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Effect of Beverages on Color and Translucency of New Tooth-Colored Restoratives

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Clinical Relevance

When exposed to dark beverages, nano-filled glass ionomer and Giomers were more susceptible to staining and translucency changes than composites but less susceptible than resin-modified glass ionomer cement. Increased staining was correlated with a decrease in translucency, compromising clinical esthetics.

ABSTRACT

This investigation examined the susceptibility to staining and translucency changes of some new tooth-colored restorative materials after immersion in different beverages. The materials studied were 3M Filtek Z350XT (ZT), 3M Filtek 350XT Flowable Restorative (ZF), Shofu Beautifil Flow Plus (BF), Shofu Beautifil II (B2), 3M Ketac Nano (N100), and 3M Photac Fil (PF). Following the manufacturers' instructions, 42 samples were made from each material and placed in an incubator at 100% humidity and 37°Celsius for 24 hours. Baseline L*, a*, b* readings were taken against white and black backgrounds using a photospectrometer. The samples were then randomly assigned to be immersed in seven beverages, namely cola drink, orange juice, red wine, vodka, black coffee, green tea, and distilled water for a period of seven days. Color readings were taken again by recording the L*, a*, b* values. Data was analyzed using *t*-tests, one-way analysis of variance with Tukey post hoc and Pearson's correlation ($p<0.05$). BF generally performed as well as the conventional composite resin materials (ZT and ZF) but N100 and B2 did not. PF had the largest staining and translucency changes. Coffee, red wine, and tea resulted in the most staining and negative translucency changes. An inverse correlation between ΔE and ΔTP was observed for all materials and beverages with the exception of orange juice.

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INTRODUCTION

Patients desire long-lasting restorations that are functional and esthetically pleasing.[1] Influences from the mass media[2] and changes in social economics have increased the esthetic demands of patients.[3] Coupled with recent efforts to phase out dental amalgam, there is a pressing need for tooth-colored materials that possesses comparable mechanical properties.

Resin-based composites and glass ionomer cements form the cornerstone of the spectrum of tooth-colored restoratives. The development of these materials has focused on modifying their biphasic compositions. Hybrid materials, with the principal base material incorporating elements and strengths from the other group, have also been developed. Today, tooth-colored restorative materials are routinely used to restore teeth. With adhesive technology and use of micromechanical retention, tooth-colored restorations are not only more conservative but also have less microleakage than amalgam restorations.[4]

Tooth-colored restorations, however, have their shortcomings. These include surface degradation (resulting in roughness), technique-sensitive bonding, fracture, and susceptibility to staining. [5–8] Studies have compared and reported on the susceptibility to staining of tooth-colored restorations in different food-simulating liquids or beverages through color or translucency changes.[9–13] Tian & others state that "most materials are susceptible to staining by 'dark' beverages while distilled water causes no perceptible color change."[10] These dark beverages have constantly shown to be coffee and red wine.[9–13]

Tooth-colored materials discolor via three mechanisms: 1) intrinsic discoloration, caused by the material itself aging; 2) extrinsic discoloration, caused by the accumulation of plaque and surface staining from diet; and 3) surface degradation, with staining agents reacting with the material (absorption).[1,15] The susceptibility to staining of tooth-colored restorations has been attributed to both internal and external factors. Factors include the material itself, the environment, the patient, and the clinician. The composition of the matrix, amount of filler loading and filler size, along with the biphasic nature of resin-based composites, are important intrinsic components to consider. Externally, the type of staining agent, the duration of exposure, and its compatibility with the matrix of the material are factors influencing the susceptibility to staining. The patient's diet and oral hygiene habits, along with the clinician's manipulation of the material, are no doubt important as well.[16]

New hybrid tooth-colored restorative materials that combine resin-based composite and glass ionomer technology are constantly being developed. They include nano-ionomers (Ketac N100) and pre-reacted glass ionomer filled composites (Giomer). Ketac N100 (N100) contains nanofillers and clusters of nano-sized zirconia/silica that result in a highly packed filler composition. Bala & others[17] and Coutinho & others[18] examined the surface roughness after polish and the bonding effectiveness to tooth structure of Ketac N100, respectively. The studies concluded that N100 had the smoothest surface after polishing compared with other glass ionomer cements. The bond strength to tooth structure of N100 was comparable to conventional glass ionomer cement (Fuji IX GP) but lower than resin-modified glass ionomer cement (Fuji II LC).[18] The fluoride release profile was deemed comparable to other resin-modified glass ionomer cements.[19]

Giomers are novel resin-based composites developed from surface-modified pre-reacted glass ionomer cement (SMPRG) technology. Giomers have methacrylate-based resin matrixes similar to resin-based composites, with SMRPG fillers instead of traditional quartz and glass fillers. Studies have shown that Giomers have better polishability and higher flexural strength and fluoride release compared with regular glass ionomer cements.[20–22] Compared with resin-based composites, Giomers were shown to have similar mechanical properties in terms of compressive strength, flexural strength, fracture toughness, micro-hardness, and polymerization shrinkage.[23]

Studies have been conducted to examine the staining susceptibility of Giomers in food- simulating liquids and limited beverages,[10] but there have been limited studies examining staining susceptibility of nano-ionomers and injectable hybrid Giomers and their performance in comparison to other materials.

This study investigated the color and translucency changes of these new restorative materials. Standard and flowable materials' susceptibilities to staining and translucency changes were compared. The staining ability and translucency change caused by the different beverages were also compared, and possible correlations between color and translucency change were investigated.

METHODS AND MATERIALS

Six commercial tooth-colored restorative materials were selected for this experiment: two resin-based composites, 3M Filtek Z350XT (ZT) and 3M Filtek

Table 1: *Technical Profiles and Manufacturers of the Materials Evaluated*

Material/Shade/ Lot number	Category	Composition		Mean filler size (μm)	Manufacturer
Filtek™ Z350XT/ A2/ N454576	Nanocomposite	Silane Treated Ceramic Silane Treated Silica UDMA BISEMA6	BISGMA Silane Treated Zirconia Polyethylene Glycol Dimethacrylate TEGDMA 2,6-Di-Tert-Butyl-P-Cresol	0.6 to 1.4	3M™ ESPE™ St Paul, MN, USA
Filtek™ Z350XT Flowable/A2/ N452481	Nanocomposite	Silane Treated Ceramic BISGMA TEGDMA Silane Treated Silica	Silane Treated Zirconium Oxide BISEMA6 Functionalized Dimethacrylate Polymer	0.6 to 1.4	3M™ ESPE™ St Paul, MN, USA
Beautifil Flow Plus/ A2/121240	Giomer	BISGMA TEGDMA	Aluminofluoro-borosilicate glass Al_2O_3 DL-Camphorquinone	0.01–4.0	Shofu Dental Corporation, Osaka, Japan
Beautifil/A2/111268	Giomer	BISGMA TEGDMA	Aluminofluoro-borosilicate glass Al_2O_3, DL-Camphorquinone	0.01–4.0	Shofu Dental Corporation, Osaka, Japan
Ketac™ Nano/A2/ N432469	Nanofilled RMGIC	Paste A: Silane Treated Glass Silane Treated Zirconia PEGDMA Silane Treated Silica HEMA Glass Powder BISGMA TEGDMA	Paste B: Silane Treated Ceramic Copolymer Of Acrylic And Itaconic Acids Water HEMA	0.0001(nanoparticle)-0.1(nanoclusters)	3M™ ESPE™ St Paul, MN, USA
Photac™ Fil/A2/ 501018	RMGIC	Powder: Silane Treated Glass Powder N,N-Dimethylbenzocaine	Liquid: 2-Hydroxyethyl Methacrylate Copolymer Of Acrylic Acid-Maleic Acid Water Mono- and Di- HEMA Phosphate, Magnesium Salt Diurethane Dimethacrylate	7–40	3M™ ESPE™ St Paul, MN, USA

BISEMA6; bisphenol A polyethylene glycol diether dimethacrylate; Bis-GMA, bisphenylglycidyl dimethacrylate; BISGMA, bisphenol A diglycidyl ether dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; PEGDMA, polyethylene glycol dimethacrylate; RMGIC, resin-modified glass ionomer cement; TEGDMA, triethylene glycol dimethacrylate; UDMA, urethane dimethacrylate.

Z350XT Flowable Restorative (ZF); two Giomers, Shofu Beautifil II (B2) and Beautifil Flow Plus (BF); and two glass ionomer cements, 3M Ketac Nano (N100) and 3M Photac Fil (PF). The technical profiles of the materials are described in Table 1.

The materials were activated and mixed according to the manufacturer's instructions, where applicable. They were packed into standardized circular molds measuring 9 mm in diameter and 1 mm in thickness. The molds and materials were then covered with Mylar strips on the top and bottom and placed between two microscope slides. Finger pressure was then applied to extrude excess material and eliminate porosities. The tooth-colored materials were light-cured (COXO LED curing light, Foshan Coxo Medical Instruments Co. Ltd, Guangdong Province, China; wavelength, 440-480 nm; intensity, 1200 mW/cm^2) according to manufacturer's instructions, checked for uniform thickness with a vernier caliper, and left to fully set for 24 hours in an incubator at 100% relative humidity and a temperature of 37°C. Forty-two specimens were fabricated for each material giving a total of 250 samples. Finishing was not done to minimize potential variables.

The samples were then placed on a neutral white background with chroma of <4 Munsell units, under D55 lighting conditions with intensity between 18 and 28 lux. Baseline L*, a*, b* values were determined using a spectrophotometer (Konica Minolta CM-2600d, Tokyo, Japan) placed at the center of the sample. This was then repeated with the samples placed on a black background.

For each material, the samples were randomly assigned to seven different liquids, namely cola drink, orange juice, red wine, vodka, black coffee, green tea, and distilled water, in groups of six. The samples were immersed in the beverages and incubated at standardized conditions of 37°C and 100% humidity for seven days with the container cover fastened to prevent evaporation that could lead to changes in volumes of the beverages. Beverages were changed daily at a standardized time.

After seven days, color readings were taken using the spectrophotometer. Color change was determined with the formula: $\Delta E = [(L^*_a - L^*_b)^2 + (a^*_a - a^*_b)^2 + (b^*_a - b^*_b)^2]^{1/2}$ with the set of L*, a*, b* values taken with respect to the white background. The subscript "a" referred to readings after soaking in the beverage and the subscript "b" referred to baseline readings. The translucency parameter was determined by calculating the difference in L*, a*, b* values measured over the white and black backgrounds: $TP = [(L^*_W - L^*_B)^2 + (a^*_W - a^*_B)^2 + (b^*_W - b^*_B)^2]^{1/2}$, where subscript "W" referred to the color coordinates over the white backing and subscript "B" to those over the black backing.[24] The difference in TP (ΔTP) was then calculated by: $\Delta TP = TP_a - TP_b$.

Statistical testing was performed using SPSS Version 20 (IBM SPSS Statistics for Windows, Version 20.0, Released 2011, IBM Corp. Armonk, NY). *t*-tests; one-way analysis of variance with Tukey post hoc test and Pearson's correlation were done at a significance of α=0.05.

RESULTS

Table 2 shows the mean values and standard deviation of the results for ΔE and ΔTP. A ΔE $\geq$3.3 was used to stipulate a clinically observable color change based on the work of Ruyter et al.[25] and significant changes in translucency were also noted. Results of statistical analyses of color and translucency changes are reflected in Tables 3/4 and 5/6, respectively. Tables 7 and 8 show the results of Pearson's correlation tests examining the correlations between changes in translucency and color change with specific beverages and materials.

Susceptibility to Staining

Color change (ΔE) depended on both material and beverage and ranged from 0.40 ± 0.15 (B2 in water) to 18.73 ± 1.77 (N100 in coffee). In general, immersion in coffee produced the greatest change in color and immersion in water produced the least.

Clinically perceivable color change was anticipated (ΔE values $\geq$3.3) when PF was exposed to all seven beverages. For ZT, ZF, and BF, ΔE values were only $\geq$3.3 when exposed to three beverages (Table 2). For all materials evaluated, exposure to red wine and coffee is expected to result in clinically visible color changes as ΔE values were $\geq$3.3.

Changes in Translucency

Change in translucency (ΔTP) was material and beverage dependent and ranged from −7.39 ± 1.51 (PF in tea) to 0.88 ± 0.43 (ZF in water). A negative result suggests that the material became more opaque after immersion whereas a positive result suggests increased translucency. In general, coffee produced the greatest change in translucency, causing materials to become more opaque, and water produced the least change in translucency.

Translucency of the materials was affected by the different beverages. A significant increase in opacity was observed when PF was immersed in all seven beverages. In contrast, the translucency of ZF was affected by only two beverages (ie, coffee and water). For all materials evaluated, exposure to coffee resulted in a decrease in translucency. Conditioning in water and vodka resulted in increased translucency for ZF and N100, respectively.

Correlation Between ΔE and ΔTP

There was an inverse correlation between ΔE and ΔTP for all materials and beverages, except for orange juice. The strength of association was found to be moderate to strong.

DISCUSSION

In this study, the change in color and translucency of tooth-colored restorative materials after exposure to beverages for seven days was investigated. The beverages were chosen to represent the spectrum of beverages commonly consumed and tested.[9–12] Distilled water was chosen as it was previously shown to have produced no perceptible change in glass ionomer and resin-based composites. Most of the materials investigated contained nanoparticles.

A Mylar finish was selected as it gave the smoothest finish, eliminated the need for different polishing techniques applied clinically, and minimized operator variability. The samples were soaked for seven days in different beverages as tooth-colored restorative materials were shown to take up significant staining within the first week in a previous study, and any changes beyond this were not

Table 2: *Results of Statistical Analysis*

Material	Beverage	Mean Values (SD) of Materials in Respective Beverage ΔL* (SD)	Δa* (SD)	Δb* (SD)	ΔE (SD)	Clinically Visible Change	ΔT (SD)[a]
ZT	Coke	0.41 (0.96)	–0.05 (0.18)	0.27 (0.33)	0.92 (0.58)	No	–0.54 (1.60)
	Orange juice	0.89 (1.32)	–0.54 (0.40)	2.63 (0.41)	3.09 (0.43)	Yes	0.69 (0.82)
	Red wine	–9.19 (1.28)	2.15 (0.40)	8.79 (0.72)	12.96 (0.63)	Yes	–3.46 (0.91)[O]
	Vodka	1.57 (1.42)	0.53 (0.17)	0.96 (0.63)	2.29 (0.73)	No	0.55 (0.55)
	Coffee	–10.21 (1.97)	2.54 (0.55)	8.82 (0.29)	13.77 (1.66)	Yes	–3.02 (1.00)[O]
	Tea	–1.19 (0.55)	–0.31 (0.07)	2.71 (0.22)	3.02 (0.16)	No	–0.83 (0.29)[O]
	Water	–0.05 (1.07)	0.17 (0.18)	0.08 (0.40)	0.92 (0.62)	No	0.02 (0.26)
ZF	Coke	–0.19 (0.33)	0.28 (0.25)	0.35 (0.41)	0.71 (0.17)	No	0.09 (0.35)
	Orange juice	0.42 (2.19)	–0.27 (0.11)	2.19 (0.32)	2.87 (1.06)	Yes	0.37 (0.45)
	Red wine	0.69 (1.94)	–0.09 (0.19)	5.27 (0.51)	5.59 (0.59)	Yes	0.46 (0.51)
	Vodka	0.66 (1.58)	0.57 (0.10)	0.74 (0.47)	1.69 (0.93)	No	0.66 (0.68)
	Coffee	–9.59 (3.44)	2.14 (0.44)	5.43 (0.88)	10.24 (2.08)	Yes	–2.76 (0.82)[O]
	Tea	–0.24 (0.50)	0.05 (0.17)	1.74 (0.66)	1.85 (0.58)	No	–0.58 (1.37)
	Water	1.29 (1.12)	0.53 (0.09)	0.92 (0.49)	1.74 (1.10)	No	0.88 (0.43)[T]
BF	Coke	0.56 (0.97)	0.51 (0.54)	–0.03 (0.80)	1.32 (0.68)	No	–0.44 (1.05)
	Orange juice	–0.40 (0.59)	–0.40 (0.24)	1.71 (0.14)	1.69 (0.26)	No	0.20 (0.37)
	Red wine	–4.02 (2.52)	–0.13 (0.35)	13.23 (1.53)	14.07 (0.87)	Yes	–0.29 (1.87)
	Vodka	–0.87 (1.42)	–0.39 (0.81)	–0.15 (1.65)	2.23 (0.70)	No	–0.25 (1.97)
	Coffee	–11.55 (1.14)	1.71 (0.78)	7.42 (1.75)	13.98 (0.8)	Yes	–2.70 (0.84)[O]
	Tea	–2.91 (0.40)	–1.15 (0.37)	0.88 (1.00)	3.41 (0.18)	Yes	–1.37 (0.61)[O]
	Water	0.34 (1.39)	–0.36 (0.33)	–0.68 (0.42)	1.54 (0.49)	No	–0.49 (1.49)
B2	Coke	–1.58 (1.42)	–0.15 (0.34)	–3.19 (1.43)	3.85 (1.29)	Yes	–3.33 (1.05)[O]
	Orange juice	4.12 (0.34)	–0.65 (0.22)	3.72 (0.41)	5.60 (0.37)	Yes	0.62 (0.67)
	Red wine	–7.94 (2.16)	–0.39 (0.49)	15.28 (0.97)	17.33 (1.30)	Yes	–2.67 (0.90)[O]
	Vodka	0.18 (0.81)	0.27 (0.32)	–0.63 (0.77)	1.22 (0.43)	No	–0.24 (0.58)
	Coffee	–13.53 (2.09)	1.69 (0.60)	5.72 (2.60)	15.02 (1.75)	Yes	–5.37 (1.51)[O]
	Tea	–4.17 (0.52)	–1.52 (0.11)	1.09 (0.57)	4.61 (0.36)	Yes	–2.59 (0.49)[O]
	Water	–0.27 (0.23)	0.20 (0.11)	–0.04 (0.13)	0.40 (0.15)	No	0.38 (0.94)
N100	Coke	0.63 (0.56)	0.16 (0.24)	–0.65 (0.75)	1.24 (0.34)	No	–1.12 (0.74)[O]
	Orange juice	2.15 (1.14)	–0.43 (0.26)	1.20 (1.15)	2.74 (1.08)	Yes	–0.50 (1.13)
	Red wine	–3.11 (1.22)	–0.75 (0.48)	0.19 (1.20)	3.57 (0.38)	Yes	–1.69 (0.34)[O]
	Vodka	–0.20 (0.57)	–0.01 (0.08)	0.03 (0.23)	0.56 (0.23)	No	0.81 (0.12)[T]
	Coffee	–16.51 (1.97)	2.88 (1.34)	8.05 (1.94)	18.73 (1.77)	Yes	–4.57 (1.04)[O]
	Tea	–4.79 (1.04)	–1.38 (0.34)	–3.13 (0.52)	5.91 (1.03)	Yes	–2.41 (0.58)[O]
	Water	–0.21 (0.75)	–0.41 (0.19)	–1.17 (0.42)	1.48 (0.22)	No	0.41 (0.61)
PF	Coke	–2.14 (1.94)	1.70 (1.18)	1.39 (5.75)	6.37 (0.84)	Yes	–6.35 (0.99)[O]
	Orange juice	2.64 (2.31)	–0.80 (0.34)	–2.73 (3.04)	4.06 (3.59)	Yes	–3.71 (1.93)[O]
	Red wine	–1.13 (1.17)	7.86 (1.46)	–6.72 (2.80)	14.01 (1.97)	Yes	–7.31 (1.20)[O]
	Vodka	2.25 (1.36)	0.16 (0.06)	–2.45 (0.77)	3.54 (0.82)	Yes	–5.28 (2.12)[O]
	Coffee	–14.76 (2.44)	2.60 (0.61)	5.07 (1.00)	15.88 (2.25)	Yes	–5.81 (1.72)[O]
	Tea	–11.07 (2.12)	–2.55 (0.22)	–3.32 (0.54)	11.86 (2.04)	Yes	–7.39 (1.51)[O]
	Water	1.82 (0.53)	0.08 (0.17)	–2.45 (0.84)	3.13 (0.66)	Yes	–3.62 (1.36)[O]

B2, Shofu Beautifil II; BF, Beautifil Flow Plus; PF, 3M Photac Fil; N100, 3M Ketac Nano; ZF, 3M Filtek Z350XT Flowable Restorative; ZT, 3M Filtek Z350XT.
[a] *Superscript O: Significant change, more opaque; T: Significant change, more translucent.*

Table 3: *Comparisons of Color Change Induced by Different Beverages for Each Material*

Materials	Beverages
ZT	Coffee, Red wine > Tea, Orange juice, Vodka > Coke, Water
ZF	Coffee > Red wine > Orange juice, Tea, Water, Vodka > Coke;
	Orange juice > Tea, Water, Vodka, Coke
BF	Red wine, Coffee > Tea > Vodka, Orange juice, Water, Coke
B2	Red wine > Coffee > Tea, Orange juice, Coke > Vodka, Water
N100	Coffee > Tea > Red wine, Orange juice > Water, Coke, Vodka;
	Red Wine > Orange juice, Water, Coke > Vodka
PF	Coffee > Red wine, Tea > Coke, Orange juice, Vodka, Water
	Coffee, Red wine > Tea

B2, Shofu Beautifil II; BF, Beautifil Flow Plus; PF, 3M Photac Fil; N100, 3M Ketac Nano; ZF, 3M Filtek Z350XT Flowable Restorative; ZT, 3M Filtek Z350XT.

Table 4: *Comparisons of Color Change Between Different Materials When Immersed in the Same Beverage*

Beverage	Materials
Coke	PF > B2 > BF, N100, ZT, ZF
Orange juice	B2 > PF, ZT, ZF, N100, BF;
	B2, PF, ZT, ZF > N100
Red wine	B2 > PF, BF, ZT > ZF, N100
Vodka	PF > ZT, BF, ZF, B2 > N100;
	BF > ZF, B2, N100
Coffee	N100 > PF, B2, BF, ZT > ZF;
	N100, PF > B2
Tea	PF > N100, B2 > BF, ZT, ZF
	N100 > B2, BF, ZT > ZF
Water	PF > ZF, BF, N100, ZT > B2
	N100 > ZT, B2

B2, Shofu Beautifil II; BF, Beautifil Flow Plus; PF, 3M Photac Fil; N100, 3M Ketac Nano; ZF, 3M Filtek Z350XT Flowable Restorative; ZT, 3M Filtek Z350XT.

significant.[26] An A2 shade was selected as it was often used in similar studies. [9,11,12,24] A lighter shade is also more imperative as staining from beverages will generally be more visible clinically when compared with darker shades.

Color

The CIELAB colorimetric system was used in the study to evaluate color differences. In a study by Seghi & others, the authors concluded that it is "a valuable tool for material selection and restoration design, particularly in the area of aesthetic restorative dentistry." [27] There are 3 parameters to consider in the CIELAB system: 1) The L* coordinate is related to the lightness of the material; 2) the a* coordinate is related to red (more positive) and green (more negative); and 3) the b* coordinate is related to yellow (more positive) and blue (more negative).[27]

Conventional resin-based composite materials such as ZT and ZF generally fared better than novel materials such as B2 and N100 (Table 3-2). The conventional resin-modified glass ionomer cement, PF, had the greatest susceptibility to staining, corroborating a previous study.[9] No significant trend was noted for the least affected material.

An exception to the aforementioned trends was BF, which exhibited staining properties similar to that of ZF and ZT. It performed better than the other novel materials, B2 and N100, both of which demonstrated greater color changes when immersed in darker beverages. This suggested that BF had a higher resistance to staining compared with the other novel materials and might be a potential alternative to conventional materials. When comparing packable and flowable materials, ZT and ZF did not exhibit any significant differences, whereas BF performed better than B2. This was in agreement with existing literature[10] and may be attributed to the lower filler content in BF. The lower filler content in BF resulted in reduced surface roughness following erosion as fewer fillers are exposed, allowing the material to resist staining. Another possible reason could be the higher TEGDMA (triethylene glycol dimethacrylate) content in BF, which promoted greater conversion of the resin matrix,[20] decreasing its water sorption and hence susceptibility to staining.

N100, a nano-filled resin-modified glass ionomer cement, performed better than its conventional counterpart PF. This might be because N100 contains a smaller percentage of HEMA (2-hydroxyethyl methacrylate) by weight. HEMA increases water sorption and, hence, the potential for staining.[28] Another reason could be related to the maturity and the water sorption potential of the glass ionomer cement. Despite leaving the cement to set for a day, it might not have matured fully, resulting in significant water sorption and staining.[28] A third reason could be the smaller filler particle size in N100. This could have resulted in an even wearing of the surface, resulting in a smaller increase in surface roughness and staining susceptibility.

Table 5:		
Comparison of translucency change induced by different beverages for each material		
Materials	Beverages	
	Opaque →	Translucent
ZT	Red Wine > Coffee > Tea, Coke, Red Wine, Coffee, Tea > Coke	Water, Vodka, Orange juice
ZF	Coffee > Tea, Tea >	Coke, Orange juice, Red wine, Vodka > Water; Coke, Orange juice, Red wine, Vodka, Water
BF	Coffee > Tea, Water, Coke, Red wine, Vodka, Coffee, Tea, Water, Coke > Red wine	Orange juice
B2	Coffee > Coke, Red wine, Tea > Vodka,	Water, Orange Juice
N100	Coffee > Tea, Red wine > Coke > Orange juice, Tea > Red wine, Coke, Orange juice >	Water , Vodka Water
PF	Tea, Red wine > coke, Black Coffee, Vodka, Orange, Water	

When examining color change in terms of the individual L* a* b* components, it was noted that ΔL* (decrease) and Δb* (increase) were often the affected values, and there were smaller changes in Δa*. This suggested that beverages often resulted in the materials becoming darker and yellower. The trend was consistent for all materials except PF, which exhibited large changes in all 3 components, and no clear trends were observed in the increase or decrease of color parameters. This might be attributed to its susceptibility to water sorption,[29] leading to greater surface adsorption and absorption of colorants.

Comparing the effects of different beverages, it was observed that coffee generally produced the worst stains, followed by red wine and tea. These beverages exhibited negative ΔL* and positive Δb* values, indicating that the materials became darker and yellower respectively. These three beverages had varied effects on Δa*. This might be due to the variation in colorants present in the three beverages. Although previous studies suggested that tea produced more staining than red wine, this study had a different result. This might be due to the use of green tea, which had a lower amount of colorants compared with black tea. Otherwise the results corroborated with prior literature.[9–12]

Vodka and water are colorless beverages and were expected to produce the least amount of color change based on previous studies on water.[12] Vodka with an alcohol content of 40% might produce color changes by degrading the resin matrix of the materials.[30] Results pertaining to cola drink, which produced minimal staining in comparison with other dark beverages, were consistent with a study done by Tian & others in 2012.[10]

The acids in coffee, red wine, and tea might have influenced their staining ability. For glass ionomer restorative materials, acid attack from the beverages on the glass ionomer matrix released metal cations, extracting more metal cations from the glass particles, which eventually dissolved. This resulted in increased surface roughness and, over time, caused food pigments to be trapped on the surface of the material. [9] Although acidity is measured as pH, the total amount of acid present (titratable acidity) may be a better gauge. This is determined by titration against a standardized sodium hydroxide solution.[10] Correlation between pH and titratable acidity is not apparent, meaning that a beverage can have both a high pH and titratable acidity. Although

Table 6:		
Comparisons of translucency change of different materials when immersed in the same beverage		
Beverages	Material	
	Opaque →	Translucent
Coke	PF > B2 > N100, ZT, BF,	ZF
Orange juice	PF > N100,	BF, ZF, B2, ZT
Red wine	PF > ZT, B2, N100 > BF, B2 > N100, BF >	ZF ZF
Vodka	PF > BF, B2,	ZT, ZF, N100
Coffee	PF > B2 > N100, ZT, ZF, BF PF, B2, N100 > ZT	
Tea	PF > B2 > N100, BF, ZT > ZF PF > B2, N100, BF > ZT N100 > BF, ZT, ZF	
Water	PF > BF,	ZT, B2, N100, ZF

Table 7: *Correlation Between Color Change and Change in Translucency for a Specific Beverage*

Beverage	Correlation (P Value)	Strength
Coke	Yes ($p<0.001$)	–0.87 (strong)
Orange juice	No ($p=0.081$)	–0.27
Red wine	Yes ($p=0.002$)	–0.46 (moderate)
Vodka	Yes ($p=0.001$)	–0.50 (moderate)
Coffee	Yes ($p<0.001$)	–0.79 (strong)
Tea	Yes ($p<0.001$)	–0.84 (strong)
Water	Yes ($p=0.001$)	–0.51 (moderate)

Table 8: *Correlation Between Color Change and Change in Translucency for a Specific Material*

Material	Correlation (p Value)	Strength
ZT	Yes ($p<0.001$)	−0.80 (strong)
ZF	Yes ($p<0.001$)	−0.64 (moderate)
BF	Yes ($p=0.045$)	−0.31 (moderate)
B2	Yes ($p<0.001$)	−0.61 (moderate)
N100	Yes ($p<0.001$)	−0.83 (strong)
PF	Yes ($p<0.001$)	−0.56 (moderate)

B2, Shofu Beautifil II; BF, Beautifil Flow Plus; PF, 3M Photac Fil; N100, 3M Ketac Nano; ZF, 3M Filtek Z350XT Flowable Restorative; ZT, 3M Filtek Z350XT.

red wine exhibited lower pH, coffee and tea had a greater number of acids present in their composition and may have exhibited a larger total acidity. This might have increased the chemical erosion of material surfaces and worsened staining.

The presence of visible color change was not always accompanied by a ΔE of large magnitude. The interplay between the intensity of the color and how readily the colorants are taken up could be the reason for this observation. Coffee and red wine, which are dark beverages, exhibited both visible color change and a large ΔE.[9–12] In the case of orange juice, although it produced clinically significant changes ($\Delta E \geq 3.3$) in five materials, its magnitude of change was comparably lower than that of coffee, red wine, and tea. Its colorants might have been readily taken up to produce color change, but the colorants were comparatively lighter in color than the darker colorants of red wine, coffee, and tea. Although tea's colorants were also readily taken up, producing changes in four materials, the colorants were not as intense compared with coffee and red wine, leading to a smaller ΔE.

Translucency

Translucency of tooth-colored restorations depends on the passage of light through the material. It can be altered by changes on the external surface or body of the material. Translucency was quantified with the translucency parameter, which is the color difference when a specimen of uniform thickness is placed over a white and a black background and corresponds directly to common visual assessments of translucency.[24] Currently, no thresholds have been determined when considering visible clinical changes in translucency parameter.

Comparing between materials, PF was the most severely affected and had the highest ΔTP among all materials. The least affected in general was ZF. The flowable materials performed better, exhibiting a smaller increase in opacity compared with the packable materials.

An explanation for the observed trends could be that the changes in surface roughness after being exposed to the various beverages resulted in differential scattering of light and thus difference in opacity. This was probably especially true for PF because of its larger filler particle size (Table 1). Surface profilometry to compare the changes in surface roughness is needed to confirm this hypothesis.

Another potential cause for the change in opacity in resin-based composites and Giomers was the weakening of the resin/filler bond, resulting in migration of colored pigments into the resin material.[30,31] Filler particles and resin had different refractive indexes; thus visible light passing through the composite was scattered differently by the fillers and pigments, decreasing translucency.

Flowable materials such as ZF had fewer filler particles and, as such, would be least likely to be affected by changes to the resin/filler interface and subsequent incorporation of color pigments. This resulted in lower ΔE of ZF, compared with ZT, for all beverages.

Water and vodka caused minute increases in translucency in ZF and N100, respectively. Selective removal of larger filler particles and nanoclusters from ZF and N100, respectively, from the surface could have occurred, leading to a lower refractive index on the surface. The decrease in the difference in refractive index between filler particles and the matrix resulted in less surface scattering of light, allowing greater light penetration into the bulk of the material, hence increasing translucency.

Color pigments in the beverages had different refractive indexes compared with the filler particles and resin. Hence, these pigments could scatter and absorb light, resulting in an increase in opacity in the materials. Darker drinks such as coffee, tea, and red wine contained more color pigments compared with the lighter beverages, vodka, orange juice, and water. This accounts for the observed differences in the effects of different beverages on translucency of the materials.

Correlation

The correlation between susceptibility to staining and changes in translucency was explored. There was an inverse relationship of moderate to strong strength between ΔE and ΔTP for all materials and beverages ($p<0.05$) except for orange juice ($p>0.05$). Hence, when there was increased color change, there was increased opacity for all materials and beverages with the exception of orange juice.

The varying amount of absorption of color pigments from beverages due to water sorption or changes in resin/filler matrix resulted in varying intensity of staining. The absorbed pigments not only absorbed light, causing a change in color, but also scattered light, resulting in a change in opacity, giving rise to the correlation between ΔE and ΔTP. No correlation between ΔE and ΔTP was observed for orange juice. Despite a significant change in ΔE, the quantity of pigments deposited by orange juice may not be sufficient to cause changes in translucency. The actual mechanism is not known and warrants further investigation.

CONCLUSION

The study sought to investigate the effects of common beverages on the color and translucency of tooth-colored restorative materials. All materials were affected to varying degrees. PF fared the worst, followed by B2. The performance of the novel materials, in terms of both color and translucency changes, depended on their composition and which end of the spectrum of tooth-colored materials they were closer to. Materials closer to the resin-based composites end of the spectrum in terms of chemistry and structure fared better than those closer to the glass ionomer cement restoratives.

For most materials, coffee, followed by red wine and tea, was the most prominent staining beverage and produced the largest decreases in translucency as well. Clinically perceivable color change ($\Delta E \geq 3.3$) was observed in all materials for coffee and red wine. With the exception of orange juice, the change in color was inversely proportional to changes in the translucency, suggesting a negative correlation.

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Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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