https://doi.org/10.4047/jap.2024.16.1.12

3D quantitative analysis and SEM qualitative analysis of natural antagonist enamel opposing CAD-CAM monolithic zirconia or lithium disilicate tooth-supported crowns versus enamel opposing natural enamel

Piyarat Woraganjanaboon[1], Chuchai Anunmana[2]*

[1]Doctor of Philosophy Program in Dental Biomaterials Science, Faculty of Dentistry, Mahidol University, Bangkok, Thailand
[2]Department of Prosthodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand

ORCID
Piyarat Woraganjanaboon
https://orcid.org/0000-0001-6824-6929
Chuchai Anunmana
https://orcid.org/0000-0003-3910-5136

PURPOSE. This study aimed to evaluate the maximum vertical wear, volume wear, and surface characteristic of antagonist enamel, opposing monolithic zirconia or lithium disilicate crowns. **MATERIALS AND METHODS.** The study comprised 24 participants (n = 12), who were randomly allocated to receive either a 5 mol% Y-TZP or a lithium disilicate crown in positions which would oppose the natural first molar tooth. The contralateral first molar along with its antagonist was considered as the enamel opposing natural enamel control. Data collection was performed using an intraoral scanner and polyvinylsiloxane impression. The means of the maximum vertical loss and the volume loss at the occlusal contact areas of the crowns and the various natural antagonists were measured by 3D comparison software. A scanning electron microscope was subsequently used to assess the wear characteristics. **RESULTS.** The one-year results from 22 participants (n = 11) indicated no significant differences when comparing the zirconia crown's antagonist enamel (40.28 ± 9.11 μm, 0.04 ± 0.02 mm^3) and the natural enamel wear (38.91 ± 7.09 μm, 0.04 ± 0.02 mm^3) ($P > .05$). Also, there is no significant differences between lithium disilicate crown's antagonist enamel (47.81 ± 9.41 μm, 0.04 ± 0.02 mm^3) and the natural enamel wear (39.11 ± 7.90 μm, 0.04 ± 0.02 mm^3) ($P > .05$). **CONCLUSION.** While some studies suggested that monolithic zirconia caused less wear on opposing enamel than lithium disilicate, this study found similar wear levels to enamel for both materials compared to natural teeth. [J Adv Prosthodont 2024;16:12-24]

KEYWORDS
Wear; Enamel; Zirconia; Lithium disilicate; *In vivo*

Corresponding author
Chuchai Anunmana
Department of Prosthodontics, Faculty of Dentistry, Mahidol University, 6 Yothi Road, Ratchathewi, Bangkok 10400, Thailand
Tel +66-22007816
E-mail chuchai.anu@mahidol.edu

Received July 29, 2023 /
Last Revision January 16, 2024 /
Accepted February 13, 2024

This research was supported by a Mahidol University Faculty of Dentistry Grant (grant numbers DTRS-EG-2019-11, 2019).

pISSN 2005-7806 • eISSN 2005-7814

INTRODUCTION

The phenomenon of enamel wear is a process, which takes place within the oral cavity as the original form of the anatomy is gradually lost. This can occur as a consequence of either physiological or pathological causes.[1] When considering restoration work, it is important that the material chosen should wear at a rate similar to that of enamel.[2]

Ceramics are popular since they look appealing, do not contain metals, and offer good biocompatibility.[3] When porcelain veneer restorations are in place, they are prone to chipping and delamination that are the most common reasons for failure.[4,5] The response to these difficulties was the introduction of non-veneered, full-contour zirconia materials, which are now available from a number of manufacturers. In the absence of veneering, which is a sensitive process, the quality of restorations would become much more consistent. Furthermore, the appearance of zirconia materials has been enhanced through lowering the overall opacity and adding pigments to provide color.[6] In addition, the use of computer-aided design and computer-aided manufacturing (CAD-CAM) technology to perform automated design and milling to achieve the full anatomical contour would serve to lower the production costs and be time-saving.[7]

In comparison to human enamel, zirconia has higher mechanical properties; such as, hardness, elastic modulus, flexural strength, and fracture toughness.[8,9] Thus, one potential drawback is the likelihood of the opposing enamel wear when it encounters this material.[4,10,11] Numerous *in vitro* research studies have shown that the rate of enamel wearing caused by monolithic zirconia was in fact lower than that of alternative ceramics.[10-17] In the case of differing surface conditions, it was found that less wear was shown on the antagonist enamel with polished zirconia than with glazed zirconia.[6,10,11,16,18] Interestingly, the material itself showed either less wear[16] or no signs of wear.[6,11,14,15] Compared with zirconia, the studies described that lithium disilicate ceramics resulted in higher rates of enamel wear [11-13,17] ; however, the rates were similar to that of natural enamel.[17,18] Moreover, the wear rates of polished lithium disilicate were either comparable to[14] or lower[6,11,14,15] than the natural enamel wear.

Nevertheless, a systematic review of the laboratory reports showed that the testing conditions in those studies were not consistent.[19] Furthermore, it was not possible in those studies to fully simulate the conditions involved in complex wear.[20] Therefore, the findings from *in vitro* work would not necessarily agree with the results of the clinical trials.[21] Clinical data would then be much more useful in designing and implementing new ceramic materials for restorative work.[19,22] Some recent studies presented clinical findings on the subject of enamel wear with ceramics. Nonetheless, the *in vivo* results still did not match those of the *in vitro* testing in the case of the claims that lithium disilicate and zirconia generated lower rates of enamel wear that would result from porcelain veneering[23,24] or contact with the natural teeth.[24-32]

Most clinical studies of wear assessed the amount of wear indirectly from cast replicas.[28-31] However, this process still resulted in errors from the expansion of gypsum.[33] Execution of direct measuring methods that used intraoral 3D scanning (IOs) could be one method that could be used to resolve this deficiency.[34] In recent years, periodic follow-up visits with the use of IOs and patient monitoring software appear to be a reliable way of assessing surface changes in teeth.[35,36] This procedure was used in earlier experiments although there was a risk for further irregularities owing to the use of powder prior to scanning.[37] Hence, this current study used an intraoral powder-free scanner to avoid the risk of this form of imprecision. In the wear analysis process, a baseline and a follow-up digital impression were segmented, aligned and compared tooth by tooth over time to determine the degree of tooth wear.[37]

Hence, the aims of this clinical study were designed to assess the wear of zirconia crown's antagonist enamel or lithium disilicate crown's antagonist enamel and to compare with the enamel against enamel control on the opposite site in oral cavity. The null hypotheses were:

1. The wear of zirconia crown's antagonist enamel and enamel control are not different.
2. The wear of lithium disilicate crown's antagonist enamel and enamel control are not different.
3. The wear of crowns antagonist enamel between zirconia and lithium disilicate groups are not different.

https://doi.org/10.4047/jap.2024.16.1.12

MATERIALS AND METHODS

A clinical trial of a randomized, controlled, parallel group was designed in order to compare the wear of first molar antagonist enamel, opposing CAD-CAM monolithic-translucent zirconia or lithium disilicate crowns and first molar enamel against enamel on the opposite site of oral cavity. This single-blind study involved 24 participants requiring full-coverage crowns for the endodontically treated first molars that opposed natural antagonist teeth. Using a split mouth design, a single type of restoration of the crowns was conducted on each subject, and the natural enamel on the contralateral site served as the enamel control (Fig. 1).

Sample size calculation was done by the equation;

$$n = \frac{\left(z_{1-\frac{\alpha}{2}} + z_{1-\beta}\right)^2 \sigma^2}{\Delta^2}$$

According to a previous study,[29] standard deviation = 77 and Delta = 76 (151-75) were used, and the significance and power of the study were set at $\alpha < 0.05$ and 80%, respectively. Therefore, the sample size was calculated, and a total of 24 participants (n = 12) were selected to participate in this study.

This clinical trial was approved by the Ethics Committee of the Institutional Review Board, Faculty of Dentistry/Faculty of Pharmacy, Mahidol University, Bangkok, Thailand (reference no. COA.NO.MU-DT/PY-IRB 2019/029.1505). The subject recruitment was announced with the following inclusion criteria: minimum age of 18 years; good overall general health without any contraindications regarding dental treatment; not having any present temporomandibular disorders or parafunctional habits; endodontically treated first molar tooth with a complete crown treatment plan and a minimum 1:1 crown-to-root ratio; healthy natural antagonist tooth as well as two natural contralateral antagonistic molars; filling natural teeth would be allowed if at least one occlusal contact

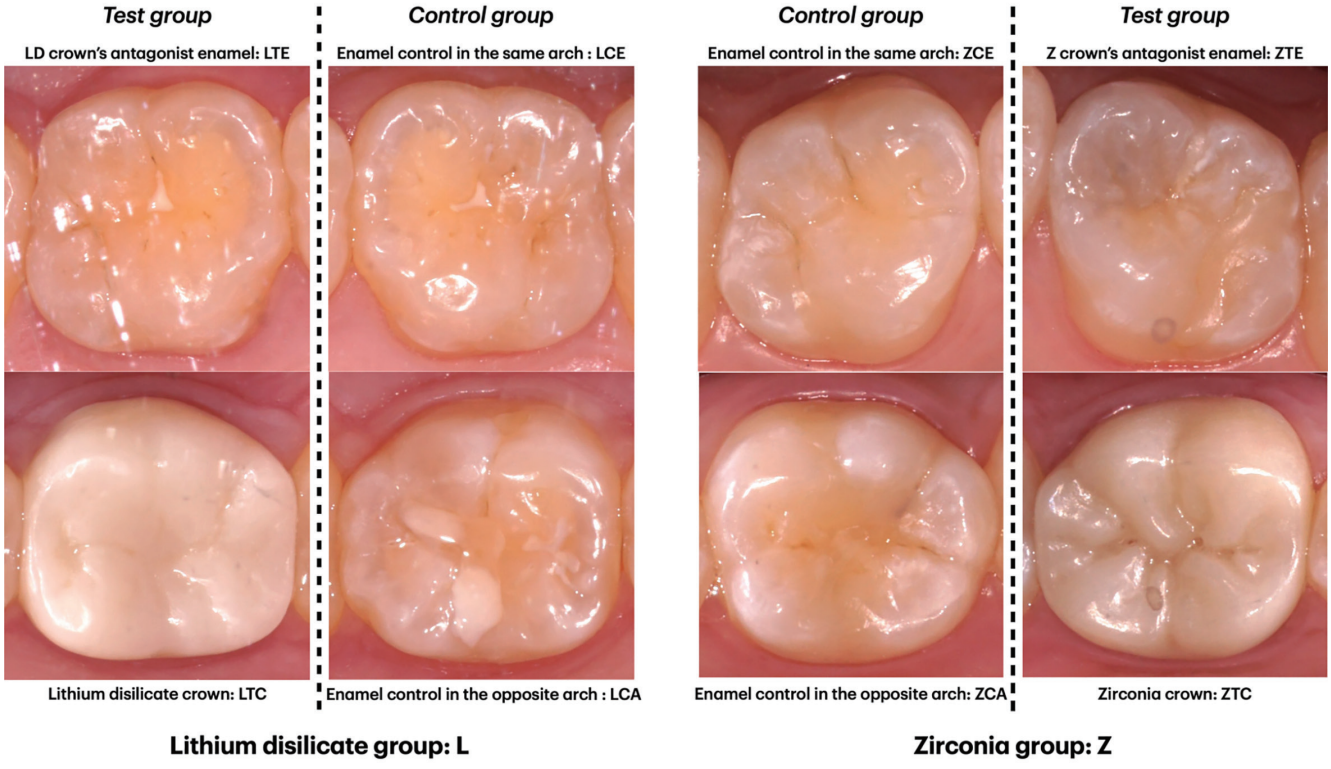

Fig. 1. Graphic presented the split-mouth study design of lithium disilicate (L) and zirconia group (Z) with acronyms following in the figure.

point was enamel[27]; normal saliva flow; willing and able to participate in the study. The exclusion criteria were: systemic disease that is not well-controlled; poor plaque control or long-term periodontitis that has not been treated; active tooth decay, acute infection or periapical lesion; teeth that cannot be restored or teeth that can be restored but with a crown-to-root ratio that exceeds 1:1; evidence of temporomandibular disorders or parafunctional habits; insufficient volume or rate of flow of saliva, or a need for medications that reduce the salivary flow. The treatment of the participants and data collection were done at the Implant Dentistry Clinic, Faculty of Dentistry, Mahidol University, Bangkok.

The participants were enrolled and assigned to interventions by one of the investigators (WP). Twenty-four participants were included in this study. The age of the participants ranged from 18 - 66 years (mean age 37; SD = 13); six participants were male and 18 were female. In order to allocate the participants, formulation of a random number table was conducted using a computer to assign the subjects to the material groups (allocation ratio 1:1). The type of provided crown was not made known to the participants. All of the participants were required to sign an informed consent form before the start of the research.

The materials for the crowns used in this study included high translucency monolithic yttrium stabilized zirconium oxide (5 mol%Y-TZP, Lava Esthetic Fluorescent FC, 3M ESPE, St. Paul, MN, USA) and low translucency monolithic lithium disilicate glass-ceramic (IPS e.max CAD LT, Ivoclar Vivadent AG). Crown preparation was performed by one of the investigators (AC). Prior to the crown preparation, the previously endodontically treated abutment tooth was prepared with the core build-up (and post if needed) for the crown support. The tooth was prepared following the guideline for a ceramic crown: an axial tooth reduction of 1 mm, occlusal reduction of 1.5 mm, and a shoulder margin with a round inner edge. The prepared tooth was cleaned using pumice and scanned using an intraoral scanner (3Shape TRIOS 3, 3Shape, Copenhagen, Denmark). The provisional crown was made by using a bis-acryl resin (Protemp 4, 3M ESPE, St. Paul, MN, USA) and cemented with zinc oxide non-eugenol temporary cement (TempBond NE, Kerr, Orange, CA, USA). The stereolithography (STL) files from the scanning process were delivered to one laboratory in order to design and mill the crown with a CAD-CAM technique.

After the definitive restoration was returned from the laboratory, the crown was tried in place, and occlusal adjustments were made using a fine diamond bur (Fine Football Diamond, Intensive). Following the occlusal adjustments, the polishing of all of the adjusted surfaces with diamond impregnated polishers was performed in the sequence of coarse, medium, and fine points (ZilMaster, Shofu Dental Corporation, Montagnola, Switzerland). The inner surface of the zirconia crown was sandblasted (30 - 50 μm median particle size alumina, 2 bars/30PSI) and then ultrasonically cleaned and dried, while the lithium disilicate crown was applied with K-ETCHANT syringe and then rinsed and dried. A resin cement (clear shade) with tooth primer (Panavia V5, Kuraray Noritake Dental Inc., Tokyo, Japan) was used to cement the definitive crowns with light-curing by blue LED (Bluephase Power Cure, Ivoclar Vivadent AG, Fürstentum, Liechtenstein) for 10 seconds on each side of crown.

The data was collected by one of the investigators (WP). One week following the cementation, a baseline examination was performed in order to ascertain whether any further adjustments were necessary, and that the patients felt comfortable regarding the crowns. For the quantitative data including maximum vertical loss and volume loss, the surface of the natural teeth and the crown were collected by using an intraoral scanner with a precision of 4.5 ± 0.9 μm.[38] Prior to scanning, the intraoral scanner was calibrated to ensure that the data error was minimal. The scanning procedure was done following the description of the technique found in a previous study.[37] For the qualitative surface investigation, low viscosity of polyvinylsiloxane impression material (Take1 Advanced, Light body wash, Kerr, Orange, CA, USA) was used to obtain the occlusal contact area. The epoxy resin material (SpeciFix-40, Struers Inc., Westlake, OH, USA) was poured to make replica models, following the manufacturer's recommendations. Occlusal contacts marked intraorally using 80 μm Hanel articulating paper (Coltene Whaledent, Langenau, Germany) were

https://doi.org/10.4047/jap.2024.16.1.12

photographed at the quadrants. Appointments for the subjects to return in 6 and 12 months were scheduled. During both periods of time, the scanning and impression were done.

For the maximum vertical loss and volume loss analysis, the process was initiated by segmenting the single first molar 3D images from the full-arch 3D images. Then, the 3D images of baseline and follow up datasets (0 - 6 M, 0 - 12 M) were aligned together by GOM Inspect software (GOM GmbH, Braunschweig, Germany). The datasets were initially aligned with "best-fit alignment" using an iterative closet point (ICP) algorithm and, after that, the two surfaces were aligned again with "reference best-fit alignment", which selects only the buccal and palatal/lingual areas so that the underestimated dataset from initial alignment was reduced (Fig. 2A-B).[39]

The maximum vertical loss (μm) was analyzed using GOM Inspect software by finding the surface deviations from superimposed 3D images of the selected area. A color code from green to dark blue indicated the amount of height loss between two surfaces. The maximum height loss of each occlusal contact area (OCA) was calculated automatically and labeled by the software (Fig. 2C). The superimposed 3D images from GOM Inspect software was used for volume loss (mm^3) analysis by NX software (SIEMENS, Foster city, CA, USA). The superimposed images was created as a solid shape by closing the bottom of images at the same virtual bottom point, after which a computer program was used to calculate the differential volume between selected occlusal areas (Fig. 2D).

For surface analysis of the wear, epoxy resin replicas were used in order to evaluate the wear patterns on the crown's antagonistis enamel (LTE, ZTE), the crowns (LTC, ZTC), and the enamel control (LCE, LCA, ZCE, ZCA) by using the scanning electron microscopy (SEM) (JSM-6610 Series, JOEL Ltd., Tokyo, Japan) with accelerating the voltage of 20 kV at a magnification of 50 - 100×.[40] The SEM images of same OCA at 0 M, 6 M, and 12 M were evaluated for the changes of surface topography by the investigator.

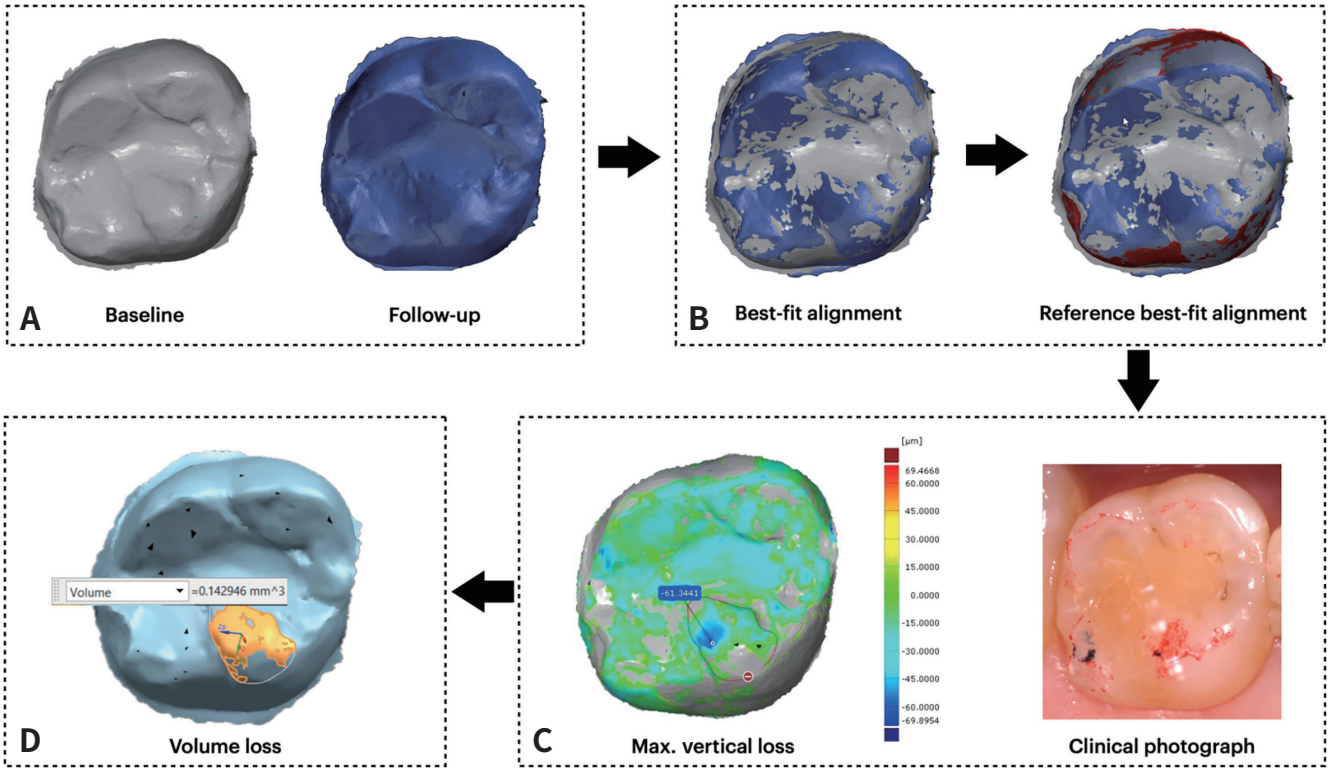

Fig. 2. (A) 3D images of baseline and follow up dataset. (B) Best-fit alignment and reference best-fit alignment of the dataset. (C) Analyzed 3D images show the surface deviations with blue to dark blue color code. (D) Superimposed 3D images show the volume loss of occlusal area.

Statistical analysis with the SPSS software (IBM SPSS statistics version 28.0, Chicago, IL, USA) was performed. An independent sample t-test and Mann-Whitney U test were used to compare the differences of two variables: the crown's antagonist enamel and the enamel control (LTE-LCE, ZTE-ZCE); and the crown's antagonistis enamel between Z and L group (ZTE-LTE). For the differences of the wear between the two times of the recall appointment, the paired t-test and the Wilcoxon signed rank test were used. The significance level was set at $\alpha < .05$.

RESULTS

A total of 22 participants provided results (n = 11). The causes for withdrawal were the cracked tooth syndrome of the antagonist tooth for one participant and an inability to return for the follow-up because of the COVID-19 pandemic for the other participant (Fig. 3). An overview of the mean of maximum vertical loss and the volume loss was presented in Table 1, Fig. 4, and Fig. 5.

Concerning the average maximum wear between the zirconia crown's antagonist enamel (ZTE) and that of the enamel control (ZCE), no significant difference was observed ($P > .05$). Nevertheless, there was a significant difference between the lithium disilicate crown's antagonist enamel (LTE) and the enamel control (LCE) at 12 M ($P < .05$). Moreover, no significant difference was found between the zirconia crown's antagonist enamel (ZTE) and the lithium disilicate crown's antagonist enamel (LTE)($P > .05$). Observing the mean of the maximum wear between 6 M and 12 M of all groups, significant differences were found ($P < .05$) (Table 2).

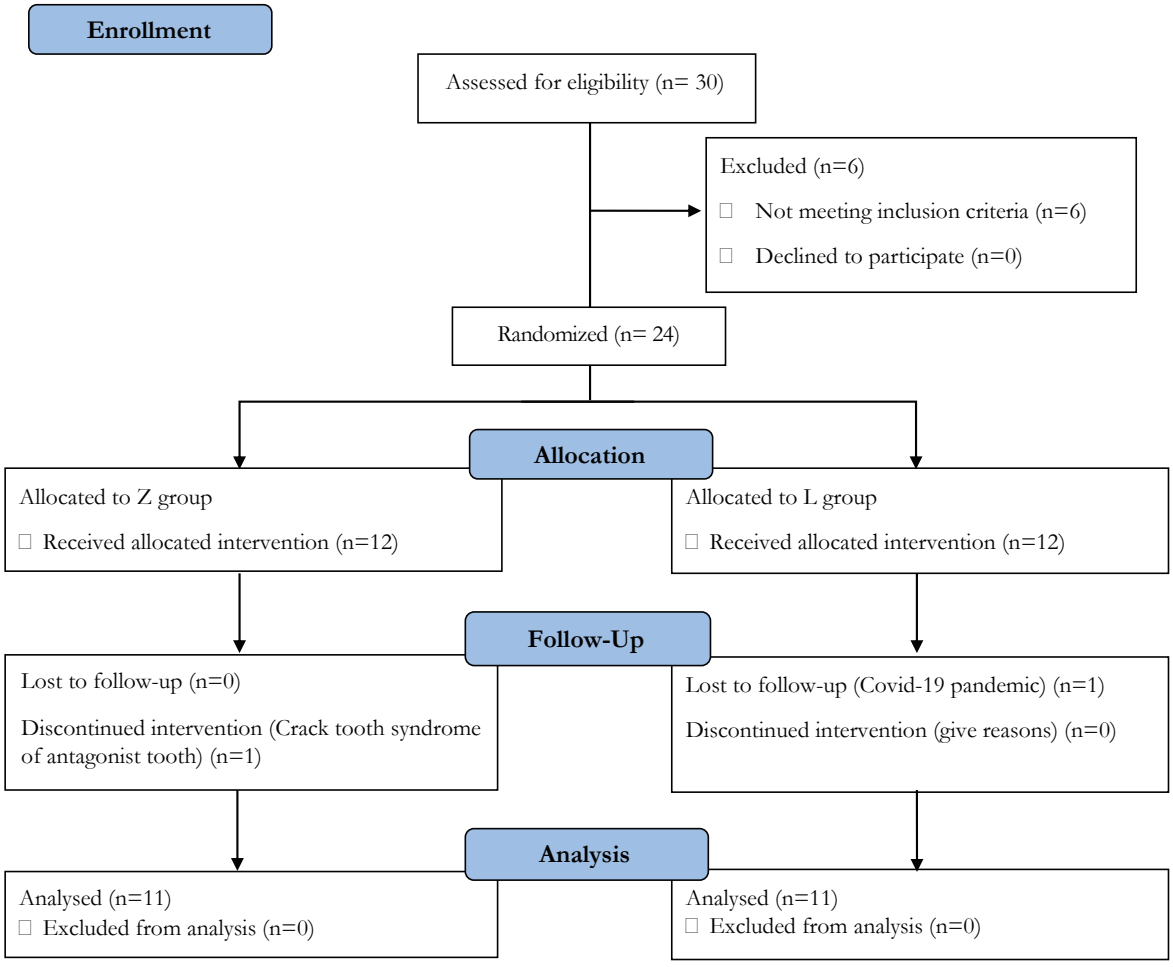

Fig. 3. CONSORT flow diagram showing the enrollment, allocation, follow-up and analysis of the participants.

https://doi.org/10.4047/jap.2024.16.1.12

Table 1. Mean (SD) of the maximum vertical loss (μm) and the maximum volume loss (mm^3) of the OCAs at 6 M and 12 M

	Mean of max. vertical loss		Mean of volume loss	
	6 M	12 M	6 M	12 M
LTC	30.416 (4.382)	35.726 (4.938)	0.032 (0.014)	0.039 (0.018)
ZTC	19.700 (2.827)	22.571 (2.710)	0.013 (0.012)	0.017 (0.013)
LTE	37.273 (6.814)	47.813 (9.409)	0.025 (0.010)	0.040 (0.018)
ZTE	31.717 (9.164)	40.277 (9.106)	0.021 (0.014)	0.038 (0.020)
LCE	33.114 (5.734)	39.114 (7.898)	0.028 (0.013)	0.040 (0.020)
ZCE	32.623 (4.937)	38.907 (7.089)	0.032 (0.010)	0.043 (0.017)
LCA	34.252 (5.874)	42.124 (6.359)	0.029 (0.020)	0.042 (0.020)
ZCA	34.186 (5.867)	39.745 (9.172)	0.027 (0.012)	0.038 (0.015)

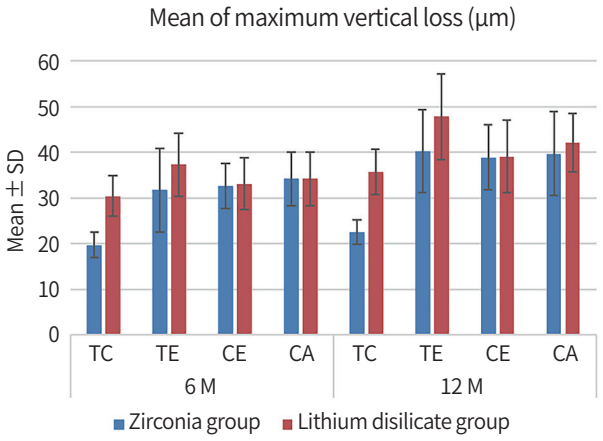

Fig. 4. The graph shows the mean of the maximum vertical loss (μm) of the OCAs following 6 M and 12 M.

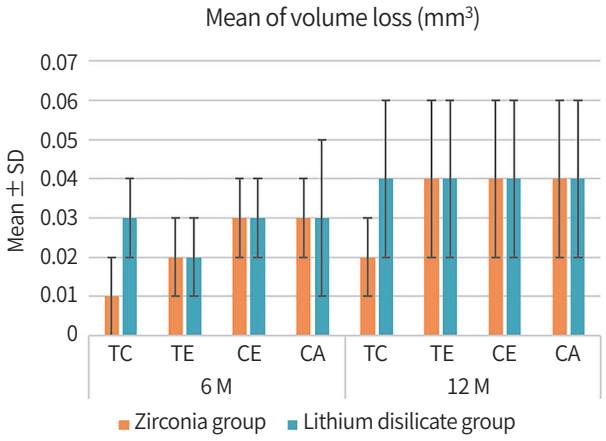

Fig. 5. The graph shows the mean of the volume loss (mm^3) of the OCAs following 6 M and 12 M.

Table 2. *P* value of paired variables of mean of the maximum vertical loss

		6 M				12 M				6 M				12 M			
		LTC	LTE	LCE	LCA	LTC	LTE	LCE	LCA	ZTC	ZTE	ZCE	ZCA	ZTC	ZTE	ZCE	ZCA
6 M	LTC																
	LTE	.012*															
	LCE		.137														
	LCA			.651													
12 M	LTC	.000*															
	LTE		.000*			.001*											
	LCE			.005*			.029*										
	LCA				.001*			.377									
6 M	ZTC	.000*															
	ZTE		.122							.001*							
	ZCE			.832							.776						
	ZCA				.979							.507					
12 M	ZTC					.000				.002*							
	ZTE						.071				.000*			.000*			
	ZCE							.949				.001*			.698		
	ZCA								.488				.002*			.813	

*: statistically significant (*P* value < .05).

For the average volume loss, no significant difference was found ($P > .05$) between the zirconia crown's antagonist enamel (ZTE) and that of the enamel control (ZCE). Furthermore, the lithium disilicate crown's antagonist enamel (LTE) and that of the enamel control (LCE) showed no significant difference ($P > .05$). Likewise, no significant difference was found between the zirconia crown's antagonist enamel (ZTE) and the lithium disilicate crown's antagonist enamel (LTE)($P > .05$). Regarding the mean of the volume wear between 6 M and 12 M of all groups, there were significant differences ($P < .05$) (Table 3).

From the comparison between SEM images of two-time interval (0 M and 12 M), a deeper pit with merging of the pit was seen on the OCA of the zirconia crown's antagonist enamel (ZTE)(Fig. 6A-B), while the OCA of the zirconia crown (ZTC) showed wear facet with irregular surface (Fig. 6C-D). The wear facet with

Table 3. *P* value of paired variables of mean of volume loss

		6 M				12 M				6 M				12 M			
		LTC	LTE	LCE	LCA	LTC	LTE	LCE	LCA	ZTC	ZTE	ZCE	ZCA	ZTC	ZTE	ZCE	ZCA
6 M	LTC																
	LTE	.243															
	LCE		.466														
	LCA			.470													
12 M	LTC	.011*															
	LTE		.003*			.758											
	LCE			.005*			1.000										
	LCA				.050*			.837									
6 M	ZTC	.003*															
	ZTE		.506							.147							
	ZCE			.457							.052						
	ZCA				.761							.340					
12 M	ZTC					.001*				.025*							
	ZTE						.842				.000*			.007*			
	ZCE							.736				.010*			.569		
	ZCA								.642				.003*			.515	

*: statistically significant (*P* value < .05).

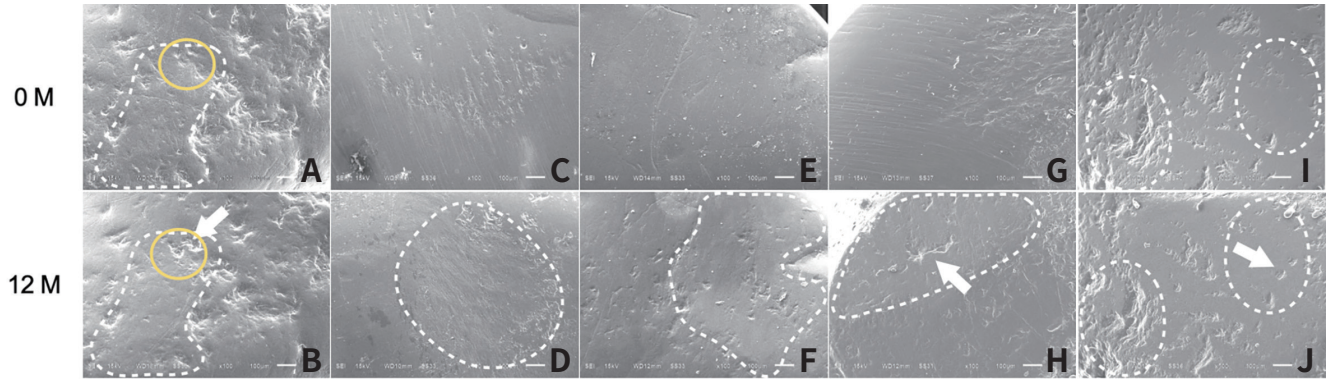

Fig. 6. SEM image of the OCA of A - B zirconia crown's antagonist enamel (ZTE) - the yellow circle and the arrow point out to the deeper pit and merging of the pit at 12 M, C - D zirconia crown (ZTC) - the dotted circle shows the wear facet, E - F lithium disilicate crown's antagonist enamel (LTE) - the dotted circle represents the wear facet, G - H lithium disilicate crown (LTC) - the dotted circle shows the wear facet and the arrow points out to glass-ceramic chipping, and I - J natural enamel (CE) - the dotted circles indicate the rougher surface of OCAs, and the arrow points to the new created pits, with ×100 magnification at 0 M and 12 M.

https://doi.org/10.4047/jap.2024.16.1.12

rougher pitted surface was seen on the OCA of the lithium disilicate crown's antagonist enamel (LTE)(Fig. 6E-F), while the wear facet with chipping of the glass ceramic was shown on the OCA of the lithium disilicate crown (LTC)(Fig. 6G-H). Moreover, the SEM images of the OCA of the natural enamel showed a rougher and deeper pitted surface (Fig. 6I-J).

DISCUSSION

The results from this study showed that the wear of zirconia crown's antagonist enamel and the wear of lithium disilicate crown's antagonist enamel were not different from the natural enamel. Also, there was no difference between the wear of crown's antagonist enamel between Z and L group. Thus, all of the null hypotheses were accepted.

The results of this study revealed that there were no significant differences in the results of the zirconia crown's antagonist enamel when compared with the natural enamel, which were similar to those of the *in vitro* research.[30,31] Moreover, the volume loss between the lithium disilicate crown's antagonist enamel and the enamel control showed no difference in the wear, which concurred with previous research.[24-26] However, the study found that at 12 months there was the highest vertical loss difference when compared between lithium disilicate crown's antagonist enamel and the enamel control. The inconsistency of this results in lithium disilicate group could be explained from the surface characteristics of the glass ceramic material which were characterized by very deep pitting wear due to the cracking feature of glass ceramic materials.[41,42] This is different from enamel and zirconia with shallower wear characteristics. Therefore, the maximum vertical loss effect measured from the deepest point of the valley was not the most accurate indication, and the total volume wear should be measured to get more accurate results.

This study was planned to be a split-mouth design so that the outcome of the enamel relative to the natural teeth and the materials employed for the restorations could be compared.[27] In addition, the results obtained from the enamel control group were used to verify the reliability of the measurement method compared to previous studies.[2] From this study, the wear results of the enamel control group of the zirconia and lithium disilicate groups were similar and the results after one year in this study was concurred with the previous research that revealed the running-in wear of 38 μm for molar teeth during the first year.[3] Although the amount of wear in the majority of clinical studies was measured in terms of the maximum vertical loss,[27-31,34] this may not be sufficient to strictly quantify the loss of height because this measure was unequally affected by time and occlusion.[37] The wear should be measured in terms of volume since it tend to increase as time passed, as the base surface area would rise proportionally to the height of the tooth, which would obviously decrease.[43-44] Thus, this research measures wear as vertical losses with the purpose of being used in comparison with results in previous clinical studies, but the volume loss was the primary interpretation for this study.

The results of this study showed that there was no distinction between the wear rate of the antagonist enamel between lithium disilicate and zirconia group, as opposed to the *in vitro* tests that showed lower wear of enamel opposing monolithic zirconia than that opposing different ceramics.[10-17] The inconsistency of these results was due to the use of the 5th generation of zirconia in this study, which had lower mechanical properties, such as hardness, fracture toughness, and flexural strength, than in previous experiments using 3rd generation of zirconia. These inferior mechanical properties may result in less wear resistance of material and greater post-polish surface roughness, all of which contribute to the increased wear of the material itself, including the enamel antagonist. The author suggests that further study of such factors is needed in the future.

This research revealed that the comparison of the wear between the zirconia crown and that of antagonist enamel was in agreement with the findings of the *in vitro* study showing that less wear of the zirconia material was observed when compared with natural enamel.[16] Moreover, the volume loss of the lithium disilicate crown was not substantially varied from that of the antagonist enamel, which was in line with those of prior research findings.[17,18] It can be explained that the zirconia can resist damage to the surface when stressed, as a consequence of its excellent

strength and toughness, ensuring its fineness and coefficient of friction do not change over the longer term.[44] This slow change in surface condition resulted in a low surface roughness change in the material, which was one of the factors affecting the amount of wear of the enamel surface. It was concluded that the surface of zirconia after wear was less rough, which resulted in less wear of the tooth enamel.[13] While the lithium disilicate glass ceramic's glass matrix is softer than that of harder crystals, it wears down much more quickly when worn against enamel, increasing both surface roughness and friction coefficient.[41] Moreover, the glass particles that break free during wear will work abrasively in a three-body action,[45] consequently increasing friction and the rate of wear due to the glass ceramic material and enamel.[46] This information can help explain why lithium disilicate glass-ceramics are linked to a high degree of enamel wear when combined with a high level of hardness.[47]

The SEM analysis of this study for the qualitative element showed that the surface of natural enamel in this study was identical to that of the *in vitro* experiments.[15,41] However, the zirconia crown's antagonist enamel produced a deeper pitted surface over one year of use, which did not correlate to the laboratory research that reported a very smooth and flat surface on the wear facet.[6,12,14,15] Also, the outcomes of the zirconia material in this research was inconsistent with the *in vitro* studies, which stated that the mechanical strength and surface characteristics of zirconia made it to preserve a smooth surface during the wear test.[13,17,41] This difference in results was due to the use of different generations of zirconia and the environment in clinical trials that differed from laboratory experiment.[6,12,14,15] This experiment used the 5th generation of zirconia, which is more translucent but has lower mechanical properties than the 3rd generation of zirconia used in the experiment. In addition, factors such as the shape of the material, the amount and direction of the force applied to the material, as well as the oral environment, could have affected the difference in results and should be further studied. The wear feature on the lithium disilicate crown's antagonist enamel in this research showed rougher and deeper pitted surfaces that was in line with previous *in vitro* experiments.[12,14,15,42] In addition, the wear characteristic of the lithium disilicate crown in this research was consistent with previous studies, which indicated that the wear trace of the lithium disilicate glass ceramic had a rougher surface and presented some of the lithium disilicate particles.[12,14,15,42] The potential cause for this attribute was that the glass matrix was worn more easily than the lithium disilicate crystalline grains that created the molded crystalline grains[41]; the delamination of glass ceramic particles would shift the abrasive style from two-body abrasion to three-body abrasion during the wear test.[41,42]

When used as a diagnostic tool for evaluating tooth wear, the IOs demonstrated acceptable levels of sensitivity.[36] The prior research confirmed the value of IOs and their ability to offer a systematic approach for the wear assessment in routine clinics.[35,36] In order to properly address wear detection, however, it is important to take into account both the faults and the conditions affecting the digital instrument.[48] Previous studies have indicated that it is not always possible to determine which parts remained stable and which areas suffered modifications in a clinical context.[48] Additionally, the full-arch impressions typically accumulate more inaccuracy than partial-arch impressions.[49,50] Therefore, tooth wear should be examined using an automated process that compares tooth by tooth.[48] The precision of the measuring systems in previous clinical studies, which was in a range from 5 to 20 μm, had made it impossible to evaluate the exact value of the wear in various tests.[27-31,34] Furthermore, earlier studies found that greater defect regions are predicted to have inaccurate readings because of more widespread erosion or longer follow-up times. Interpreting a situation where there are multiple and significant faults should be done with caution.[48] Further researches are necessary to thoroughly examine the inaccuracies during dental follow-up since there is an abundance of data in the literature examining the elements that affect the digital patient monitoring by 3D superimposition.

The limitations of this research were the small sample size and short-term follow-up time. There would be a need to conduct additional clinical assessments over a longer period and with a larger sample size. Additionally, the surface roughness should be investi-

gated in further studies.

CONCLUSION

The results indicated that the selection of monolithic zirconia and lithium disilicate crowns for clinical use could be considered appropriate and practical. Following a period of one year, the degree of the antagonistic enamel wear could be comparable to that of the natural teeth. When considering the restorations, it appeared that the zirconia showed a lower amount of wear than that of the lithium disilicate crown.

REFERENCES

1. Smith BG, Bartlett DW, Robb ND. The prevalence, etiology and management of tooth wear in the United Kingdom. J Prosthet Dent 1997;78:367-72.
2. Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G. Quantitative in vivo wear of human enamel. J Dent Res 1989;68:1752-4.
3. Kelly JR, Benetti P. Ceramic materials in dentistry: historical evolution and current practice. Aust Dent J 2011;56 Suppl 1:84-96.
4. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent 2007;98:389-404.
5. Pjetursson BE, Sailer I, Zwahlen M, Hämmerle CH. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: Single crowns. Clin Oral Implants Res 2007;18 Suppl 3:73-85.
6. Mitov G, Heintze SD, Walz S, Woll K, Muecklich F, Pospiech P. Wear behavior of dental Y-TZP ceramic against natural enamel after different finishing procedures. Dent Mater 2012;28:909-18.
7. Sannino G, Germano F, Arcuri L, Bigelli E, Arcuri C, Barlattani A. CEREC CAD/CAM chairside system. Oral Implantol (Rome) 2015;7:57-70.
8. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials 1999;20:1-25.
9. Larsson C, Vult von Steyern P, Nilner K. A prospective study of implant-supported full-arch yttria-stabilized tetragonal zirconia polycrystal mandibular fixed dental prostheses: three-year results. Int J Prosthodont 2010;23:364-9.
10. Janyavula S, Lawson N, Cakir D, Beck P, Ramp LC, Burgess JO. The wear of polished and glazed zirconia against enamel. J Prosthet Dent 2013;109:22-9.
11. Preis V, Weiser F, Handel G, Rosentritt M. Wear performance of monolithic dental ceramics with different surface treatments. Quintessence Int 2013;44:393-405.
12. Preis V, Hahnel S, Kolbeck C, Behrend D, Warkentin M, Handel G, Rosentritt M. Wear performance of dental materials: a comparison of substructure ceramics, veneering ceramics, and non-precious alloys. Adv Eng Mater 2011;13:B432-9.
13. Kim MJ, Oh SH, Kim JH, Ju SW, Seo DG, Jun SH, Ahn JS, Ryu JJ. Wear evaluation of the human enamel opposing different Y-TZP dental ceramics and other porcelains. J Dent 2012;40:979-88.
14. Rosentritt M, Preis V, Behr M, Hahnel S, Handel G, Kolbeck C. Two-body wear of dental porcelain and substructure oxide ceramics. Clin Oral Investig 2012;16:935-43.
15. Mörmann WH, Stawarczyk B, Ender A, Sener B, Attin T, Mehl A. Wear characteristics of current aesthetic dental restorative CAD/CAM materials: two-body wear, gloss retention, roughness and Martens hardness. J Mech Behav Biomed Mater 2013;20:113-25.
16. Stawarczyk B, Özcan M, Schmutz F, Trottmann A, Roos M, Hämmerle CH. Two-body wear of monolithic, veneered and glazed zirconia and their corresponding enamel antagonists. Acta Odontol Scand 2013;71:102-12.
17. Sripetchdanond J, Leevailoj C. Wear of human enamel opposing monolithic zirconia, glass ceramic, and composite resin: an in vitro study. J Prosthet Dent 2014;112:1141-50.
18. Lawson NC, Janyavula S, Syklawer S, McLaren EA, Burgess JO. Wear of enamel opposing zirconia and lithium disilicate after adjustment, polishing and glazing. J Dent 2014;42:1586-91.
19. Heintze SD, Cavalleri A, Forjanic M, Zellweger G, Rousson V. Wear of ceramic and antagonist-a systematic evaluation of influencing factors in vitro. Dent Mater 2008;24:433-49.
20. Jung YS, Lee JW, Choi YJ, Ahn JS, Shin SW, Huh JB. A study on the in-vitro wear of the natural tooth structure by opposing zirconia or dental porcelain. J Adv

Prosthodont 2010;2:111-5.
21. Heintze SD. How to qualify and validate wear simulation devices and methods. Dent Mater 2006;22:712-34.
22. Passos SP, Torrealba Y, Major P, Linke B, Flores-Mir C, Nychka JA. In vitro wear behavior of zirconia opposing enamel: a systematic review. J Prosthodont 2014;23:593-601.
23. Etman MK, Woolford M, Dunne S. Quantitative measurement of tooth and ceramic wear: in vivo study. Int J Prosthodont 2008;21:245-52.
24. Esquivel-Upshaw J, Rose W, Oliveira E, Yang M, Clark AE, Anusavice K. Randomized, controlled clinical trial of bilayer ceramic and metal-ceramic crown performance. J Prosthodont 2013;22:166-73.
25. Suputtamongkol K, Anusavice KJ, Suchatlampong C, Sithiamnuai P, Tulapornchai C. Clinical performance and wear characteristics of veneered lithia-disilicate-based ceramic crowns. Dent Mater 2008;24:667-73.
26. Silva NR, Thompson VP, Valverde GB, Coelho PG, Powers JM, Farah JW, Esquivel-Upshaw J. Comparative reliability analyses of zirconium oxide and lithium disilicate restorations in vitro and in vivo. J Am Dent Assoc 2011;142 Suppl 2:4S-9S.
27. Stober T, Bermejo JL, Rammelsberg P, Schmitter M. Enamel wear caused by monolithic zirconia crowns after 6 months of clinical use. J Oral Rehabil 2014;41:314-22.
28. Mundhe K, Jain V, Pruthi G, Shah N. Clinical study to evaluate the wear of natural enamel antagonist to zirconia and metal ceramic crowns. J Prosthet Dent 2015;114:358-63.
29. Stober T, Bermejo JL, Schwindling FS, Schmitter M. Clinical assessment of enamel wear caused by monolithic zirconia crowns. J Oral Rehabil 2016;43:621-9.
30. Lohbauer U, Reich S. Antagonist wear of monolithic zirconia crowns after 2 years. Clin Oral Investig 2017;21:1165-72.
31. Esquivel-Upshaw JF, Kim MJ, Hsu SM, Abdulhameed N, Jenkins R, Neal D, Ren F, Clark AE. Randomized clinical study of wear of enamel antagonists against polished monolithic zirconia crowns. J Dent 2018;68:19-27.
32. Gou M, Chen H, Kang J, Wang H. Antagonist enamel wear of tooth-supported monolithic zirconia posterior crowns in vivo: A systematic review. J Prosthet Dent 2019;121:598-603.
33. Stober T, Johnson GH, Schmitter M. Accuracy of the newly formulated vinyl siloxanether elastomeric impression material. J Prosthet Dent 2010;103:228-39.
34. Hartkamp O, Lohbauer U, Reich S. Antagonist wear by polished zirconia crowns. Int J Comput Dent 2017;20:263-74.
35. Schlenz MA, Schlenz MB, Wöstmann B, Jungert A, Ganss C. Intraoral scanner-based monitoring of tooth wear in young adults: 12-month results. Clin Oral Investig 2022;26:1869-78.
36. García VD, Freire Y, Fernández SD, Murillo BT, Sánchez MG. Application of the intraoral scanner in the diagnosis of dental wear: an in vivo study of tooth wear analysis. Int J Environ Res Public Health 2022;19:4481.
37. DeLong R. Intra-oral restorative materials wear: rethinking the current approaches: how to measure wear. Dent Mater 2006;22:702-11.
38. Hack GD, Patzelt SBM. Evaluation of the accuracy of six intraoral scanning devices: an in-vitro investigation. JADA 2015;10:1-5.
39. O'Toole S, Osnes C, Bartlett D, Keeling A. Investigation into the accuracy and measurement methods of sequential 3D dental scan alignment. Dent Mater 2019;35:495-500.
40. Derrien G, Le Menn G. Evaluation of detail reproduction for three die materials by using scanning electron microscopy and two-dimensional profilometry. J Prosthet Dent 1995;74:1-7.
41. Wang L, Liu Y, Si W, Feng H, Tao Y, Ma Z. Friction and wear behaviors of dental ceramics against natural tooth enamel. J European Ceram Soc 2012;32:2599-606.
42. Lee A, Swain M, He L, Lyons K. Wear behavior of human enamel against lithium disilicate glass ceramic and type III gold. J Prosthet Dent 2014;112:1399-405.
43. Delong R, Pintado MR, Douglas WH. The wear of enamel opposing shaded ceramic restorative materials: an in vitro study. J Prosthet Dent 1992;68:42-8.
44. Peters MC, Delong R, Pintado MR, Pallesen U, Qvist V, Douglas WH. Comparison of two measurement techniques for clinical wear. J Dent 1999;27:479-85.
45. Ratledge DK, Smith BG, Wilson RF. The effect of restorative materials on the wear of human enamel. J Pros-

https://doi.org/10.4047/jap.2024.16.1.12

thet Dent 1994;72:194-203.
46. Çulhaoğlu A, Park J. A comparison of the wear resistance and hardness of two different indirect composite resins with a ceramic material, opposed to human enamel. European J Gen Dent 2013;2:274.
47. Ludovichetti FS, Trindade FZ, Werner A, Kleverlaan CJ, Fonseca RG. Wear resistance and abrasiveness of CAD-CAM monolithic materials. J Prosthet Dent 2018; 120:318.e1-8.
48. Gimenez-Gonzalez B, Setyo C, Picaza MG, Tribst JPM. Effect of defect size and tooth anatomy in the measurements of a 3D patient monitoring tool. Heliyon 2022;8:e12103.
49. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on active triangulation technology with blue light for implants: effect of clinically relevant parameters. Implant Dent 2015;24:498-504.
50. Ender A, Zimmermann M, Mehl A. Accuracy of complete- and partial-arch impressions of actual intraoral scanning systems in vitro. Int J Comput Dent 2019;22: 11-9.