The Open Dentistry Journal
DOI: 10.2174/0118742106330806240916071809, 2024, 18, e18742106330806
ISSN: 1874-2106

RESEARCH ARTICLE OPEN ACCESS

In vitro Evaluation of the Stain Removal Efficacy between Two Whitening Dentifrices during Orthodontic Treatment

Zhen Herr Eugene Yeoh[1], Khairil Aznan Mohamed Khan[1,*], Murshida Marizan Nor[1], Badiah Baharin[2] and Haslina Rani[3]

[1]*Orthodontics Unit, Department of Family Oral Health, Faculty of Dentistry, University Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia*
[2]*Periodontics Unit, Department of Restorative Dentistry, Faculty of Dentistry, University Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia*
[3]*Dental Public Health Unit, Department of Family Oral Health, Faculty of Dentistry, University Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia*

Abstract:

Background: This *in-vitro* study aimed to assess and compare the efficacy of a newly developed whitening dentifrice, Dentaklin White (TG), to Colgate Total® Whitening (CG), utilising a toothbrushing simulator machine.

Methods: Twenty enamel specimens were prepared and randomly divided into CG and TG. Orthodontic brackets were attached to the enamel specimens and were then stained with a mixture of coffee, tea, and chlorhexidine. A short 0.019x0.025" stainless steel (SS) archwire was ligated onto the brackets subsequently. All the specimens were subjected to a toothbrushing simulator for specific duration. The CIE L*a*b* colour change (ΔE) was evaluated using digital image analysis at T1 (2 weeks), T2 (4 weeks), and T3 (12 weeks) compared to T0 (baseline). Archwire roughness was analysed using a profilometer at T4 (2 years) compared to T0.

Results: The results indicated that there was a significant change in tooth colour associated with brushing duration for both CG and TG ($p<0.05$) with no significant difference between the two dentifrices ($p>0.05$). Both dentifrices notably removed more stains at Site A ($p<0.05$) and increased wire surface roughness ($p<0.05$) without a statistically difference between them ($p>0.05$).

Conclusion: Dentaklin White (TG) demonstrated comparable efficacy to Colgate Total® Whitening (CG).

Keywords: Whitening dentifrice, Orthodontic stains, Arch-wire roughness, Enamel roughness, Spectrophotometry, Tooth colour analysis.

*Address correspondence to this author at the Orthodontics Unit, Department of Family Oral Health, Faculty of Dentistry, University Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia; E-mail: aznankhan@ukm.edu.my

Cite as: Yeoh Z, Khan K, Marizan Nor M, Baharin B, Rani H. *In vitro* Evaluation of the Stain Removal Efficacy between Two Whitening Dentifrices during Orthodontic Treatment. Open Dent J, 2024; 18: e18742106330806.
http://dx.doi.org/10.2174/0118742106330806240916071809

Received: July 09, 2024
Revised: August 19, 2024
Accepted: September 05, 2024
Published: ?? ??, 2024

1. INTRODUCTION

The global increase in aesthetic dental treatments, including tooth whitening and orthodontic procedures, is evident in Malaysia as well [1, 2]. Dental stains are categorized into extrinsic and intrinsic types. Extrinsic stains are caused by compounds incorporated into the tooth surface, such as from coffee, tea, and tobacco, or by chemical interactions with substances like cationic

antiseptics and metal salts [3], particularly on rough and porous enamel. Although professional prophylaxis using paste, pumice, and air polishing can remove extrinsic stains, their development on the labial surface of front teeth can be unpleasant, especially for those undergoing orthodontic treatment.

Among active ingredients commonly found in whitening dentifrices include hydrogen peroxide or carbamide peroxide, which serve as bleaching agents to break down stains on the enamel and dentin layers of the teeth [3, 4]. Additionally, enzymes like papain and bromelain, derived from papaya and pineapple, help break down protein-based stains on the teeth. There are also stain removal agents such as polyphosphates and tetrasodium pyrophosphate, which work by preventing future staining and inhibiting the formation of tartar and stains by reducing the adherence of stain-causing compounds to the teeth. These products are marketed to address tooth staining and discoloration. Whitening dentifrices not only mechanically remove stains but also decrease the absorption of new stains. The convenience of use and cost-effectiveness compared to dental visits contribute to the growing popularity of whitening dentifrices in the market.

Progress in research technology has resulted in a rise in the creation and availability of tooth whitening dentifrices with different formulations such as those containing sodium bicarbonate [4]. Apart from its stain removal benefits, sodium bicarbonate also offers additional advantages when used in dentifrices. It can reduce the acidity of dental plaque, leading to a decrease in cavities and aiding in the remineralization of early-stage carious [5]. Moreover, the antibacterial properties of sodium bicarbonate have been extensively studied, showing positive effects on oral pathogens and promoting gingival health [6].

The stain-removing ability of a dentifrice is typically linked to its level of abrasiveness, which, at higher levels, can lead to undesirable tooth wear [7]. In this study, a newly developed whitening dentifrice with sodium bicarbonate (Dentaklin White) is compared to a marketed whitening dentifrice with hydrated silica (Colgate Total® Whitening). The clinical importance of comparing these two products lies in demonstrating that a locally produced dentifrice with lower abrasiveness can offer comparable cleaning efficacy and whitening effects to a commercially available, highly abrasive dentifrice, owing to the differences in their main ingredients. Furthermore, although the use of whitening dentifrice is common among orthodontic patients, there is also lack of data on the abrasiveness of dentifrice to the surface roughness of orthodontic arch wire. Hence, we also assessed the efficacy of a newly developed whitening and its effects on orthodontic stainless-steel arch wire.

2. MATERIAL AND METHODS

An *in-vitro* study was conducted (Ethical approval: JEP-2021-784) to evaluate a new locally developed whitening dentifrice, Dentaklin White, as a test group (TG) against commercially established whitening dentifrice, Colgate Total® Whitening as the control group (CG). The ingredients (taken from the sample's package) and compositions [7] of the two dentifrices are as in the Table **1**.

The study was conducted on extracted sound human premolar enamel specimens using tooth-brushing simulator machine, to assess the stains removal efficacy and orthodontic arch wire surface roughness.

PS software 3.1.2 was used to calculate the sample size. The differences in means and standard deviation (SD) of stains removal were estimated as 3.28 and 2.46 respectively as reported in a previous study Schwarzbold *et al* [7], utilizing 8 samples per study group. To detect the difference of 3.28 with 80% power and alpha 0.05, we needed 10 samples in each experimental group. Hence, a total sample of 20 was calculated for both test and control group (Fig. **1**).

Table 1. Ingredients and composition of dentaklin white and colgate total® whitening.

Component	Dentaklin White	Colgate Total® Whitening
Active ingredient	Sodium Fluoride	Stannous Fluoride
Inactive ingredients	Water, Glycerin, Disodium Cocoyl Glutamate, Xantham Gum, Charcoal, Phenoxyethanol, Triethylene Glucol, Steviol Glycosides	Water, Glycerin, Sorbitol, PEG-12, Tetrasoium Pyrophosphate, Flavour, Sodium Lauryl Sulphate, Zinc Phosphate, Cellulose Gum, Sodium Citrate, Microcrystalline Cellulose, Sodium Saccharin, Cocamidopropyl Betaine, Xanthan Gum, Citric Acid, Sucralose, Titanium Dioxide.
Abrasive agents	Sodium bicarbonate	Hydrated silica
Particle size	5-25 µm	15-20 µm
Sodium Lauryl Sulphate (foaming agent)	Nil	Yes
Essential oils	Mentha Piperita (Peppermint) Oil, Orange (Citrus Aurantium Dulces) Oil, Cinnamomum Zeylanicum Leaf Oil, Eugenia Caryophyllus (Clove) Bud Oil	Not known
Colour & Texture	Black, Paste	White, Paste
Flavour	Sweet cherry peppermint (stevia natural sweetener)	Peppermint
pH (average)	8.5	7.4

Table 4. Colour changes (ΔE) for CG and TG according to Site and time of toothbrushing.

Site of Enamel	Time of Toothbrushing	Control Group	Test Group
		Mean (SD)	Mean (SD)
Site A	T1-T0	11.050 (3.720)	11.086 (1.609)
	T2-T0	14.756 (4.875)	13.505 (3.274)
	T3-T0	17.422 (4.978)	14.981 (3.331)
Site B	T1-T0	6.148 (1.578)	8.641 (1.294)
	T2-T0	9.216 (2.133)	10.433 (1.652)
	T3-T0	11.665 (2.754)	13.821 (2.081)

Table 5. Tests of within-subjects' effects of Site A and Site B according to time of toothbrushing for CG and TG.

Factor	Control Group		Test Group	
	F	p-value	F	p-value
Site	14.993	0.004*	5.641	0.042*
Time of Toothbrushing	72.253	0.000*	57.830	0.000*
Site * Time of Toothbrushing	1.079	0.361	5.450	0.014*

Note: Tests of within-subjects' effects, significant at p<0.05.

Table 6. Mean difference of colour change at Site A and B between CG and TG according to time of toothbrushing.

Time of Toothbrushing	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		p-value
			Lower	Upper	
T1-T0	2.457	1.554	-0.903	5.816	0.138
T2-T0	2.468	1.954	-1.637	6.573	0.223
T3-T0	4.597	1.718	0.987	8.206	0.015*

Note: Independent T-test, significant at p<0.05.

Table 7. Comparison of orthodontic archwire surface roughness between CG and TG.

Types of Dentifrice	CG Control Group		TG Test Group	
	Mean difference	p-value	Mean difference	p-value
Pre-test - Post-test	-0.021 (0.012)	0.004*	-0.018 (0.011)	0.001*
Difference between CG and TG	p = 0.499			

Note: Paired T-test, significant at p<0.05

Two-way repeated measure ANOVA indicates that there was a site of enamel (*p<0.05)* and time of tooth brushing (*p<0.001)* significantly affect the colour changes ΔE in both CG and TG (Table **5**).

However, significant interaction between the site of enamel with time of brushing on the ΔE was only observed in the TG (*p<0.05)*. The differences in ΔE between Site A and Site B were calculated. Significant main effect of the types of dentifrice on the differences in colour changes between Site A and Site B observed (*p=0.003)*. Hence, independent t-test was carried out to determine if there was a statistical difference between the control and test dentifrice at each timepoint (T1-T0, T2-T0, and T3-T0). There was a significant difference in the colour change between the CG and TG at T3-T0, whereby the TG recorded a less mean difference of 4.597 between Site A and Site B than the CG, *p=0.015*. (Table **6**).

3.2. Orthodontic Archwire Surface Roughness

At T4 (2 years of tooth brushing), the orthodontic wire surface became significantly rougher in CG at -0.021µm (*p<0.001)* and in TG at -0.018µm (*p=0.001)*. Although the CG recorded a higher roughness value compared to TG, this difference was not statistically significant (*p>0.05)* (Table **7**).

3.3. SEM Image of Orthodontic Archwire

The surface of a 0.019x0.025" orthodontic SS arch wires were analysed using SEM. The wire exhibited lines and grooves running parallel to the long axis of the wire, with some minor pitting visible at 1000x magnification prior to toothbrushing. After simulating 2 years of toothbrushing, both

the CG and TG showed a rougher surface and texture, with visible scratches, grooves, and signs of wear along the wire. The wire surface became more irregular, but there was no residual dentifrice or debris observed on its surface (Fig. **7**).

3.4. Elemental Analysis of Orthodontic Archwires

The elemental analysis of arch wire showed that there is no difference in the arch wire elemental pre-brushing and post-brushing, indicating that no obvious deposition of dentifrice elements on the arch wire that could affect the surface roughness (Fig. **8**).

4. DISCUSSION

In our study, we used photography image analysis to assess the amount of stain removal in the enamel specimens. To reduce the error, the enamel specimens were allowed to dry at room temperature for 30 minutes. The images were taken using the same setting and in a dark room to prevent any additional light source that could affect the result. This technique was proven to be effective when used in both lab study [12] and clinical study [13]. The previous study used the magnetic lasso tool in Adobe Photoshop for point selection, which may result in inaccuracy of results due to different points selection on different images. To ensure high accuracy and consistency of point selection in this study, the image taken at different time points were overlapped in Adobe Photoshop at the same angle and location with six points marked on the image with the L*a*b* value. Other objective measurements of stains removal include the use of spectrophotometer and colorimeter [14]. In our study, the enamel specimens were not polished to produce a flat surface and hence the use of a spectrophotometer can be subject to errors due to the natural curvature of the enamel specimens [15].

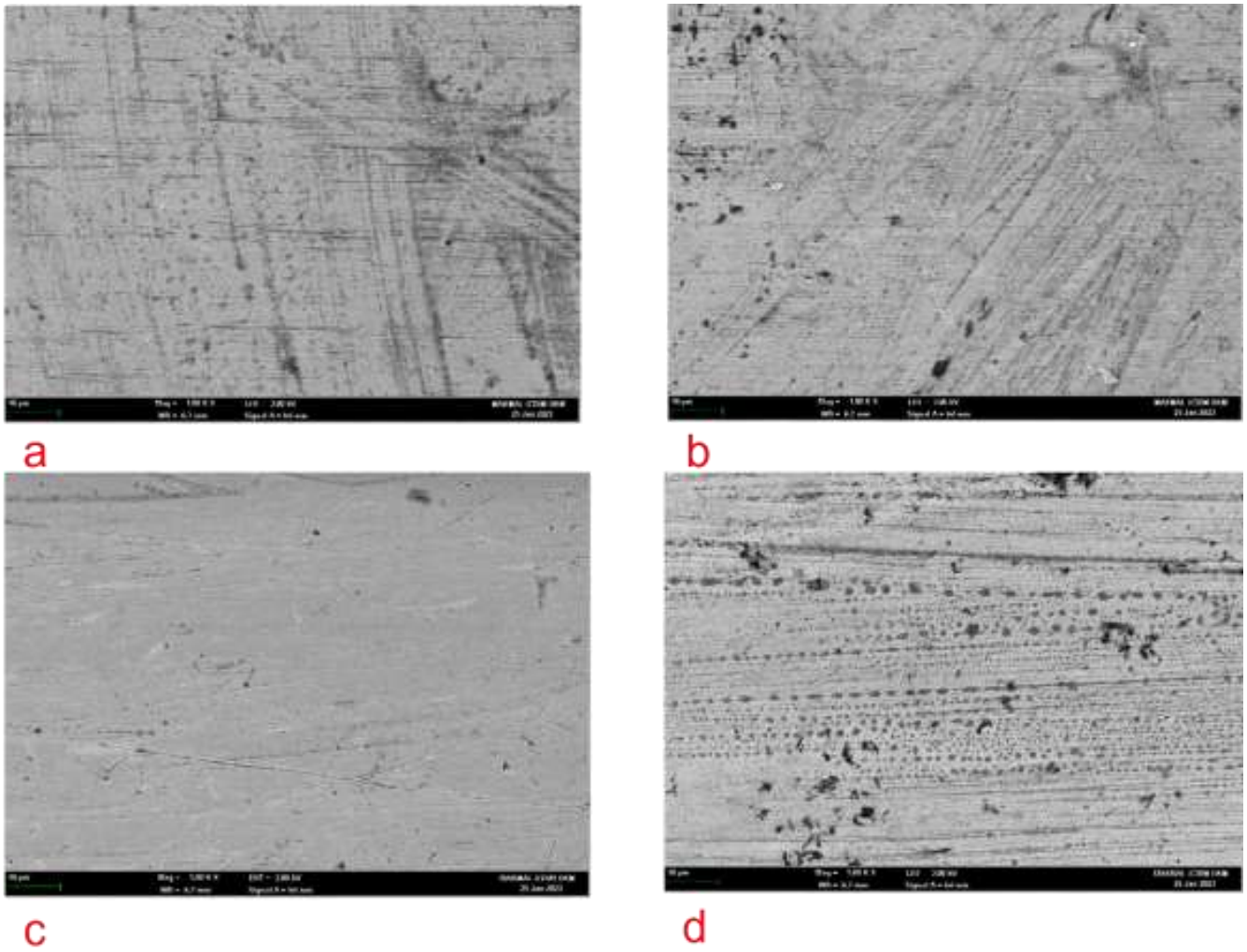

Fig. (7). SEM image at x1000 magnification of 0.019x0.025” SS arch wire. (**a**) Pre-test CG (**b**) Post-test CG (**c**) Pre-test TG and (**d**) Post-test TG.

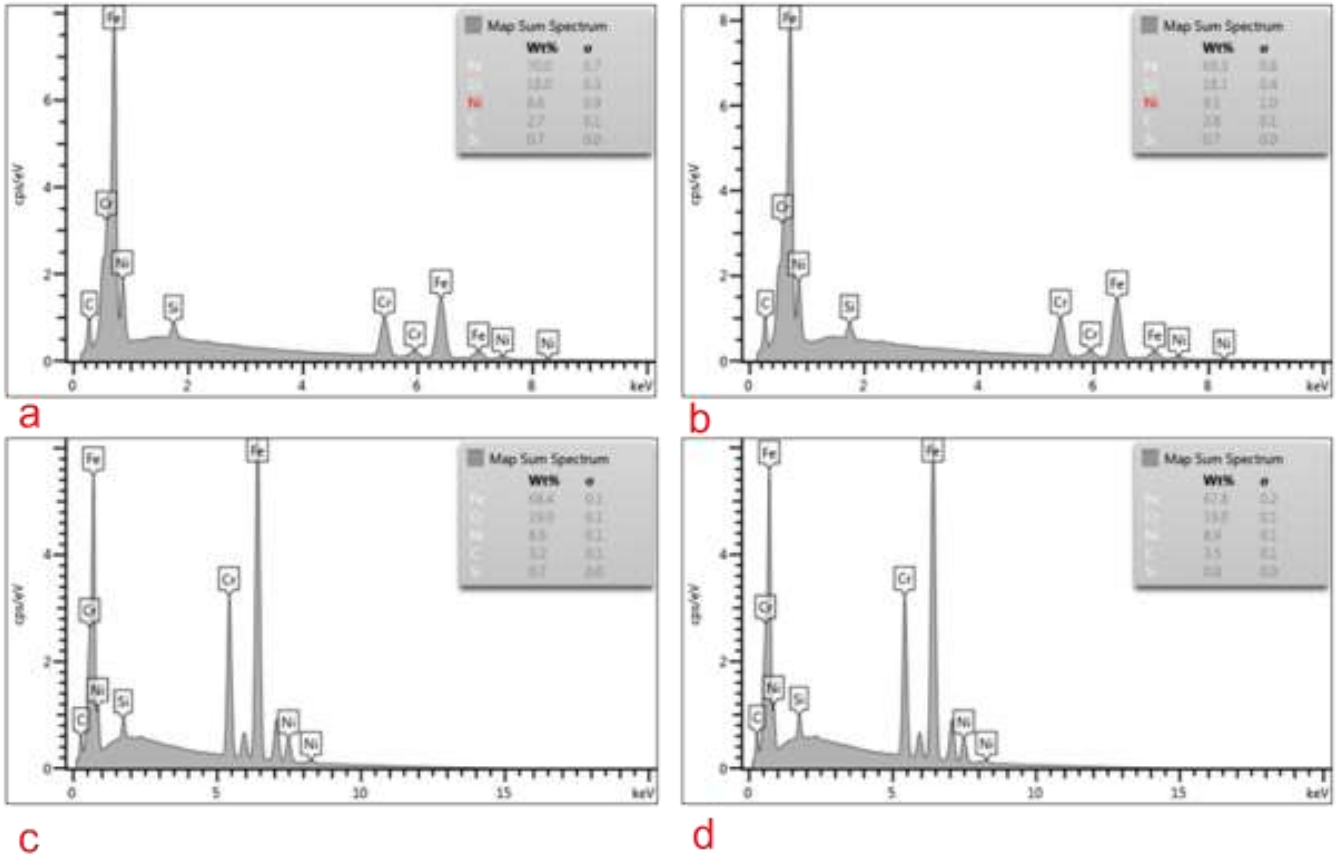

Fig. (8). Elemental analysis of 0.019x0.025" SS arch wire. (**a**) Pre-test CG, (**b**) Post-test CG, (**c**) Pre-test TG, and (**d**) Post-test TG.

Our study found that there was no statistical difference between the TG and CG, which was in agreement with study done by Alshara *et al* [16]. However, study done by Schemehorn *et al* was in favour of hydrated silica [17]. While more studies showed that sodium bicarbonate was superior to silica in stain removal [18, 19], our study found no difference between both groups. The differences in the abrasivity of whitening dentifrices dependent on particle size, shape, hardness and possibly the pH [20]. In our study the particle sizes and pH of sodium bicarbonate in TG are similar to hydrated silica found in Colgate Total Whitening dentifrice, hence there was no difference in efficacy of stain removal between the two. In addition, the TG did not have peroxide added to further enhance the whitening effects [20]. Other than that, the insignificant result can be due to a generally lower concentration of sodium bicarbonate used in the dentifrice [21] and does not contain sodium lauryl sulphate (SLS) that is responsible for foam production and lowers the stains molecules' surface tension [22].

The stain removal efficacy of CG and TG was further subdivided into Site A and Site B, which is a modification of Ortho-Plaque Index (OPI) [23]. This is due to Site A is easily accessible to the toothbrush and whitening dentifrice in comparison to Site B. This was reflected in our results showing that Site A had significantly more ΔE than Site B in both CG and TG. This could be due to the presence of orthodontic archwire and the horizontal movement of the toothbrush resulting in less diffusion and contact of abrasive agents to the enamel surface underneath the archwire as abrasive materials is only effective in areas that a toothbrush's bristles can access [20]. The lesser differences in ΔE between Site A and Site B indicate that the ΔE between both sites is almost similar, hence a higher ΔE at Site B, which is impeded by the orthodontic wire. The significant result at T3 may be due to sodium bicarbonate having a better penetration compared to the hydrated silica. The result suggested that the use of test dentifrice is better for patients with conventional fixed appliances after the use of 3 months.

The roughness reading was gained from the depth of wire, as this is the site that is in contact with the orthodontic bracket's slot during sliding mechanics. Hence, any changes to the orthodontic wire's surface characteristic at this site may result in an alteration of frictional force. Both CG and TG resulted in a significant increase of archwire surface roughness at T4. Elevated surface roughness can lead to a significant rise in frictional forces due to increased contact between the bracket and wire [24]. This can result in a reduction of orthodontic force by 50% or greater, ultimately diminishing the effectiveness of orthodontic treatment and

may result in anchorage loss [25]. Nevertheless, the clinical significance of the resulting increased friction force, remains uncertain.

5. LIMITATION

This is an *in-vitro* study involving small sample size that may not be a true resemblance to real clinical situations, for example in crowded teeth during alignment stage, types of toothbrushes and toothbrushing technique. Hence, it is suggested that future clinical trials can be carried out involving larger samples and more types of whitening dentifrices. It would be valuable to evaluate the prevention of stain uptake in the future study as well.

CONCLUSION

From our study, it can be concluded that:

1) Both Dentaklin White and Colgate Total® Whitening dentifrices had the same stain removal efficacy during orthodontic treatment.

2) The stain removal efficacy was higher at Site A compared to Site B for both Dentaklin White and Colgate Total® Whitening dentifrices with a significant difference at T3.

3) The orthodontic SS archwire became rougher after brushing with both Dentaklin White and Colgate Total® Whitening dentifrices.

Dentaklin White dentifrice had equal efficacy with Colgate Total® Whitening for stains removal during orthodontic fixed appliance treatment and slightly superior in accessing hidden areas after 3 months of use.

AUTHORS CONTRIBUTION

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

LIST OF ABBREVIATIONS

ANOVA	=	Analysis Of Variance
CG	=	Control Group
CIE L*a*b*	=	Colour space defined by the International Commission on Illumination
DSLR	=	Digital Single-Lens Reflex
SEM	=	Scanning Electron Microscopy
SD	=	Standard Deviation
SPSS	=	Statistical Package for the Social Sciences
TG	=	Test Group
UKM	=	University Kebangsaan Malaysia
ΔE	=	Delta E

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Research Ethical Committee of Universiti Kebangsaan Malaysia, reference number: (UKM/PPI/111/8/JEP-2021-784).

HUMAN AND ANIMAL RIGHTS

All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or research committee and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

All patients provided written informed consent prior to enrolment.

AVAILABILITY OF DATA AND MATERIAL

The data and materials used in this manuscript are not publicly available to ensure confidentiality and compliance with ethical standards. However, they will be made available by the corresponding author upon reasonable request, provided the requester meets the criteria for access to confidential data.

FUNDING

This study was funded by Funding Agent: Irma Ariandi Global Sdn Bhd (manufacturer of Dentaklin White) Funding ID: 1240483H / 201701026317 Grant number: DD-2022-006.

CONFLICT OF INTEREST

The authors declared no conflict of interest financial or otherwise.

ACKNOWLEDGEMENTS

We would like to express our extreme gratitude to Irma Ariandi Global Sdn Bhd, and Faculty of Dentistry, University Kebangsaan Malaysia for supporting this study.

REFERENCES

[1] Ravindranath S, En JTS, Heng APK. Orthodontic treatment need and self-perceived psychosocial impact of dental esthetics in a university adult population in Malaysia. J Indian Orthod Soc 2017; 51(2): 69-74. http://dx.doi.org/10.4103/jios.jios_214_16

[2] Tin-Oo MM, Saddki N, Hassan N. Factors influencing patient satisfaction with dental appearance and treatments they desire to improve aesthetics. BMC Oral Health 2011; 11(1): 6. http://dx.doi.org/10.1186/1472-6831-11-6 PMID: 21342536

[3] Kalyana P, Shashidhar A, Meghashyam B, SreeVidya KR, Sweta S. Stain removal efficacy of a novel dentifrice containing papain and Bromelain extracts - An *in vitro* study. Int J Dent Hyg 2011; 9(3): 229-33. http://dx.doi.org/10.1111/j.1601-5037.2010.00473.x PMID: 21356017

[4] Li Y. Stain removal and whitening by baking soda dentifrice. J Am Dent Assoc 2017; 148(11) (Suppl.): S20-6. http://dx.doi.org/10.1016/j.adaj.2017.09.006 PMID: 29056186

[5] Ciancio SG. Baking soda dentifrices and oral health. J Am Dent Assoc 2017; 148(11): S1-3. http://dx.doi.org/10.1016/j.adaj.2017.09.009 PMID: 29056183

[6] Sabharwal A, Scannapieco FA. Baking soda dentifrice and periodontal health. J Am Dent Assoc 2017; 148(11) (Suppl.): S15-9. http://dx.doi.org/10.1016/j.adaj.2017.09.010 PMID: 29056185

[7] Schwarzbold CG, Cuevas-Suárez CE, Pacheco RR, *et al. In vitro*

efficacy of commercial and experimental proteolytic enzyme-based whitening dentifrices on enamel whitening and superficial roughness. J Esthet Restor Dent 2021; 33(6): 849-55.
http://dx.doi.org/10.1111/jerd.12690 PMID: 33615676

[8] Eisenburger M, Addy M, Hughes JA, Shellis RP. Effect of time on the remineralisation of enamel by synthetic saliva after citric acid erosion. Caries Res 2001; 35(3): 211-5.
http://dx.doi.org/10.1159/000047458 PMID: 11385202

[9] Bizhang M, Schmidt I, Chun YHP, Arnold WH, Zimmer S. Toothbrush abrasivity in a long-term simulation on human dentin depends on brushing mode and bristle arrangement. PLoS One 2017; 12(2): e0172060.
http://dx.doi.org/10.1371/journal.pone.0172060 PMID: 28222156

[10] Mazumdar P, Chowdhury D, Chatterjee S, Jajoo N. Effect of four different dentifrices applied by customized automated brushing device on enamel surface abrasion: An *in vitro* profilometric study. J Conserv Dent 2019; 22(2): 191-5.
http://dx.doi.org/10.4103/JCD.JCD_392_18 PMID: 31142992

[11] Khamverdi Z, Kasraie Sh, Rezaei-Soufi L, Jebeli S. Comparison of the effects of two whitening toothpastes on microhardness of the enamel and a microhybride composite resin: An *in vitro* study. J Dent 2010; 7(3): 139-45.
PMID: 21998788

[12] Lath DL, Johnson C, Smith RN, Brook AH. Measurement of stain removal *in vitro* : A comparison of two instrumental methods. Int J Dent Hyg 2006; 4(3): 129-32.
http://dx.doi.org/10.1111/j.1601-5037.2006.00191.x PMID: 16958740

[13] Chakravarthy PK, Acharya S. Efficacy of extrinsic stain removal by novel dentifrice containing papain and bromelain extracts. J Young Pharm 2012; 4(4): 245-9.
http://dx.doi.org/10.4103/0975-1483.104368 PMID: 23493413

[14] Joiner A, Luo W. Tooth colour and whiteness: A review. J Dent 2017; 67: S3-S10.
http://dx.doi.org/10.1016/j.jdent.2017.09.006 PMID: 28928097

[15] van der Burgt TP, ten Bosch JJ, Borsboom PCF, Kortsmit WJPM. A comparison of new and conventional methods for quantification of tooth color. J Prosthet Dent 1990; 63(2): 155-62.
http://dx.doi.org/10.1016/0022-3913(90)90099-X PMID: 2304021

[16] Alshara S, Lippert F, Eckert GJ, Hara AT. Effectiveness and mode of action of whitening dentifrices on enamel extrinsic stains. Clin Oral Investig 2014; 18(2): 563-9.
http://dx.doi.org/10.1007/s00784-013-0981-8 PMID: 23616153

[17] Schemehorn BR, Moore MH, Putt MS. Abrasion, polishing, and stain removal characteristics of various commercial dentifrices *in vitro*. J Clin Dent 2011; 22(1): 11-8.
PMID: 21290981

[18] Koertge TE, Brooks CN, Sarbin AG, Powers D, Gunsolley JC. A longitudinal comparison of tooth whitening resulting from dentifrice use. J Clin Dent 1998; 9(3): 67-71.
PMID: 10518865

[19] Yankell SL, Emling RC, Petrone ME, *et al*. A six-week clinical efficacy study of four commercially available dentifrices for the removal of extrinsic tooth stain. J Clin Dent 1999; 10(3 Spec No): 115-8.

[20] Joiner A. Whitening toothpastes: A review of the literature. J Dent 2010; 38 (Suppl. 2): e17-24.
http://dx.doi.org/10.1016/j.jdent.2010.05.017 PMID: 20562012

[21] Kleber CJ, Moore MH, Nelson BJ. Laboratory assessment of tooth whitening by sodium bicarbonate dentifrices. J Clin Dent 1998; 9(3): 72-5.
PMID: 10518866

[22] Sheen S, Pontefract H, Moran J. The benefits of toothpaste--real or imagined? The effectiveness of toothpaste in the control of plaque, gingivitis, periodontitis, calculus and oral malodour. Dent Update 2001; 28(3): 144-7.
http://dx.doi.org/10.12968/denu.2001.28.3.144 PMID: 11819975

[23] Heintze SDJ-BP, Finke C, Miethke R. Oral health for the orthodontic patient. (1st ed.). Hanover Park, Ill: Quintessence Publishing Co 1999; pp. 67-70.

[24] Amini F, Rakhshan V, Pousti M, Rahimi H, Shariati M, Aghamohamadi B. Variations in surface roughness of seven orthodontic archwires: An SEM-profilometry study. Korean J Orthod 2012; 42(3): 129-37.
http://dx.doi.org/10.4041/kjod.2012.42.3.129 PMID: 23112943

[25] Rapiejko C, Fouvry S, Grosgogeat B, Wendler B. A representative ex-situ fretting wear investigation of orthodontic arch-wire/bracket contacts. Wear 2009; 266(7-8): 850-8.
http://dx.doi.org/10.1016/j.wear.2008.12.013