Water-blockage ability of swimming mouthguards

Yada Anantawat*, Sasipimon Chanrat, Antika Chingtanasan, Thanyaporn Wattanakornkaew, Thanyanan Prasertthavornsira, Vanida Sinsomwongsakul, and Krich Homklai

College of Dental Medicine, Rangsit University, Pathum Thani, Thailand
*Corresponding author, E-mail: yada.a@rsu.ac.th

Abstract

Swimming-related dental erosion has been an ongoing crisis worldwide, especially among competitive swimmers. Despite being one of the preventive recommendations, data on swimming mouthguards and their water-blockage ability remains lacking. This research aimed to evaluate the water-blockage ability among four mouthguard designs, comprising 1) Short-margin, 2) Short-margin and gingival margin indentation, 3) Long-margin, and 4) Long-margin and gingival margin indentation. Four sets of mouthguards were individually made for twenty-six participants. Coated with CCP-ACP paste on the inner surface, each set of mouthguards was worn by a volunteer participant who would later swish his/her mouth with colored water, thus imitating swimming action. The degree of the mouthguard's water-blockage ability was categorized as absolute (no leakage at all), 75% (leakage found in not more than 3-4 teeth per arch), and less than 75% (leakage found in more than 3-4 teeth per arch). The absolute water-blockage ability was displayed the most in the mouthguards with long-margin and gingival margin indentation (65.38% within the design), followed by the mouthguards with only long-margin (57.69% within the design). The chi-square test acknowledged a significant association between mouthguard design and the degree of water-blockage ability at a 95% confidence level. The long-margin mouthguards, with or without gingival margin indentation, demonstrated significantly superior water-blockage ability compared to the short-margin mouthguards. The gingival margin indentation, however, did not significantly improve the water-blockage ability.

***Keywords**: Dental Erosion, Swimming Mouthguard, Swimming-related Dental Erosion, Water Blockage, Mouthguard Designs*

1. Introduction

Nowadays, quite a few young swimmers visit dental clinics with signs and symptoms of dental erosion. These swimmers often had intensive training comprising several hours per day in chlorinated swimming pools. They normally express the chief complaint of dentine hypersensitivity and/or discoloration of their front teeth. A chemical chlorinated compound is put into swimming pools to reduce bacteria levels and other disease-causing contaminations in the water but can lead to highly acidic conditions of the pool water when used excessively, causing adverse effects on swimmers' dentition (Centerwall et al., 1986; Chuenarrom, Daosodsai, & Benjakul, 2010; Rose & Carey, 1995). International protocol regarding this issue mainly focuses on the control of chlorine input and pH-level maintenance of swimming pools. However, such maintenance has been poorly operated in Thailand according to prior studies (Chanduaykit et al., 2005; Limsintaropas & Leelasithorn, 1995; Ongthiemsak et al., 2016; Thaweboon et al., 1998). As a result, the dentitions of many Thai swimmers, especially competitive swimmers, have been permanently damaged by acidic pool water. Besides supportive care, swimming mouthguards have also been recommended to prevent extensive dental erosion among competitive swimmers (Kitsahawong, 2006; Lukkananuruk & Tuongratanaphan, 2014; Ungchusak et al., 2004). Swimming mouthguards as a tool to prevent dental erosion have been around for nearly two decades. They have been studied and reported on to relieve the symptoms of dental hypersensitivity. Also, applying remineralizing coating media inside the mouthguard has resulted in an efficient reduction in dental erosion (Itthikul et al., 2013; Rirattanapong, Vongsavan, & Tepvichaisillapakul, 2011; Sitthisomwong et al., 2008). Nevertheless, few aspects of the swimming mouthguard have been investigated, including its ability to prevent water leakage. Further, the design has not been standardized. Different designs of swimming mouthguards were evaluated and studied by Tuongratanaphan et al. in 2012, including both long and short-margin designs, with and without indentation along the gingival margin. The short margin was designed to reduce the chance of tissue irritation and the indentation along the gingival margin was aimed to create a vacuum-sealing effect. However, the long-margin design with gingival margin indentation was the only one selected to be used among swimmers in the study. Therefore, this study aimed to investigate the water-blockage ability of four designs of swimming mouthguards when combined with the use of a remineralizing coating media.

2. Objectives

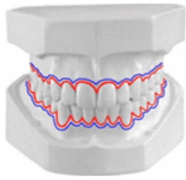
To evaluate water-blockage ability among four swimming mouthguard designs in a clinical simulation.

3. Materials and Methods

The following protocol was approved by the Ethics Review Board of Rangsit University (COA. No. RSUERB2022-125), and all the procedures were conducted at the pediatric dental clinic, College of Dental Medicine, Rangsit University. Twenty-six participants with permanent dentition were recruited at the College of Dental Medicine, Rangsit University according to the inclusion criteria, which included healthy participants aged between 20-30 years old with normal occlusion and well-aligned teeth. Participants with any allergy to ethylene vinyl acetate (EVA), moderate-to-severe dental crowding, more-than-1-mm dental spacing, unrestored carious lesion, unrestored dental defect, a defective restoration, or large/ multiple exostoses/ tori were excluded from the study. The team of researchers comprised five fifth-year dental students and two pediatric dentists, who were the operators in this study. All participants were asked to read the patient information sheet before signing a written consent form. Then, full mouth cleaning was done using ultrasonic scalers, hand scalers, rubber cups with prophylaxis paste, and dental floss. The operators took the participant's dental impression using alginate and perforated stock trays, and the most immaculate pair of impressions was used to make dental models in stone type IV. Each dental model was closely examined for any voids, beads, chipping, or irregularity that appeared on the mouthguard-relating area. Only mild adjustment of the dental model was allowed to mimic the actual dental and gingival features. Voids or beads larger than 2 mm in diameter were considered nonadjustable, and the participant would be asked to come in for a new impression to create a new dental model. Each dental model was properly trimmed and stored in a separate container labeled with a sample ID.

The custom-made swimming mouthguards were made in four designs, including 1) Short-margin, 2) Short-margin and gingival margin indentation, 3) Long-margin, and 4) Long-margin and gingival margin indentation. The outlines of the different mouthguard designs are shown in Figure 1.

Design 1: Short-margin
All margin outline was at 1-1.5 mm below gingival line.



Design 2: Short-margin and gingival margin indentation
One-millimeter-deep preparation was made along the area of free gingival on the dental model. All margin outline was at 1 - 1.5 mm below gingival line.

Design 3: Long-margin
The buccal/ labial and lingual margin outline was extended 3 - 5 mm beyond the gingival line, and curved away from all frenum attachment. The palatal margin was slightly beyond the last pair of palatal rugae.

Design 4: Long-margin and gingival margin indentation
The buccal/ labial and lingual margin outline was extended 3 - 5 mm beyond the gingival line, and curved away from all frenum attachment. The palatal margin was slightly beyond the last pair of palatal rugae. One-millimeter-deep preparation was made along the area of free gingival on the dental model.

Figure 1. Four designs for swimming mouthguards on dental models

Each mouthguard was made with 0.06-inch EVA sheets (3A MEDES® Easy-Vac Gaskets) heated until 1-inch sagged with the thermoforming vacuum machine (UltraVacTM Vacuum Former, Ultradent Product, Inc.). The order of the laboratory process was the fabrication of the long-margin and the short-margin mouthguard designs, interrupted by a preparation along the area of free gingiva on the working dental model, then continuing with the fabrication of the other two mouthguard designs. The 1-mm-deep preparation into the dental model along free gingiva, done with a slow-speed round diamond bur, was to create indentation along the gingival margin of the mouthguard, once fabricated. Each pair of the fabricated mouthguards was kept in separate ventilated boxes and stored according to the sample ID.

Within a week of mouthguard fabrication, the participant was scheduled for the water-blockage ability test. The teeth of the participant were cleaned with prophylaxis paste using a rubber cup with a prophy handpiece and flossed before mouthguard try-in. Upon the try-in, an operator checked the qualities of each mouthguard, including adaptation, irritation, and displacement during oral movement. A marginal adjustment was done in case of the margin overextended into the movable soft tissue area. When all four designs of mouthguards were properly fitted, the participants randomly drew the order of each mouthguard from four tickets (designs 1 - 4). Then, four separate mouthguard tests were performed according to the randomized design sequence. Each test began with an operator, a fifth-year dental student, evenly applying 5 ml of Tooth Mousse (GC Corporation, Japan) inside the upper and lower mouthguard. Subsequently, the operator quickly wiped the area of the participant's arch with gauze and inserted each mouthguard. A thorough removal of the excessive Tooth Mousse was done using sterile gauze and saliva suction. The participant was asked to swish his/her mouth left and right with 20 ml of green-colored solution 10 times for 20 seconds (approximately 2 seconds per swish) and then spit it out. Afterward, the same operator gently wiped the solution residual on the outer surface of the mouthguard with gauze. The teeth were immediately examined under the same dental unit's light, using a clear mouth mirror, by an experienced pediatric dentist serving as the examiner. A tooth with any color water leakage was counted as a leaked tooth (LT). The examiner and the participants were blinded to the mouthguard design during the data recording. All data were entered onto a computer using SPSS. Both descriptive and analytical approaches were used in the data analysis. Testing of the association between mouthguard designs and the degree of water-blockage ability was carried out using a chi-square test. A non-parametric test (Friedman test) was used to compare the mean numbers of leaked teeth (LT) per arch.

4. Results and Discussion

The cross-tabulation analysis demonstrated the distribution of different water-blockage abilities among the four mouthguard designs, see Table 1. The total pieces of mouthguard design 1 (short-margin), design 2 (short-margin and gingival margin indentation), design 3 (long-margin), and design 4 (long-margin and gingival marginal indentation) were 45, 46, 52, and 52, respectively. Some mouthguards from design 1 and design 2 were excluded from the studies after quality control inspection. Each mouthguard's water-blockage ability was categorized as absolute water-blockage ability (no leakage at all), 75% water-blockage ability (leakage found in not more than 25% of the arch or not more than 3-4 teeth), and less than 75% water-blockage ability (leakage found in more than 25% of the arch or more than 3-4 teeth).

The highest proportion of absolute water-blockage ability was found in design 4 (long-margin and gingival margin indentation) at 65.38% within the design, followed by design 3 (long-margin) at 57.69% within the design, and design 1 (short-margin) at 42.22% within the design, while the absolute water-blockage ability in design 2 (short-margin and gingival margin indentation) was the lowest at 34.78%. Thus, the chance of having absolute water-blockage ability was the highest in the mouthguards with long-margin and gingival margin indentation, and the lowest in the mouthguards with short-margin and gingival margin indentation.

Chi-square analysis confirmed the relation of mouthguard designs to the different water-blockage abilities with an X^2 value of 15.566 (p=0.016), confirming that at least one design had a significant effect on the water-blockage ability. Post-hoc analysis using adjusted residual and Bonferroni correction further specified only one significant relation, which was mouthguard design 2 (short-margin and gingival margin indentation) and its likelihood to demonstrate 75% water-blockage ability more than expected.

Table 1. Water-blockage ability according to the numbers (%) of teeth with leakage in the arch of four mouthguard designs

Water-blockage ability	**Design 1**		**Design 2**		**Design 3**		**Design 4**		**Total**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Absolute	19	42.22	16	34.78	30	57.69	34	65.38	99	100
75%	15	33.33	24	52.17[1]	15	28.85	12	23.08	66	100
less-than-75%	11	24.44	6	13.04	7	13.46	6	11.54	30	100
Total	45	100	46	100	52	100	52	100	195	100

X^2 for the difference between mouthguard design and level of leakage = 15.566; df=6; p=0.016

[1]Significant with post-hoc analysis of X^2 via adjusted residual and Bonferroni correction (p= 0.003)

An intraclass correlation coefficient indicated a good level of intra-rater and test-retest reliability (ICC=0.820, n=28). The Shapiro-Wilk test was performed using the IBM SPSS Statistics 20, and it was found that the numbers of leaked teeth (LT) among the four mouthguard designs were not normally distributed.

A non-parametric analysis (Friedman test) indicated a significant difference among the four mouthguard designs in terms of the number of teeth with leakage or leaked teeth (LT) (p=0.000), as seen in Table 2. Further post-hoc analysis with Bonferroni correction found three pairs of mouthguard designs with significant differences in LT. The most significant differences in LT were observed between design 1 (short-margin) and design 4 (long-margin and gingival margin indentation) (p=0.000), and between design 2 (short-margin and gingival margin indentation) and design 4 (long-margin and gingival margin indentation) (p=0.000), followed by the difference between design 1 (short-margin) and design 3 (long-margin) (p=0.004). The rankings of mouthguard designs according to their mean LT from lowest to highest were design 4 (long-margin and gingival margin indentation) at 0.7 teeth per arch, design 3 (long-margin) at 1 tooth per arch, design 2 (short-margin and gingival margin indentation) at 1.66 teeth per arch, and design 1 (short-margin) at 2.02 teeth per arch.

Table 2. Analysis of the number of teeth with leakage (LT) per arch in different mouthguard designs

	N	Mean LT±SD (per arch)	Mean ranks	Percentiles 25th	50th	75th	Test statistics p-value[2]
Design 1: Short-margin	43	2.02±2.38	2.86	.00	1.00	3.00	Design 2 = 0.405 Design 3 = 0.004[b] Design 4 = 0.000[b]
Design 2: Short-margin & gingival margin indentation	43	1.66±1.95	2.88	.00	1.00	3.00	Design 3 = 0.048 Design 4 = 0.000[b] Design 1 = 0.405
Design 3: Long-margin	43	1.00±1.59	2.23	.00	.00	2.00	Design 4 = 0.076 Design 1 = 0.004[b] Design 2 = 0.048
Design 4: Long-margin & gingival margin indentation	43	0.70±1.82	2.02	.00	.00	1.00	Design 1 = 0.000[b] Design 2 = 0.000[b] Design 3 = 0.076
p-value[1]							0.000[a]

[1] Friedman Test; [a] Significance at 95% confidence (p<0.050).

[2] Pairwise signed-rank tests; [b] Significance at 95% confidence with Bonferroni correction (p<0.008).

From this data, the superior water-blockage ability in the long-margin mouthguards (designs 3 and 4) was strongly supported. Observation in the area of leakage was made in the long-margin mouthguards (see Table 3). It was demonstrated that the highest area of leakage in the long-margin designs was in the posterior teeth (26.92%), followed by both anterior and posterior teeth (8.65%), with a slight chance of leakage in only the anterior teeth (2.88%).

Table 3. Area of leakage in the long-margin mouthguard designs

	Design 3 & 4	
	n	%
None	64	61.54
Posterior teeth	28	26.92
Both anterior and posterior teeth	9	8.65
Anterior teeth	3	2.88
Total	104	100.00

According to the results of this study, mouthguard design 4 with long-margin and gingival margin indentation provided the highest frequency of absolute water-blockage ability. The result concurred with the study by Tuongratanaphan et al., which reported significant effectiveness in reducing tooth hypersensitivity among 29 swimmers who wore the long-margin swimming mouthguard with dental model preparation (Tuongratanaphan et al., 2012). There were a few minor differences in the design of the long-margin and gingival margin indentation swimming mouthguard in this study compared to that of Dr. Tuongratanaphan. For example, the long margin of the mouthguard in this study was limited to 3-5 mm beyond the gingival line, while a mouthguard from the previous study was located at 3 mm from the buccal and lingual vestibules. The modification was decided during a pilot study, in which difficulty was faced in locating the appropriate margin in the posterior area of the mouthguard. In the posterior area of the dental arch, the vestibule was shallow and occasionally located less than 3 mm from the gingival margin. Another modification is that the preparation along the free gingival line of the dental model in this study was limited to the width of the free gingiva and 1 mm in depth, while the previous was 3 mm in width. Nonetheless, it is essential to mention that the design in this study was modified from the original design of Dr. Tuongratanaphan in 2012. Thus, acknowledgment is given to their study.

The long margin of the mouthguard provides further distance for water to reach the tooth surface and creates a more adaptive surface area when fabricated with caution, which can increase the retentiveness and fitness of the swimming mouthguard. As a result, the long-margin designs displayed significantly higher water-blockage ability than the short-margin designs. The indentation along the gingival margin was designed to create a sealing effect along the cervical area of the tooth, but its actual influence on the water blockage ability in this study was unclear. The long margin with gingival margin indentation displayed insignificantly higher water-blockage ability than the long margin without the indentation. On the other hand, considering mean ranks and proportion of absolute water-blockage ability, the short margin with gingival margin indentation had lower blockage ability than the short margin without the indentation, and the difference was also statistically insignificant. Further research may be needed to determine the impact of the gingival margin indentation on the water blockage ability of the mouthguard.

The study by Tuongratanaphan et al. in 2012 reported the satisfaction level with the swimming fitness of the mouthguard, or its adaptability to the dentition, which was increased significantly when a small amount of 1.1% sodium fluoride gel was used as the media inside the mouthguard. Even though this study might have used a different type of media, a pilot study showed a more distinctive level of leakage in the subjects wearing the mouthguard without any media when compared to the ones wearing the mouthguard with CPP-ACP as the media.

Concerning the ability of the mouthguard to reduce tooth hypersensitivity in swimmers, Itthikul et al. (2013) reported that wearing a swimming mouthguard could effectively reduce tooth hypersensitivity, though there was no statistical difference between using 1.1% sodium fluoride gel as a media and using without a media (Itthikul et al., 2013). The mouthguard's ability to reduce tooth hypersensitivity might have not been directly investigated in this study, but CPP-ACP was reported to increase the hardness of eroded enamel caused by chlorinated water when used either plainly or in combination with 900 ppm fluoride paste, as suggested in the *in vitro* study by Rirattanapong, Vongsavan, & Tepvichaisillapakul in 2011. Clinical studies on tooth hypersensitivity when using CPP-ACP as a mouthguard media should be investigated further.

Although this study demonstrated very promising results for swimming mouthguards in blocking water from contacting teeth, the best preventive measure for dental erosion in swimmers remains in the hands of pool managers and entrepreneurs to run efficient operations and quality controls, keeping the pool water clean and pH level between 7.2 - 8.4, and never lower than 5.5 (Health, 2007). As this study was a clinical simulation of human oral movement during swimming, the test duration was much shorter than a normal session of swimming practice, and the design with the highest water-blockage ability still offers no guarantees in terms of compliance among swimmers. Thus, further investigation into these aspects, especially among swimmers during real-life swimming sessions, should be undertaken.

5. Conclusion

The long-margin mouthguards, with or without gingival margin indentation, demonstrated significantly superior water-blockage ability compared to short-margin mouthguards. The gingival margin indentation did not significantly improve water-blockage ability. Additional studies are necessary to further determine the most appropriate design for swimming mouthguards.

6. Acknowledgements

This research was supported financially by the College of Dental Medicine, Rangsit University. Without determinative contribution from all of the volunteer participants, this study could not have been achieved. The authors sincerely thank all the friends and colleagues who kindly assisted in this research. The authors would also like to express gratitude to Professor La-ongthong Vajrabhaya for her valuable advice and continuous encouragement.

7. References

Centerwall, B. S., Armstrong, C. W., Funkhouser, L. S., & Elzay, R. P. (1986). Erosion of dental enamel among competitive swimmers at a gas-chlorinated swimming pool. *American Journal of Epidemiology, 123*(4), 641-647. https://doi.org/10.1093/oxfordjournals.aje.a114283

Chanduaykit, S., Ungchusuk, C., Promma, S., & Sukanwaranil, S. (2005). Risk factors assessment to identify dental erosion among swimmers. *Thailand Journal of Health Promotion and Environment, 28*(2), 50-58.

Chuenarrom, C., Daosodsai, P., & Benjakul, P. (2010). Erosive Potential of Low Ph Swimming Pool Water on Dental Enamel. *Journal of Health Research, 24*(2), 91-94.

Health, M. o. P. (2007). *Suggestion of the Ministry of Public Health: The regulation for swimming pool business and other related business*. Bangkok: Public health law administration center. Retrieved June 1, 2023, from https://laws.anamai.moph.go.th/th/recommendation/193119

Itthikul, T., Sitthisomwong, P., Pongrojpao, P., Weangtanchantra, D., Charoonanan, P., & Intaranonwilai, S. (2013). Soft mouthguard with sodium fluoride gel in reducing dental hypersensitivity in swimmers. *Journal of the Dental Association of Thailand, 63*(2), 69-78.

Kitsahawong, K. (2006). Correction of dental sensitivity in dental erosion using mouth guard: A case report. *Khon Kaen University Dental Journal, 9*(1), 19-25.

Limsintaropas, W., & Leelasithorn, S. (1995). Dental erosion among swimming athletes in Phitsanulok province. *Journal of the Dental Association of Thailand, 45*(2), 98-104.

Lukkananuruk, N., & Tuongratanaphan, S. (2014). Dental Erosion in Competitive Swimmer. *Chiang Mai Dental Journal, 35*(2), 25-34.

Ongthiemsak, C., Daosodsai, P., Chuenarrom, C., & Benjakul, P. (2016). Guideline of swimming pool water quality control to reduce the risk of tooth erosion of swimmers *Songklanakarin Dental Journal, 4*(2).

Rirattanapong, P., Vongsavan, K., & Tepvichaisillapakul, M. (2011). Effect of five different dental products on surface hardness of enamel exposed to chlorinated water in vitro. *Southeast Asian Journal of Tropical Medicine and Public Health, 42*(5), 1293-1298. https://pubmed.ncbi.nlm.nih.gov/22299456

Rose, K. J., & Carey, C. M. (1995). INTENSIVE SWIMMING: CAN IT AFFECT YOUR PATIENTS' SMILES? *The Journal of the American Dental Association, 126*(10), 1402-1406. doi:https://doi.org/10.14219/jada.archive.1995.0051

Sitthisomwong, P., Pongrojpao, S., Tulapornchai, C., Meanmonchai, P., Nuwattana, M., & Tantangchareonchai, W. (2008). The effect of closed fitting mouth guard with fluoride gel on surface hardness of enamel after soaking in chlorinated water. *Journal of the Dental Association of Thailand, 58*(2), 93-102.

Thaweboon, B., Kritpet, T., Buajeeb, W., & Thaweboon, S. (1998). Prevalence of enamel erosion in Thai swimmers and related factors. *Journal of the Dental Association of Thailand, 48*(3), 134-142.

Tuongratanaphan, S., Homnan, J., Pakdee, P., Chatchawanpan, C., & Jantawuttikul, A. (2012). Suitable Mouth Guard for Swimming Athletes: A Study in Amphur Muang, Chiang Mai. *Chiang Mai Dental Journal, 33*(1), 77-85.

Ungchusak, C., Nuntajivakornchai, J., Parkpien, K., & Ekkarntrong, P. (2004). Protective effects of closed-fitting mouthguard for protection of dental erosion among swimming athletes. *Journal of the Dental Association of Thailand, 54*(4), 235-241.