciences (2015), http://dx.doi.org/10.1016/j.jds.2014.08.005

61. Unlu N, Cobankara FK, Ozer F. Effect of elapsed time following bleaching on the shear bond strength of composite resin to enamel. *J Biomed Mater Res B Appl Biomater* 2008; 84:363—8.
62. Kwon SR, Li Y, Oyoyo U, Aprecio RM. Dynamic model of hydrogen peroxide diffusion kinetics into the pulp cavity. *J Contemp Dent Pract* 2012;13:440—5.
63. Stokes AN, Hood JA, Dhariwal D, Patel K. Effect of peroxide bleaches on resin-enamel bonds. *Quintessence Int* 1992;23: 769—71.
64. Dishman MV, Covey DA, Baughan LW. The effects of peroxide bleaching on composite to enamel bond strength. *Dent Mater* 1994;10:33—6.
65. Lago AD, Garone-Netto N. Microtensile bond strength of enamel after bleaching. *Indian J Dent Res* 2013;24:104—9.
66. Can-Karabulut DC, Karabulut B. Influence of activated bleaching on various adhesive restorative systems. *J Esthet Restor Dent* 2011;23:399—408.
67. Güler E, Gönülol N, Özyilmaz ÖY, Yücel AÇ. Effect of sodium ascorbate on the bond strength of silorane and methacrylate composites after vital bleaching. *Braz Oral Res* 2013;27: 299—304.
68. Cavalli V, Reis AF, Giannini M, Ambrosano GM. The effect of elapsed time following bleaching on enamel bond strength of resin composite. *Oper Dent* 2001;26:597—602.
69. McGuckin RS, Thurmond BA, Osovitz S. Enamel shear bond strengths after vital bleaching. *Am J Dent* 1992;5:216—22.
70. Titley KC, Torneck CD, Ruse ND, Krmec D. Adhesion of a resin composite to bleached and unbleached human enamel. *J Endod* 1993;19:112—5.
71. Türkün M, Kaya AD. Effect of 10% sodium ascorbate on the shear bond strength of composite resin to bleached bovine enamel. *J Oral Rehabil* 2004;31:1184—91.
72. Akin M, Ozyilmaz OY, Yavuz T, Aykent F, Basciftci FA. Effect of Nd:YAG laser bleaching and antioxidizing agents on the shear bond strength of brackets. *Photomed Laser Surg* 2013;31: 365—70.
73. Berger SB, De Souza Carreira RP, Guiraldo RD, et al. Can green tea be used to reverse compromised bond strength after bleaching? *Eur J Oral Sci* 2013;121:377—81.
74. Spyrides GM, Perdigão J, Pagani C, Araujo MA, Spyrides SM. Effect of whitening agents on dentin bonding. *J Esthet Dent* 2000;12:264—70.
75. Titley KC, Torneck CD, Smith DC, Applebaum NB. Adhesion of a glass ionomer cement to bleached and unbleached bovine dentin. *Endod Dent Traumatol* 1989;5:132—8.
76. Souza-Gabriel AE, Vitussi LO, Milani C, Alfredo E, Messias DC, Silva-Sousa YT. Effect of bleaching protocols with 38% hydrogen peroxide and post-bleaching times on dentin bond strength. *Braz Dent J* 2011;22:317—21.
77. Barcellos DC, Benetti P, Fernandes Jr VV, Valera MC. Effect of carbamide peroxide bleaching gel concentration on the bond strength of dental substrates and resin composite. *Oper Dent* 2010;35:463—9.
78. Lima AF, Fonseca FM, Freitas MS, Palialol AR, Aguiar FH, Marchi GM. Effect of bleaching treatment and reduced application time of an antioxidant on bond strength to bleached enamel and subjacent dentin. *J Adhes Dent* 2011; 13:537—42.
79. Lima AF, Sasaki RT, Araújo LS, et al. Effect of tooth bleaching on bond strength of enamel-dentin cavities restored with silorane- and dimethacrylate-based materials. *Oper Dent* 2011;36:390—6.
80. Do Rego MV, dos Santos RM, Leal LM, Braga CG. Evaluation of the influence of dental bleaching with 35% hydrogen peroxide in orthodontic bracket shear bond strength. *Dental Press J Orthod* 2013;18:95—100.
81. Firoozmand LM, Brandao JV, Fialho MP. Influence of micro-hybrid resin and etching times on bleached enamel for the bonding of ceramic brackets. *Braz Oral Res* 2013;27:142—8.
82. Yu H, Li Q, Attin T, Wang Y. Protective effect of resin coating on the microleakage of Class V restorations following treatment with carbamide peroxide *in vitro*. *Oper Dent* 2010;35: 634—40.

Please cite this article in press as: Yu H, et al., Effects of bleaching agents on dental restorative materials: A review of the literature and recommendation to dental practitioners and researchers, Journal of Dental Sciences (2015), http://dx.doi.org/10.1016/j.jds.2014.08.005