Research Article

Effect of brushing using different dentifrices on discoloration and roughness of resin composites with different compositions

Patrick Nabholz, DDS, **Jeffery Scott Nordin**, DDS, MS, **Brian R. Morrow**, MS
& **Franklin Garcia-Godoy**, DDS, MS, PhD, PhD

Abstract: Purpose: To evaluate the changes in color, translucency, roughness, and depth loss of various composites with different formulations (Filtek One Bulk Fill, Admira Fusion X-tra Bulk-fill, and XRV Herculite) after toothbrushing using dentifrices containing charcoal and charcoal-free. **Methods:** 32 resin composite discs (8.0 x 1.5 mm) were prepared for each Filtek One Bulk Fill, Admira Fusion X-tra Bulk-fill, and XRV Herculite. Discs were evaluated with a spectrophotometer for color and roughness measurements before and after treatments. Sample treatment included toothbrushing on a V-8 toothbrushing machine for 10,000× to simulate daily oral care with four different dentifrices (Colgate Total SF, Crest Pro-Health Complete Protection Intensive Cleaning+Whitening, Colgate Total Whitening Charcoal, and Crest Charcoal 3D White). After toothbrushing, color (ΔE_{00}), roughness (Ra and Rz), depth loss (DL), and translucency (TP_{00}, and ΔTP_{00}) were remeasured and deduced from initial measurement for the standard difference in each respective parameter. Data were calculated and statistically analyzed independently using a two-way repeated measures ANOVA and Holm-Sidak post-hoc test with $P< 0.05$ significance. **Results:** Admira and Filtek, when brushed with Colgate Total SF resulted in less roughness and DL when compared to both charcoal dentifrices. Admira was found slightly rougher than Herculite and Filtek with Crest Pro-Health and similar to both charcoal groups. However, Admira with Crest Pro-Health was similar to Herculite and Filtek but significantly different from both charcoal groups. All dentifrices had a significant staining effect on all composites relative to the baseline color. Admira and Filtek composites were above the clinical acceptance threshold (AT) of 1.8 for ΔE_{00}, with Herculite only surpassing the limit with Crest Charcoal. Lastly, Herculite with all dentifrices was below the clinical perceptibility threshold (PT) for translucency difference. Both Admira and Filtek were above the ΔTP_{00} PT but less than the AT for all dentifrices except Colgate Charcoal. (*Am J Dent* 2025:38 Sp Is A:20A-25A).

Clinical significance: Charcoal dentifrices changed the color of Admira samples. Colgate charcoal resulted in a significantly different color change versus using Colgate Total and Crest Pro-Health. All three resins resulted in statistically significant color change when using all non-charcoal-containing dentifrices.

✉: Dr. Franklin Garcia-Godoy, Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, 875 Union Ave, Memphis, TN 38163 USA. E-✉: fgarciagodoy@gmail.com

Introduction

Resin composite color changes over time due to being exposed to the oral environment.[1] These color changes are influenced by factors such as surface roughness, exposure time to the staining agents, plaque, and the type of resin used.[2-4] The color change is many times the reason for the replacement of resin composites.[5]

An additional factor that may influence the surface roughness and staining removal of resin composites is tooth-brushing with dentifrices.[1,6-8]

The effect of dentifrices with charcoal on composite roughness and color has been reported with different results; one reported[9] that the charcoal dentifrice tested had no whitening effect and no significant effect on tooth surface roughness; another study[10] showed that most of the charcoal toothpastes tested caused marginal staining of the resin composite restorations; and a recent systematic review[11] of clinical studies showed that charcoal activated dentifrices possess a lower whitening effect than other alternatives and are less safe due to their high abrasive potential. [1]

This study evaluated the changes in color, translucency, roughness, and depth loss of resin composites with different formulations after toothbrushing simulation using various dentifrices: charcoal-containing versus charcoal-free. The research hypotheses were: (1) there was no difference in color or roughness between all tested materials before and after the brushing with different dentifrices; (2) there was no difference in color or roughness of each material when brushed with charcoal containing versus charcoal free dentifrice from the same brand.

Materials and Methods

Thirty-two resin composite discs (10 × 1.5 mm) were fabricated in stainless steel ring molds for each of the three composite groups: Filtek One Bulk Fill,[a] Admira Fusion X-tra Bulk-fill,[b] and XRV Herculite,[c] for a total of 96 sample discs, Discs were evaluated for color with a spectrophotometer (CM-700d[d]) and stylus profilometer (Dektak XT Stylus Profiler[e]) for roughness measurements before and after toothbrushing treatments. Samples were randomized to the following dentifrice groups: Crest Pro-Health Complete Protection Intensive Cleaning+Whitening,[f] Colgate Total SF,[g] Crest Charcoal 3D White,[f] and Colgate Total Whitening Charcoal[g] with N=8 per dentifrice. Discs were evaluated for color and roughness, with a color spectrophotometer and a stylus profilometer; respectively, before and after toothbrushing treatments.

The toothbrushing was achieved using a V8 toothbrushing machine[h] and standard brushes (ADA medium standard

Table 1. Roughness results for arithmetical mean height (Ra) and difference in Ra (D-Ra) means and standard deviations.

Material	Paste	Baseline Ra	Toothbrushing Ra	D-Ra (Toothbrushing – Baseline)
Admira	Crest Pro-Health	0.06 ± 0.031	0.98 ± 0.21 a, b, c, d, e, f, g, h	0.92 ± 0.20 α, A, B
	Colgate Total SF	0.07 ± 0.02	0.66 ± 0.23 a, i, j	0.58 ± 0.22 α, β, γ
	Crest Charcoal	0.05 ± 0.03	1.01 ± 0.33 i, k, l, m, n, o, p, q	0.96 ± 0.34 β
	Colgate Charcoal	0.06 ± 0.03	1.24 ± 0.15 b, j, r, s, t, u, v, w, x, y	1.18 ± 0.15 γ, Γ, Δ
Filtek	Crest Pro-Health	0.07 ± 0.01	0.75 ± 0.22 k, r	0.68 ± 0.23 A
	Colgate Total SF	0.06 ± 0.01	0.60 ± 0.11 c, l, s, z	0.55 ± 0.11
	Crest Charcoal	0.07 ± 0.02	0.73 ± 0.12 d, m, t	0.66 ± 0.13
	Colgate Charcoal	0.06 ± 0.02	0.63 ± 0.17 e, n, u	0.57 ± 0.17 Γ
Herculite	Crest Pro-Health	0.06 ± 0.02	0.68 ± 0.25 f, o, v	0.62 ± 0.25 B
	Colgate Total SF	0.05 ± 0.02	0.70 ± 0.07 g, p, w	0.65 ± 0.07
	Crest Charcoal	0.05 ± 0.02	0.87 ± 0.32 x, z	0.82 ± 0.31
	Colgate Charcoal	0.04 ± 0.01	0.65 ± 0.17 h, q, y	0.60 ± 0.17 Δ

For Ra measurements within rows, all baseline versus toothbrushing values were statistically significantly different (P< 0.05) between time points for material paste groups. For Ra measurements within toothbrushing, the same lower-case superscript letters indicate a statistically significant difference (P< 0.05) between restorative materials for the respective paste.
For D-Ra measurements, the same lower-case Greek superscript letters indicate a statistically significant difference (P< 0.05) between dentifrices within each resin material group. For D-Ra measurements, the same capital Greek superscript letters indicate a statistically significant difference (P< 0.05) between resin materials within each dentifrices group.

Table 2. Roughness results for maximum peak to valley height (Rz) and difference in Rz (D-Rz) means and standard deviations.

Material	Paste	Baseline Rz	Toothbrushing Rz	D-Rz (Toothbrushing – Baseline)
Admira	Crest Pro-Health	0.41 ± 0.21	4.986 ± 1.16	4.58 ± 1.25 X
	Colgate Total SF	0.51 ± 0.21	3.641 ± 1.30 u	3.13 ± 1.26 x, y
	Crest Charcoal	0.38 ± 0.26	5.845 ± 2.53	5.46 ± 2.58 x
	Colgate Charcoal	0.38 ± 0.24	7.305 ± 1.03 u, v, w, x, y, z	6.93 ± 1.08 y, Y, Z
Filtek	Crest Pro-Health	0.45 ± 0.15	4.260 ± 0.85	3.81 ± 0.87
	Colgate Total SF	0.38 ± 0.15	3.311 ± 0.79 v	2.93 ± 0.87
	Crest Charcoal	0.48 ± 0.10	4.043 ± 0.79	3.57 ± 0.78
	Colgate Charcoal	0.43 ± 0.20	3.364 ± 0.85 w	2.94 ± 0.94 Y
Herculite	Crest Pro-Health	0.26 ± 0.13	3.368 ± 0.74 x	3.11 ± 0.79 X
	Colgate Total SF	0.36 ± 0.16	3.970 ± 0.79 y	3.62 ± 0.77
	Crest Charcoal	0.24 ± 0.06	5.109 ± 2.20	4.87 ± 2.22
	Colgate Charcoal	0.25 ± 0.08	3.394 ± 0.65 z	3.15 ± 0.64 Z

For Rz measurements within rows, all baseline versus toothbrushing values were statistically significantly different (P< 0.05) between time points for material paste groups. For Rz measurements within columns, means with the same lower-case superscript letters indicate a statistically significant difference (P< 0.05) between restorative materials for the respective paste.
For D-Rz measurements the same lower-case superscript letters indicate a statistically significant difference (P< 0.05) between dentifrices within each resin material group. For D-Rz measurements the same capital superscript letters indicate a statistically significant difference (P< 0.05) between resin materials within each dentifrices group.

brushes[i]). Samples were brushed a total of 10,000× to simulate 1 year of toothbrushing,[12] as daily oral care with sample rotation and dentifrice remixing to ensure uniform brushing throughout. Each dentifrice was mixed thoroughly at five parts dentifrice to eight parts deionized water for toothbrushing purposes.[13]

Roughness measurements - Surface roughness measurements were obtained using a stylus profilometer (Dektak XT Stylus Profiler) with the aid of Mountains[j] software. Surface roughness was measured both before (baseline) and after toothbrushing with the mechanical toothbrushing simulation using a stylus profilometer (DektakXT). The measurement area was 5 mm in length x 4 mm in width, with enough area for the brushed and unbrushed area on the sample. Each measurement was evaluated with the Mountains software, using ISO 4287 measurements for calculating Ra (arithmetic average height parameter) and Rz (maximum peak to valley height). Ra represents the average absolute deviation of the roughness from the mean line. While Rz represents the total maximum height from the deepest point to the highest peak. In addition, the differential of the Ra and Rz (D-Ra and D-Rz) was calculated by subtracting the final toothbrushing value minus the initial baseline measurements.[8,14-17]

Depth loss (DL) data were determined by calculating height change from the masked shoulder of the sample after toothbrushing abrasion test by subtracting the unbrushed height from the brushed depth over the measurement area.[8]

Color measurements - Color measurements were obtained using a color spectrophotometer (CM-700d) following the CIE L*a*b* colorimetric system. Three automatic measurements were performed for each sample, and averaged into values for L′ (lightness), C′ (chroma), and H′ (hue) were used for the assessment. Color change or difference was expressed in terms of DE2000 (ΔE_{00}) according to the CIE DE2000 equation:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta h'}{K_h S_h}\right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta h'}{K_h S_h}\right)}$$

where ΔL′, ΔC′ and Δh′ are the differences among the corresponding lightness, chroma, and hue components of color formula along with the combination of parametric and weighting coefficients $K_L S_L$, $K_C S_C$, and $K_h S_h$.[8,18-23]

Table 3. Depth Loss (DL) results in a difference in vertical height between the unbrushed surface and brushed surface. (Unbrushed-Brushed).

Paste	Admira	Filtek	Herculite
Crest Pro-Health	6.97 ± 0.44 a,b,c,A	5.80 ± 0.60 d,A	6.25 ± 1.02 e
Colgate Total SF	5.07 ± 0.75 a	4.92 ± 0.85 d	5.46 ± 0.82 f
Crest Charcoal	10.06 ± 2.23 a,b	9.93 ± 1.20 d	10.00 ± 1.82 e,f
Colgate Charcoal	11.45 ± 2.03 a,c	11.67 ± 0.85 d	11.12 ± 1.45 e,f

The same lower-case letters indicate a statistically significant difference between dentifrices within each resin material group (vertical).
The same capital letters indicate a statistically significant difference between resin materials within each dentifrices group (horizontal).

Table 4. Color difference (ΔE_{00}) results for a difference in color between the baseline unbrushed surface and toothbrushed surface.

Paste	Admira	Filtek	Herculite
Crest Pro-Health	3.62 ± 0.49 F	2.81 ± 1.03 G	0.91 ± 0.13 h,F,G
Colgate Total SF	4.79 ± 1.47 f,g,H,I	3.21 ± 1.36 H,J	1.75 ± 0.77 I,J
Crest Charcoal	3.04 ± 1.07 f	3.52 ± 1.51	2.72 ± 1.42 h
Colgate Charcoal	2.35 ± 1.42 g	2.49 ± 1.24	1.39 ± 0.67

The same lower-case letters indicate a statistically significant difference between dentifrices within each resin material group (vertical).
The same capital letters indicate a statistically significant difference between resin materials within each dentifrices group (horizontal).

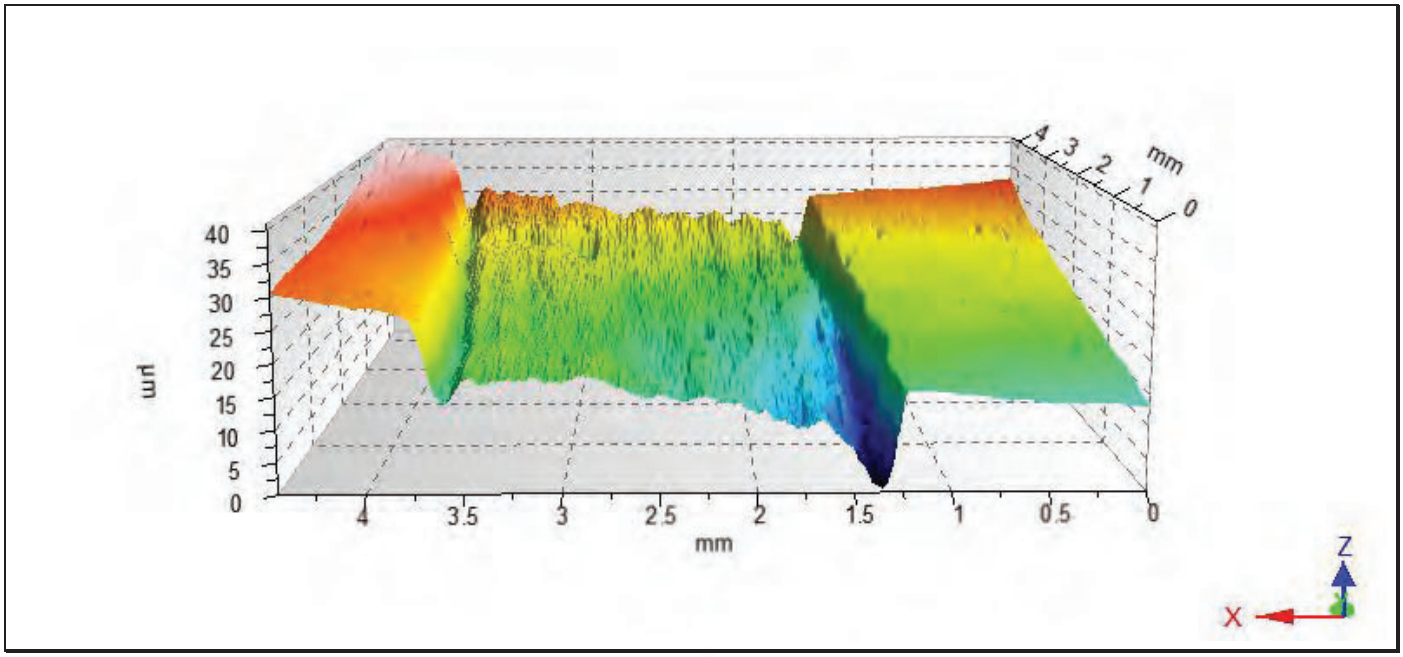

Fig. 1. Surface roughness 3D images from Mountains software demonstrating both roughness and depth loss results for Admira brushed with Colgate Charcoal.

Color difference results were compared to previous study data for CIE DE2000 50:50 limits as follows: $\Delta E_{00} = 0.8$ for the perceptibility threshold (PT) and $\Delta E_{00} = 1.8$ for the acceptability threshold (AT) as used in dental applications.[23-25]

Translucency measurements - Translucency measurements were obtained using the translucency parameter (TP_{00}) using the difference in color measurements made with white minus the black background tiles. Translucency was conveyed in terms of TP_{00} according to the adaptation of the CIE DE2000 equation as follows:

$$TP_{00} = \sqrt{\left(\frac{\Delta L_{(W-B)}{}'}{K_L S_L}\right)^2 + \left(\frac{\Delta C_{(W-B)}{}'}{K_C S_C}\right)^2 + \left(\frac{\Delta h_{(W-B)}{}'}{K_h S_h}\right)^2 + R_T \left(\frac{\Delta C_{(W-B)}{}'}{K_C S_C}\right)\left(\frac{\Delta h_{(W-B)}{}'}{K_h S_h}\right)}$$

Differences in translucency parameter (ΔTP_{00}) due to toothbrushing were calculated also by subtracting the baseline corresponding TP_{00} from the toothbrushed TP_{00}. The ΔTP_{00} values were compared to prior study data for ΔTP_{00} 50:50 limits as follows: $\Delta TP_{00} = 0.6$ for the PT and $\Delta TP_{00} = 2.6$ for the AT.[23,26]

Data were statistically analyzed (SigmaPlot[k]) independently for each measurement (Ra, Rz, D-Ra, D-Rz, and TP_{00}) using a two-way repeated measures ANOVA and Holm-Sidak post-hoc test with $P < 0.05$ significance. The DL, ΔE_{00} and ΔTP_{00} data were statistically analyzed independently using a two-way ANOVA and Holm-Sidak post-hoc test with $P < 0.05$ significance.

Results

Tables 1 and 2 show the toothbrushing results mean and standard deviations for abrasion roughness (Ra and Rz) values and difference in roughness (D-Ra and D-Rz) along with statistical indications. Vertical height changes due to abrasion of the samples are reported in Table 3 for DL. Surface changes in color difference (ΔE_{00}) values are in Table 4 and Fig. 1 which represent the potential staining effect of the dentifrices on the respective composite. Table 5 displays the TP_{00} and ΔTP_{00} for toothbrushing means and standard deviations for abrasion translucency parameter results.

An increase in abrasion roughness (D-Ra, D-Rz, Ra, and Rz) is noted and statistically different for all resin materials with charcoal dentifrices. Representative roughness profile images are shown in Figs. 1-4. Likewise, an increase in DL is noticeable and statistically different for all resin materials with the charcoal dentifrices at twice the rate of more conventional dentifrices. Admira exhibited the most overall abrasion roughness and DL in conjunction with the charcoal dentifrices. In general, Colgate Total SF represented a normal level of dentifrice for this study's purpose and displayed the least amount of abrasion and DL.

Table 5. Translucency parameter results in color (TP_{00}) for differences between white and black backgrounds of unbrushed surface and after completing various toothbrushing treatments on the corresponding surfaces. Difference in translucency parameter results in color (ΔTP_{00}) results report baseline unbrushed surfaces TP_{00} differences and tooth brushed surface TP_{00} means and standard deviations.

Material	Paste	Baseline TP_{00}	Toothbrushing TP_{00}	ΔTP_{00} (Toothbrushing - Baseline)
Admira	Crest Pro-Health	8.18 ± 0.96	6.72 ± 0.84 c	-1.46 ± 0.45 p. P
	Colgate Total SF	8.65 ± 0.27 a	7.46 ± 0.68	-1.19 ± 0.69 q, Q
	Crest Charcoal	8.48 ± 0.80 b	7.87 ± 0.83 d	-0.61 ± 0.92
	Colgate Charcoal	7.70 ± 1.05	7.89 ± 1.01 e	0.19 ± 1.44 p, q
Filtek	Crest Pro-Health	6.90 ± 1.32 a, b	6.14 ± 0.84 d, e f, g, h, j	-0.76 ± 1.09
	Colgate Total SF	8.04 ± 0.90	6.88 ± 0.95	-1.16 ± 1.26 R
	Crest Charcoal	8.14 ± 0.90	7.11 ± 0.77	-1.03 ± 0.73
	Colgate Charcoal	7.54 ± 0.63	7.52 ± 0.94	-0.03 ± 0.74
Herculite	Crest Pro-Health	7.87 ± 0.49	8.18 ± 0.29 c, f	0.30 ± 0.30 P
	Colgate Total SF	7.63 ± 0.80	7.70 ± 0.80 g	0.07 ± 0.94 Q, R
	Crest Charcoal	7.46 ± 0.84	7.13 ± 0.59 h	-0.34 ± 0.98
	Colgate Charcoal	7.84 ± 0.91	7.74 ± 0.91 j	-0.09 ± 1.37

For TP_{00} measurements within rows, all baseline versus toothbrushing values were statistically significantly different ($P < 0.05$) between time points for material paste groups. For TP_{00} measurements within columns, means with the same lower-case superscript letters indicate a statistically significant difference ($P < 0.05$) between restorative materials for the respective paste.
For ΔTP_{00} measurements the same lower-case superscript letters indicate a statistically significant difference ($P < 0.05$) between dentifrices within each resin material group. For ΔTP_{00} measurements the same capital superscript letters indicate a statistically significant difference ($P < 0.05$) between resin materials within each dentifrice group.

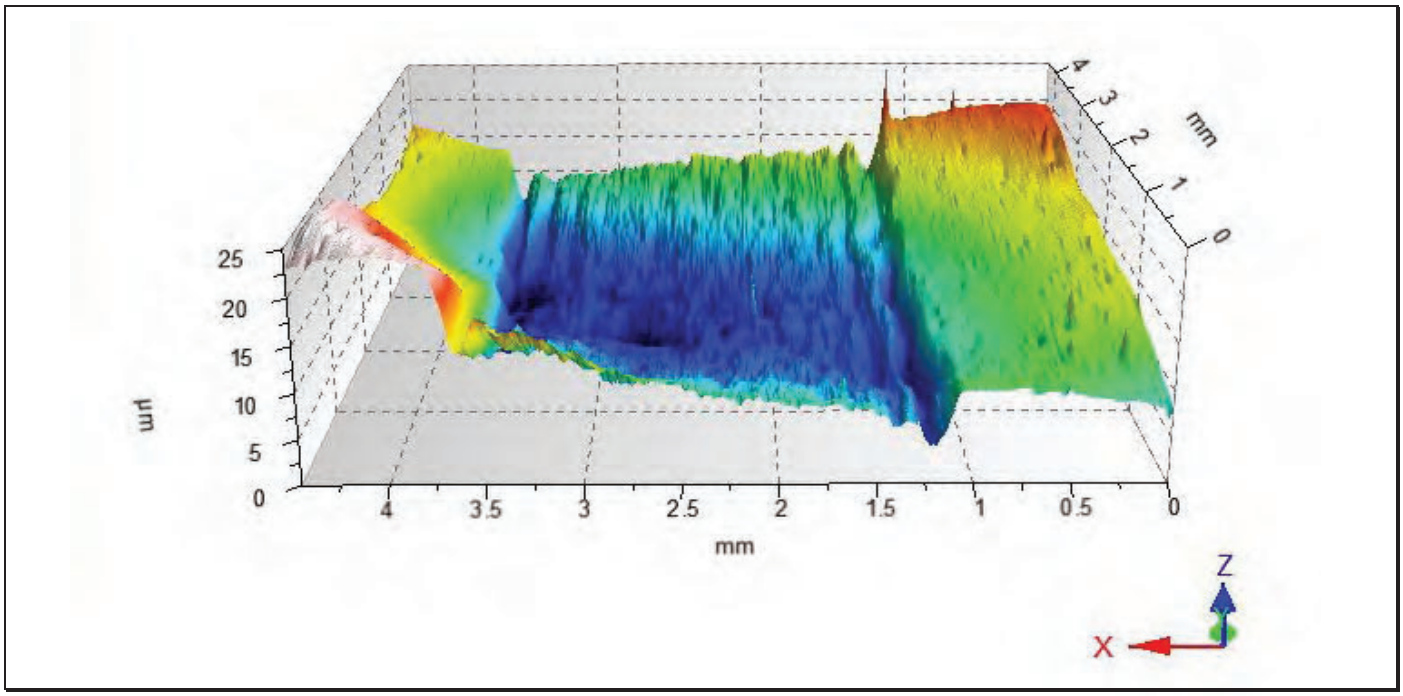

Fig. 2. Surface roughness 3D images from Mountains software demonstrating both roughness and depth loss results for Herculite brushed with Crest Pro-Health.

All combinations of dentifrices had a staining effect concerning color relative to the baseline on the Admira and Filtek composites above the AT for ΔE_{00}. All Herculite combinations were above the PT for ΔE_{00} and only Crest Charcoal crossed above the AT.

Translucency measurements across samples range from 6.1 to 8.6 for TP_{00} values. Filtek with Crest Pro-Health was statistically different in baseline and after toothbrushing from other dentifrice and material combinations. The ΔTP_{00} range from 0.3 to -1.46 with most samples reducing translucency due to abrasion and staining effects. Herculite with all dentifrices maintained translucency below the PT limit for ΔTP_{00}. Both Admira and Filtek with Colgate Charcoal also were less than the PT limit. However, Admira and Filtek with all other combinations were above the PT limit but not greater than the AT limit.

Discussion

Human observers perceived color change (perceptibility threshold) at ΔE equals 1 and an acceptability threshold of ΔE equals 1.8 for DE2000.[23-28] Based on these results, the present laboratory study showed that the human eye should perceive the color differences found.

This study showed that charcoal toothpastes affected the color and surface roughness of the composites tested compared to the non-charcoal toothpastes rejecting the two hypotheses. Similar results were recently reported.[10] However, one study[9] reported that the charcoal toothpaste tested showed no significant enamel color change or roughness change compared to the non-charcoal toothpaste tested.

All the toothpastes used in this study contained abrasives (mainly silica), which contribute to the surface roughness of

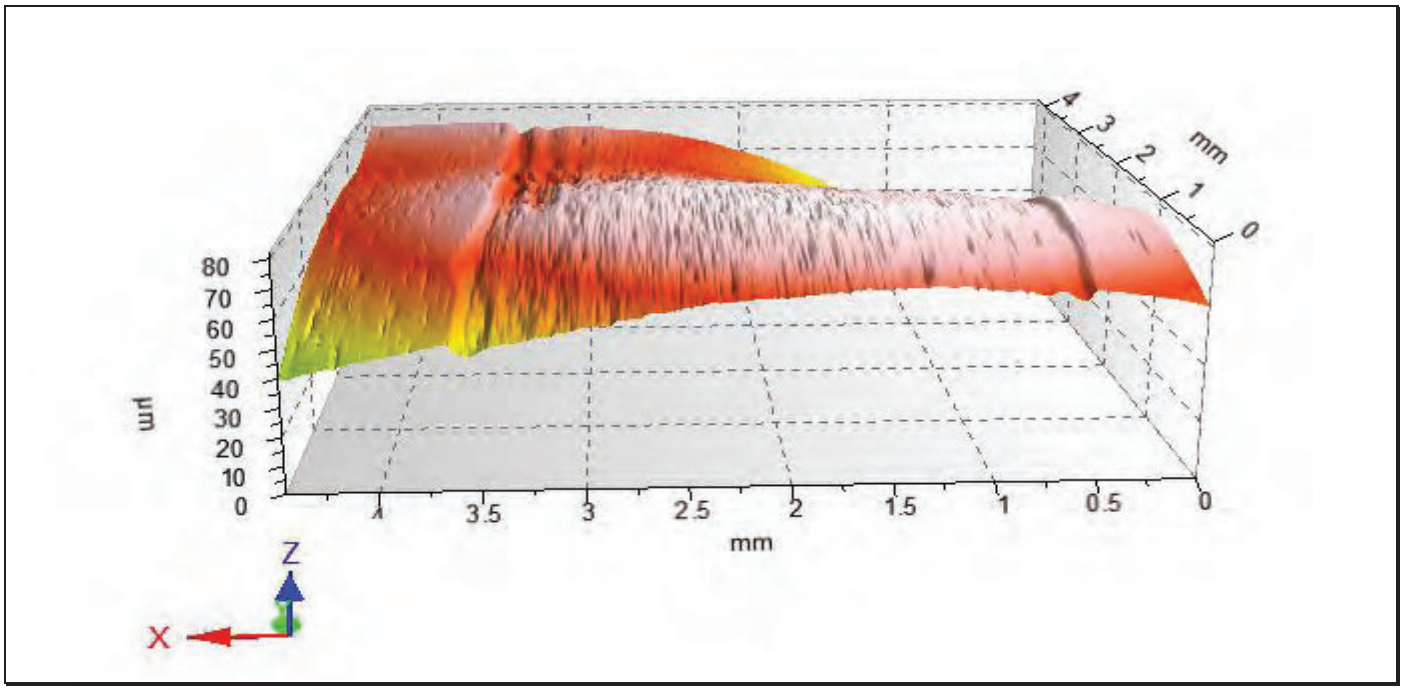

Fig. 3. Surface roughness 3D images from Mountains software demonstrating both roughness and depth loss results for Filtek brushed with Colgate Total SF.

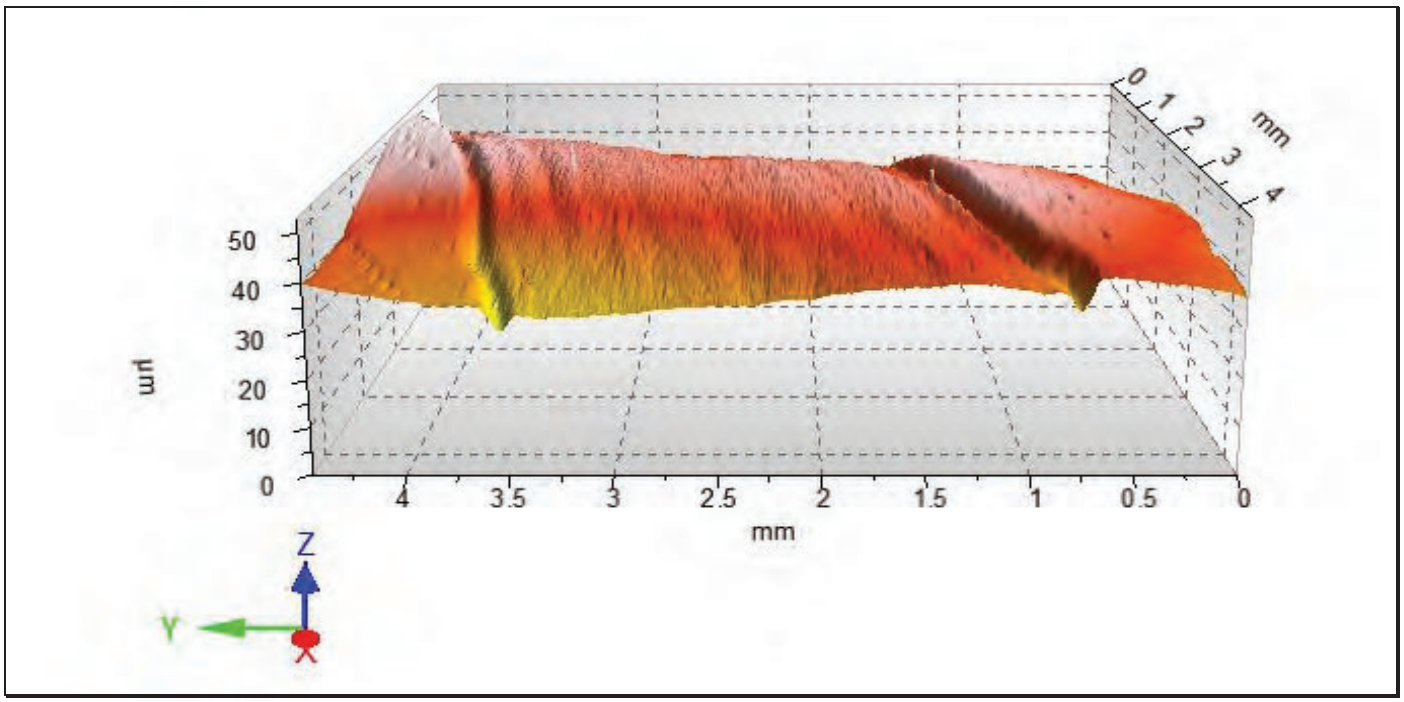

Fig. 4. Surface roughness 3D images from Mountains software demonstrating both roughness and depth loss results for Herculite brushed with Crest Charcoal.

composites as shown in this study. The reason for the color changes in the charcoal-based toothpaste could be due to pigments included in their formulation or the charcoal particles that may interact with the composite monomers. This needs further investigation.

In the present study, color was determined with a color spectrophotometer to obtain more quantitative measurements than using color guides.[29] The different charcoal toothpaste formulations evaluated produced different results; therefore, the null hypothesis was rejected.

Further studies may evaluate the effect of different charcoal toothpaste formulations on the different resin composite formulations.

a. 3M Oral Health, St. Paul, MN, USA.
b. Voco, Cuxhaven, Germany.
c. Kerr Dental, Brea, CA, USA.
d. Konica Minolta, Osaka, Japan.
e. Bruker, Billerica, MA, USA.
f. Procter & Gamble, Cincinnati, OH, USA.
g. Colgate-Palmolive, New York, NY, USA.
h. Sabri Dental Enterprises, Downers Grove, IL, USA.
i. ADA, Chicago, IL, USA.
j. Digital Surf, Besançon, France.
k. Inpixon HQ, Palo Alto, CA, USA.

Disclosure statement: The authors declared no conflict of interest. Supported in part by the UTHSC College of Dentistry Alumni Endowment Fund and Tennessee Dental Association Foundation.

Dr. Nabholz is a pediatric dentistry resident, Dr. Nordin was Associate Professor, Department of General Dentistry, Mr. Morrow is a Senior Research Specialist, Department of Bioscience Research, and Dr. Garcia-Godoy is Professor, Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, Tennessee, USA.

References

1. Villalta P, Lu H, Okte Z, Garcia-Godoy F, Powers JM. Effects of staining and bleaching on color change of dental composite resins. *J Prosthet Dent* 2006;95:137-142.
2. Bagheri R, Burrow MF, Tyas M. Influence of food-simulating solutions and surface finish on susceptibility to staining of aesthetic restorative materials. *J Dent* 2005;33:389-398.
3. Reis AF, Giannini M, Lovadino JR, Ambrosano GM. Effects of various finishing systems on the surface roughness and staining susceptibility of packable composite resins. *Dent Mater* 2003;19:12-18.
4. Omata Y, Uno S, Nakaoki Y, Tanaka T, Sano H, Yoshida S, Sidhu SK. Staining of hybrid composites with coffee, oolong tea, or red wine. *Dent Mater J* 2006;25:125-131.
5. Demarco FF, Collares K, Coelho-de-Souza FH, Correa MB, Cenci MS, Moraes RR, Opdam NJM. Anterior composite restorations: A systematic review on long-term survival and reasons for failure. *Dent Mater* 2015;31:1214-1224.
6. García-Godoy F, Ellacuria J. Effectiveness of Sonicare power toothbrush to remove chlorhexidine stains. *Am J Dent* 2002;15:290-292.
7. Turssi CP, Messias DC, Hara AT, Hughes N, Garcia-Godoy F. Brushing abrasion of dentin: Effect of diluent and dilution rate of toothpaste. *Am J Dent* 2010;23:247-250.
8. Law V, Levy LC, Morrow BR, Garcia-Godoy F. Effect of whitening dentifrices on toothbrush abrasion on composites. *Am J Dent* 2022; 35:161-164.
9. Rashid S, Hendren J, Elgendy H, Oak E, Shahinian C, Gabriel A, ElSalhy M. Impact of brushing with charcoal on tooth color and enamel loss: An in vitro study. *Am J Dent* 2022;35:133-136.
10. Bragança GF, Soares PF, Simeão Borges J, Fernandes Vilela AB, Santos Filho PC, Soares CJ. Effects of charcoal toothpaste on the surface roughness, color stability, and marginal staining of resin composites. *Oper Dent* 2022;47:214-224.
11. Tomás DBM, Pecci-Lloret MP, Guerrero-Gironés J. Effectiveness and abrasiveness of activated charcoal as a whitening agent: A systematic review of in vitro studies. *Ann Anat* 2022;29:151998.
12. Garcia-Godoy F, Garcia-Godoy A, Garcia-Godoy C. Effect of a desensitizing paste containing 8% arginine and calcium carbonate on the surface roughness of dental materials and human dental enamel. *Am J Dent* 2009;22(Sp Is A):21A-24A.
13. Schneiderman E, Colón EL, White DJ, Schemehorn B, Ganovsky T, Haider A, Garcia-Godoy F, Morrow BR, Srimaneepong V, Chumprasert S. A profilometry-based dentifrice abrasion method for V8 brushing machines. Part III: Multi-laboratory validation testing of RDA-PE. *J Clin Dent* 2017;28:56-61.
14. García-Godoy F, García-Godoy A, García-Godoy F. Effect of APF Minute-Foam on the surface roughness, hardness, and micromorphology of high-viscosity glass ionomers. *J Dent Child (Chic)* 2003;70:19-23.
15. Hosoya Y, Shiraishi T, Odatsu T, Miyazaki M, García-Godoy F. Effects of polishing on surface roughness, gloss and color of surface reaction type pre-reacted glass-ionomer filled resin composite. *Am J Dent* 2011;24:138-142.
16. Hosoya Y, Shiraishi T, Ando S, Miyazaki M, Garcia-Godoy F. Effects of polishing on surface roughness and gloss of S-PRG filled flowable resin composite. *Am J Dent* 2012;25:227-230.
17. Ismail HS, Ali AI, Garcia-Godoy F. Influence of manual and ultrasonic scaling on surface roughness of four different base materials used to elevate proximal dentin-cementum gingival margins: An in vitro study. *Oper Dent* 2022;47:E106-E118.
18. Luo MR, Cui G, Rigg B. The development of the CIE 2000 colour difference formula: CIEDE2000. *Color Res Appl* 2001;26:340-350.
19. Kim TH, García-Godoy F, Ko CC, Park JK, Kim HI, Kwon YH. Effect of temperature on the mass and color stability of additional photoinitiator containing composite resins. *Dent Mater J* 2013;32:628-636.
20. Ceci M, Viola M, Rattalino D, Beltrami R, Colombo M, Poggio C. Discoloration of different esthetic restorative materials: A spectrophotometric evaluation. *Eur J Dent* 2017;11:149-156.
21. Parks HB, Morrow BR, Pameijer C, Garcia-Godoy F. Staining and whitening products induce color change in resin composites. *Am J Dent* 2021;34:240-244.
22. Pate JD, Wells MH, Morrow BR, Ragain JC, Garcia-Godoy F. Color stability of prefabricated pediatric zirconia crowns following sterilization. *Pediatr Dent* 2021;43:50-56.
23. O'Neill C, Kreplak L, Rueggeberg FA, Labrie D, Shimokawa CAK, Price RB. Effect of tooth brushing on gloss retention and surface roughness of five bulk-fill resin composites. *J Esthet Restor Dent* 2018;30:59-69.
24. Sanchez NP, Gonzalez MD, Belles DM, Frey GN, Paravina RD. Staining- and aging-dependent changes in color and translucency of 3D-printed resin-modified ceramics. *Am J Dent* 2023;36:227-232.
25. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, Sakai M, Takahashi H, Tashkandi E, Perez MdelM. Color difference thresholds in dentistry. *J Esthet Restor Dent* 2015;27(Suppl 1):S1-S9.
26. Paravina RD, Pérez MM, Ghinea R. Acceptability and perceptibility thresholds in dentistry: A comprehensive review of clinical and research applications. *J Esthet Restor Dent* 2019;31:103-112.
27. Salas M, Lucena C, Herrera LJ, Yebra A, Della Bona A, Pérez MdelM. Translucency thresholds for dental materials. *Dent Mater* 2018;34:1168-1174.
28. Marchesan MA, James CM, Lloyd A, Morrow BR, Garcia-Godoy F. Effect of access design on intracoronal bleaching of endodontically treated teeth: An ex vivo study. *J Esthet Restor Dent* 2018;30:E61-E67.
29. Chen H, Chen H, Huang J, He J, Lu E. A systematic review of visual and instrumental measurements for tooth shade matching. *Quintessence Int* 2012;43:649-659.