THE EFFICACY OF UNIVERSAL CERAMIC POLISHING KIT ON THE SURFACE ROUGHNESS OF VARIOUS CERAMIC TYPES

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เอกลักษณ์ ภู่แสนธนาสาร : ประสิทธิผลของหัวขัดเซรามิกชนิดยูนิเวอร์ซัลต่อความหยาบผิวของเซรามิกชนิดต่างๆ. (THE EFFICACY OF UNIVERSAL CERAMIC POLISHING KIT ON THE SURFACE ROUGHNESS OF VARIOUS CERAMIC TYPES) อ.ที่ปรึกษาหลัก : ผศ. ทพญ. ดร.ปรารมภ์ ซาลิมี, อ.ที่ปรึกษาร่วม : ผศ. ทพญ. ดร.ณฤดี ลิ้มปวงทิพย์

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของความหยาบพื้นผิวของเซรามิกชนิดต่าง ๆ ภายหลังขัดด้วยหัวขัดเซรามิกชนิดยูนิเวอร์ซัล มีวิธีการโดยนำเซรามิก 3 ชนิด ได้แก่ไอพีเอส อีแมกซ์แคด เซลทรา ดูโอ และไวต้า วายแซด เอกซ์ที จำนวน 8 ชิ้นงานต่อกลุ่ม ขึ้นรูปชิ้นงานขนาด 5 x 7 x 4 มิลลิเมตร โดยนำชิ้นงานไปฝังติดกับเรซินใสในท่อพีวีซีขนาดเส้นผ่านศูนย์กลาง 14 มิลลิเมตร ชิ้นงานทุกชิ้นจะถูกกรอผิวหน้าด้วยหัวกรอกากเพชรละเอียดเป็นเวลา 15 วินาที ตามด้วยการขัดด้วยหัวขัดชนิดหยาบและละเอียดเป็นเวลาอย่างละ 60 วินาที โดยทำการวัดค่าความหยาบผิวทุก 15 วินาที ในการขัดแต่ละขั้นตอน ค่าความหยาบพื้นผิวจะถูกบันทึกโดยใช้เครื่องวัดความหยาบพื้นผิวชนิดไม่สัมผัสที่กำลังขยาย 50 เท่า โดยพื้นที่ที่ทำการวัดจะตั้งฉากกับทิศทางที่ขัด และวัดค่าความหยาบพื้นผิว 5 จุดในแต่ละชิ้นงาน มีการใช้ภาพถ่ายกล้องจุลทรรศน์อิเล็กตรอนชนิดส่องกราดบันทึกพื้นผิวของชิ้นงานเมื่อผ่านการขัดแต่ละขั้นตอน ใช้แรงในการขัด 1 นิวตัน จากสถิติการวิเคราะห์ความแปรปรวนแบบวัดซ้ำ ผลการศึกษาพบว่าเซรามิกทุกชนิดที่ผ่านการขัดด้วยหัวขัดหยาบ 15 วินาทีจะมีค่าความหยาบพื้นผิวลดลงอย่างมีนัยสำคัญเมื่อทำการเปรียบเทียบกับขั้นตอนการกรอด้วยหัวกรอกากเพชร โดยภายหลังจากที่เสร็จสิ้นกระบวนการขัดแล้วพบว่าชิ้นงานของไวต้า วายแซด เอกซ์ที มีความหยาบพื้นผิวที่ต่ำที่สุดตามด้วย เซลทรา ดูโอ และ ไอพีเอส อีแมกซ์แคด ตามลำดับ จากผลลัพธ์ของค่าความแตกต่างระหว่างความหยาบพื้นผิวเฉลี่ยก่อนและหลังขัด พบว่าการขัดด้วยหัวขัดหยาบและละเอียดจะมีประสิทธิภาพใน ไวต้า วายแซด เอกซ์ที มากกว่า เซลทรา ดูโอ และ ไอพีเอส อีแมกซ์แคด ตามลำดับ

สาขาวิชา	ทันตกรรมประดิษฐ์	ลายมือชื่อนิสิต ....
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The objective of this vitro study was to determine the effect of polishing performance of a universal ceramic polishing kit on the surface roughness of various ceramics. The ceramic specimen size 5 x 7 x 4 mm of lithium disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent, Liechtenstein), translucent zirconia (VITA YZ XT, VITA Zahnfabrik, Germany) and zirconia-reinforced lithium silicate (Celtra Duo, Dentsply Sirona, United States) (n=8) were fixed with clear resin in PVC block, 14 mm in diameter. The specimens were ground with fine diamond bur for 15 seconds to simulate clinical gross contouring.The two-step polishing process started with coarse polishing (EVE Diacera H2DCmf) for 60 seconds and followed by fine polishing (EVE Diacera H2DC) for 60 seconds. The surface roughness (Ra) of specimens were measured after grinding process and every 15 seconds of the polishing process. The Ra measurement was analyzed using a non-contact optical profilometer (Alicona infinitefocusSL, Graz, Austria) at 50X magnification for quantitative measurements. The area of measurement was perpendicular to the polished direction and 5 areas were measured in each specimen. SEM micrographs were used for qualitative measurements of the surface. The force in the polishing process was controlled to 1 N by a customed-made device. From one-way repeated measures ANOVA, the result showed that when compared with the grinding step, the Ra of all ceramic types was significantly lower after being polished by coarse polisher at 15 seconds. After all polishing process, VITA YZ XT exhibited the lowest Ra followed by Celtra Duo and IPS e.max CAD, respectively. From one-way ANOVA, the results of Δ Mean Ra showed that coarse and fine polishing bur was more effective in VITA YZ XT than Celtra Duo and IPS e.max CAD, respectively.

Field of Study:	Prosthodontics	Student's Signature ....
Academic Year:	2021	Advisor's Signature ....
		Co-advisor's Signature ....

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Ekaluck Poosanthanasarn

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CHAPTER I
INTRODUCTION

Nowadays, esthetic becomes an important factor for dental prostheses. Dental ceramic plays an important role in making fixed prostheses due to their natural appearance like natural teeth. Dental ceramic products are inorganic structures that have nonmetallic, low thermal, and low electrical conductivity properties.[1, 2]

There are two major groups in dental ceramic that have different compositions, characteristics, and indications: glass-matrix ceramics and polycrystalline ceramics groups. In glass-matrix ceramics groups such as leucite-based and lithium disilicate-based, provide excellent in esthetic and translucence.[3] Polycrystalline ceramics groups, such as alumina and stabilized zirconia, provide excellent mechanical properties but the disadvantage is opacity. Moreover, zirconia-reinforced lithium silicate or ZLS has been introduced which compose of zirconium dioxide diffused in the glass matrix phase to enhance mechanical properties and enhance great esthetic due to the presence of a glass matrix phase.[4, 5]

Although restorations from the laboratory process are well-polished, an occlusal and proximal adjustment in the clinical situation is often required. Grinding and polishing of ceramic are usually performed to provide proper contact, contour, margin, and smooth surfaces. After grinding the restorations to a proper contour, the outcome is the rough surface of the restorations due to the coarse abrasive particles in a device which cause the opposing and adjacent teeth to wear.[6] Surface roughness is an important property of restorations that affect bacterial colonization, plaque accumulation, secondary caries, and wear of the antagonist.[7] Thus, polishing after grinding the restoration is necessary to reduce the surface roughness and provide smooth, shiny, and gloss restorations. The effectiveness of polishing devices depends on various factors such as polishing speed, polishing forces, mechanical properties, and structure of the substrate being polished.[8] Since many types of all-ceramic restorations have been widely used, the ceramic polishing kits are created for their own ceramic groups. Porcelain polishing kits consist of silica-carbide as main abrasive, while zirconia polishing kits consist of diamond particles as main abrasive due to its high surface hardness. Because of the variety of ceramic polishing kits, dentists seem have to buy each kit separately. Lately, manufacturers have provided a universal ceramic polishing kit which can polish all types of ceramic restorations. However, few studies have investigated the surface roughness of various ceramics after polishing with a universal ceramic polishing kit with the same protocol. For such reason, the aim of this study was to evaluate the surface roughness of various ceramic types after polishing with a universal ceramic polishing kit.

Research question

1. Would polishing duration affect the surface roughness of each ceramic type after polishing with a universal ceramic polishing kit?

2. Would various ceramic types affect the surface roughness after polishing with a universal ceramic polishing kit?

Objective

To determine the effect of the polishing steps and ceramic types on the surface roughness of various ceramic types after being polished with a universal ceramic polishing kit.

Hypothesis

Hypothesis 1

Null hypothesis

H_0: There is no difference in surface roughness of each ceramic type after polishing with a universal ceramic polishing kit with different polishing duration.

Alternative hypothesis

H_1: There is the difference in surface roughness of each ceramic type after polishing with a universal ceramic polishing kit with different polishing duration.

Hypothesis 2

Null hypothesis

H_0: There is no difference in surface roughness of various ceramics after polishing with a universal ceramic polishing kit.

Alternative hypothesis

H_1: There is the difference in surface roughness of various ceramics after polishing with a universal ceramic polishing kit.

Keywords

1. Lithium disilicate glass ceramic
2. Polishing
3. Surface roughness
4. Zirconia
5. Zirconia-reinforced lithium silicate

Type of research

Laboratory experimental research

CHAPTER II
LITERATURE REVIEW

Ceramics in dentistry

All ceramic materials have become widely used due to their biocompatibility, color stability, chemical durability, wear-resistance, and esthetics. Moreover, they provide good mechanical, physical, and thermal properties.(1) Due to the problems of layering porcelain chipping or delamination in multilayered prostheses, monolithic prostheses have become widely used for all-ceramic restorations.(9) There are two groups of all-ceramic systems which are glass-matrix ceramics and polycrystalline ceramics which depend on the structure of the crystalline phase, fabrication method, and the amount of glass phase.(4, 5)

In the glass-matrix ceramics group which composes of at least one crystalline phase and glassy matrix phase, lithium disilicate-based glass-ceramics exhibit good esthetic and mechanical properties when compare with mica-based or leucite-based.(3, 10, 11) Lithium disilicate glass-ceramics can be used as inlays, onlays, veneers and full coverage crowns in both anterior and posterior teeth due to their strength.(12) Lithium disilicate ($Li_2Si_2O_5$) was formed by the crystallization process of lithium metasilicate (Li_2SiO_3) which reacts with glassy phase (SiO_2) under proper sintering temperature.(9) The crystalline phase has a needle-like shape with an interlocking network in a glass matrix which can stop crack propagation.(3, 12, 13)

In lithium disilicate glass-ceramics, IPS e.max (Ivoclar Vivadent, Schaan, Liechtenstein) are widely used materials which can be divided into two forms: IPS e.max Press and IPS e.max CAD. IPS e.max Press was released in 2001, which is a castable ingot that uses a lost-wax technique to create the restoration. While in 2006, IPS e.max CAD has been introduced to process with CAD/CAM technology. IPS e.max CAD block is prepared in a partially-crystallize state which the crystalline phase is lithium metasilicate embedded in a glassy phase. This state has the advantages in that the block is easy to be milled and reduces the wear of the milling machine tool. This milling process is known as “soft milling”. After milling IPS e.max CAD to the desired shape of restorations, the post-sintering process is continued to form a fully-crystallize state in which lithium disilicate is formed. Due to less time-consuming process of CAD-CAM workflow, restoration from IPS e.max CAD block can also be fabricated in a one-visit appointment and has been widely used nowadays.[3, 12, 14]

In the polycrystalline group, stabilized zirconia is a widely used material due to excellent mechanical properties with an acceptable appearance.[15, 16] Zirconia is compatible with human tissue and susceptible to low plaque accumulation.[17, 18] Zirconia is polymorphic material that can present in three phases; monoclinic, tetragonal, and cubic depend on the temperature. Monoclinic phase forms when the temperature is between room temperature and 1167°C which provides lower mechanical properties than the others. Tetragonal phase forms when the temperature is between 1167°C and 2367°C and provides excellent in mechanical properties. Cubic phase forms when the temperature is more than 2367°C and provides average mechanical properties.[1] Due to the weak mechanical properties in the monoclinic phase, conventional dental zirconia usually incorporated with 3mol% of yttria to form partially stabilized tetragonal zirconia polycrystal or 3Y-TZP. 3Y-TZP provides excellent mechanical properties and high fracture toughness due to transformation toughening which is a process that stops crack propagation. This process occurs when tensile stress is applied to zirconia which will locally change the tetragonal form of zirconia into the monoclinic form which results in volume expansion for 3 - 4% and then provide compressive stress around the crack tips.[1, 19,

20) The disadvantage of 3Y-TZP is opacity due to the high contents of alumina and anisotropic of tetragonal phase which makes light scattering.[21-23] To solve this problem, 3Y-TZP usually use with layering-porcelain to improve esthetics but it can cause porcelain-chipping or delamination of the restoration.[24] So, monolithic zirconia has been introduced to solve the zirconia substructure with a layering-porcelain problem. Monolithic zirconia is widely used in many platforms such as crowns, bridges, and implant abutments.[1]

To solve the problem of low translucency of 3Y-TZP which composes of a tetragonal phase of more than 90%, the yttria content has been increased to provide a more cubic phase.[23] Cubic phase has an isotropic property which decreases light scattering and provides excellent translucency. Moreover, the cubic phase can against low-temperature degradation (LTD) which makes it stable when exposes to the oral cavity. Increasing 3mol% of yttria to 5mol% will produce 5Y-ZP which compose of 50% of the cubic phase while 8mol% of yttria will produce a completely cubic phase which has the most excellent translucency and optical properties.[25] Although the cubic phase has excellent in esthetic this phase is brittle and has weaker mechanical properties than the tetragonal phase.[26] Thus, increasing yttria compositions in zirconia restorations can provide translucency but decrease in strength.

Due to the excellent esthetic in lithium disilicate-based glass ceramics and great mechanical properties of monolithic zirconia restorations as mentioned above, the zirconia-reinforced lithium silicate or ZLS has been introduced. Zirconia-reinforced lithium silicate have lithium silicate as their major components in the crystalline phase and add zirconium dioxide (approximately 10% by weight) into the glass matrix.[27] Lithium silicate crystals in ZLS shown smaller particles size 4-6 times than lithium disilicate crystals in lithium disilicate-based glass ceramics. These smaller lithium silicate crystals provide high polishability, while zirconia fillers strengthen the restorations by crack interruption.[9, 28] Thus, zirconia-reinforced lithium silicate gain both benefit in mechanical properties from zirconium dioxide and esthetic in glass-ceramic.[3]

Process for grinding and polishing

Wear is the process of material removal from the surface of a solid body as a result of a mechanical process which causes surface defects, flaws, and roughness. Wear can be classified into abrasive, adhesive, erosion, fretting and chemical types.[29] Grinding and polishing with dental polishing kits usually cause abrasive wear. Abrasive wear is the process in which abrasive particles cause micro cuttings, microfracture, fatigue, and detachment of grain as shown in figure 1. Scratches, grooves, and ripples are the phenomena caused by abrasive wear.[30]

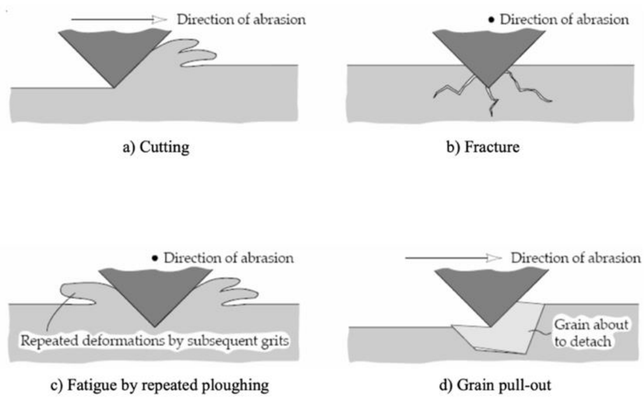

Figure 1 Mechanism of abrasive wear[30]

Abrasive wear can be divided into two types which are two-body abrasion and three-body abrasion. Two-body abrasion occurs when there are two rubbing parts involved in the process without any particles trapped between each part such as dental polishing kits in which abrasive particles solidly fixed to the device. Three-body abrasion occurs when there are free particles between each rubbing surface such as polishing pastes. Figure 2 shows two types of abrasive wear.[8] Two-body abrasion provides ten times wear faster than three-body abrasion.[30]

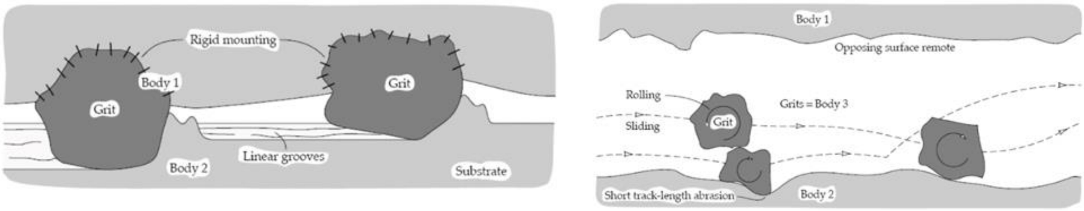

Figure 2 Two types of abrasive wear[30]

Grinding and polishing procedures are important for both direct and indirect restorations to produce good esthetic and lifelong restorations.[1] These procedures are important steps in dentistry because they decrease surface roughness which prevents crack propagation and plaque accumulation, removes an excessive part and refine margins of restoration, produces great esthetic and optical properties, makes proper contact, contour and occlusion, and provide smooth surfaces in all surfaces of restorations which reduce wear on opposing and adjacent teeth.[8] Grinding refers to the process of gross contouring to provide the correct shape and dimensional precision of restorations. Coarse abrasive grits bonded into the device were sunk into a material to perform grinding. These scattering grits have a variety of shapes and can deteriorate, chip, and fall off during grinding. Components of grinding devices such as types of abrasive, grain size, grain concentration, coating, and bond can affect surface integrity. Moreover, characteristics of the material such as structure, grain size, and chemical composition can affect surface integrity too. Coarse particles on grinding devices and large grain sizes of material usually provide a rough surface. The process of grinding was shown in figure 3. Polishing refers to the process of removing surface scratches or defects as result of the grinding process and making gloss and shiny restorations. Polishing burs compose of finer abrasives than the grinding bur and perform only the top layer of the surface. Fine abrasive grits sustained in polisher to provide micro-cutting edges on the material. Figure 4 shows the polishing process.[31]

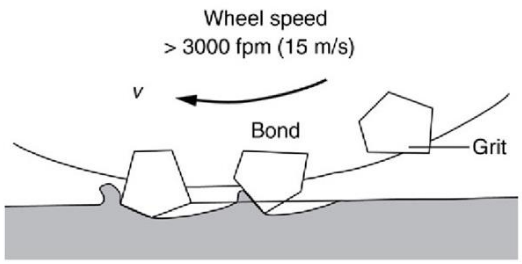

Figure 3 Grinding process[31]

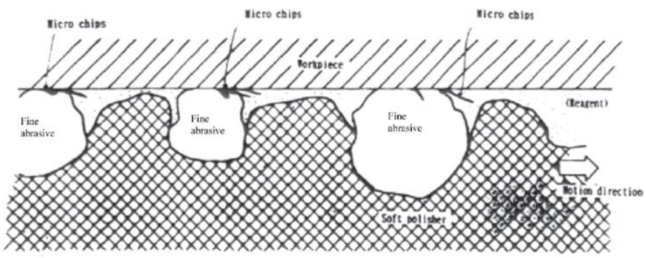

Figure 4 Polishing process[31]

Effectiveness of polishing procedures depends on many factors such as properties and structure of materials to be polished, the hardness between substrate and device, compositions and size of abrasive particles in a device, polishing forces, polishing duration, polishing speed, lubrication, etc.[8] Polishing ceramic specimens with higher speed than recommendations by manufacturer produce smoother surface than lower speed but decrease the strength of restorations due to crack development.[32] Heintze et al. (2019) stated that polishing forces varies among each dentist and the same dentist with different time. Male dentists have higher polishing forces than female dentists with statistically significant. About 75% of polishing time, the polishing forces applied less than 2 N.[33] Siegel et al. (1999) stated that most dentists applied forces about 100 grams at the bur tip.[34] The shape of polishing instruments affects the polishing forces.[33] Polishing with the smaller abrasive particle sizes produces lower surface roughness values than bigger particle sizes.[35]

Grinding and polishing burs

There are various types of ceramic polishing kits which commercially available. Porcelain polishing kits such as Ceramiste and Ceramaster. Lithium disilicate polishing kit such as OptraFine and Meisinger Luster for lithium disilicate. Zirconia polishing kit such as Meisinger Luster for zirconia and Komet ZR polishing kit. Due to the various types of ceramic polishing kits, universal ceramic polishing kits have been introduced to polish various types of ceramics such as EVE DIACERA and Jiffy Universal. These polishing kits vary among abrasive particle size, particle type, particle shape, density, and types of a binder.[36] Contents of each polishing kit was shown in Table 1.

Sarikaya et al. (2010) stated that polishing kits and disks can produce more smooth surface than polishing pastes alone or in combination with disks.[37] Diamond-impregnated abrasive polishing kits have more effective in reducing the surface roughness than silica carbide-impregnated abrasive polishing kits due to the hardness properties. Moreover, zirconia polishing kits have more effective than porcelain polishing kits due to the proper density and size of the diamond particles in the kits.[38, 39] Scherrer et al. (2020) found that there is no statistically difference in surface roughness between lithium disilicate and zirconia crowns after polishing with two-steps or three-steps polishing kits.[40] Vichi et al. (2018) stated that VITA Suprinity provides higher polishability than IPS e.max CAD due to the microstructure of crystalline phase and zirconium dioxide dissolved in the glass phase. However, the aforementioned research used different polishing kits on each material.[41] Both two-steps and three-steps polishing kits significantly reduce surface roughness on zirconia specimens.[42]

Surface roughness

Occlusal adjustment and recontouring restorations in clinical situations of direct and indirect restorations are essential steps. Occlusal grinding in ceramic restorations always produce rough surfaces which continue to form micro-cracks.[43, 44] Surface roughness is an important property of restorations. Surface roughness affects the translucency of restorations. Awad et al. (2015) stated that in ceramic restorations, a rough surface provides less translucency value than a smooth surface.[45] Fracture toughness is also affected by surface roughness because in rough surface presents superficial cracks which perform crack propagation.[46] Although surface roughness does not correlate to flexural strength but relates to bacterial colonization, plaque accumulation, secondary caries, wear of the antagonist, periodontal problems, discoloration, esthetics, and material properties.[43, 47-51]

In ceramic restorations, stress concentration points occur at rough surfaces.[1] Polishing and glazing are two options of surface finishing in ceramics prostheses to reduce surface roughness.[52] Appropriate polishing technique can provide a value of surface roughness similar to glazing technique.[48, 53] Moreover, some authors stated that polishing glass-ceramic restorations provide lower surface roughness and smoother than the glazed surface.[54-56] Similarly, polishing zirconia restorations can reduce surface roughness better than glazing.[57] Glazed zirconia restorations tend to wear the opposing antagonists more than properly polished zirconia.[57] Glazed zirconia restorations have a thin layer of 30-50 micron which after being opposed to antagonists, this layer gradually disintegrates from restorations. Thus the rough surface of zirconia restorations are exposed to antagonists.[58]

Normally, enamel to enamel contact has a mean surface roughness of about 0.64 micron.[59] Jones et al. (2004) stated that patients cannot be able to sense the roughness of the restorations if the mean surface roughness less than 0.5 micron.[60] Quirynen et al. (1996) stated that the surface roughness threshold which susceptible to plaque accumulation is about 0.2 micron.[61, 62]

Measurement of surface roughness

Measurement of surface roughness in dental material usually uses arithmetic average roughness or Ra parameter. Ra parameter refers to the arithmetic mean of the absolute values of vertical deviation from the mean line through the profile within the measuring length. The formula to calculate the Ra parameter is shown in figure 5, where l is a sampling length and f(x) is a vertical deviation.[63]

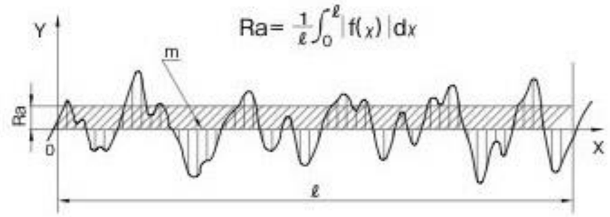

Figure 5 The formula to calculate arithmetic average roughness or Ra parameter[64]

The lower Ra value can prefer to the smoother surface.[65] Measurements of surface roughness can be divided into two types : 1) contact type and 2) non-contact type

1) Contact type

This type of measurement has the instrument contacts to the surface of material such as a mechanical profilometer. The principle of contact type is electronic amplification. The tip of stylus contacts the surface of a material with a small force and the vertical movement of the stylus is measured then transforms into an electronic signal by a transducer. The signal was amplified and displays the surface roughness in the surface profile. Contact type sensitive to surface height. The disadvantage of this type is the sharp or inappropriate size of the stylus tip can damage the surface of the material, especially with the soft surface material.[66] Moreover, in the area of deep scratches or narrow pit on the surface of a specimen, the tip of the stylus can fails to detect the roughness.[40, 67]

2) Non-contact type

This type of measurement doesn't contact the surface of a material. It uses optical or microscopy imaging methods to measure the surface roughness such as an optical profilometer. The non-contact type uses a light beam instead of the stylus tip to create the surface profile. The advantage of this type is non-destructive to the surface. Moreover, the non-contact type uses less time than the contact type. The limitation of this type is artifacts. Non-contact type sensitives to surface qualities such as optical constants, an inclination of surface, fine surface features that cause diffraction, and deep valleys.[66]

Although the profilometer can measure the quantitative surface roughness in the Ra parameter but still lack the qualitative of the material surface. Whitehead et al. (1995) stated that Ra is a true amplitude parameter but doesn't provide information about the profile shape and morphology of the material.[68] The different materials that present the nearby Ra value can present different topographic patterns.[35] Scanning electron microscope (SEM) can provide the qualitative of surface material such as surface textures, microscopic and macroscopic surface. Using of SEM, the specimens which are insulator need to be coated with gold or carbon and must measure in vacuum situation.[63] Using the profilometer and SEM together can provide both quantitative and qualitative measurements of surface roughness.

Table 1 The example of ceramic polishing kits and their details

Instrument	Manufacturer	Contents
Ceramaster	Shofu Inc, Japan	silica carbide-impregnated silicone
Ceramiste	Shofu Inc, Japan	diamond-impregnated silicone
OptraFine	Ivoclar Vivadent AG, Schaan, Liechtenstein	synthetic rubber, diamond granulate, and titanium oxide
Meisinger Luster for lithium disilicate	Hager & Meisinger GmbH, Neuss, Germany	NA
Meisinger Luster for zirconia	Hager & Meisinger GmbH, Neuss, Germany	silicon dioxide matrix and diamond abrasive
Komet ZR	Komet, USA	NA
EVE DIACERA	EVE Ernst Vetter GmbH, Germany	synthetic monocrystalline diamond in polyurea binder
JIFFY UNIVERSAL	Ultradent, USA	multigrit diamond particles

CHAPTER III

MATERIALS AND METHODS

Materials used in this study

1. Lithium disilicate glass ceramic: IPS e.max CAD (Ivoclar Vivadent) Shade A3 Low translucent

2. Monolithic zirconia: Vita (ZahnfabrikH.RauterGmbH&Co) Shade A3 Extra translucent (XT)

3. Zirconia-reinforced lithium silicate: Celtra Duo (Dentsply Sirona) Shade A3 Low translucent

4. Fine diamond bur: Meisinger fine diamond bur (Hager & Meisinger GmbH, Neuss, Germany)

5. Coarse polishing burs: EVE Diacera H2DCmf (EVE Ernst Vetter GmbH, Pforzheim, Germany)

6. Fine polishing burs: EVE Diacera H2DC (EVE Ernst Vetter GmbH, Pforzheim, Germany)

7. Custom device for controlling the force of burs

8. Optical profilometer (Alicona infinitefocusSL, Graz, Austria)

9. Scanning electron microscope (SEM) (Quanta 250 FEG, FEI, United States)

10. Micromotor (NAKANISHI INC, Japan)

11. Digital Vernier caliper (Digimatic, Mitutoyo, Japan)

12. Ultra-sonic cleaner (Bransonic model 5210, Branson, USA)

13. Low speed Saw (Buehler, USA)

Table 2 Ceramics detail from manufacturer datasheet

Ceramic Material	Manufacturer	Type	Compositions
IPS e.max CAD (LT) shade A3	Ivoclar Vivadent	Lithium disilicate glass ceramic	SiO_2 (57-80%), Li_2O (11–19%), K_2O (0-13%), P_2O_5 (0-11%), ZrO_2 (0-8%), ZnO (0-8%), Al_2O_3 (0-5%), MgO (0-5%), Colouring oxides (0-8%)
VITA YZ XT shade A3	VITA Zahnfabrik H. Rauter GmbH & Co. KG	Translucent zirconia	ZrO_2 (86-91%), Y_2O_3(8-10%), HfO_2(1-3%), Al_2O_3 (0-1%), Pigments (0-1%)
CELTRA DUO (LT) shade A3	Dentsply Sirona	Zirconia-reinforced lithium silicate	SiO_2 (58%), Li_2O (15%), P_2O_5(5%), ZrO_2 (10.1%), Al_2O_3 (1.9%), CeO_2(2%), Tb_2O_3(1%)

Table 3 Grinding and polishing burs details

Instrument	Product code	Manufacturer's usage recommendation	Composition	Dimensions (mm)	Polishing Speed (rpm)
Meisinger fine diamond bur (Hager & Meisinger GmbH, Neuss, Germany)	881F 014	Smoothing	Diamond grit (27-76 μm)	1.4 x 8	300,000
EVE DIACERA HP (EVE Ernst Vetter GmbH, Pforzheim, Germany)	H2DCmf	Coarse polishing	Diamond impregnated (25-35 μm) in polyurea	4 x 13	10,000
	H2DC	Fine polishing	Diamond impregnated (3-6 μm) in polyurea	4 x 13	10,000

Specimen preparation

1. Sample size calculation

From the pilot study, the number of specimens calculated by using G*Power program (μ_1 = 0.672, μ_2 = 0.525, σ_1 = 0.083, σ_2 = 0.085, α = 0.05, and β = 0.20) resulted in sample size n = 7 for each group as shown in figure 6. Then the adjustment of the sample size was made for 10% error resulted in n = 8 per group.

2. Specimen preparation

2.1. Ceramic specimen fabrication

Lithium disilicate glass ceramics block (IPS e.max CAD; Ivoclar Vivadent; shade A3 low translucent), translucent zirconia disc (VITA YZ® XT ZrO_2; VITA Zahnfabrik H. Rauter GmbH & Co. KG; shade A3) and zirconia-reinforced lithium silicate (Celtra Duo; Dentsply Sirona; shade A3 low translucent) were prepared in the laboratory in according to the manufacturer's instructions into a rectangular shape to a final dimension of about of 5x7 ± 0.05 mm and thickness of 4 ± 0.01 mm as shown in figure 7.

2.2. Block preparation

Lithium disilicate glass ceramic block (IPS e.max CAD) was divided and prepared in the final dimension from the pre-crystallized or blue state. The sintering process follows the manufacturer's recommendations.[14] The translucent zirconia blank (Vita YZ XT) was divided and prepared in the green stage in an enlarged dimension about 6.5 x 9 ± 0.2 mm x 5.3 ± 0.2 mm due to the 20% sintering shrinkage. The sintering process follows the manufacturer's recommendations.[69] Zirconia-reinforced lithium silicate block (Celtra Duo) was divided into final dimension without sintering process due to the fully crystallization.[70] Digital Vernier caliper (Digimatic, Mitutoyo, Japan) was used to measure each specimen's dimension. All specimens were cleaned in an ultrasonic bath (Bransonic model5210, Branson, USA) of distilled water for 10 minutes and dried with absorbent paper. Each specimen was fixed with clear resin in PVC pipe as shown in figure 8.

Polishing procedure

In this study, a custom device for controlling the force has been used to control the inaccuracy and instability of direct human forces. The device composes of an electronic control panel, pressure gauge, direction control joystick, load cell, handpiece-connector. A load cell is a transducer that converts the polishing force into a measurable electrical output (pressure gauge). Direction control joystick can control the specimen in both vertical and horizontal directions to provide the desired polishing force. A slow-speed handpiece (NSK Nakanishi Inc., Tochigi, Japan) was used to polish specimens. The polishing force was controlled to 1 N, according to the pilot survey from 10 post-graduate students in prosthodontic department in Chulalongkorn University. The polishing speed was followed the manufacturer's recommendation (Table 3).

The specimens were ground with Meisinger fine diamond bur (grit sizes 27-76 μm) for 15 seconds to simulate clinical gross contouring and then measure for the roughness value (Ra). The polishing process started by coarse polishing for 60 seconds and followed by fine polishing for 60 seconds. The polishing direction was in forward-backward direction. The polishing bur was changed in every 4 specimens. The Ra of each specimen was measured after grinding step and every 15 seconds in coarse and fine polishing steps. Before the Ra measurement, the specimens were cleaned with distilled water in an ultrasonic device for 5 minutes. The diagram is shown in Figure 9.

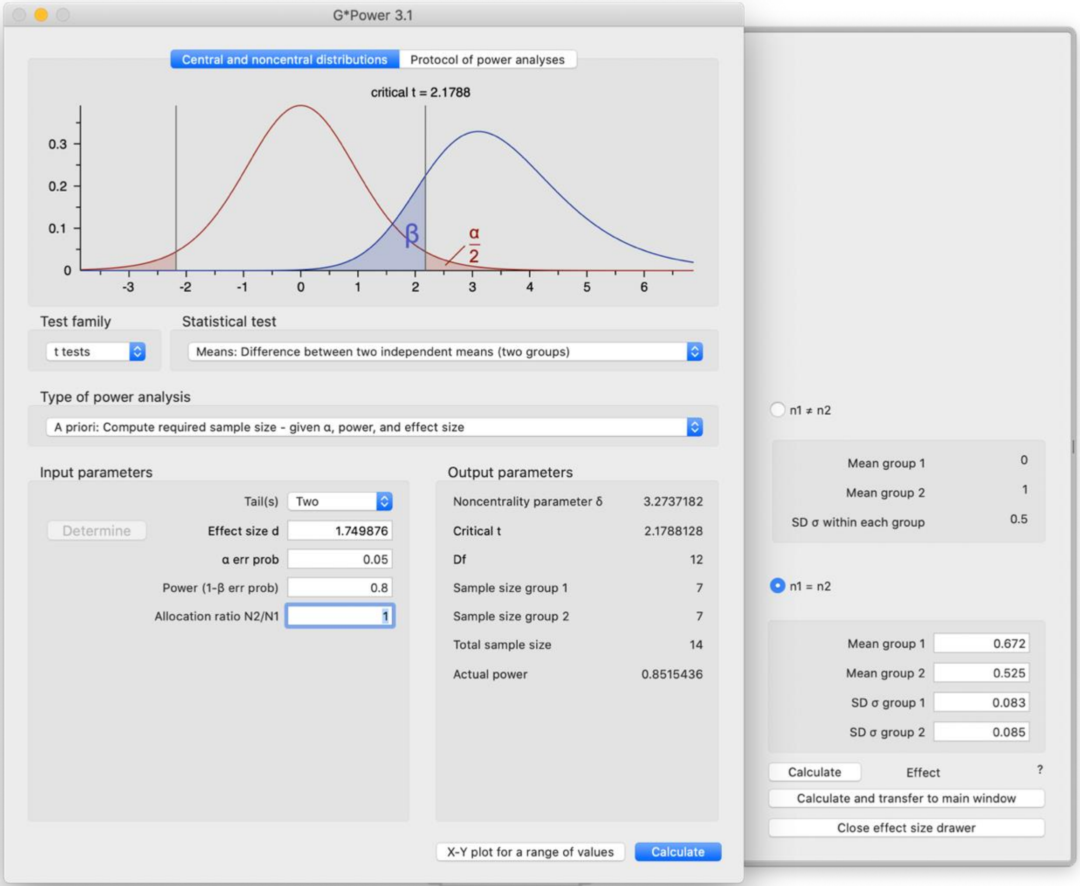

Figure 6 Sample size calculation in G*Power program

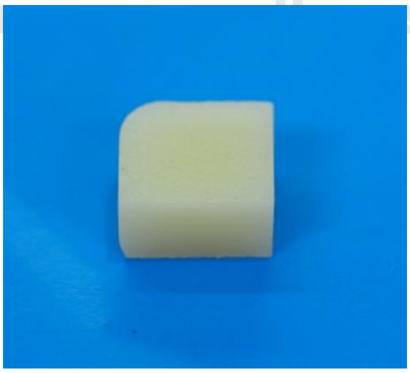

Figure 7 Prepared ceramic specimen

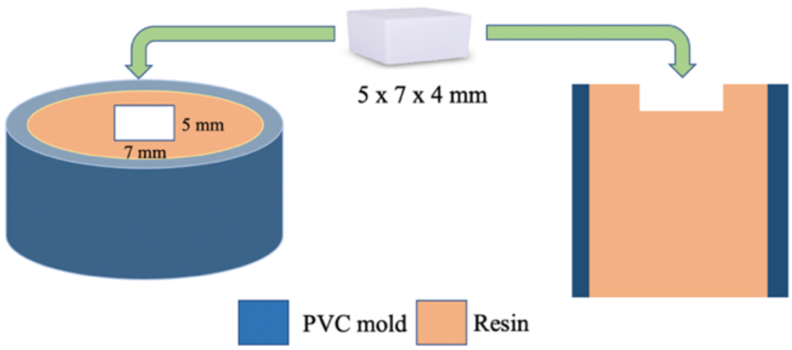

Figure 8 Ceramic specimen fixed in PVC pipe with clear resin

Surface roughness measurement

The surface roughness (Ra) of each specimen was analyzed using a non-contact optical profilometer (Alicona infinitefocusSL, Graz, Austria) with 50X magnification. The surface roughness of grinding and polished specimens was measured in each step. In each specimen, five measurement areas (0.4x0.4 mm) were measured which consist of the center of the specimen and 1 mm apart from the center of the specimen in four directions. The area of surface roughness measurement was perpendicular to the polished direction and provided 4 mm in evaluation length, according to ISO 4288 standards.[71] For the control group, the laboratory-polished specimens of each ceramic (n=3) were used.

Scanning Electron Microscope (Quanta 250 FEG, FEI, United States) was used to provide qualitative information in randomly one specimen from each group. Using of SEM, the specimens which are insulator need to be coated with gold or carbon and must measured all specimens in a vacuum.[63]

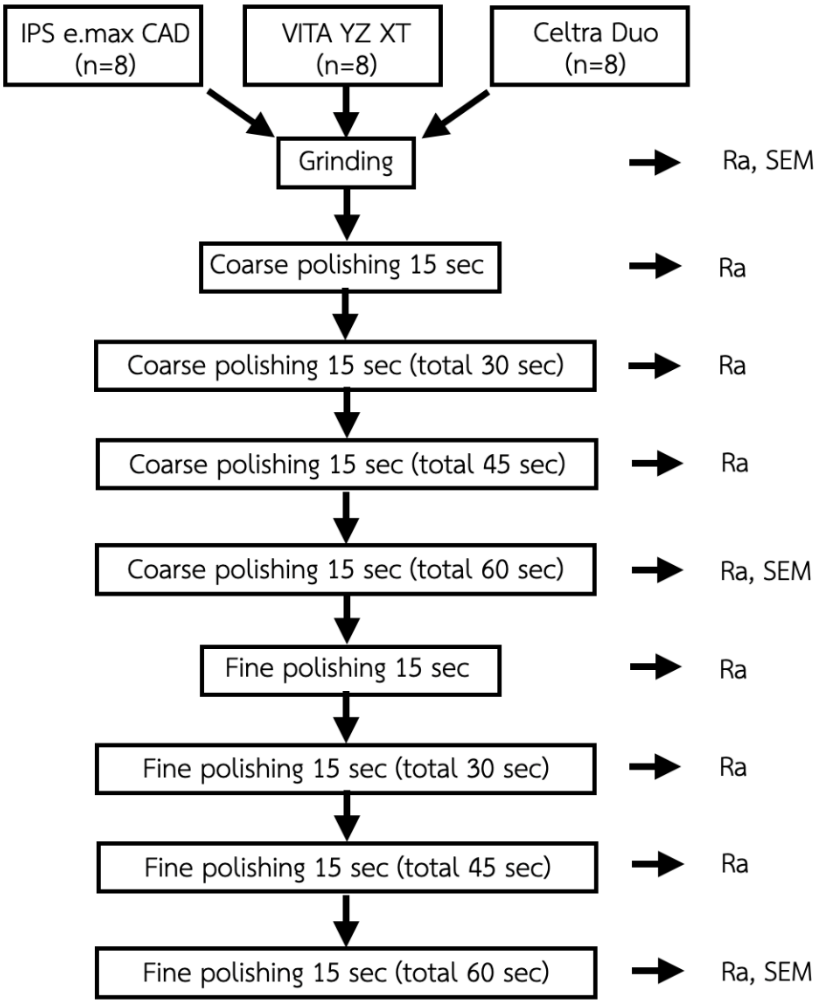

Figure 9 Diagram of experimental process in this study

Figure 10 Coarse and fine polisher of EVE Diacera polishing system

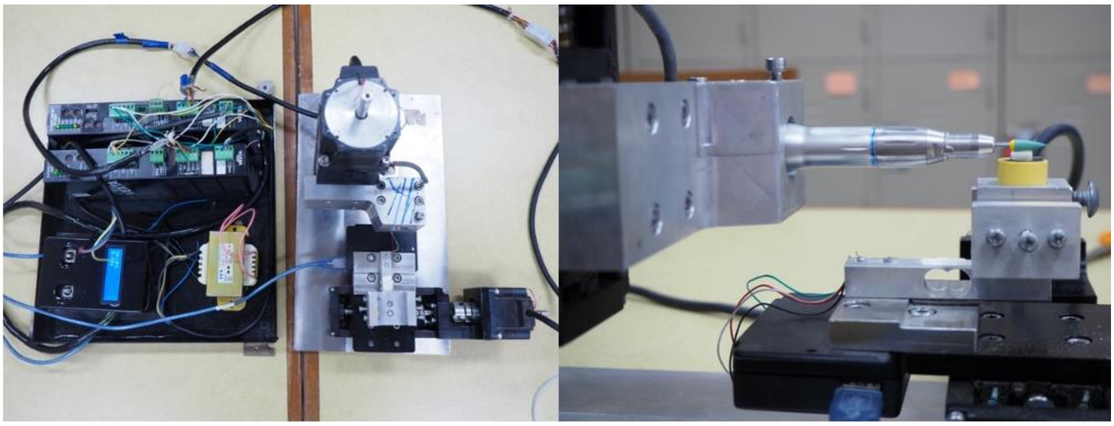

Figure 11 Custom device for controlling the force of burs

Statistics analysis

Data were analyzed using SPSS Statistics for Windows, Version 22.0 (IBM, Armonk, NY). One-way repeated measures ANOVA and Post-hoc comparisons by Bonferroni test were used to determine the effect of each polishing duration on the Ra in each step. One-way ANOVA was used for mean comparison of the Ra in all polishing steps between ceramic groups. Paired samples t-test was used for comparison in Δ Mean Ra between both polishing steps in the same material type while one-way ANOVA was used for comparison in Δ Mean Ra between ceramic groups within the same polishing step. A P-value < 0.05 was considered statistically significant.

CHAPTER IV

RESULTS

The results of surface roughness measurements are reported in Table 4. the Shapiro-Wilk test at significant level of 0.05 showed a normal distribution of the data. Each polishing duration in either coarse polishing or fine polishing steps reduced Ra with no significant different in all three ceramic types. From one-way repeated measures ANOVA, after polishing IPS e.max CAD with coarse polishing for 15 seconds, the Ra decreased significantly compared to grinding and continually decreased after coarse polishing without significant difference. After fine polishing for 30 seconds, the Ra value began to be significantly lower than that of coarse polishing at 15 second. In VITA YZ XT and Celtra Duo, coarse polishing after 15 seconds showed significantly lower Ra than grinding. The fine polishing at 15 seconds began to show significantly lower Ra than coarse polishing. VITA YZ XT showed the lowest Ra after the final polishing, followed by Celtra Duo and IPS e.max CAD, respectively.

From the one-way ANOVA, ceramic types had a significant effect on Ra. After grinding, VITA YZ XT showed significantly higher Ra than IPS e.max CAD and Celtra Duo. While in fine polishing at 30, 45 and 60 seconds, VITA YZ XT showed significantly lower Ra than IPS e.max CAD. When compared the roughness in the final polishing at 60 seconds to the after grinding step, the total polishing process showed more roughness reduction in VITA YZ XT than Celtra Duo and IPS e.max CAD respectively as shown in Table 5.

The mean(±SD) Ra of IPS e.max CAD, VITA YZ XT and Celtra Duo from the control group which was polished from the laboratory were 0.728(±0.094) µm, 0.617(±0.025) µm and 0.695(±0.081) µm respectively.

Table 4 Mean(±SD) of surface roughness IPS e.max CAD and VITA YZ XT of control groups (μm)

Material type	Grinding	Coarse Polishing				Fine Polishing			
		15s	30s	45s	60s	15s	30s	45s	60s
IPS e.max CAD	1.469 (±0.110) ^{aA}	1.063 (±0.155) ^{b}	1.043 (±0.108) ^{b}	0.945 (±0.099) ^{bc}	0.936 (±0.147) ^{bc}	0.824 (±0.192) ^{bcd}	0.727 (±0.087) ^{cdA}	0.686 (±0.075) ^{dA}	0.654 (±0.077) ^{dA}
VITA YZ XT	1.889 (±0.223) ^{aB}	1.262 (±0.198) ^{b}	1.058 (±0.233) ^{bc}	0.998 (±0.252) ^{bcd}	0.902 (±0.331) ^{bcde}	0.714 (±0.149) ^{cde}	0.599 (±0.074) ^{deB}	0.563 (±0.098) ^{deB}	0.516 (±0.100) ^{eB}
Celtra Duo	1.641 (±0.121) ^{aA}	1.259 (±0.125) ^{b}	1.129 (±0.194) ^{bc}	1.092 (±0.183) ^{bc}	1.01 (±0.187) ^{bcd}	0.789 (±0.123) ^{cde}	0.704 (±0.092) ^{deAB}	0.613 (±0.074) ^{eAB}	0.602 (±0.079) ^{eAB}

*Different small letter indicates significant different between time points within the same material type ($P<0.05$)

*Different capital letter indicates significant different between material types within the same time point ($P<0.05$)

Table 5 Δ Mean(±SD) of Ra between both coarse and fine polishing steps compared to grinding

Material types	**Δ** Mean Ra after coarse polishing (μm)	**Δ** Mean Ra after fine polishing (μm)
IPS e.max CAD	0.533 (±0.151)^{aA}	0.815 (±0.151)^{bA}
VITA YZ XT	0.987 (±0.417)^{aB}	1.373 (±0.248)^{bB}
Celtra Duo	0.631 (±0.199)^{aAB}	1.039 (±0.129)^{bA}

*Different small letter indicates significant difference between both polishing steps in the same material type (P<0.05)

*Different capital letter indicates significant difference between material types within the same polishing step. (P<0.05)

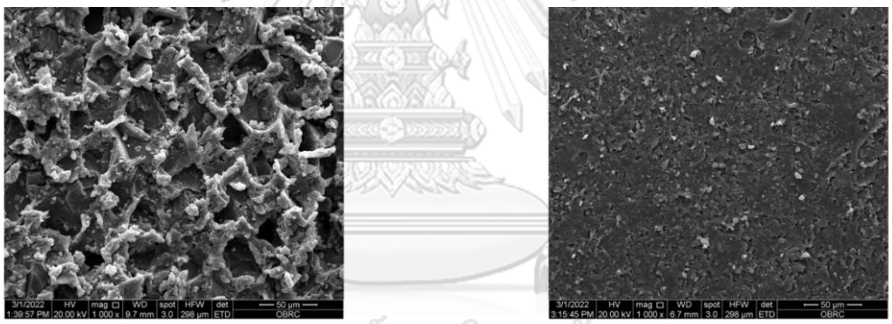

Figure 12 Scanning electron micrographs (SEM) 1000X of coarse and fine polishers

From the SEM micrographs, the fine polishing bur exhibited the finer microstructure than the coarse polishing bur as shown in figure 12. The filler size in the fine polishing bur showed more homogeneous and smaller than those in a coarse polishing bur which corresponded to the manufacturer’s data. The SEM micrographs of the ceramic specimens were shown in figure 13. All ceramic specimens showed scratches of the surface with groove pattern after grinding with fine diamond bur. In all ceramic types, the surface showed shallower grooves after coarse polishing, while they exhibited smooth surface after fine polishing. When compared with control group, the specimens polished after fine polishing bur provided similar surface texture.

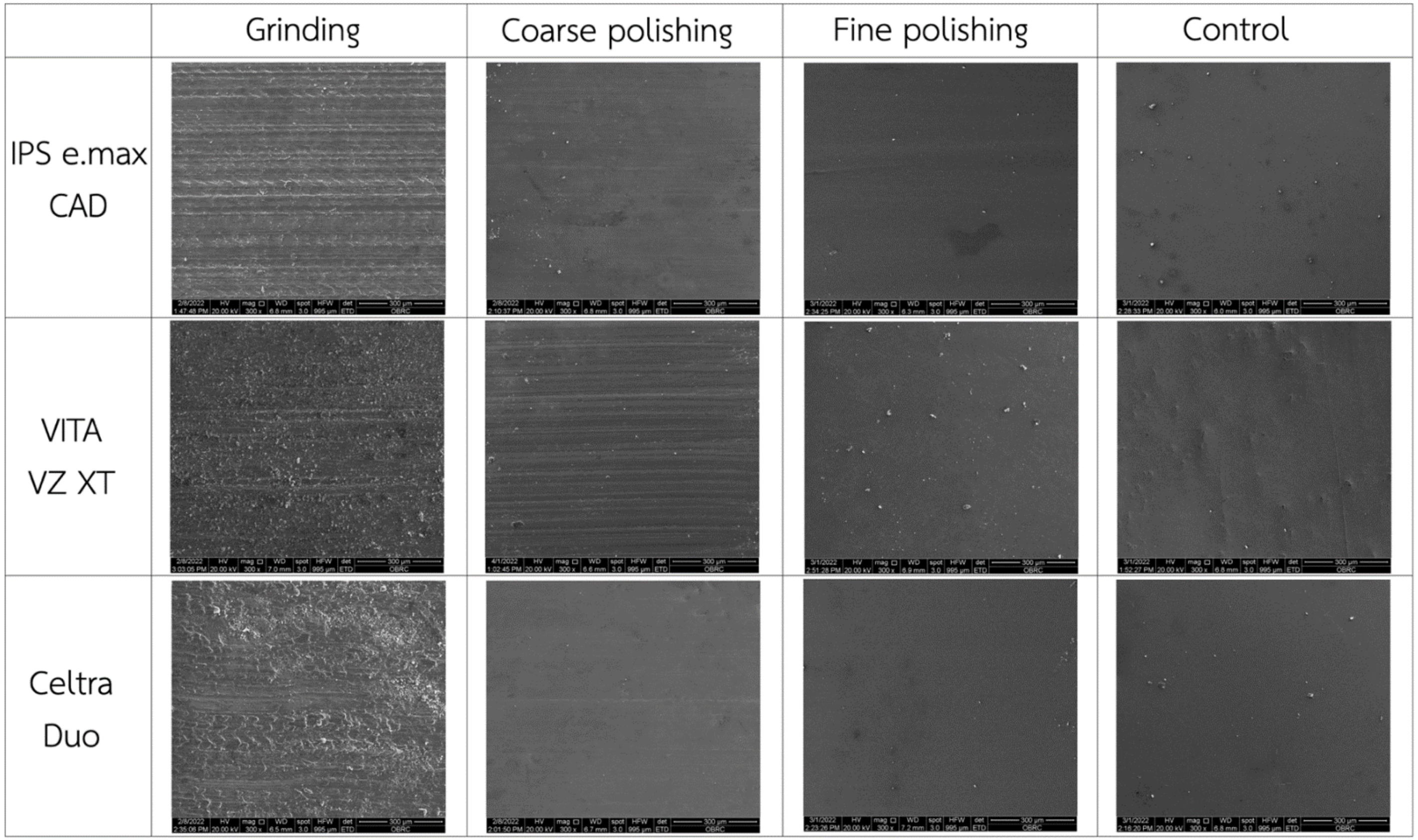

Figure 13 Scanning electron micrographs (SEM) 300X of all ceramic types after grinding and polishing by universal polishing kit compared with control groups.

CHAPTER V
DISCUSSION

This study used IPS e.max CAD in low translucency (LT), VITA YZ XT (extra translucent zirconia) and Celtra Duo in low translucency (LT) which provided similar translucency level as found in the study of Sen & Isler that the extra translucent zirconia had comparable optical properties to lithium disilicate glass ceramic with low translucency and Awad et al. found that Celtra Duo in low translucency provided comparable optical properties to lithium disilicate glass ceramic with low translucency.[(45, 72)] The translucency level of materials can affect the measurement of surface roughness from the optical profilometer due to the reflection of light, the low translucency level provided more accurate measurement than the high translucency level as experienced by the author. The pressure used in polishing restorations by most dentists was about 100 grams or approximately 1 N at the bur tip.[(34)] Moreover, the pilot survey also found that 8 of 10 dentists applied forces about less than 100 grams. Therefore, the polishing force was controlled to 1 N by a custom device in this study. The coarse and fine polishing direction in this study was perpendicular to the grinding direction. Thus, the polishing direction that is parallel or oblique with the grinding direction can provide different surface roughness values from this study.

Although the microstructural in IPS e.max CAD, VITA YZ XT and Celtra duo were different, coarse polishing of all ceramic types required 15 seconds to exhibit a significant smoother surface compared to grinding. However, fine polishing of both VITA YZ XT and Celtra Duo required 15 seconds while IPS e.max CAD required 30 seconds to exhibit a significant smoother surface compared to a roughness at coarse polishing at 15 seconds. From Δ Mean Ra after coarse and fine polishing, VITA YZ XT exhibited the most roughness reduction followed by Celtra Duo and IPS e.max CAD, respectively. This can be explained by the larger grain size of IPS e.max CAD than Celtra Duo and VITA YZ XT, respectively. The grain size of IPS e.max CAD consisted of interlocked lithium disilicate crystals, 5 μm in length and 0.8 μm in diameter.[73] Some needle-like crystals structure of IPS e.max CAD might be perpendicular the polishing direction which required more duration to reduce roughness. The grain size of VITA YZ XT and Celtra Duo was approximately about 0.815 and 1 μm, respectively.[72, 74] Thus, the finer microstructure exhibited a smoother surface after polishing.[41]

The result that IPS e.max CAD exhibited the highest surface roughness after final polishing compared with Celtra Duo and VITA YZ XT were similar to the study of Vichi et al. (2018). They found that surface roughness of IPS e.max CAD did not change significantly after polishing for 30 or 60 seconds, and IPS e.max CAD exhibited higher Ra than VITA Suprinity which is zirconia-reinforced lithium silicate glass ceramic.[41] While in VITA YZ XT exhibited the lowest Ra after polishing with coarse and fine polishing. More polishing duration consequentially smoothened the surface of the zirconia.[75] This can be explained due to the finer microstructure of VITA YZ XT as mentioned above. Furthermore, the abrasive size in polishing burs used also play an important role in polishing ceramics since the size of abrasive particles affects the effectiveness of polishing procedures.[8] A universal ceramic polishing kit used in this study was EVE Diacera which is a two-step polishing kit that consists of EVE Diacera H2DCmf and EVE Diacera H2DC composed of polyurea as binder with synthetic monocrystalline diamond sizes 25-35 μm and 3-6 μm respectively.[76] Though the small grit size in fine polisher should provide a smoother surface from coarse polishing burs, but it may not well effective to polish the former rough surface of large ceramic grain size left from coarse polishing as found in the results of IPS e.max CAD.

After polishing, the surface roughness of all ceramic types was lower than the control group as polished from the laboratory. The surface roughness of enamel was reported approximately 0.64 µm.[59] Compared to our results, the step with fine polisher on VITA YZ XT at 30 seconds, Celtra Duo at 45 seconds and IPS e.max CAD at 60 seconds provided the Ra value near to this level. Therefore, after polishing all ceramic types by a universal ceramic polishing kit could create surface roughness near to enamel.

Further studies by comparing with more types of polishing burs such as porcelain polishing kits, lithium disilicate polishing kits and zirconia polishing kits or increasing the force or duration in polishing protocol may be advantageous.

Conclusions

Within the limitations of this study, it can be concluded as follow:

1. Coarse and fine polishing burs continually reduced the surface roughness of VITA YZ XT, Celtra Duo and IPS e.max CAD when increasing duration.
2. After grinding, VITA YZ XT showed the greatest surface roughness. After coarse polishing, surface roughness of all ceramic types did not significantly different. After fine polishing, VITA YZ XT showed the lowest surface roughness, followed by Celtra Duo and IPS e.max CAD.

REFERENCES

1. Anusavice KJ, Phillips RW, Shen C, Rawls HR. Phillips' Science of Dental Materials. 12th ed: St. Louis, Mo. : Elsevier/Saunders; 2013.
2. Chapter 11 - Restorative Materials—Ceramics. In: Sakaguchi RL, Powers JM, editors. Craig's Restorative Dental Materials (Thirteenth Edition). Saint Louis: Mosby; 2012. p. 253-75.
3. Fu L, Engqvist H, Xia W. Glass-Ceramics in Dentistry: A Review. Materials (Basel). 2020;13(5).
4. Kelly JR, Benetti P. Ceramic materials in dentistry: historical evolution and current practice. Aust Dent J. 2011;56 Suppl 1:84-96.
5. Gracis S, Thompson V, Ferencz J, Silva N, Bonfante E. A New Classification System for All-Ceramic and Ceramic-like Restorative Materials. The International journal of prosthodontics. 2015;28:227-35.
6. Al Hamad KQ, Abu Al-Addous AM, Al-Wahadni AM, Baba NZ, Goodacre BJ. Surface Roughness of Monolithic and Layered Zirconia Restorations at Different Stages of Finishing and Polishing: An In Vitro Study. Journal of Prosthodontics. 2019;28(7):818-25.
7. Rashid H. The effect of surface roughness on ceramics used in dentistry: A review of literature. Eur J Dent. 2014;8(4):571-9.
8. Jefferies SR. Abrasive finishing and polishing in restorative dentistry: a state-of-the-art review. Dent Clin North Am. 2007;51(2):379-97, ix.
9. Silva LHD, Lima E, Miranda RBP, Favero SS, Lohbauer U, Cesar PF. Dental ceramics: a review of new materials and processing methods. Braz Oral Res. 2017;31(suppl 1):e58.
10. Quinn JB, Sundar V, Lloyd IK. Influence of microstructure and chemistry on the fracture toughness of dental ceramics. Dental Materials. 2003;19(7):603-11.
11. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part I. Pressable and alumina glass-infiltrated ceramics. Dental Materials. 2004;20(5):441-8.

12. Kang S-H, Chang J, Son H-H. Flexural strength and microstructure of two lithium disilicate glass ceramics for CAD/CAM restoration in the dental clinic. Restor Dent Endod. 2013;38(3):134-40.

13. Dahiya M, Duhan S. Bioactive glass/glass ceramics for dental applications. 2018. p. 1-26.

14. IPS e.max CAD. Scientific Documentation [Internet]. Ivoclar Vivadent. [cited 17 April 2021]. Available from: https://downloadcenter.ivoclarvivadent.com/en/download-center/scientific-documentations/.

15. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. J Prosthodont Res. 2013;57(4):236-61.

16. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008;24(3):299-307.

17. Hisbergues M, Vendeville S, Vendeville P. Zirconia: Established facts and perspectives for a biomaterial in dental implantology. J Biomed Mater Res B Appl Biomater. 2009;88(2):519-29.

18. Lim K-T, Lee J-H, Lim I-G, Park S-H, Lim H-P, Kim O. Comparison of biofilm on titanium and zirconia surfaces: in vivo study. The Journal of Korean Academy of Prosthodontics. 2013;51:245.

19. Vagkopoulou T, Koutayas S, Koidis P, Strub J. Zirconia in dentistry: Part 1. Discovering the nature of an upcoming bioceramic. The European journal of esthetic dentistry : official journal of the European Academy of Esthetic Dentistry. 2009;4:130-51.

20. Hannink RHJ, Kelly PM, Muddle BC. Transformation Toughening in Zirconia-Containing Ceramics. Journal of the American Ceramic Society. 2000;83(3):461-87.

21. Zhang Y, Lawn BR. Novel Zirconia Materials in Dentistry. J Dent Res. 2018;97(2):140-7.

22. Zhang F, Reveron H, Spies BC, Van Meerbeek B, Chevalier J. Trade-off between fracture resistance and translucency of zirconia and lithium-disilicate glass ceramics for monolithic restorations. Acta Biomater. 2019;91:24-34.

23. Zhang Y. Making yttria-stabilized tetragonal zirconia translucent. Dent Mater. 2014;30(10):1195-203.

24. Christensen GJ. Porcelain-fused-to-metal versus zirconia-based ceramic

restorations, 2009. J Am Dent Assoc. 2009;140(8):1036-9.

25. Shahmiri R, Standard OC, Hart JN, Sorrell CC. Optical properties of zirconia ceramics for esthetic dental restorations: A systematic review. J Prosthet Dent. 2018;119(1):36-46.

26. Zhang F, Inokoshi M, Batuk M, Hadermann J, Naert I, Van Meerbeek B, et al. Strength, toughness and aging stability of highly-translucent Y-TZP ceramics for dental restorations. Dent Mater. 2016;32(12):e327-e37.

27. Elsaka SE, Elnaghy AM. Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. Dent Mater. 2016;32(7):908-14.

28. Zarone F, Ruggiero G, Leone R, Breschi L, Leuci S, Sorrentino R. Zirconia-reinforced lithium silicate (ZLS) mechanical and biological properties: A literature review. Journal of Dentistry. 2021;109:103661.

29. Eyre TS. The mechanisms of wear. Tribology International. 1978;11(2):91-6.

30. Kovaříková I, Szewczyková B, Blaškoviš P, Hodúlová E, Lechovič E. Study and characteristic of abrasive wear mechanisms. Materials Science and Technology. 2009;1:1-8.

31. Doi T, Uhlmann E, Marinescu ID. Handbook of ceramics grinding and polishing: William Andrew; 2015.

32. Ahmad R, Morgano SM, Wu BM, Giordano RA. An evaluation of the effects of handpiece speed, abrasive characteristics, and polishing load on the flexural strength of polished ceramics. J Prosthet Dent. 2005;94(5):421-9.

33. Heintze SD, Reinhardt M, Müller F, Peschke A. Press-on force during polishing of resin composite restorations. Dental Materials. 2019;35(6):937-44.

34. Siegel SC, von Fraunhofer JA. Dental cutting with diamond burs: heavy-handed or light-touch? J Prosthodont. 1999;8(1):3-9.

35. Silva T, Salvia A, Carvalho R, Silva E, Pagani C. Effects of Different Polishing Protocols on Lithium Disilicate Ceramics. Brazilian Dental Journal. 2015;26:478-83.

36. Incesu E, Yanikoglu N. Evaluation of the effect of different polishing systems on the surface roughness of dental ceramics. The Journal of Prosthetic Dentistry. 2020;124(1):100-9.

37. Sarikaya I, Güler AU. Effects of different polishing techniques on the surface roughness of dental porcelains. J Appl Oral Sci. 2010;18(1):10-6.

38. Goo CL, Yap A, Tan K, Fawzy AS. Effect of Polishing Systems on Surface Roughness and Topography of Monolithic Zirconia. Oper Dent. 2016;41(4):417-23.

39. Park C, Vang MS, Park SW, Lim HP. Effect of various polishing systems on the surface roughness and phase transformation of zirconia and the durability of the polishing systems. J Prosthet Dent. 2017;117(3):430-7.

40. Scherrer D, Bragger U, Ferrari M, Mocker A, Joda T. In-vitro polishing of CAD/CAM ceramic restorations: An evaluation with SEM and confocal profilometry. Journal of the Mechanical Behavior of Biomedical Materials. 2020;107:103761.

41. Vichi A, Fonzar RF, Goracci C, Carrabba M, Ferrari M. Effect of Finishing and Polishing on Roughness and Gloss of Lithium Disilicate and Lithium Silicate Zirconia Reinforced Glass Ceramic for CAD/CAM Systems. Operative Dentistry. 2018;43(1):90-100.

42. Preis V, Grumser K, Schneider-Feyrer S, Behr M, Rosentritt M. The effectiveness of polishing kits: influence on surface roughness of zirconia. Int J Prosthodont. 2015;28(2):149-51.

43. Rashid H. The effect of surface roughness on ceramics used in dentistry: A review of literature. Eur J Dent. 2014;8(4):571-9.

44. Scurria MS, Powers JM. Surface roughness of two polished ceramic materials. The Journal of Prosthetic Dentistry. 1994;71(2):174-7.

45. Awad D, Stawarczyk B, Liebermann A, Ilie N. Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. J Prosthet Dent. 2015;113(6):534-40.

46. Matzinger M, Hahnel S, Preis V, Rosentritt M. Polishing effects and wear performance of chairside CAD/CAM materials. Clin Oral Investig. 2019;23(2):725-37.

47. Aykent F, Yondem I, Ozyesil AG, Gunal SK, Avunduk MC, Ozkan S. Effect of different finishing techniques for restorative materials on surface roughness and bacterial adhesion. J Prosthet Dent. 2010;103(4):221-7.

48. Khayat W, Chebib N, Finkelman M, Khayat S, Ali A. Effect of grinding and polishing on roughness and strength of zirconia. J Prosthet Dent. 2018;119(4):626-31.

49. Hmaidouch R, Müller WD, Lauer HC, Weigl P. Surface roughness of zirconia for

full-contour crowns after clinically simulated grinding and polishing. Int J Oral Sci. 2014;6(4):241-6.

50. Bollen CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. Dent Mater. 1997;13(4):258-69.

51. Motro PF, Kursoglu P, Kazazoglu E. Effects of different surface treatments on stainability of ceramics. J Prosthet Dent. 2012;108(4):231-7.

52. Silva T, Salvia A, Carvalho R, Pagani C, Rocha D, Silva E. Polishing for glass ceramics: Which protocol? Journal of Prosthodontic Research. 2014;58.

53. Brewer JD, Garlapo DA, Chipps EA, Tedesco LA. Clinical discrimination between autoglazed and polished porcelain surfaces. The Journal of Prosthetic Dentistry. 1990;64(6):631-5.

54. Oliveira-Junior OB, Buso L, Fujiy FH, Lombardo GH, Campos F, Sarmento HR, et al. Influence of polishing procedures on the surface roughness of dental ceramics made by different techniques. Gen Dent. 2013;61(1):e4-8.

55. Fasbinder DJ, Neiva GF. Surface Evaluation of Polishing Techniques for New Resilient CAD/CAM Restorative Materials. J Esthet Restor Dent. 2016;28(1):56-66.

56. Mohammadibassir M, Rezvani MB, Golzari H, Moravej Salehi E, Fahimi MA, Kharazi Fard MJ. Effect of Two Polishing Systems on Surface Roughness, Topography, and Flexural Strength of a Monolithic Lithium Disilicate Ceramic. J Prosthodont. 2019;28(1):e172-e80.

57. 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(1):22-9.

58. 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(4):433-49.

59. Willems G, Lambrechts P, Braem M, Vuylsteke-Wauters M, Vanherle G. The surface roughness of enamel-to-enamel contact areas compared with the intrinsic roughness of dental resin composites. J Dent Res. 1991;70(9):1299-305.

60. Jones CS, Billington RW, Pearson GJ. The in vivo perception of roughness of restorations. Br Dent J. 2004;196(1):42-5; discussion 31.

61. Quirynen M, Bollen CM, Papaioannou W, Van Eldere J, van Steenberghe D. The influence of titanium abutment surface roughness on plaque accumulation and gingivitis: short-term observations. Int J Oral Maxillofac Implants. 1996;11(2):169-78.

62. Bollen CM, Papaioanno W, Van Eldere J, Schepers E, Quirynen M, van Steenberghe D. The influence of abutment surface roughness on plaque accumulation and peri-implant mucositis. Clin Oral Implants Res. 1996;7(3):201-11.

63. Bhushan B. Surface roughness analysis and measurement techniques. 2000. p. 49-119.

64. Kusyairi I, Himawan H, Choiron M, Irawan Y. Manufacture of Origami Pattern Crash Box Using Traditional Investment Casting Method. IOP Conference Series: Materials Science and Engineering. 2019;494:012006.

65. Ersu B, Yuzugullu B, Ruya Yazici A, Canay S. Surface roughness and bond strengths of glass-infiltrated alumina-ceramics prepared using various surface treatments. J Dent. 2009;37(11):848-56.

66. Vorburger T, Rhee H-G, Renegar T, Song JF, Zheng X. Comparison of optical and stylus methods for measurement of surface texture. The International Journal of Advanced Manufacturing Technology. 2007;33:110-8.

67. Whitehead SA, Shearer AC, Watts DC, Wilson NH. Comparison of two stylus methods for measuring surface texture. Dent Mater. 1999;15(2):79-86.

68. Whitehead SA, Shearer AC, Watts DC, Wilson NH. Comparison of methods for measuring surface roughness of ceramic. J Oral Rehabil. 1995;22(6):421-7.

69. VITAZahnfabrik. Product information [Internet]. VITAZahnfabrik H. Rauter GmbH & Co. KG. [cited 20 April 2021]. Available from: https://www.vita-zahnfabrik.com.

70. Celtra Duo Brochure [Internet]. Dentsply Sirona. [cited 23 April 2021]. Available from: https://www.dentsplysirona.com/en-us/categories/restorative/celtra-duo.html.

71. Standardization IOf (1996) ISO 4288: Geometrical product specifications (GPS)-Surface texture: profile method—rules and procedures for the assessment of the surface texture.

72. Sen N, Isler S. Microstructural, physical, and optical characterization of high-translucency zirconia ceramics. The Journal of Prosthetic Dentistry. 2020;123(5):761-8.

73. Isabelle D, Holloway J. Ceramics for Dental Applications: A Review. Materials.

2010;3.
74. Belli R, Wendler M, de Ligny D, Cicconi MR, Petschelt A, Peterlik H, et al. Chairside CAD/CAM materials. Part 1: Measurement of elastic constants and microstructural characterization. Dent Mater. 2017;33(1):84-98.
75. Munkongsujarit S, Salimee P, editors. Effect of polishing systems, forces and durations on surface roughness of monolithic zirconia. The 20th National Graduate Research Conference; 2019; Khon Kaen University.
76. EVE Product information [Internet]. [cited 10 April 2021]. Available from: https://www.eve-rotary.com/en/downloads/.

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