Aesthetic changes of restorative materials related to application of topical fluorides
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ABSTRACT
Objectives: This study aimed to identify and compare aesthetic changes following application of 1.23% acidulated phosphate fluoride gels (APF), 0.4% stannous fluoride gels (SnF₂) and/or 2% neutral sodium fluoride gels (NaF) to composite resin (CR), glass ionomer cement (GIC) and/or resin-modified glass ionomer cement (RMGIC) in vitro.

Materials and Methods: A total of 300 specimens of dental restorative materials including GIC, RMGIC and CR were packed in plastic arrays, selectively polished, and then topically applied with APF, SnF₂, NaF, phosphoric acid etchant, and tap water, respectively. Aesthetic changes of restorative materials were assessed by three examiners with shade guides. Additional experiments included tooth-brushing and application of plaque disclosing solution on the specimens.

Results: Application of NaF (p= 0.001, OR= 6253.1), APF (p= 0.001, OR= 40.5) and/or SnF₂ (p= 0.002, OR= 12.7) more likely discoloured restorative materials than immersion in tap water. Phosphoric acid did not differ in the discolouring potential with tap water (p= 0.734). CR had a higher risk of discoulration compared to RMGIC (p= 0.001, OR= 4.5). There was no difference in the discoulration potential between GIC and RMGIC (p=0.065). Unpolished restorative materials were more likely to show discolouration than polished ones after topical application of fluorides (p= 0.045, OR= 1.9).

Conclusion: This study has suggested that NaF has the highest risk potential to discoulour dental restorations, followed by APF and SnF₂. A higher susceptibility amongst CR has been confirmed. Polishing dental restorations has provided a protective effect against discoulration induced by topical fluorides. Future investigations are indicated.
INTRODUCTION
Fluoride (F-) has been found relevant to improvement of oral health for 70 years [Bibby, 1942]. Effects of fluoride to the dentition are generally achieved via systemic and topical pathways [Cameron and Widmer, 2008; Carey, 2014; ten Cate and van Loveren, 1999]. Systemic fluoride is ingested and incorporated into the dentition by transforming hydroxyapatite crystals of enamel and dentine to fluorapatite at the developmental stage of teeth [Carey, 2014; ten Cate and van Loveren, 1999]. Topical fluoride protects teeth from demineralisation, promotes remineralisation and shows antibacterial effects [Carey, 2014; ten Cate and van Loveren, 1999]. After teeth erupt and become fully developed, only topical fluoride but not systemic fluoride can provide an anticariogenic effect. Fluoridated toothpaste is the most commonly used approach of topical fluorides, whilst other sources of topical fluorides such as fluoridated mouth rinse and specially formulated topical fluoride can also be applied at home or by dental professionals [Cameron and Widmer, 2008; Carey, 2014].

Concentrated fluoride products designed specifically for topical applications by dental professionals vary in chemical composition and concentration. Some commonly used products include 1.23% (12300ppm F) acidulated phosphate fluoride gels (APF), 0.4% (1000 ppm F) stannous fluoride gels (SnF2) and 2% (9000ppm F) neutral sodium fluoride gels (NaF) [Cameron and Widmer, 2008]. As a matter of fact, standard adult fluoridated toothpaste has a typical fluoride concentration of 1000-1100ppm [Cameron and Widmer, 2008]. In spite of the variety of topical fluoride products and the benefit to teeth, past studies have also reported a detrimental effect of topical fluorides on dental restorations, specifically changes in aesthetics of tooth-coloured materials [Cehreli et al., 2000; Kula et al., 1983; Lin and Huang, 2015; Papagiannoulis et al., 1997; Turssi et al., 2001; Wang and Huang, 2007; 2014; Yaffe and Zalkind, 1981].

Previous studies have demonstrated an association between topical application of APF gel and aesthetic changes of various restorative materials. Composite resin (CR) has been found susceptible to surface degradation, evident as increased surface roughness, following application of APF gels [Cehreli et al., 2000; Kula et al., 1983; Papagiannoulis et al., 1997; Turssi et al., 2001; Wang and Huang, 2007; Yaffe and Zalkind, 1981]. Loss of filler particles as a result of acid dissolution has been attributed as a potential cause of surface degradation of restorative materials [Cehreli et al., 2000; Kula et al., 1983; Kula et al., 1997; Soeno et al., 2001; Turssi et al., 2001; Yaffe and Zalkind, 1981]. Weight loss of CR after APF gel application could indicate loss of filler particles [Kula et al., 1983; Kula et al., 1997]. Macrofilled and barium containing CR were more susceptible to surface degradation than microfilled and zirconium filled CR which were not affected by APF [Papagiannoulis et al., 1997; Tanoue et al., 2004]. Of further note, earlier studies have reported an effect of APF on changing the surface morphology and/or inducing visible stains at the tooth-restoration margin of glass ionomer cements (GIC), resin-modified glass ionomer cements (RMGIC) and polyacid modified CR [Cehreli et al., 2000; Lin and Huang, 2015; Neuman and Garcia-Godoy, 1992; Turssi et al., 2001].

Only a few papers have reported an influence of SnF2 application on restorative materials and their conclusions were controversial. A past study has demonstrated that SnF2 gels did not stain CR and microfilled resin [Cooley and Barkmeier, 1983]. Another study has not found any change in surface morphology of barium containing CR and microfilled CR [Papagiannoulis et al., 1997]. Nevertheless, application of SnF2 gels
could increase surface roughness of zirconium-reinforced CR [Papagiannoulis et al., 1997] and result in weight loss of CR [Kula et al., 1997].

Similarly, literatures have reported controversial findings about the relationship between NaF and aesthetic changes of restorative materials. Some studies have suggested that neutral NaF did not affect the surface morphology of CR [De Witte et al., 2003; Debner et al., 2000; Papagiannoulis et al., 1997; Turssi et al., 2001]. In contrast, several researchers have demonstrated that NaF resulted in weight loss of CR [Kula et al., 1997] and/or surface roughness of GIC [Billington et al., 2000; De Witte et al., 2003]. Of further note, RMGIC was not as susceptible to NaF as GIC [Debner et al., 2000; Turssi et al., 2001]. Fuji II LC which is an RMGIC product was not affected by NaF application [Debner et al., 2000; Turssi et al., 2001] except becoming more translucent after a prolonged use of NaF mouthwash [Garcia et al., 2002]. On the other hand, Photac-Fil which is another RMGIC was susceptible to surface degradation following NaF and/or APF gel application [Turssi et al., 2001]. This could result from fragility of Photac-Fil, since both acidic and alkaline solutions contributed to surface erosion [Turssi et al., 2001].

Except for a paper reporting a negligible influence of tooth-brushing on restorations applied with NaF [Debner et al., 2000], we believe that no previous work has reported a comparison of the effect of polished against unpolished surfaces of restorative materials. In addition, no literature has suggested a discolouring potential of APF gel against phosphoric acid etchant. Furthermore, different study designs used and controversial research findings reported in the literature have not contributed to a consistent comparison among the effects of professionally applied topical fluorides on various restorative materials. Hence, the aim of this study was to carry out case-control research to identify and compare aesthetic changes following application of APF, SnF$_2$ and/or NaF to CR, GIC and/or RMGIC in vitro.

MATERIALS AND METHODS
In this study, three different restorative materials were the subject of testing, including Fuji IX (GC America), Fuji II LC (GC America) and Z100 composite resin (3M ESPE). These materials represented GIC, RMGIC and CR, respectively. A shade of A2 was selected amongst all restorative materials in order to create the same benchmark for assessment of later discolouration. The manufacturer’s instructions were followed regarding mixing, placing and setting of all materials. The size of the sample was calculated with the Epi Info (Version 7, Centers for Disease Control and Prevention, Atlanta, GA, USA). We estimated that 18 specimens was the minimum number of subjects required for each test. The estimation was made with a two-sided significance at 5%, an explanatory power at 80%, and a ratio of Controls to Cases at 1, with 30.3% of Controls and 99.9% of Cases with exposure [Wang and Huang, 2014]. To account for an estimated rate of missing specimens of 10%, twenty specimens per restorative material was decided and packed in plastic arrays containing 96 cylindrical wells, each well with a capacity of 200 μL. A total of five plastic arrays (grouped A to E) were prepared, one for each immersion. Each plastic array housed two subgroups of 10 specimens of each restorative material (Subgroup 1 and 2 for GIC, Subgroup 3 and 4 for RMGIC, and Subgroup 5 and 6 for CR), totalling 60 specimens per array and 300 specimens in total. The specimens were left dry for 24 hours, and then all of the even numbered subgroups were polished with Sof-Lex discs under water spray.
Each of the five plastic arrays (grouped A to E) was applied with a different solution, including 1.23% APF gel (pH=3.5) for Group A, 0.4% SnF$_2$ gel (pH=3) for Group B, 2% NaF gel (pH=7) for Group C, 37% phosphoric acid etchant (pH=1) for Group D, and tap water (pH=7) for Group E (the control group). The tap water was collected from the Perth metropolitan area, Western Australia, with a 0.8 ppm F$^-$ concentration [Water Corporation, 2012].

Each plastic array representing a group was immersed in the corresponding test solution for 5 minutes. The plastic arrays were then removed from the solutions and any excess removed with absorbent paper towel. After an hour, each specimen was rinsed thoroughly with tap water and over the next 24 hours, immersed in tap water, chosen for its similar pH and fluoride concentration to normal resting saliva [Guyton and Hall, 2005; Oliveby et al., 1990]. Each specimen was then assessed with the material manufacturers’ standard shade guides by three examiners using a blind testing method in order to determine changes in shade [Lin and Huang, 2015; Wang and Huang, 2014], and the results recorded in the database as Test 1. Every 10th sample was re-examined to test for reliability. The specimens were then brushed with an electric toothbrush for 2 minutes, rinsed with tap water and the shade of the specimens evaluated by three examiners with blind testing. The data collected were recorded as Test 2. Following that, plaque disclosing solution was applied to each specimen and retention of the solution on the surface of the restorative material was assessed by three examiners with blind testing. The data were recorded as Test 3.

Cohen’s Kappa Coefficient of Agreement was used to measure the inter-examiner reliability [Altman, 1991]. A statistical analysis of the data produced a categorical dependent variable based upon occurrence (yes/no) of discolouration and/or staining with plaque disclosing solution. Independent variables tested included polishing of the surface (yes/no), tooth-brushing (yes/no), fluoride products (APF/SnF$_2$/NaF), and restorative materials (GIC/RMGIC/CR). A logistic regression model was applied to assess the individual contribution of independent variables studied [Altman, 1991]. The level of two-sided significance was set at 5%.

RESULTS
The Kappa values for occurrence of aesthetic changes in Test 1, Test 2 and Test 3 were 0.96, 0.96 and 1.00, respectively. These values indicated an ‘almost perfect’ inter-examiner agreement.

In Test 1, application of NaF (p= 0.001, OR= 6253.1), APF (p= 0.001, OR= 40.5) and/or SnF$_2$ (p= 0.002, OR= 12.7) more likely discoloured restorative materials than immersion in tap water. Phosphoric acid did not present a different discolouring potential than tap water (p= 0.734). After tooth-brushing in Test 2, none of the restorative materials previously applied with NaF, APF, SnF$_2$ and/or phosphoric acid showed a difference in discolouration rate than those immersed in tap water (p≥0.240). Upon application of plaque disclosing solution in Test 3, restorative materials previously applied with NaF (p= 0.036, OR= 2.5), APF (p= 0.006, OR= 3.7) and/or SnF$_2$ (p= 0.011, OR= 3.2) had a higher risk of stain retention than those immersed in tap water.

After Test 1, CR showed a higher likelihood of discolouration than RMGIC (p= 0.001, OR= 4.5). There was no difference in the discolouration potential between GIC and RMGIC (p=0.065). After tooth-brushing (Test 2), CR (p= 0.001, OR= 147.5) and GIC (p= 0.001, OR= 453.8) more likely displayed an aesthetic change than RMGIC.
After application of plaque disclosing solution (Test 3), retention of the stain was more likely identified in GIC than in CR (p= 0.001, OR= 3.8). RMGIC and CR did not differ in the retention rate of the stain (p= 0.424).

Unpolished restorative materials more likely showed discoloration than their counterparts after topical application of fluorides (Test 1) (p= 0.045, OR= 1.9) but not after tooth-brushing (Test 2) (p=0.296). Retention of stain from plaque disclosing solution (Test 3) was more likely seen on the surface of polished restorative materials than that of unpolished ones (p= 0.007, OR= 2.2).

DISCUSSION
This is the first study to report that NaF has the highest risk potential to discolor restorative materials, followed by APF and SnF₂, according to the odds ratios estimated. The risk potential of inducing discoloration from NaF was 492 times and 154 times of that from SnF₂ and APF, respectively. The discoloration was found removable by tooth-brushing and consequently no difference in the discoloring rate between topical fluorides and tap water could be identified after the restorations were brushed with an electric toothbrush. This indicated a possibility that the visible discoloration induced by topical fluorides was a stain of an extrinsic nature. Nevertheless, in Test 3 a higher frequency of staining retention was seen on restorative materials previously treated with topical fluorides. Since plaque disclosing agents could retain to restorative surfaces that were intrinsically stained as a result of uneven surface morphology [Hino et al., 2005], surface degradation caused by topical fluorides was also suspected by this study. This agreed with earlier papers that have reported surface degradation following topical fluoride application [Cehreli et al., 2000; Kula et al., 1983; Papagiannoulis et al., 1997; Turassi et al., 2001; Wang and Huang, 2007; Yaffe and Zalkind, 1981]. On the other hand, application of 37% phosphoric acid on the surface of restorative materials did not result in discoloration. Although a previous study has reported an increasing rate of discoloration upon a decreasing pH level of APF, only the pH range equal to or higher than 3.5 has been examined [Wang and Huang, 2014]. The pH value of 37% phosphoric acid used for etching was approximated as 1 and this was more acidic than APF (pH=3.5) and SnF₂ (pH=3) used in this study. As neutral NaF presented a higher risk potential of discoloring dental restorations than APF and SnF₂, fluoride was therefore more influential than acidity regarding discoloring potentials. A comparison of SnF₂ at various pH values would be unattainable, since precipitation of SnF₂ occurred readily when the pH value was larger than 4 [Muhler and Day, 1952]. In order to confirm the influence from fluoride and acidity, further investigations into the discoloring effect of NaF at various pH values are indicated.

This study has also confirmed that CR had a higher susceptibility of discoloration induced by topical fluorides. This disagreed with Lin and Huang who have reported the highest staining potential of GIC followed by RMGIC and CR [Lin and Huang, 2015]. Previous studies have suggested surface degradation of CR as a relevant outcome following application of APF [Cehreli et al., 2000; Kula et al., 1983; Papagiannoulis et al., 1997; Turassi et al., 2001; Wang and Huang, 2007; Yaffe and Zalkind, 1981]. As CR has been found more resistant to acid than GIC and RMGIC [Hengtrakool et al., 2011], the high discoloration rate of CR reported by our study could also indicate that fluoride was more influential to discoloration than acidity. This study has also suggested that GIC had aesthetic changes more often than RMGIC after tooth-brushing, even though the difference has been insignificant before tooth-brushing. Of further note, a past study
has identified a significant degree of surface roughness after tooth-brushing on GIC, specially Fuji IX [Carvalho et al., 2012]. Thus, the aesthetic changes of Fuji IX GIC restorations after tooth-brushing could result from physical removal of surface particles by a toothbrush other than chemical removal by topical fluorides. This could also contribute to stain retention on the surface of GIC restorations in our study.

On the other hand, this study has suggested a protective effect of polishing on discolouration induced by topical fluorides. Because a polished surface of restorative materials showed less irregularity to topical fluorides, the increased resistance acquired from polishing was understandable. Nevertheless, the protective effect disappeared after tooth brushing. Upon application of a plaque disclosing agent, polished surfaces showed stain retention more readily than unpolished ones. This disagreed with a recent article which has reported a higher stain resistance of polished composite resin [Barakah and Taher, 2014]. Thus, tooth-brushing may have resulted in polished surfaces rougher than unpolished ones.

Although this study has reported findings with clinical relevance, interpreting the outcomes however should carefully take research limitations into account. Firstly, products of the same type of topical fluorides and/or restorative materials could show different risk potentials of aesthetic changes. Yeh et al have suggested that the APF gels containing complex colloidal magnesium aluminum silicate smectite clay did not cause surface changes of CR, compared to APF products without the component [Yeh et al., 2011]. Another study has also reported different susceptibility to topical-fluoride-induced surface degradation between two products of RMGIC [Turssi et al., 2001]. Hence, results reported by our study may not apply to other products of topical fluorides and restorative materials. Secondly, test accuracy of aesthetic changes inspected with shade guides might be compromised although an ‘almost perfect’ inter-examiner agreement has been reported. Implementation of techniques such as scanning electron microscopy [Cehreli et al., 2000; Kula et al., 1983; Kula et al., 1997; Neuman and Garcia-Godoy, 1992; Papagiannoulis et al., 1997; Soeno et al., 2001; Wang and Huang, 2007], photomicrograph [Turssi et al., 2001] and/or spectroscopy [Papagiannoulis et al., 1997] could benefit the methodology of this study.

CONCLUSION
This study has demonstrated that NaF has the highest risk potential for discolouring dental restorations, followed by APF and SnF₂. A higher susceptibility to topical fluorides on CR has also been confirmed. In addition, polishing dental restorations has provided a protective effect against discolouration induced by topical fluorides.

Aesthetic change attributed to topical fluoride application is an issue that dental clinicians should notice. Topical fluoride products with a lower discolouring risk potential can be selected and used for those patients whose teeth have been restored with tooth-coloured materials. To safely enhance anticariogenicity of fluoride without introducing the detrimental discolouration, succeeding investigations into the mechanism of discolouration are indicated.

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REFERENCE


