EFFECT OF SIMULATING TOOTH BRUSHING ON SURFACE CHANGE OF DIFFERENT CERAMIC MATERIALS

Khaled Haggag*, Muhammad Abbas**, Hussein Ramadan*** and Mohamed Fawzy***

ABSTRACT

Objectives: Purpose of the present study was to evaluate the surface roughness of current ceramics before and after tooth brushing abrasion, using simulated tooth brushing wear testing.

Materials and Methods: 40 ceramic samples (Zirconia ceramics, Vita Enamic, Lava Ultimate, & E-max ceramics) were cut from corresponding 4 types of ceramic blocks using microtome, then 40 samples were divided into 4 groups (n=10). Each sample has a fixed dimension about 10 x 10 x 2mm (thickness). The 3-body simulated tooth brushing wear testing was performed using a programmable logic controlled equipment; ROBOTA chewing simulator* integrated with thermo-cyclic protocol, then Surface roughness of each material (Ra) was measured with USB digital surface profile gauge.

Results: Total effect of material; regardless to toothbrush wear simulation cycles, totally there was no-significant (p=0.1379 > 0.05) difference between all materials where (Zr ≥ e.max ≥ V enamic ≥ L ultimate) with their mean values respectively after 24 months (Zr; 0.25898 ±0.0035, e.max; 0.25428 ±0.0029, V enamic; 0.25413 ±0.0049, L ultimate; 0.25403 ±0.0028). Total effect of toothbrush wear simulation cycles; irrespective of material, totally toothbrush wear simulation cycles did not affect roughness significantly (p=0.8281 > 0.05) difference between all materials where (18 m ≥ baseline ≥ 6 m ≥24 m ≥ 12 m).

Conclusions: Brushing of ceramic materials with conventional dentifrices non-significantly increased surface roughness, where results of surface roughness present within the clinically acceptable range, not insult the patient intraorally.

INTRODUCTION

Tooth brushing using different types of tooth pastes is considered the most popular habit carried out by many individuals for improvement of their oral hygiene in several countries. Regardless of different types of brushes either power operated (include: battery-operated oscillating, rechargeable sonic effect brushes, or rechargeable operated oscillating brushes) or manually operated brushes...
have positive effect on stain removal and plaque removal.\(^{(1-3)}\) This cleaning effect of regular tooth brushing may be attributed in different studies to the mechanical effect of the brush itself as well as the mechanical/chemical traits or criteria of tooth paste.\(^{(4,5)}\) Regardless of these advantages of tooth brushing, negative effect of brushing such as dental hypersensitivity and tooth surface erosion and surface wear of some dental restorations may result.\(^{(6-8)}\)

Various all ceramic fixed dental prostheses (metal-free restorations) have introduced in dental market and commonly used nowadays to ameliorate appearance or aesthetic.\(^{(9-11)}\) These materials are extremely several in the clinical employment either in coping and monolithic form, microstructure (polycrystalline ceramics, predominantly glass-based ceramics, resin-based ceramics) and manufacturing technique.\(^{(10,12,13)}\)

Ceramic fixed dental prostheses might suffer from surface roughness after extended usage in patient’s mouth, although their higher mechanical properties and their higher resistance to wear in oral environment,\(^{(14)}\) but sometimes the brushing action might affect surface roughness and jeopardize the aesthetic of these restorations.

Yttrium-stabilized tetragonal zirconia polycrystals (Y-TZP) is one of recently used ceramic materials, it is characterized by its higher resistance to alkalis and acids, good biocompatible material, good wear resistance and mechanical properties.\(^{(14,15)}\) Furthermore, new hybrid ceramic materials (resin-based ceramic, resin-nano ceramics and polymer infiltrated ceramic) have been introduced into dental market and available nowadays for CAD/CAM technology. It combines the mechanical properties of both polymers and ceramics.\(^{(16,17)}\)

Until now, there are inadequate researches and few studies examining and interesting with wear behavior of different ceramic restorations such as veneered zirconia, full contoured zirconia, and hybrid ceramics,\(^{(8-20)}\) moreover there are also insufficient researches and studies concerning with effect of tooth brushing on a surface change of different cemented ceramic restorations.

Purpose of the present study was to evaluate the surface roughness of current ceramics before and after toothbrush abrasion. The null hypothesis was that tooth brushing does not affect the surface roughness and wear of dental restorations.

**MATERIALS AND METHODS**

40 ceramic samples (Zirconia ceramics, Vita Enamic, Lava Ultimate, & E-max ceramics) were cut from corresponding 4 types of ceramic blocks using micro saw (Isomat 4000 micro saw, Buehler, USA), then 40 samples were divided into 4 groups (n=10). Each sample has a fixed dimension about 10 x 10 x (2mm thickness).

**TABLE (1) Materials used in the study names, types and manufacturers**

<table>
<thead>
<tr>
<th>Brand</th>
<th>Material type</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prettau</td>
<td>Translucent monolithic zirconia</td>
<td>Zirkonzahn, Taufers, Italy</td>
</tr>
<tr>
<td>IPS E-max CAD</td>
<td>Lithium Disilicate ceramics</td>
<td>Ivoclar, Liechtenstein, Germany</td>
</tr>
<tr>
<td>Vita Enamic</td>
<td>Glass ceramic in a resin interpenetrating matrix</td>
<td>Vita, VITA Zahnfabrik, Germany</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>Resin nano-ceramic</td>
<td>3M EPSE, N525442 Deutschland, Germany</td>
</tr>
</tbody>
</table>

**Tooth brush wear simulation test**

The 3-body simulated tooth brushing wear testing was performed using a programmable logic controlled equipment; the newly developed four chambers multimodal Dual-axis ROBOTA chewing simulator* integrated with thermo-cyclic protocol operated on servo-motor (Model ACH-09075DC-T, AD-Tech Technology Co., Ltd., Germany) (fig.1A).
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The device allows simulation of the vertical and horizontal movements simultaneously. Each of the chambers consists of an upper Jackob’s chuck as tooth brush antagonist holder that can be tightened with a screw and a lower plastic sample holder in which the sample can be embedded (fig. 1 B1). The ceramic samples were embedded in Teflon housing in the lower sample holder (fig. 1 B2). A weight of 300 g, which is comparable to 3 N of brushing force was exerted according to previous studies (table: 1).

TABLE (2) Wear test parameters used in the study

<table>
<thead>
<tr>
<th>Vertical movement: 1 mm</th>
<th>Horizontal movement: 3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rising speed: 90 mm/s</td>
<td>Forward speed: 90 mm/s</td>
</tr>
<tr>
<td>Descending speed: 40 mm/s</td>
<td>Backward speed: 40 mm/s</td>
</tr>
<tr>
<td>Cycle frequency 1.6 Hz</td>
<td>Weight per sample: from 300 g</td>
</tr>
<tr>
<td>Torque: 2.4 N.m</td>
<td></td>
</tr>
</tbody>
</table>

Simulated tooth brushing was performed using toothbrush heads with soft nylon bristles (Oral B Indicator; Procter & Gamble Nanning, Kwangsi, China) under 300-gr load. The toothbrush heads were changed after every 5,000 strokes. For each sample, 20,000 strokes were performed at a frequency of 180 strokes/min. A double pass of the toothbrush head was considered a stroke. Assuming that 10,000 cycles represented approximately 1 year of tooth brushing, (21) the cycles were divided into different aging simulations of 6 months (5,000 strokes); 12 months (10000 strokes), 18 months (15000 strokes) and 24 months (20000 strokes).

**Abrasive medium:**

Slurry was prepared by mixing a 2:1 ratio of deionized water and a sodium fluoride 0.22% w/w (1000 ppm F) particle dentifrice (Colgate maxfresh; Colgate-Palmolive, Bangna-Trad, Amphur Muang, Chonburi, Thailand) immediately before testing. After testing, the samples were cleaned with running water followed by an ultrasonic bath for 10 min.

**Wear evaluation by roughness measurement**

Surface roughness (Ra) was measured with USB digital surface profile gauge (fig. 2), cut-off -0.25 mm (Elcometer 224/2, Elcometer Instruments, Great Britain) and data were recorded using computer software (Elcomaster 2, Elcometer Instruments). The surface profile needle (radius of 2.5 µm) was positioned perpendicular over each test sample performing five readings in different locations of the sample surface. After the five readings, the mean surface roughness values were obtained.

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![Figure (1) ROBOTA chewing simulator* integrated with thermo-cyclic protocol](image)
To achieve a better reflection on the surface of the samples and qualitative analysis of the wear areas, samples were examined and photographed using the same USB Digital microscope (Scope Capture Digital Microscope, Guangdong, China) at fixed magnification of X 90. Digital microscope images were cropped to 350 x 400 pixels using Microsoft office picture manager to specify/standardize area of roughness measurement. This area was chosen on the basis of the dimension of the typical bacteria expected to adhere to restoration surface in vivo. Subsequently, a 3D image of the surface profile of the samples was created using a digital image analysis system WSxM software (Ver 5 develop 4.1, Nanotec; Electronica, SL). The unworn surface served as a reference. With this method, a 3-dimensional geometry of the worn surface was generated.

**Statistical analysis**

Data analysis was performed in several steps. Initially, descriptive statistics for each group results. One-way ANOVA followed by pair-wise Tukey’s post-hoc tests were performed to detect significance between groups at each wear simulation cycles and between cycles within each material. Two-way ANOVA was done to show effect of each variable (material and wear simulation cycles). Statistical analysis was performed using Graph-Pad InStat statistics software for Windows (www.graphpad.com). P values ≤0.05 are statistically significant in all tests.

**RESULTS**

**Roughness changes**

The mean values and standard deviations (SD) for wear measured by roughness average (Ra measured in µm) recorded on all materials before and after each wear simulation cycles summarized in (table 2) and graphically represented in the column chart (figure 3) and (figure 4).

**Baseline;** before tooth brushing, there was no-significant (p=0.1599 > 0.05) difference between all materials where (e.max ≥ Venamic ≥ Zr ≥ L ultimate).

**After 6 months** simulated tooth brushing, there was no-significant (p=0.1006 > 0.05) difference between all materials where (e.max ≥ L ultimate ≥ Zr ≥ Venamic).

**After 12 months** simulated tooth brushing, there was no-significant (p=0.9161 > 0.05) difference between all materials where (L ultimate ≥ Zr ≥ e.max ≥ Venamic).

**After 18 months** simulated tooth brushing, there was significant (p=0.002 < 0.05) difference between all materials where (Zr ≥ Venamic ≥ L ultimate ≥ e.max).

**After 24 months** simulated tooth brushing, there was no-significant (p=0.1556 > 0.05) difference between all materials where (Zr ≥ e.max ≥ Venamic ≥ L ultimate).

With Zr material group; there was no-significant (p=0.0788 > 0.05) difference between different simulated tooth brushing cycles where (18 m ≥ 24 m ≥ 12m ≥ baseline ≥ 6 m).

With Venamic material group; there was no-significant (p=0.3344 > 0.05) difference between
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(675)

different simulated tooth brushing cycles where
\(18 \text{ m} \geq \text{ baseline} \geq 12 \text{ m} \geq 6 \text{ m} \geq 24 \text{ m}\)

With **L ultimate material** group; there was non-significant (\(p=0.3108 > 0.05\)) difference between different simulated tooth brushing cycles where
\(18 \text{ m} \geq 12 \text{ m} \geq 6 \text{ m} \geq 24 \text{ m} \geq \text{baseline}\)

With **e.max material** group; there was significant (\(p=0.008 < 0.05\)) difference between different simulated tooth brushing cycles where
\(6 \text{ m} \geq \text{ baseline} \geq 12 \text{ m} \geq 24 \text{ m} \geq 18 \text{ m}\)

**Total effect of material;** regardless to toothbrush wear simulation cycles, totally there was nonsignificant (\(p=0.1379 > 0.05\)) difference between all materials where \(Zr \geq e.max \geq V enamic \geq L \text{ ultimate}\).

**Total effect of toothbrush wear simulation cycles;** irrespective of **material**, totally toothbrush wear simulation cycles did not affect roughness significantly (\(p=0.8281 > 0.05\)) difference between all materials where \(18 \text{ m} \geq \text{ baseline} \geq 6 \text{ m} \geq 24 \text{ m} \geq 12 \text{ m}\).

**TABLE (2)** Wear results (Mean values ±SD) by roughness change for experimental material groups before and after each toothbrush wear simulation cycles

<table>
<thead>
<tr>
<th>Variables</th>
<th>Experimental material groups</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zirconia</td>
<td>V enamic</td>
</tr>
<tr>
<td><strong>Baseline</strong></td>
<td>0.25533 ±0.0034</td>
<td>0.25652 ±0.0022</td>
</tr>
<tr>
<td><strong>6 months</strong></td>
<td>0.2545 ±0.0033</td>
<td>0.25438 ±0.0012</td>
</tr>
<tr>
<td><strong>12 months</strong></td>
<td>0.25562 ±0.0028</td>
<td>0.25473 ±0.0022</td>
</tr>
<tr>
<td><strong>18 months</strong></td>
<td>0.2590 ±0.0015</td>
<td>0.25692 ±0.0011</td>
</tr>
<tr>
<td><strong>24 months</strong></td>
<td>0.25898 ±0.0035</td>
<td>0.25413 ±0.0049</td>
</tr>
<tr>
<td><strong>ANOVA</strong></td>
<td></td>
<td>0.0788 ns</td>
</tr>
</tbody>
</table>

*; significant (\(p<0.05\))  ns; non-significant (\(p>0.05\))

**Fig. (3)** Column chart of the mean values of surface roughness of ceramic samples
DISCUSSION

Surface roughness of dental restorations may result from long term dentifrices usage that might cause several problems such as surface stains, attraction of dental plaque & wear of occluding teeth. Various kinds of ceramic blocks are available in the market recently, most of these materials exhibited higher hardness and higher resistant to both wear and staining & their low susceptibility to fracture.\textsuperscript{(25, 26)} Little data is available about the effect of tooth brushing/dentifrices combination on the surface properties of current dental materials, including ceramics. Some studies were performed on ceramic blocks reported higher failure of restorations fabricated from these blocks and attributed this failure to their surface roughness and increased wear pattern.\textsuperscript{(26, 27)}

Brushing effects on the surface properties of dental materials were evaluated in the study using simulated tooth brushing abrasion test, which is
considered a typical model in the literature. The load of brushing application in the present study was (300 g) that is near to the range of clinical application and consistent with other studies (200 g to 350 g).

The discussion regarding how much Ra values that considered clinically acceptable are controversial opinions in the literature, however, Ra values after brushing with conventional dentifrice in the present study is agreed with another study & were clinically acceptable where it presents within the Ra range from 0.25 um to 0.5um, which is undetectable clinically by the tongue. Because surface roughness on the order of 0.3 mm can be detected clinically by the tip of the patient’s tongue and might cause discomfort for the patient. The Ra values obtained in this study disagree and differ from the values obtained in other studies in which the Ra values ranged from 0.18 to 0.98 um.

In the present study different kinds of ceramic blocks (Zirconia, e.max, Vita enamic & Lava ultimate) were used to include different classification of ceramics as possible. Roughness values (Ra) is different in all kinds of ceramics tested in the study resulting different wear pattern of each type of ceramics, that is closely influenced by microstructure and physical characteristics of ceramic type, specifically hardness, flexural strength and fracture toughness.

Another influencing factor is the abrasiveness of the slurry formed by the dentifrice during brushing & physical characteristics of the abrasive particles, namely shape, size, acuteness, and hardness. Thus, the abrasive type, the chemical reaction between detergents and abrasives, the pH, and the rheologic properties of the final slurry can change surfaces in different ways. Another probable explanation is ceramic materials with small grain size in matrix such as zirconia enable it to be more resistant to wear action than e.max & other types of ceramics that have more large grain size particles (.04 um of zirconia & 2 um of lithium disilicated tested specimens).

Even with the higher hardness zirconia blocks, the results found in this study showed that all zirconia specimens brushed with dentifrice subjected to more roughness and surface topography that is agree with some investigators. That is may be attributed to its low temperature degradation that occurs in moist environments. Another explanation is probably related to the influence of pH variations and the concentration of fluoride on the zirconia’s susceptibility to degradation. While a neutral pH does not change the microstructural appearance of zirconia surfaces, but alkaline and acid pHs may corrode the surface of the material. Low temperature degradation is responsible for grain push-out, increased surface roughening & wear. On the other hand different results, such as unchanged roughness after brushing with conventional dentifrice and roughened ceramic surfaces after brushing with whitening dentifrice, have been published in other studies.

Although, homogenous and smooth wear patterns can be seen for lithium disilicate (e.max blocks) may be considerably attributed to smaller grain size of lithium disilicate crystals when compared with leucite crystals of glass based ceramics. The null hypotheses of the study is partially rejected because surface roughness and wear of dental restorations occurred but with no significant differences.

One limitation of this study is the only single polishing protocol using diamond instrument for all ceramic types. Diamond particle sizes and their distribution may affect polishing surfaces of each type of ceramic. More over one type of tooth paste used in the present study. During intraoral tooth brushing, tooth paste is diluted & buffered by action of salivary flow, their ions & protein content may diminish roughening action of brushing, it may be performed in other future studies, also several types of abrasives and tooth paste can be tested in the future.
Conclusion; Brushing of ceramic materials with conventional dentifrices non-significantly increased surface roughness, where results of surface roughness present within the clinically acceptable range, not insult the patient intraorally.

CONCLUSIONS

1- Brushing of ceramic materials used in this study (Prettau, Vita enamic, Lava ultimate, and IPS e max CAD) with conventional dentifrices not significantly increase surface roughness.

2- Surface roughness increased consequently from zirconia ≥ e max CAD ≥ Vita enamic ≥ lava ultimate.

3- Surface roughness after 18 months was prominent than other times

4- Surface roughness of all used materials was within the clinically acceptable range.

REFERENCES


