RESEARCH ARTICLE

Wear assessment of current aesthetic crowns compared with human enamel after two finishing procedures: *In vitro* study

[version 1; peer review: 1 approved with reservations]

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Abstract

Background: Surfaces of ceramic crowns are modified several times before being exposed to wear in the oral cavity. Grinding and different finishing procedures may be associated with teeth wear due to increased surface roughness. Limited data is available with regard to the effect of polishing procedures on the surface roughness and wear behavior of ceramic crowns. This study was conducted to assess the influence of polished and polished-ground-repolished surface finish on the roughness and wear performance of three ceramic crowns.

Methods: 36 natural 1st molar teeth were prepared using a CNC milling machine and classified into three groups (n=12/group): zirconia, E-max and hybrid ceramic (VITA ENAMIC) crowns. Each group was classified into two subgroups (n=6/subgroup): polished and polished-ground-repolished crowns. Natural molar teeth served as an unrestored control group (n=6). All samples were loaded into a chewing simulator for 100,000 cycles and subjected to 600 thermo-cycles in temperature changes to simulate changes in intraoral temperature. Natural maxillary 1st premolar teeth were collected and only buccal half (cusp) of sectioned tooth was used as antagonists. A profilometer was used to detect the roughness before and after masticatory cycles. The occlusal surface was analysed using a scanning electron microscope (SEM).

Results: The E-max crown group had the highest mean surface roughness value (0.267µm) followed by VITA ENAMIC crown group (0.266 µm), while the lowest mean surface roughness value recorded for zirconia crown (0.257µm). The difference between these means was not significant. The polished-ground-repolished group had a higher mean surface roughness (0.266 µm) compared with the polished group (0.260 µm), which was not significantly different.

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Conclusions: All tested ceramic crowns showed surface roughness with values within acceptable clinical parameters ($\sim 0.2 \mu\text{m}$). Additionally, intraoral polishing procedures could be considered a reliable technique for smoothing of zircona, E.max and VITA ENAMIC crowns after occlusal adjustment.

Keywords

Teeth wear, Full ceramic crowns, CAD/CAM, surface roughness, Enamel

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Introduction

Wear of teeth is considered one of the most important issues when choosing a dental ceramic^{1,2}. The wear may affect the thickness of the restoration and the natural enamel, which impairs the esthetic appearance and limits tooth survival rates^{3,4}. Recent studies suggest that surface roughness highly influences o tooth wear⁵. A smooth ceramic surface enhances the function and aesthetics of teeth, and prevents gingival inflammation and the accumulation of stains and plaque on the surface of a restoration⁶, while a rough surface may abrade natural teeth, which compromises the appearance of the restoration⁷.

The repeated incidence of veneer chipping with bilayered restorations has prompted the development of monolithic restorations fabricated from high strength ceramics^{8,9}. The present research was performed to compare the influence of polished and repolished procedures on surface roughness of the tooth and what impact on the wear rate of monolithic crowns this would have.

Methods

The materials tested in the study are listed in [Table 1](#).

In total, 42 intact mandibular 1st molar teeth with three roots were collected from patients (age range 40–50 years) from the Dental Surgery Clinic at Faculty of Dentistry, Cairo University, as part of routine periodontal treatment. Patients provided written informed consent for their extracted teeth to be used for subsequent research purposes.

After removal, each tooth was sterilized in 0.5% sodium hypochlorite (ADWIC Egypt) and stored in saline solution. All teeth were mounted in epoxy resin (IN2 INFUSION; Easy Composites, USA) blocks using a plastic ring (25 × 35 mm). To simulate the function of the periodontium, the root was covered with thin layer of condensation silicone (Zetaplus; Zhermack-SpA, Italy)¹⁰. A specially designed centralizing device was fabricated to allow accurate centralization of the tooth in the plastic ring during construction of the epoxy resin block ([Figure 1](#)).

Table 1. Materials used in the present study.

	Materials	Type	Manufacturer
Crowns	Katana multi-layer zirconia	Y-TZP	Kuraray Noritake Dental Inc, Tokyo, Japan
	Lithium disilicate ceramic	IPS E.max CAD	Ivoclar Vivadent, Schaan, Liechtenstein
	VITA ENAMIC	Hybrid ceramic	VITA Zahnfabrik, Säckingen, Germany
Cement	Rely X™ Ultimate	Dual cure resin cement used for all ceramic crowns	VITA Zahnfabrik, Säckingen, Germany
Polishing equipment	Fine diamond instrument	Red band diamond particle 50-60 um grit	MANI, Shioya, Japan
	Technical Polishing Kit	Dedeco Hi-glaze polishing kit	MANI, Shioya, Japan
		VITA ENAMIC Technical kit	VITA Zahnfabrik, Säckingen, Germany
		1-Step Kenda Zircovis diamond polishing kit (blue-green band) medium grit size (69-32 µm)	KENDA AG, Vaduz, Liechtenstein
	Clinical Kit	1- Step Kenda Nobilis diamond polishing kit (violet-red) contained fine grit size of 32-8µm	KENDA AG, Vaduz, Liechtenstein
		Diamond polishing paste	Pearl surface Z
			Kuraray Noritake Dental Inc, Tokyo, Japan

Figure 1. A centralizing device for locating the tooth in the center of the block.

Teeth were prepared in a standardized manner using a CNC milling machine (CNC Premium 4820-i-mes, Germany). The external surface of the tooth was reduced to remove the height of contour creating a 1mm deep chamfer finish line with a 10° total convergence angles. The height of tooth was reduced 2 mm with a flat occlusal table (Figure 2 and Figure 3).

Crown construction

Fabrication of the crowns. In order to standardize the shape and dimensions of all samples, CAD/CAM technology (CEREC in-Lab SW 15.1) was used according to the instructions of the manufacturer for different types of ceramic crowns. To obtain a 3D image, the prepared tooth was sprayed using an optical reflection medium (Optispray; Sirona Dental, Bensheim, Germany) and scanned using the CEREC Omnicam (Sirona Dental). After the scanned image was displayed on the computer screen, all scanning parameters (length: 8.05 mm; width: 7.19 mm; height: 6.34mm) of each tooth were restored in computer software (CEREC in-Lab software version 15.1, Sirona Dental).

Sintering of the zirconia ceramic crowns. Firing of zirconia crowns in a sintering furnace (TABEO Furnace; MIHM-VOGT, Germany) was carried out at approximately 9 hours, reaching around 1500°C within 4 hours then decreased to room temperature within 3 hours. All zirconia crowns were checked over their corresponding teeth for seating and inspected to detect eventual defects generated by sintering.

Crystallization of E.max CAD ceramic crowns. Programat P510 furnace (Ivoclar Vivadent, Schaan, Liechtenstein) was used. The starting temperature was 403°C and increased to 820°C, which was held for 10 minutes; then increased to 840°C, which was held for 7 minutes. After finishing of the firing cycle, crowns were removed and allowed to cool at room temperature. All crowns were checked over their corresponding teeth for seating and inspected to detect eventual defects generated by crystallization.

Finishing and polishing of the crowns

Zirconia crowns. Crowns were polished with a special polishing kit (Dedeco, Hi-glaze polishing Bur, USA) according to the manufacturer's guidelines in a 3-step procedure at 10.000 rpm with a laboratory micromotor (Forte 100 Dental Micro Motor Unit Handpiece; Saeshin, Korea) under water cooling for 30 seconds in one direction with a constant light pressure by the same operator¹¹⁻¹³. At the final step, Pearl surface Z was added to the polisher (fine grit size) to polish the entire crown surface¹⁴ without water to obtain a high luster gloss surface.

E-max CAD and VITA ENAMIC crowns. VITA ENAMIC crowns were prepolished by the disc of the medium grit size at 7.000 rpm hand piece under dry condition for 1 minute. Then, the polisher of extra-fine grit size was used at 5000 rpm. Wet polishing of E-max CAD crown was performed using VITA ENAMIC technical kit similar to the method used for VITA ENAMIC crowns.

Surface pretreatment

Zirconia crowns. Zirconia crowns were treated with 110 µm alumina particles using an airborne-particle-abrasion device (UMG Dental Lab Sandblaster; Tangshan UMG Medical Instrument, China) for 20 second¹⁵.

Figure 2. Tooth preparation using CNC Milling Machine.

Figure 3. 3D diagram illustrating the prepared tooth. Image created by authors using Autodesk Maya Software 2016.

E-max CAD and VITA ENAMIC crowns. The internal surfaces of crowns were treated with 5-% hydro-fluoric acid gel. Then, silane coupling agent (BISCO, Schaumburg, USA) was applied.

Crown cementation

35% phosphoric acid (3M ESPE) was placed on the teeth for 15 seconds and then rinsed for 10 sec. A thin layer of dentin bonding agent (3M ESPE, Paul, USA) was applied and polymerized (Elipar II) for 10 sec. Rely x ultimate resin cement was applied onto the internal surface of the crown which was then placed in position with gentle finger pressure. After that, the crowns were polymerized for 40 sec and then stored in H₂O for 24 hrs¹⁶.

Occlusal adjustment

Half of each group (zirconia, E-max CAD and VITA ENAMIC groups (n=18)) were ground at the functional cusp (mesiobuccal and distobuccal cusp) with a fine diamond bur under water spray for 15 sec in sweeping movement by a single operator.

Repolishing procedures

Zirconia crowns. Crowns were repolished again by a single operator, using Kenda Zircovis polishing system with a low speed handpiece under standardized conditions (permanent water cooling, 30 second, 10,000 rpm and a constant light pressure) in sweeping motion^{12,17}.

E-max CAD and VITA ENAMIC crowns. E-max CAD and VITA ENAMIC crowns were repolished again using Kenda Nobilis polishing system under standardized conditions (permanent water cooling, 30 second, 10,000 rpm and a constant light pressure) as suggested by the manufacturer (Figure 4).

Wear test and measurements

Selection of the abradar (antagonist) specimen. In total, 42 sound and freshly extracted maxillary 1st premolar teeth were collected from patients (age range, 15–20 years) from the Dental Orthodontic Clinic at Faculty of Dentistry, Cairo University as a part of orthodontic treatment. After removal, the teeth were sterilized in 0.5% sodium hypochlorite (ADWIC Egypt) and transferred to distilled saline solution.

Preparation of human enamel antagonist specimens. Each tooth was sectioned vertically (bucco-palatally) into two halves using a diamond cutting disk (Single and Double sided diamond discs, NTI Inter flex, Kerr, Italia) attached to a low speed hand piece (Dental Latch Low Speed Contra-Angle Handpiece, NSK, Japan) with coolant. Only buccal half (cusp) of sectioned 1st premolar tooth was used as antagonists⁴. Jakob's chuck holder was designed to mount the coronal portion of sectioned maxillary 1st premolar tooth (Figure 5).

Wear testing. Samples were loaded into a chewing simulator (ROBOTA chewing simulator; ROBOTA Model ACH-09075DC-T, LTD., Germany) for 100,000 cycles and subjected to 600 thermo-cycles (laboratory method of exposing ceramic crowns to temperature ranges similar to those occurring in the oral cavity) between 5°C and 55 °C for 60 second each which simulate changes in the intraoral temperature, maintained by a thermo-statically controlled liquid circulator (Model

ACH-09075DC-T, AD-TECH TECHNOLOGY CO., LTD., Germany) (Figure 6).

The samples were embedded in Teflon housing in the lower sample holder which was filled with water and kept the samples wet during the testing and removed the debris from the surface. The buccal half (cusp) of sectioned 1st premolar tooth antagonist was positioned on the ceramic crown to achieve wear contact with lateral movement of 2 mm and loaded with 49 Newton, which is equivalent to a normal chewing force in the oral cavity (Figure 7). The test was repeated 100,000 times to clinically simulate a six month chewing condition^{9,18}.

Figure 4. Polishing of e-max CAD crown.

Figure 5. Buccal section of the maxillary 1st premolar tooth fixed in the Jakob's chuck holder.

Figure 6. ROBOTA chewing simulator.

Figure 7. 3D diagram illustrating the component of the chewing simulator chamber. Image created by authors using Autodesk Maya Software 2016.

Data analysis

The 3D surface of the crowns were analyzed before and after the wear test using an USB digital microscope (Aven 26700-300 Zip-Scope USB Digital microscope, WITec, China) with a magnification of 120 X for roughness measurement¹⁹. The surface roughness

expressed in micron (μm) was calculated using a digital image analysis system (WSxM software, Version 5 develop 4.1, Nanotec, Electronica, SL, Spain) by superimposing the 3D surfaces before and after the wear test (Figure 8–Figure 10). The images were recorded with a resolution of 1280×1024 pixels per image.

Figure 8. 3D surface topography of zirconia sample. Polished with (a) Dedco kit; (b) Kenda kit.

Figure 9. 3D surface topography of e.max sample. Polished with (a) Technical kit; (b) Kenda kit.

One sample of each subgroup was scanned using a scanning electron microscope (HITACHI, SU8200 series, Tokyo, Japan) at X500 magnification.

Two-factorial ANOVA was done to detect effect of two different types of polishing on the surface roughness of various ceramic crown (zirconia, E-max CAD, VITA ENAMIC). **GraphPad**

Instat statistics software (Graph Pad InStat, Version 3, U-S-A) for Windows was used for statistical analysis. P values ≤ 0.05 are considered to be statistically significant in all tests.

Results

Surface roughness between all groups (before chewing simulation) was not statistically significant (Table 2).

Figure 10. 3D surface topography of VITA ENAMIC sample. Polished with (a) Technical kit; (b) Kenda kit.

Table 2. Surface roughness values of various crowns after two different types of polishing before chewing simulation.

Variable		Mean	± SD	95% confidence intervals		t value	P value
				Lower	Upper		
Control		0.2594	±0.0195	0.239	0.2798	----	---
Zirconia	Polished	0.2561	±0.0205	0.2345	0.2776	0.4113	0.6894 ns
	Re-polished	0.2499	±0.0301	0.2184	0.2815		
E.max	Polished	0.2606	±0.0251	0.2335	0.2878	0.4444	0.6662 ns
	Re-polished	0.2552	±0.0150	0.2394	0.271		
VITA ENAMIC	Polished	0.2578	±0.0180	0.2389	0.2766	0.4768	0.6436 ns
	Re-polished	0.2495	±0.0382	0.2094	0.2896		

ns: non-significant ($p > 0.05$). (Control, $n=6$; zirconia/E.max/VITA ENAMIC, $n=6$ /group)

Surface roughness after chewing simulation revealed that; E.max re-polished crown had the highest surface roughness ($0.2725 \mu\text{m}$), while the lowest surface roughness value was recorded for the zirconia re-polished group ($0.2570 \mu\text{m}$). The different between surface roughness for all three crowns after chewing simulation was not statistically significant ($P=0.666$; Table 3).

SEM images for zirconia crowns, both polished and repolished, showed the smoothest surface compared with the other two crowns. For all polished-ground-repolished samples, surface changes, such as pitting, ridges and deep grooves, were observed on the ceramic (Figure 11–Figure 13).

Discussion

The advancement of dentistry has made it possible to construct full monolithic crowns with improved wear resistance. Intraoral adjustments of ceramic crowns may result in surface roughness; therefore, technical and intraoral polishing is a necessary procedure²⁰. Numerous studies have compared different finishing procedures;²¹ however, there is little research comparing different finishing procedures and the resulting wear behavior.

In the present study, natural teeth were used as they have characteristics closer to the clinical condition²². The teeth were embedded in epoxy blocks simulating alveolar bone²³, and a specially designed centralizing device was used, which was an

Table 3. Surface roughness values of various crowns after two different types of polishing after six month chewing simulation.

Variable		Mean	± SD	95% confidence intervals		t-value	P value
				Lower	Upper		
Control		0.2574	±0.0311	0.2248	0.2900	----	---
Zirconia	<i>Polished</i>	0.2572	±0.0061	0.2508	0.2636	0.4339	0.966 ns
	<i>Re-polished</i>	0.2570	±0.0095	0.2471	0.267		
E.max	<i>Polished</i>	0.2629	±0.0177	0.2443	0.2815	0.4499	0.786 ns
	<i>Re-polished</i>	0.2725	±0.0241	0.2471	0.2978		
VITA ENAMIC	<i>Polished</i>	0.2617	±0.0152	0.2457	0.2777	0.8974	0.390 ns
	<i>Re-polished</i>	0.2707	±0.0193	0.2505	0.2909		

ns: non-significant ($p>0.05$) **Figure 11.** Scanning electron micrograph images of zirconia crown. (a) Polished sample, some remnants of the polishing paste, narrow voids and smooth scar (black arrows) observed; (b) ground sample, marked major void defects (white arrow) observed; (c) repolished sample, smooth shallow paralleled striation observed.

Figure 12. Scanning electron micrograph images of e.max crown. (a) Polished sample, deep grooves observed (white arrows); (b) ground sample, formation of ridges and deep grinding grooves observed (white arrows); (c) repolished sample, small voids (white arrows) and direction of polishing (black arrow) observed.

important step for accurate centralization of the tooth in the epoxy blocks²⁴. A constant seating force by the fingertip of a single operator was applied before curing to simulate the clinical cementation steps carried out by operators in clinical practice^{25,26}.

The polishing procedures with dental laboratory polishing kits were chosen to simulate the surface conditions after milling. In the current study, samples were roughened with a fine

diamond instrument, which ensures more uniform grind on the surface²⁷. The same operator with a light pressure was used throughout the study to polish all samples in order to standardize the procedures^{11–13}.

The samples were subjected to 600 thermo-cycles between 5°C and 55°C to simulate changes in the intraoral temperature. This thermal-cycling caused additional ageing of the

Figure 13. Scanning electron micrograph images of VITA ENAMIC crown. (a) Polished sample, wide smooth dotted area observed; **(b)** ground sample, formation of rough parallel furrows observed; **(c)** repolished sample, smoothed wide spread pitted area observed.

samples²⁸. The chewing force of the wear test device was 49 Newton with a frequency of ~1–1.6 Hz which simulated average chewing load in the oral cavity and equals the normal occlusal force reported in previous studies^{12,29}.

Roughness values obtained after repolishing procedures were within the clinically acceptable value as reported by previous studies^{12,30}. It could be assumed that the tested ceramic repolished surfaces produced only minimal wear to the opposing

enamel (neglected wear). This also may indicate the efficiency of the polishing procedures carried out after grinding in smoothing the resulting roughness, which may explain the non-significant difference between the effect of the two surface finishings tested regardless of the characteristic differences of the three ceramic materials tested under chewing simulation. The results of the SEM were in agreement with previous studies^{11,31} as they concluded that finishing procedures might remove some of the defects on the ceramic surface.

When the effect of crown material is considered, the results revealed that the highest surface roughness value was in E.max ceramic crowns (0.267), then VITA ENAMIC ceramic crowns (0.266), while the lowest roughness was recorded for zirconia crown (0.257), but these differences were not significant. Rashid³² previously said that despite the variation in base line crystalline structures between these ceramics, smooth surface can be produced for different ceramics with the same polishing steps. Therefore, the present results were not a surprising result, as the same kits were used in the current study.

Conclusion

- All tested crowns showed surface roughness within acceptable clinical parameters when subjected to a different surface finish and six-month chewing simulation.
- No change in the wear behavior was encountered with the three tested ceramic materials with the applied surface finishing procedures.
- Intraoral polishing procedures could be considered a reliable technique for smoothing of the zirconia, E.max and VITA ENAMIC crowns after occlusal adjustment.

Data availability

Underlying data

Open Science Framework: Wear Assessment of Current Esthetic Crowns Against Human Enamel After Two Finishing

Procedures: In vitro study, <https://doi.org/10.17605/OSF.IO/MYGWD>³³.

This project contains the following underlying data:

- Zip file containing images of digital microscope for each crown, before and after six month chewing simulation.
- Results.xls: raw surface roughness values for each crown and treatment, before and after six month chewing simulation.
- SEM raw, unedited images for those shown in Figure 11–Figure 13.
- 3D topography files for the images shown Figure 8–Figure 10.
- CEREC software images.

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

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Peer review discontinued Peer review at F1000Research is author-driven. Currently no reviewers are being invited. What does this mean?

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Reviewer Report 18 September 2020

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The authors investigated an area of clinical relevance. In general, the study was well designed and straightforward. The reviewer has the following comments that the authors may consider to improve the article:

1. The Authors are suggested to present the data in the results section with emphasis on the statistical analysis, but not the mean values.
2. For the grouping methods, why not add one group of polished-ground crowns as positive control?
3. Please state the rationale of adopting the current chewing cycles and thermocycling.
4. In the Abstract section, it was written "A profilometer was used....", which is controversial to the description in the M&M section.
5. Please add essential description of the polishing systems used in the present study. The reviewer is confused with the polishing systems used in different groups. The authors used "Kenda" kits for all the repolishing? if so, it seems unreasonable.
6. What is the accuracy and detection limit of the USB digital microscope?

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Fixed Prosthodontics, Material Sciences

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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