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UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
POSTGRADUATE DENTAL COLLEGE
NAVAL POSTGRADUATE DENTAL SCHOOL
8955 WOOD ROAD
BETHESDA, MARYLAND 20889

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Name of Candidate: Yamel A. Ramirez
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6/25/21

Jeffrey J. Kim
RESEARCH DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Chairperson

6/25/21

Richard S. Adcook
OPERATIVE DENTISTRY DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Member

6/25/21

Stephen S. Yune
COMPREHENSIVE DENTISTRY DEPARTMENT, NAVAL POSTGRADUATE DENTAL SCHOOL
Committee Member

CHARCOAL-CONTAINING DENTIFRICE AND ITS EFFECT ON THE TOOTH & GLASS IONOMER RESTORATION INTERFACE

by

Yamel A. Ramirez
Lieutenant Commander, Dental Corps
United States Navy

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ABSTRACT

CHARCOAL-CONTAINING DENTIFRICE AND ITS EFFECT ON THE TOOTH & GLASS IONOMER RESTORATION INTERFACE

Yamel A. Ramirez, DDS, 2021

Thesis directed by: Jeffrey J Kim, D.D.S., Ph.D.

Associate Professor, Research Department, NPDS, NMLPDC

Objective: This study compared the effects of charcoal-containing and charcoal-free dentifrices on the integrity of tooth-to-restoration interface. A secondary aim observed color shade change before and after a two-year tooth-brushing simulation. **Methods**: Bovine incisors (N=20) were extracted and stored in 0.05% sodium azide solution. Teeth were restored with a Class V preparation design using conventional glass ionomer, then divided into two groups (10 charcoal vs. 10 charcoal-free). The shades of tooth enamel, cementum and restoration were recorded. The right half of each specimen (left half control) was exposed to a two-year tooth brushing simulation with charcoal or charcoal-free dentifrice. **Results**: The restoration interfaces were preserved after tooth brushing simulation. No premature wear patterns on enamel, cementum or restoration surfaces were observed after tooth brushing simulation with charcoal or charcoal-free dentifrice. Differential shade changes between charcoal and charcoal-free dentifrice were noted after

tooth brushing simulation. **Conclusions**: Activated charcoal in dentifrices did not worsen the tooth-restoration interface and conferred minimal to no tooth whitening benefit.

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LIST OF ABBREVIATONS

CFT	Charcoal-free toothpaste
CRI	Cementum-to-restoration interface
CT	Charcoal-containing toothpaste
ERI	Enamel-to-restoration interface
GI	Conventional glass ionomer
HVGIC	High-viscosity glass ionomer cement
NaN_3	Sodium azide
TBS	Tooth brushing simulator/simulation
VES	Vita Easyshade V spectrophotometer

CHAPTER 1: Introduction

HISTORY & CURRENT TRENDS

In the United States, consumers spent approximately $ 8.2 billion on oral healthcare products in 2018. By 2024, that amount is projected to reach $ 12.5 billion. Out of the most common healthcare products, dentifrices or toothpastes amount to 38%.[1]

In 2018, toothpastes alone accounted for $ 3.12 billion among eight well-known United Sates and European Union manufacturers, and this is through traditional distribution channels that are highly consolidated via convenience stores, supermarkets, pharmacies & drug stores. Advertisements used keywords such as “refreshing, whitening, deep-cleaning and antibacterial” to attract consumers.[1]

However, there have been significant changes in US consumer behavior with online platforms available to everyone with internet and cellular access. In this information era, traditional distribution channels are alive and well, but competition is ever increasing through new online-exclusive manufacturers and retailers employing the powers of social media. Even celebrities and professional product “influencers” with millions to spend on marketing and advertising are claiming a piece of the oral healthcare market. In addition to the tried & true buzzwords, the new keywords are “All natural, organic, eco-friendly, environmentally responsible, fluoride-free” and even “charcoal-activated”. The quality, safety and effectiveness of these online products remain to be seen.

Charcoal in oral healthcare products is gaining popularity and is a great example of such change among US consumers. For millennia, charcoal in its various forms has

been used for many different claimed health benefits to include as a poison detoxifier taken intra-orally and as an odor absorber on wounds. Additionally, many populations all over the world have a long history with using charcoal as part of their oral hygiene practices, even in this present day[2, 3]. Currently, we readily find charcoal impregnated floss, mouth rinses and toothbrush bristles in addition to charcoal-containing dentifrices. These products are advertised as "great for polishing and whitening, Do-It-Yourself (DIY) dental care, naturally detoxifying, micro-cleaning crystals" and of course, "fluoride-free". Advertised as having superior health and esthetic benefits, charcoal-containing dentifrices are touted to remove stains and absorb toxins better than charcoal-free dentifrices to whiten teeth and freshen breath. However, the effects on the tooth surface, shade and restorations are mostly unknown.[2, 4]

The activated charcoal in dentifrices may act as a strong abrasive and may potentially result in premature wear on the enamel, cementum/dentin, and dental restorations, which could then lead to premature failure of existing dental restorations. Most, if not all, charcoal containing dentifrices have not been reviewed nor approved by the Food and Drug Administration. Manufacturers carefully label and advertise so that their dentifrices are classified as a cosmetic and not as a drug. Cosmetics are not subjected to FDA regulations.[2, 4]

Bleaching, as with the use of in-office or at-home trays with gels of hydrogen peroxide or carbamide peroxide, respectively, function by infiltrating enamel to oxidize molecules that lighten the tooth from within. Although some whitening toothpastes contain hydrogen peroxide, most contain an abrasive in some form of a hydrated silica or sodium bicarbonate, similar to an exfoliant, where the act of brushing with it physically

and mechanically removes superficial stains, but does not whiten from within the tooth. In addition to hydrated silica & sodium bicarbonate, activated charcoal is added to some dentifrices as an abrasive to remove stains producing the effect of visually whiter teeth.

An association has been established that the combination of aggressive brushing and/or brushing with a dentifrice causes the gradual wear of tooth enamel as well as gingival recession[5]. When using a whitening dentifrice containing abrasives such as activated charcoal in conjunction with tooth brushing, the rate of wear of enamel may potentially increase as compared to brushing with a dentifrice containing no charcoal. Over time, this serves to promote increasingly thinner enamel, which allows more show-through of the underlying dentin that in itself is darker (lower value) and more yellow than enamel, thereby producing the opposite intention of a "whitening" dentifrice.

Additionally, according to the US National Health and Nutrition Examination Survey 1999-2004, it is estimated that adults 20-64 years of age had an average of seven (7.19) tooth fillings. In 1999, approximately 86 million composite resin restorations were placed compared to 71 million amalgam restorations, which marks a definite trend toward more esthetic, tooth-colored restorations.[6] Although studies have been conducted, there are insufficient data regarding the effects of dentifrice abrasives, particularly charcoal-containing dentifrices on the interface between tooth enamel and the glass ionomer restoration.

Concerning dentifrice regulation and the clinical implications, the Food & Drug Administration regulates two types of certifications: 1) Approval and 2) Clearance. Both certifications are proven safe and effective; however, the Approval certification is reserved for new drugs like a new type of fluoride that prevents or fights against

caries. Since new drugs require extensive study, it can be very expensive for manufacturers to be approved. Clearance, on the other hand, is the FDA's certification for drugs that are substantially the same or functionally equivalent, and have already been approved, such as sodium fluoride that is found in many dentifrices. In essence, the FDA regulates the claim not the product itself.[7]

The American Dental Association Council on Scientific Affairs thoroughly assesses the scientific evidence on safety and effectiveness of dentifrice products, and for this product to receive the ADA Seal of Acceptance, it must fulfill three requirements: It must have fluoride; it must not contain an ingredient, like sugar, that contributes to caries; and it must not have a Relative Dentin Abrasivity factor above 250.[7]

New "cosmetic" dentifrices can not make claims such as "anti-cavity" and, instead make the claim that its product is to be effective in whitening and promote to be a "safer" alternative by not containing "dangerous chemicals" such as fluoride. In doing so, these products avoid FDA regulation and can be sold to consumers labeled under cosmetics. There are little to no studies on the safety and efficacy on these new cosmetic dentifrices, and there are insufficient data regarding the effects of dentifrice abrasives, particularly charcoal-containing dentifrices on the interface between the tooth and glass ionomer restoration. The purpose of this investigation is to study the effects of a commercially available dentifrice containing charcoal and its effect on this interface as compared to a non-charcoal dentifrice of the same brand.

CHAPTER 2: Materials and methods

STUDY DESIGN

Extracted, whole bovine incisors were collected from a cattle processing plant, and the teeth were rinsed with tap water and stored in 0.05% sodium azide (NaN_3) (Sigma-Aldrich, St. Louis, MO) until their use. Twenty teeth were divided into two groups (n=10) as follows:

Group A: Charcoal-free toothpaste (CFT)

Group B: Charcoal-containing toothpaste (CT)

One half of the facial surface of each tooth was protected/covered by lab putty while the second half was exposed to the tooth brushing simulation (TBS). The protected half of the facial surface acted as a control (aka pre-brushing). Microscopic images were captured before and after TBS to compare the effects on the tooth-to-restoration interfaces, as well as the effects on the surfaces of the enamel, cementum and restoration. Additionally, the color shade of each tooth (enamel, cementum and restoration) was assessed using the Vita Easyshade V spectrophotometer (VES).

TOOTH PREPARATION

Using a flat-end tapered coarse-grit diamond bur (Brasseler USA), all teeth received a non-beveled Class V preparation (5mm width by 2mm height by 2mm depth) overlapping the enamel and cementum, then filled with high-viscosity glass ionomer cement (Fuji IX HVGIC, GC America, Alsip, IL) (Figs. 1 & 2). Poly-acrylic acid 20% (Cavity Conditioner, GC America) was applied to all prepared surfaces per manufacturer's instructions, and HVGIC was placed. The restorations were finished with

Sof-Lex Extra-Thin Contouring and Polishing Discs fine-grit (3M USA). All teeth were numbered and stored in 0.9% isotonic saline solution for 24 hours to allow complete setting of the restorative material. The shade of each tooth in both groups was visually recorded after at least 24 hours of hydration using the VES for comparison of pre- & post-TBS (Fig. 3). Using a digital stereo-optical microscope (Hirox), micrograph images were captured of the enamel-to-restoration interface (ERI) and cementum-to-restoration interface (CRI) on both halves of each tooth's facial surface (4 total images per tooth) prior to TBS.

Each of the twenty bovine teeth were randomly assigned ten to each group as mentioned in the study design. Each tooth was placed within a toothbrush well using lab putty (Coltene). The putty was also used to cover one-half the facial surface of the tooth in order to protect it from the tooth brushing action (Fig. 4). The lab putty was allowed to fully set according to manufacturer's instructions before subjecting to TBS.

TOOTH BRUSHING SIMULATION

The samples were subjected to the tooth brushing simulator (SD Mechatronik ZM-3, Germany) to simulate brushing twice per day for 2 years. The brushing times assumed a total of 28 teeth in a person's mouth with three surfaces per teeth (facial, occlusal, lingual), and brushing for two minutes (120 seconds) twice per day, or 240 seconds total. Therefore, in 120 seconds of brushing 28 teeth, each tooth will be brushed 4.29 seconds, assuming each tooth is brushed an equal amount of time. Then, each tooth is assumed to have three surfaces, which brings the brushing time to 1.43 seconds per surface. Brushing is performed twice per day, so the total brushing time for one surface of a tooth per day, which in this case contains our restoration sample, is 2.86 seconds.

Over a two-year period (assuming 720 days), a single surface of a tooth is brushed approximately 2,059.2 seconds or 34.32 minutes, which again, assumes equal brushing time for every surface of every tooth for two minutes. The total TBS was rounded up to 36 minutes for ease of application, then this number was divided six times, so that at every 6 minutes the brush heads and specimens would be rinsed with tap water and a fresh, pea-sized (~ 0.25 grams) application of toothpaste added.

In this study, each sample was subjected to 36 minutes total tooth brushing simulation using a soft bristle toothbrush (Acclean, classic adult 41-tuft straight-handle, 0.007 Soft DuPont Tynex) wetted with tap water (Fig. 5). Group A samples received a charcoal-free toothpaste (CFT) (Colgate Total Whitening, Colgate-Palmolive, New York) and Group B received a charcoal-containing toothpaste (CT) (Colgate Total Charcoal Deep Clean) of 0.25 grams each placed on the brush head. The brush heads were loaded onto the tooth brushing simulator with a brushing force of 200 grams or approximately 2 Newtons (Fig. 6). At the completion of every six-minute interval, the samples and the brush heads were rinsed with tap water for 5-10 seconds, and a fresh 0.25 grams application of toothpaste was placed on the wet brush heads for a subsequent round of tooth brushing until a total of 36 minutes elapsed.

DATA COLLECTION

After completion of the tooth brushing simulation, data collection was analyzed per section. The enamel-to-restoration (ERI) and cementum-to-restoration (CRI) interfaces (Table 1) in addition to the enamel, cementum, and restoration surfaces (Tables 2, 3, & 4, respectively) were documented and photographed using a digital stereo-optical microscope (Hirox) (Figs. 7-10). Additionally, the final shade for enamel, cementum,

and restoration was documented for comparison against pre-brushing color shade using the Vita Easyshade V (Tables 5, 6, & 7, respectively).

CHAPTER 3: Results

The results of this study for both Group A (CFT) and B (CT) showed no change on the control half (protected from TBS) of the facial surface of the tooth at the ERI and CRI as expected. The control half was unaffected on the enamel, cementum and restoration surfaces. The exposed half of the facial surface of each tooth in Groups A & B, subjected to TBS exhibited fair to excellent integrity of the ERI (Figs. 7 & 9 and Table 1) & CRI (Figs. 8 & 10 and Table 1). This study defined a fair marginal integrity as the restoration having some discontinuity with the tooth, but serviceable and clinically acceptable. Excellent interface integrity was defined as the restoration being fully adapted to the tooth. The interfaces on the exposed half were more finished/polished in contrast to the pre-TBS micrographs (Figs. 7-10). The enamel, cementum and restoration surfaces were minimally affected by the abrasive action of both toothpastes (CFT & CT) and were not distinct in comparison (Figs. 7-10 and Tables 2-4).

A comparison of color shade change was also analyzed before and after TBS. Table 5 (enamel), Table 6 (cementum), and Table 7 (glass ionomer) depict these results. It was observed that TBS differentially changed color shades all surfaces tested (enamel, cementum, and glass ionomer). However, these changes were minimal (e.g., A2 -> A3), and there were no discernible uniformed directionalities.

Within the limitations of this study, the null hypothesis was accepted. The charcoal-containing dentifrice used in this study showed minimal to no disruption of the ERI and CRI after a two-year tooth brushing simulation; the enamel, cementum and restoration surfaces were not visibly worn other than appearing finished & polished; and

although there were some color shade change improvements, it was not improved consistently among all specimens.

CHAPTER 4: Discussion

SAFETY

Based on the materials and results of this study (e.g., margin and wear characteristics), it appears that the charcoal-containing toothpaste (CT) is as safe as the charcoal-free toothpaste (CFT) on enamel, cementum and the tooth-to-restoration interface. The pre- & post-tooth brushing simulation (TBS) micrograph comparisons showed that enamel/cementum surface stains were removed adequately by both toothpastes (CFT & CT). Any unfinished or rough glass ionomer restorative material overlapping the ERI or CRI was finished smoothly and polished further after TBS to give the restorative margin a more refined appearance. However, it is important to re-iterate that only one brand of dentifrice was tested in this study and more research is needed using various brands of charcoal-containing dentifrices to gain a more definitive conclusion. It is also important to note the charcoal dentifrices on the market lack FDA clearance/approval, ADA Seal of Acceptance, and other forms of independent testing or safety verifications. Furthermore, there may be other factors such as biological effects concerning soft tissues and the oral microbiome that are not known with the active charcoal in these "cosmetic" dentifrices.

EFFICACY

With regards to the marketing claims that adding activated charcoal in dentifrices improves whitening, based on this study's color shade change data, CT did not show superior results compared to CFT. Even with extrinsic stains on the surface of the tooth, the charcoal-containing toothpaste did not prove superior to the charcoal-free toothpaste and showed comparable results pre- and post-TBS. Since overall whitening effects were

not observed in this study, it still remains to be seen how effective charcoal-containing dentifrices are in oral cavity. Although the results showed no additional wear or diminished marginal integrity, we could not find any additional benefit for adding activated charcoal in dentifrices other than marketing appeal.

LIMITATIONS

To the best of our knowledge, this study is the first investigation of charcoal-containing dentifrices on restorative material and marginal integrity. Our study design and results contain several limitations.

The dentifrices (CT and CFT) used in this study are from one manufacturer to minimize product variabilities. There are several small companies and international corporations producing charcoal containing dentifrices with known and unknown formulations, and active and inactive ingredients. Some dentifrices are likely to contain a higher concentration of charcoals, and abrasive wear and shade color change characteristics may differ from what we have reported here. The toothbrushes were all the same type and brand, made specifically for standardized research settings. A 200-gram load is an average manual force for a person and does not consider lighter or heavier brushing forces that may affect some people more than others. The Relative Dentin Abrasivity was not measured for the charcoal-containing toothpaste for this study. The tooth brushing simulation was conducted to replicate approximately two-years of brushing. Similar studies conducted up to 4-year tooth brushing cycles, and perhaps it would have been conducive to keep this study in line with these studies. The original design of this study called for bisecting of the bovine incisor along the long axis of the tooth to compare & contrast the cross-sectional depth of the restoration and the ERI &

CRI before and after TBS, therefore quantification of restoration wear and marginal integrity was not accomplished. Additionally, this experiment was conducted *in vitro* on bovine incisors without thermocycling. A follow-up *in vivo* study using human subjects is advised to confirm the results from this study.

CHAPTER 5: Conclusions

New emerging oral healthcare products are available through online retailers with little or no experience in healthcare product manufacturing processes. From these online retailers or independent manufacturers, fluoride-free dentifrices are sold and heavily promoted as a natural and safer alternative. Fluoride is the only chemical compound that is scientifically proven to have anti-cariogenic effects. It has a long track record of safety and effectiveness as an active ingredient in dentifrices, mouth washes, drinking water, certain foods, and dental restoratives from the scientific, regulatory and professional communities. However, fluoride avoidance or fear among some people in the general population persists. Oral healthcare providers should be aware that some companies are capitalizing on the scientifically unfounded or overly exaggerated fluoride risks, and are using the cosmetic designation to bypass stringent FDA regulations on dentifrices and other oral healthcare products. Clinical and product updates through quality CE courses are urgently needed for oral healthcare providers. Now is an opportune time for providers to ask their patients about the types of home oral healthcare products they use and recommend products that were developed by sound scientific research and verified by an independent laboratory. Patient education and patients making informed and smart decisions will be critical in the future.

SUMMARY

The charcoal dentifrice tested in this study maintained the integrity of the restoration to tooth interface both on enamel and cementum with minimal to no wear on each of the surfaces of enamel, cementum and HVGIC restoration. However, the efficacy of charcoal on superior teeth whitening claim could not verified. Color shade change after

brushing simulation with the charcoal dentifrice was variable, but mostly darkened, especially with the cementum and restoration.

Table 1. Marginal Integrity: Excellent, Fair, Poor. R.ERI = Right Enamel-to-Restoration Interface. R.CRI = Right Cementum-to-Restoration Interface. Group B (CT): Tooth 20 exhibited Fair CRI marginal integrity; tooth 21 Fair ERI + CRI marginal integrity.

TOOTH	R.ERI	R.CRI	
1	Excellent	Excellent	Charcoal-Free Dentifrice
2	Excellent	Excellent	
3	Excellent	Excellent	
4	Excellent	Excellent	
5	Excellent	Excellent	
6	Excellent	Excellent	
7	Excellent	Excellent	
8	Excellent	Excellent	
9	Excellent	Excellent	
10	Excellent	Excellent	
11	Excellent	Excellent	Charcoal Dentifrice
12	Excellent	Excellent	
13	Excellent	Excellent	
14	Excellent	Excellent	
15	Excellent	Excellent	
16	Excellent	Excellent	
19	Excellent	Excellent	
20	Excellent	Fair	
21	Fair	Fair	
22	Excellent	Excellent	

Table 2. Enamel Surface Integrity (No Wear or Wear). The right-side enamel (RE) surface exhibited No Wear in both Groups after TBS.

TOOTH	RE	
1	No Wear	Charcoal-Free Dentifrice
2	No Wear	
3	No Wear	
4	No Wear	
5	No Wear	
6	No Wear	
7	No Wear	
8	No Wear	
9	No Wear	
10	No Wear	
11	No Wear	Charcoal Dentifrice
12	No Wear	
13	No Wear	
14	No Wear	
15	No Wear	
16	No Wear	
19	No Wear	
20	No Wear	
21	No Wear	
22	No Wear	

Table 3. Cementum Surface Integrity (No Wear or Wear). The right-side cementum (RC) surface exhibited No Wear in both Groups after TBS.

TOOTH	RC	
1	No Wear	Charcoal-Free Dentifrice
2	No Wear	
3	No Wear	
4	No Wear	
5	No Wear	
6	No Wear	
7	No Wear	
8	No Wear	
9	No Wear	
10	No Wear	
11	No Wear	Charcoal Dentifrice
12	No Wear	
13	No Wear	
14	No Wear	
15	No Wear	
16	No Wear	
19	No Wear	
20	No Wear	
21	No Wear	
22	No Wear	

Table 4. Glass Ionomer Surface (No Wear or Wear). The right-side glass ionomer (RGI) surface exhibited minimal to No Wear in both Groups after TBS.

TOOTH	RGI	
1	No Wear	Charcoal-Free Dentifrice
2	No Wear	
3	No Wear	
4	No Wear	
5	No Wear	
6	No Wear	
7	No Wear	
8	No Wear	
9	No Wear	
10	No Wear	
11	No Wear	Charcoal Dentifrice
12	No Wear	
13	No Wear	
14	No Wear	
15	No Wear	
16	No Wear	
19	No Wear	
20	No Wear	
21	No Wear	
22	No Wear	

Table 5. Enamel Color Shade Change, Pre-/Post-TBS. Group A (CFT) exhibited color shade change improvement on 4 out of 10 teeth. Group B (CT) exhibited color shade change worsening on 3 out of 10 teeth and improvement on 2 out of 10 teeth.

TOOTH	ENAMEL PRE	ENAMEL POST	
1	A1	A1	Charcoal-Free Dentifrice
2	B2	B2	
3	A2	B2	
4	A1	A1	
5	A3	A3	
6	A3	B2	
7	B2	B2	
8	A3	B2	
9	A3	B2	
10	A1	A1	
11	A1	A1	Charcoal Dentifrice
12	A3	B2	
13	A1	A1	
14	B2	A3	
15	A1	A1	
16	A3	B2	
19	B2	B2	
20	B2	A2	
21	A3	A3	
22	A1	B2	

Table 6. Cementum Color Shade Change, Pre-/Post-TBS. Group A (CFT) exhibited color shade change worsening on 1 out of 10 teeth. Group B (CT) exhibited color shade change worsening on 3 out of 10 teeth and improvement on 1 out 10 teeth.

TOOTH	CEMENTUM PRE	CEMENTUM POST	
1	A2	A3	Charcoal-Free Dentifrice
2	A3	A3	
3	B4	B4	
4	B4	B4	
5	A3	A3	
6	A3	A3	
7	A1	A1	
8	B1	B1	
9	A1	A1	
10	A3	A3	
11	B3	A4	Charcoal Dentifrice
12	A3	C3	
13	A3	A3	
14	A3	C2	
15	A3	A3	
16	A3	A3	
19	A1	A1	
20	A1	A1	
21	A1	B1	
22	A1	A1	

Table 7. Glass Ionomer Color Shade Change, Pre-/Post-TBS. Group A (CFT) exhibited color shade change worsening on 6 out of 10 teeth; improvement on 1 out of 10 teeth. Group B (CT) exhibited color shade change worsening on 2 out of 10 teeth; improvement on 2 out of 10 teeth.

TOOTH	RESTORATION PRE	RESTORATION POST	
1	B2	A2	Charcoal-Free Dentifrice
2	A2	A3	
3	A3	A3	
4	B2	A3	
5	A3	A3	
6	B2	A3	
7	A3.5	C3	
8	B4	A3.5	
9	A4	A3.5	
10	A3	A3	
11	A3	A3.5	Charcoal Dentifrice
12	A3.5	A3	
13	A3	A3	
14	A3	A3	
15	A3	A3	
16	A3	A3	
19	A4	A4	
20	A4	B4	
21	A3.5	A4	
22	A3	A3	

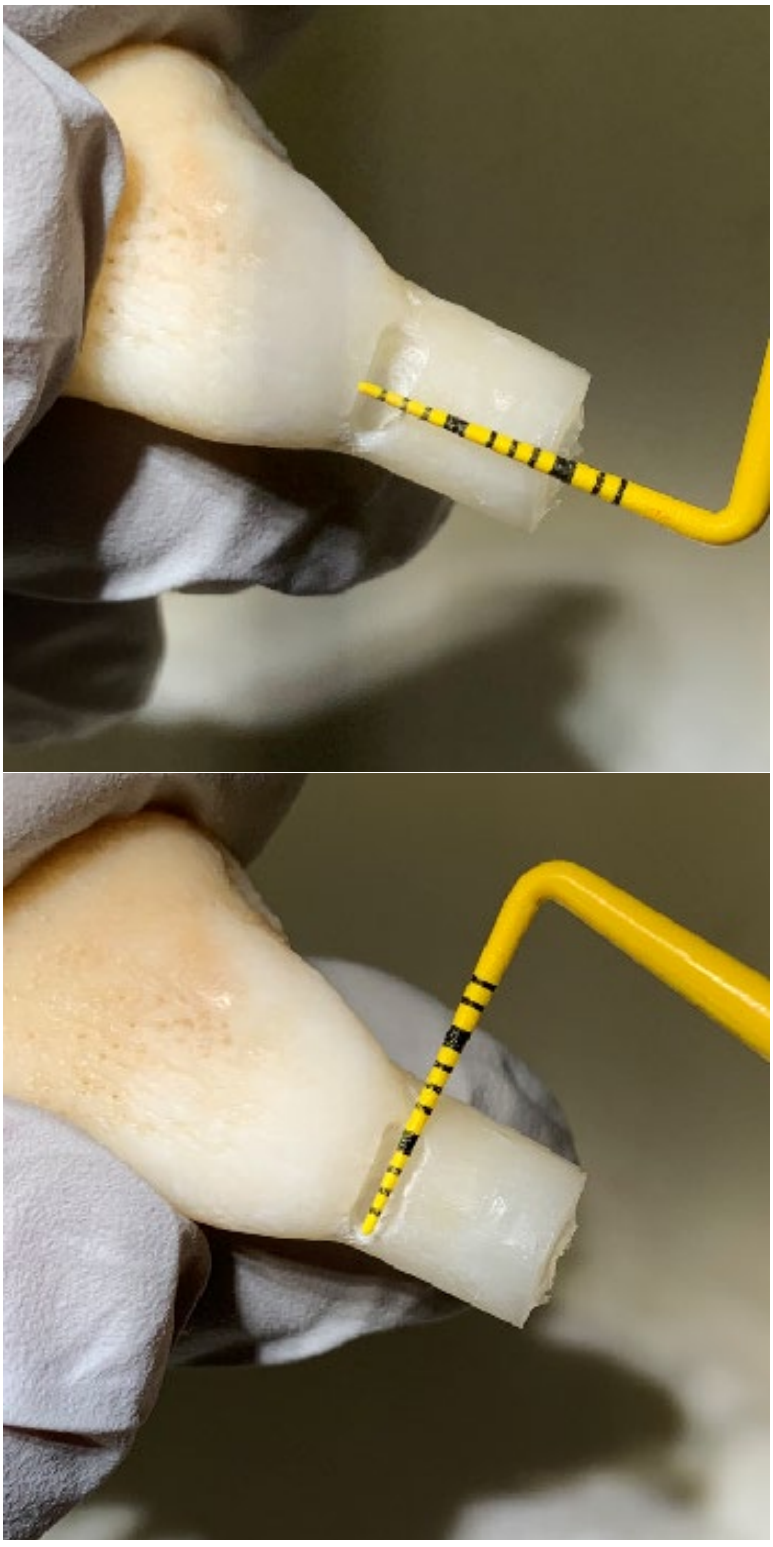

Figure 1. Class V preparation. The preparations overlapped both the enamel and root surface to simulate a common clinical scenario. The preparation was approximately 2mm height x 5mm width x 2mm depth.

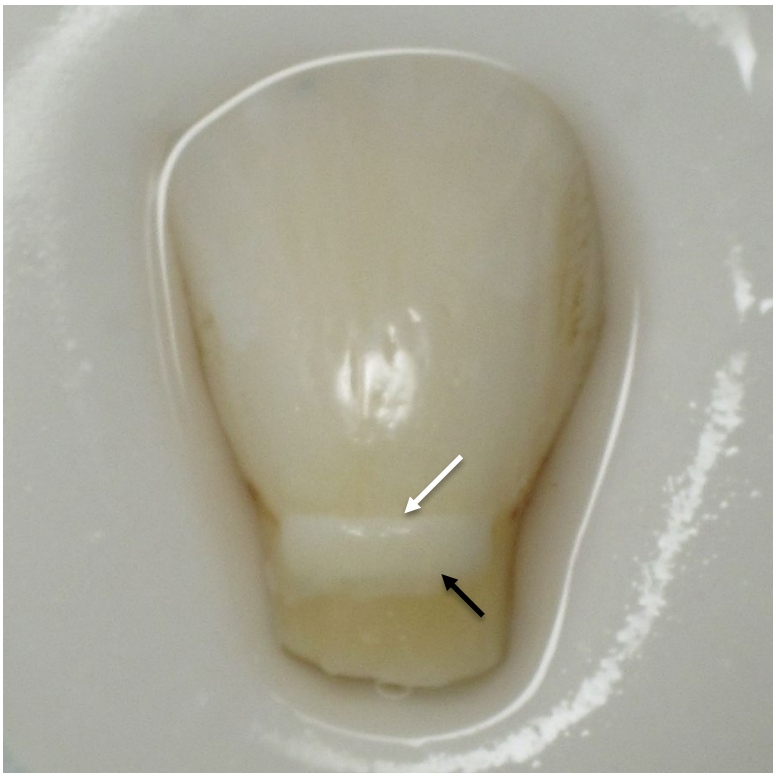

Figure 2. Finished Class V preparation on bovine incisor. The enamel-to-restoration interface (white arrow). The cementum-to-restoration interface (black arrow).

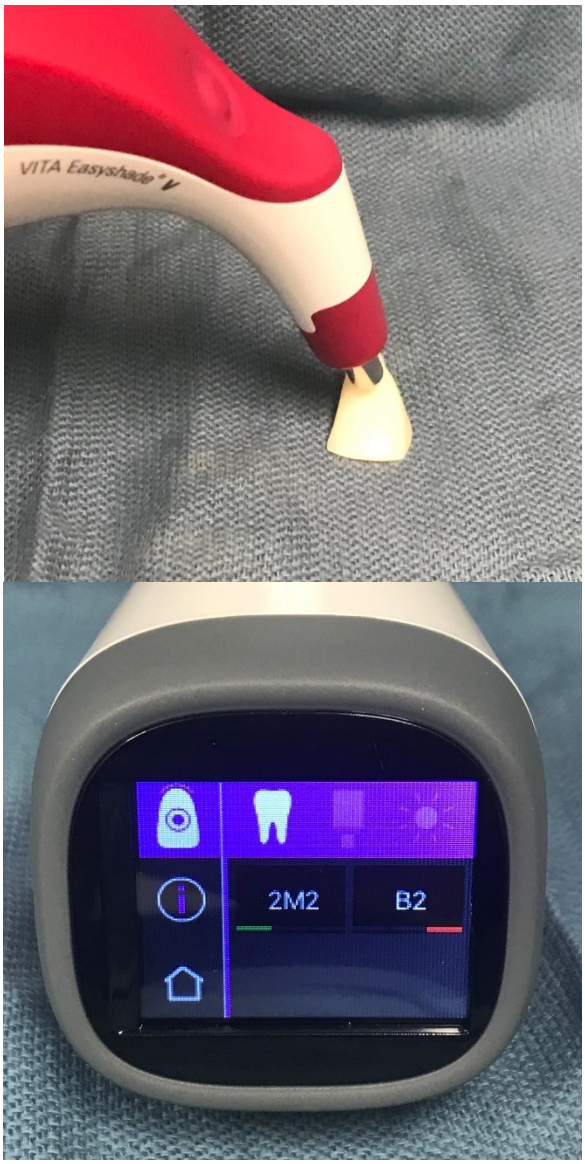

Figure 3. Color shade documentation. The VITA Easyshade V was used on the enamel, cementum and restoration surface to capture the pre-TBS and post-TBS color shade.

Figure 4. Embedding and protection of one-half facial surface. Lab putty was used to embed the specimen in the toothbrushing well with the left side of the facial surface protected from TBS.

Figure 5. Toothbrush with pea-sized amount of charcoal toothpaste (CT). Acclean, classic adult 41-tuft straight-handle design with rounded, diamond-polished bristle ends – 0.007 soft DuPont Tynex.

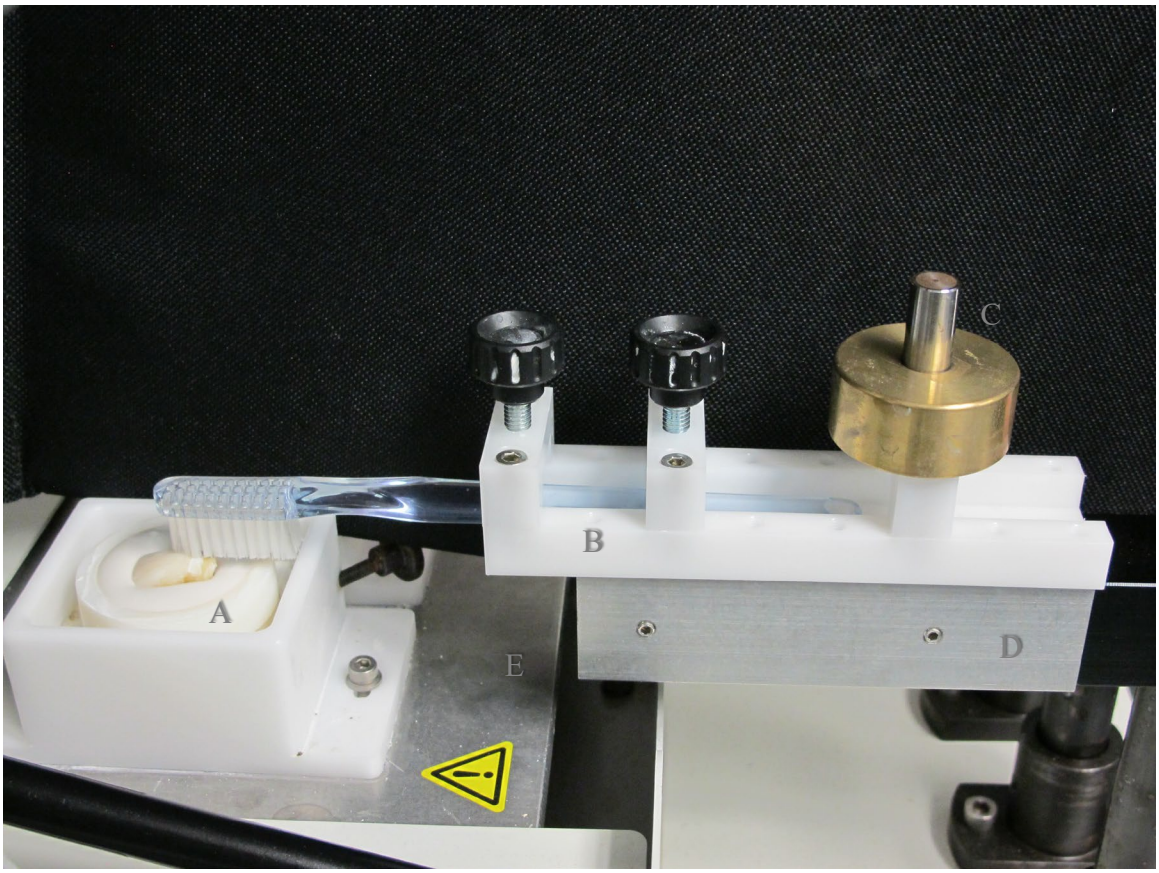

Figure 6. Toothbrushing simulation setup. (A) The specimen placed in the cylindrical well with the toothbrush resting on the tooth. (B) Toothbrush holder. (C) 200 gram load. (D) Toothbrush platform. (E) Dynamic platform.

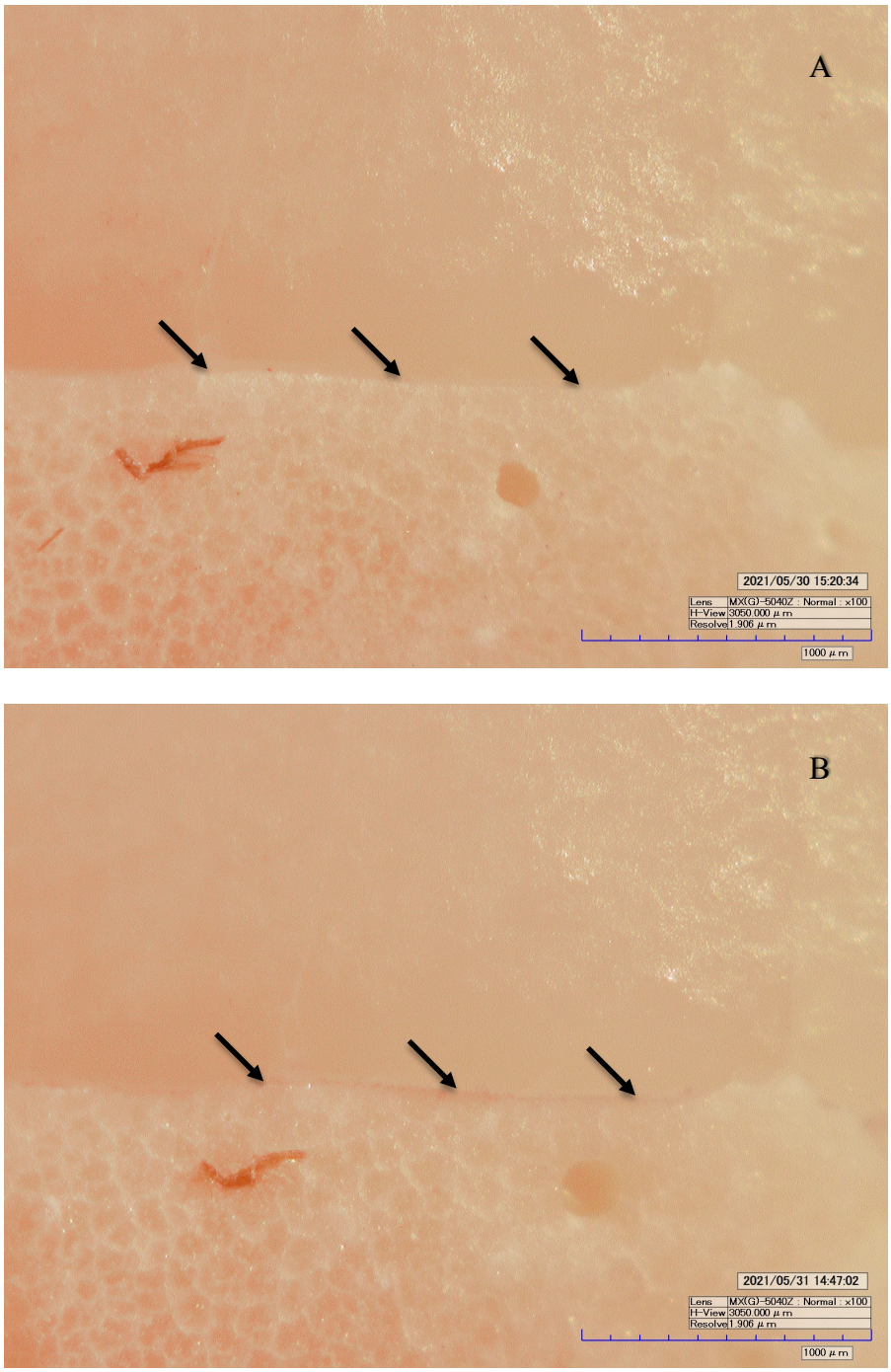

Figure 7. Group B (Charcoal Toothpaste): Enamel-Restoration Interface (ERI). (A) ERI before toothbrushing simulation (TBS) with charcoal toothpaste. Note sharp, clean distinction of ERI (arrows). (B) ERI after TBS with charcoal toothpaste. Note altered ERI (arrows). The margin is darker and not as adapted to the enamel edge (3500 μm).

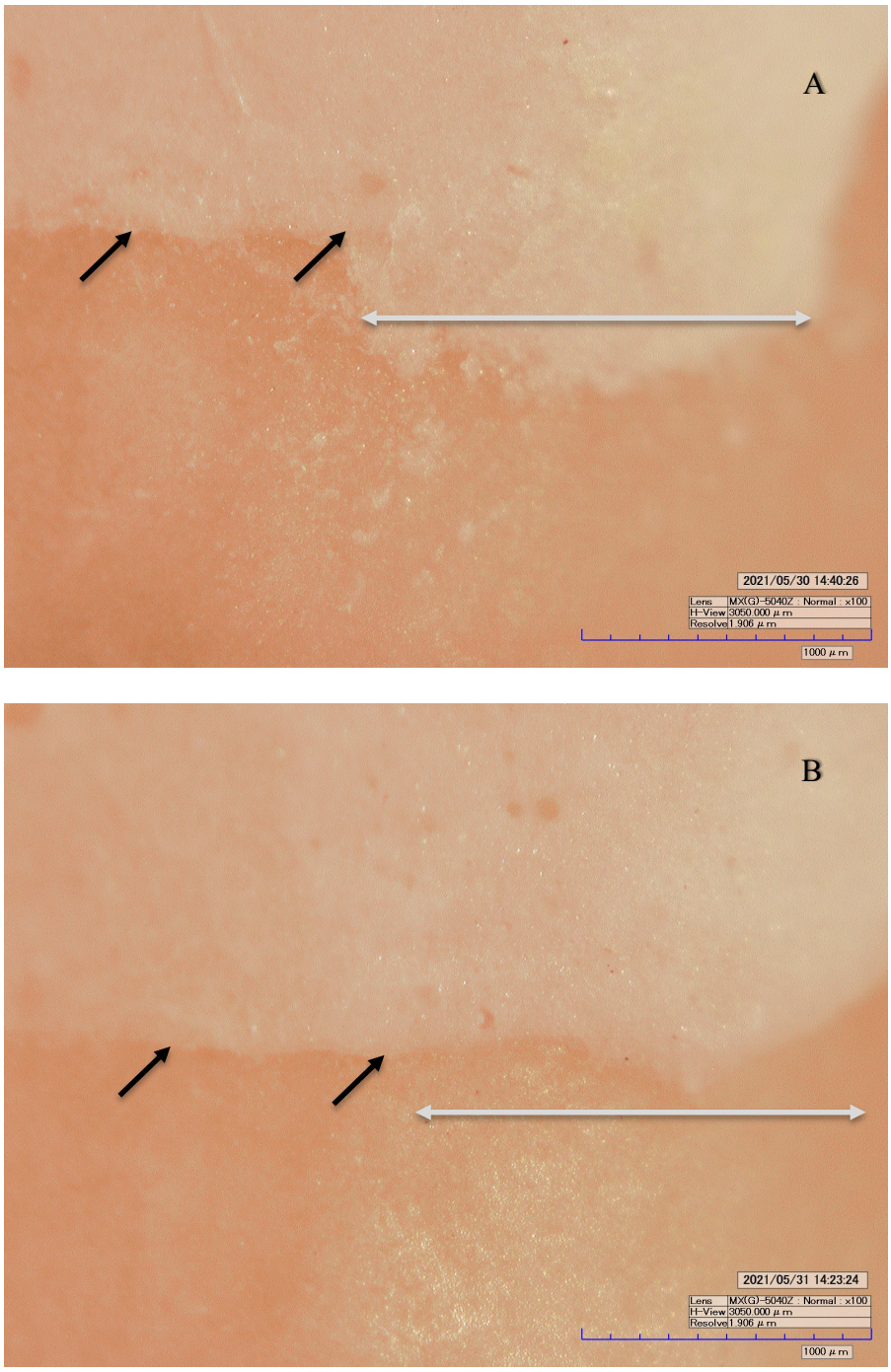

Figure 8. Group B (Charcoal Toothpaste): Cementum-Restoration Interface (CRI). (A) CRI before toothbrushing simulation (TBS) with charcoal toothpaste. Note rough & unfinished CRI (arrows) with excess HVGIC (double arrow). (B) CRI after TBS with charcoal toothpaste. The CRI (arrows) and both cementum and restoration surfaces are smoother, more polished. However, CRI integrity appears preserved (3500 µm).

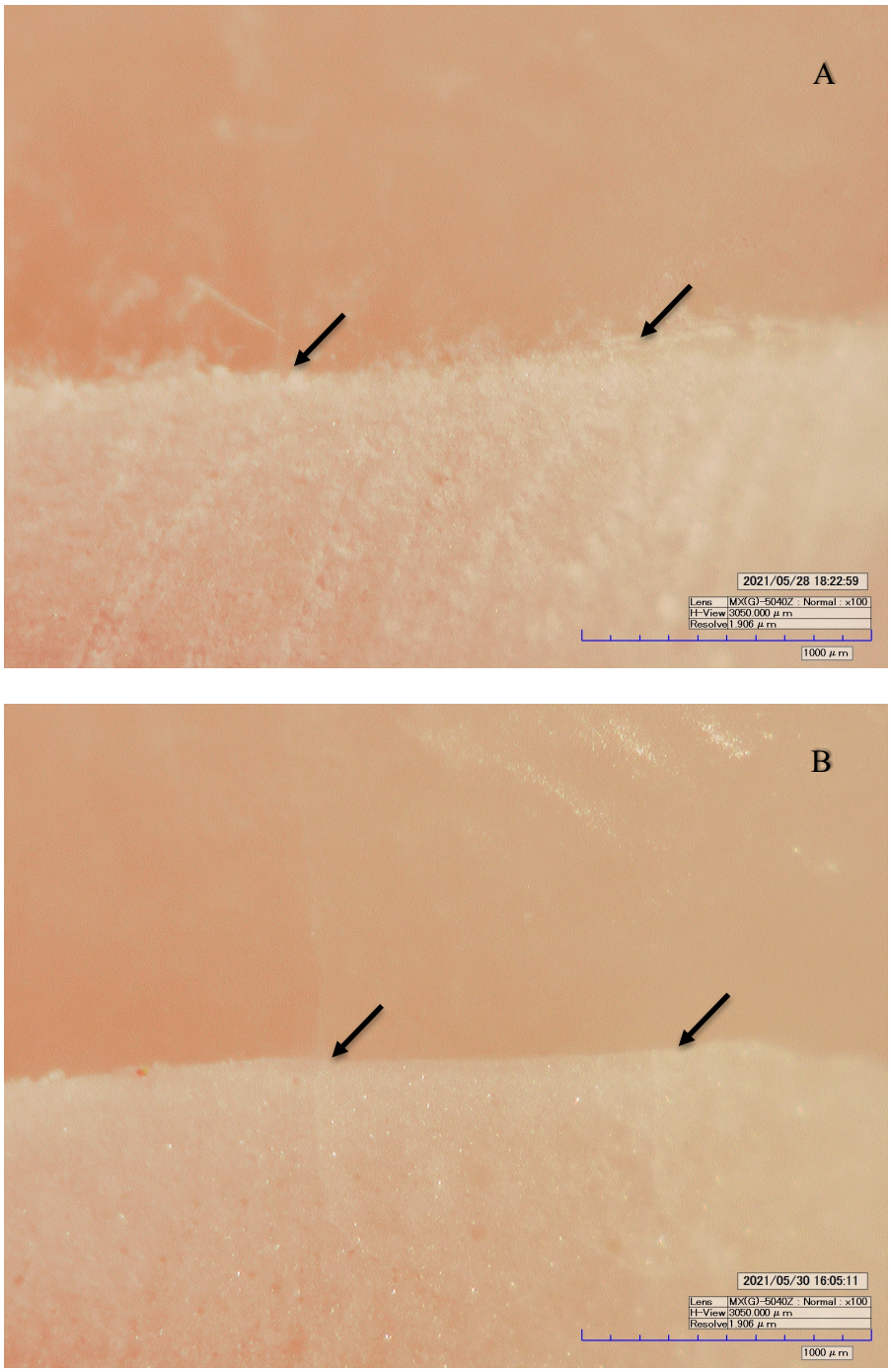

Figure 9. Group A (Charcoal-Free Toothpaste): Enamel-Restoration Interface (ERI). (A) ERI before toothbrushing simulation (TBS) with charcoal-free toothpaste (CFT). Note rough & unfinished ERI (arrows). (B) ERI after TBS with CFT. The ERI (arrows) and both cementum and restoration surfaces are smoother, more polished. However, ERI integrity appears preserved (3500 µm).

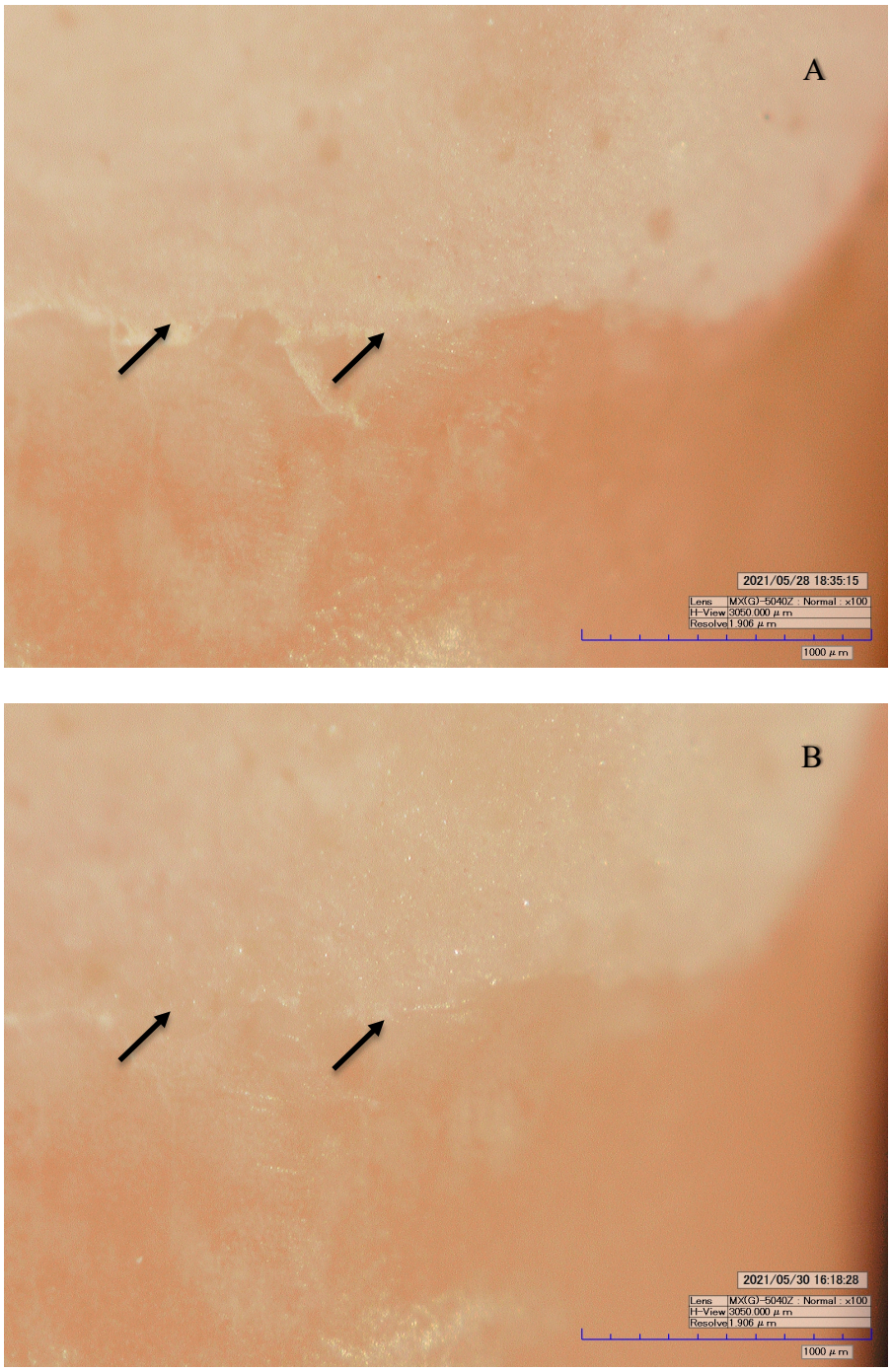

Figure 10. Group A (Charcoal-Free Toothpaste): Cementum-Restoration Interface (CRI). (A) CRI before toothbrushing simulation (TBS) with charcoal-free toothpaste (CFT). Note rough & unfinished CRI (arrows). (B) CRI after TBS with CFT. The CRI (arrows) and both cementum and restoration surfaces are smoother, more polished. However, CRI integrity appears preserved (3500 μm).

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