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ORIGINAL ARTICLE

Evaluation of the surface roughness of a standard abraded dental porcelain following different polishing techniques†

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KEYWORDS
chairside adjustment;
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surface roughness

Abstract *Background/purpose:* To evaluate the surface roughness of the metal ceramic VITA VMK 95, a standard dental porcelain used for metal-ceramic restorations.
Materials and methods: Glazed ceramic blocks of VITA VMK 95 were grinded using a rugby-shaped diamond bur in order to mimic the chairside-adjustment process and then polished using two polishing techniques. Polishing was performed using Sof-Lex discs or Sof-Lex discs followed by polishing with brushes and a prophylaxis paste. To evaluate the surface roughness, confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM) using the Genie digital image capture system were performed. Average roughness (Ra), root mean square roughness (Rq), valley roughness (Rv), and peak roughness (Rp) were evaluated using CLSM.
Results: The results were analyzed using one-way analysis of variance with the post hoc Tukey test at a significance level of 5%. There were statistically significant differences between the rough group and the two polished groups ($P < 0.05$). There was no statistically significant difference between the two polished groups ($P > 0.05$).
Conclusions: Although the Sof-Lex discs significantly reduced the surface roughness, their use with the prophylaxis paste and polishing brushes did not cause a further reduction in the surface roughness.

Introduction

Ceramics have a vast variety of applications in modern dentistry. However, they are brittle in nature and, for that reason, it is sometimes necessary to fuse them to alloys in order to reinforce them.

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Dental porcelain is a type of ceramic that is mainly composed of feldspar, quartz, and kaolin.[1] This material is fired at very high temperatures, and the subsequent glazing of the porcelain provides an aesthetic and hygienic surface that is suitable for crowns and other restorations.[2] Ideally, finished porcelain restorations from a technical laboratory should not require any modifications when fitted into the patient's mouth (this is usually the case). However, sometimes restorations cannot be fitted to the patient's mouth, possibly due to laboratory errors or a lack of clinical expertise. In this case, it then becomes necessary to adjust the occlusion for the comfort of the patient. In addition, some reduction in the proximal contacts and refining of the cervical margins may also be required.[3] These adjustments require chairside polishing to reduce the incidence of porcelain fracture and opposing tooth wear. The polishing of dental ceramics has long been advocated as a way to restore luster after adjustment by grinding, and there are various polishing kits available to achieve that purpose.[4] The roughness of the intraoral surface has a major impact on the initial adherence and the retention of microorganisms; furthermore, if the roughness is subgingival, the retention of microorganisms is higher.[5]

When a porcelain restoration is adjusted intraorally, the material becomes abrasive and encourages plaque retention. This causes damage to the opposing tooth and the restoration. Usually, intraoral adjustments are not required if the appropriate clinical techniques are used and the skills of the laboratory technician are good. Ideally, a restoration that has been fabricated and finished in the laboratory should retain its surface glaze after it has been fitted to the abutment teeth in the oral cavity.[6] However, this is not always the case, and these restorations often end up requiring adjustment. These modifications, as mentioned previously, are needed to correct occlusal interferences and improve the aesthetic qualities of the restorative material. A rough surface will abrade the opposing tooth or restoration, which is why it is required that the adjusted surface be polished and finished in an appropriate manner.

The aim of this study was to evaluate the surface roughness of a standard abraded dental porcelain. The surfaces that were evaluated and analyzed included roughened (to mimic chairside adjustment) and polished surfaces. The chairside polishing included the use of Sof-Lex aluminum oxide discs, polishing brushes, and commercially available prophylaxis polishing paste.

Materials and methods

After calculating the statistically appropriate sample size ($n = 22$ per group), the study was designed with the idea of testing two different polishing regimes: 1) Sof-Lex discs (3M ESPE, St. Paul, USA); and 2) Sof-Lex discs and prophylaxis paste (Conventional Coarse Grade Prophylaxis Paste, SS White, Prima Dental Group, Gloucester, UK) that was applied using polishing brushes (JUN CUP NYLON BRUSHES, Stoddard, Letchworth Herts, UK).

Accordingly, 66 VITA VMK95 (Vita Zahnfabrik, Bad Säckingen, Germany) ceramic porcelain samples were prepared, polished, and glazed in the dental laboratory of the Leeds Dental Institute (LDI), per the manufacturer's guidelines. All of the glazed specimens were roughened using a rugby ball-shaped diamond bur (no. 7506; Shank FG, SS White) at chairside, and 22 random specimens were selected for evaluation using confocal laser scanning microscopy (CLSM; Leica TCS SP2 with AOBS Leica Microsystems, GmbH, Germany) and scanning electron microscopy (SEM; Jeol JSM 35, Jeol LTD., Japan). The samples were returned to the specimen pool after measurement, and all 66 samples were then polished using Sof-Lex discs and 22 random specimens were selected for evaluation. The same regimen was applied to the next group, and then the 66 samples that were polished with Sof-Lex were returned to the specimen pool after measurement and then polished using the prophylaxis paste and polishing brushes, after which 22 random specimens were selected and evaluated.

The chairside roughening of the porcelain samples was achieved using the rugby ball-shaped diamond bur available at LDI. This was done using a high-speed handheld device (High Speed Hand Piece, NSK, Nakanishi, Japan) and lubricated using water. The bur was applied to the porcelain samples in one direction, against the direction of the rotation of the bur. The bur was applied against the direction of rotation of the bur because this allows more efficient cutting/grinding of the surface. The roughening of the porcelain samples was performed using intermittent pressure, which was applied to simulate clinical conditions. The speed of the handheld device was controlled using a foot paddle, with the aim of keeping it moderate and constant. A bur was used to roughen 10 porcelain specimens, then changed. The bur was changed after 10 specimens with the expectation that the bur would lose its cutting efficiency by this point. This group was named the rough group.

Chairside polishing of the samples was achieved as follows:

1. All of the 66 samples were polished using Sof-Lex finishing and polishing discs. For the current study, 13-mm Sof-Lex discs were used. All four grain sizes of Sof-Lex discs were used for polishing (i.e., coarse grit, medium grit, fine grit, and superfine grit of grain size 100, 29, 14, and 5 μm, respectively).
2. For each sample, new Sof-Lex discs of each grit size were used during the polishing procedure. All of the Sof-Lex discs were applied to the porcelain samples in one direction for 20 seconds each (80 seconds total) using a slow-speed handheld device (Slow Speed Hand Piece, NSK, Nakanishi, Japan) at moderate speed, making sure that only light intermittent pressure was applied. The pressure was kept constant as much as possible for each sample. From the 66 available samples, 22 randomly selected samples were chosen for observation. This polishing technique was named polishing technique 1 (PT1).
3. The 22 samples selected for PT1 were put back, and the total sample size of 66 was maintained. The samples were then subjected to polishing with the polishing brushes and prophylaxis paste for 30 seconds across the entire surface of the sample. The brushes were applied using a slow-speed handheld device at a moderate

speed with intermittent pressure, after which 22 random samples from the total were selected for observation. This polishing technique was named polishing technique 2 (PT2).

To evaluate the surface roughness, samples from each group were placed on the stage of the CLSM. The roughened and polished surfaces were placed upright, and the scan was carried out across three regions of interest of each sample. The CLSM available at the Oral Biology Department of Leeds Dental Institute (LDI) is a laser scanning microscope (Model No: Leica TCS, SP2 with AOBS, Leica Microsystems, GmbH, Germany).

The scan was carried out as follows. Reflected light images of the samples were generated using an Ar/Kr laser using a $5\times/0.15$ objective lens in xyz scan mode, a scan format of 512×512 pixels, and a scan speed of 400 Hz. The stage of the CLSM was moved through the z-direction between the first detected and the last detected reflex of light on the specimen. Objective magnification of $5\times/0.15$ was selected because this lens provides a scanned surface area of $9\,mm^2$, which is larger than the scanned surface areas that could be measured using the other lenses that were available at LDI. In addition, the optical properties of the $5\times/0.15$ lens allow deeper penetration of light into the samples.

Optical sections that were $10\,\mu m$ apart through the z-axis were taken to generate a series of images. The image series was converted to a topographical image using Leica confocal processing software (Leica Microsystems, GmbH, Germany), and a region of interest ($8.5\,mm^2$) was created to be used for all of the samples. A roughness profile was generated for the region of interest that included surface area, average height/roughness (Ra), root mean square roughness (Rq), minimum valley (Rv), and maximum peak (Rp) (please see the section below for the definitions of these parameters).

For each of the three regions of interest of each sample, the following roughness parameters were measured[7]:

(a) Ra: Defined as the arithmetic average of the profile ordinates within the measured section. This can also be called the average height.
(b) Rq: Defined as the root mean square value of the profile ordinates within the measured sections.
(c) Rv: Defined as the depth of the deepest valley, which is based on the average height.
(d) Rp: Defined as the maximum height on a profile ordinate, which is based on the average height.

SEM, which was interfaced with Genie software (Deben Engineering, Debenham, UK), was also used for the visual evaluation of the samples from the different groups. The selected samples to be observed under SEM were first sputtered with a gold coating using an Agar Auto Sputter Coater (Agar Scientific, Essex, UK).

Results

Analysis of the results was carried out using SPSS (version 13; SPSS Inc., Chicago, IL, USA). Visual analysis was carried out along with the statistical analysis by observing the samples under SEM. Results were analyzed using one-way analysis of variance (ANOVA) with the post hoc Tukey test at a significance level of 5%. The results indicate that there were statistically significant differences in terms of all of the surface roughness profile parameters between the rough group and PT1 ($P < 0.05$) and PT2 ($P < 0.05$). The results also indicate that there were no statistically significant differences in terms of the profile parameters between the two polished groups (i.e., PT1 and PT2) ($P > 0.05$).

The two SEM diagrams photographically illustrate the differences in surface roughness between the polished samples and the roughened surfaces. This reinforces the surface roughness data that were obtained from the CLSM analysis of the surfaces. Fig. 1 shows a rougher surface than that of the polished surface with disruption to the ordered structure, as shown in Fig. 2. The surface roughness parameters of each material are presented in the Table 1.

Discussion

Many studies can be found in the dental literature that evaluate surface roughness using Ra. Various techniques have been used to quantify surface roughness using Ra, the most common being tactile profilometry.[8,9] There is some variation in the Ra values depending on the technique used, and thus direct comparisons are not easy. A study was conducted in which a correlation between the Ra values obtained by tactile and optical profilometry methods was drawn using Ra values obtained using SEM and CLSM.[10] Diamond-coated titanium alloys were used as the test specimens, and the results indicate that the Ra values of the same samples obtained using different methods were significantly different. It was also found that CLSM and SEM offer valid data on surface roughness that can be accompanied by topographical images.

However, Ra does not fully characterize the surface roughness of a material, and one of the reasons that many dental studies have been criticized is because they only used this parameter to evaluate roughness.[3] Thus, to obtain information regarding the peaks and valleys of the surface of a material, two parameters—peak roughness (Rp) and valley roughness (Rv)—are described in the British Standard.[7]

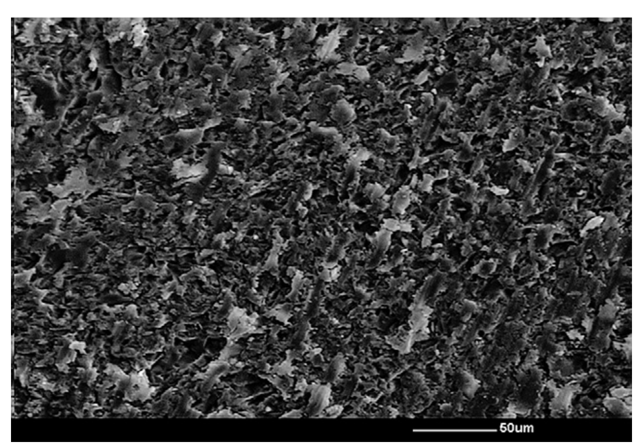

Figure 1 Representative SEM image of a rough sample.

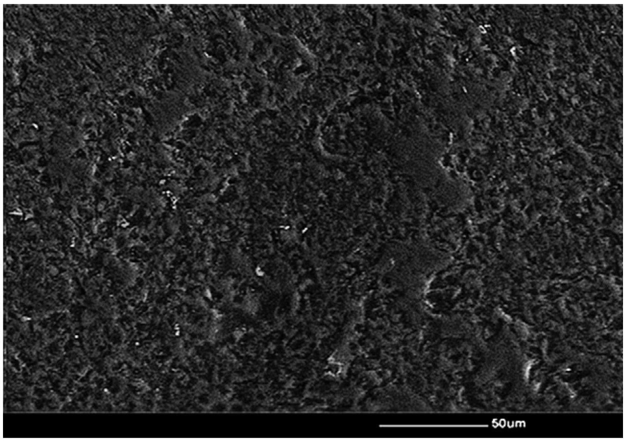

Figure 2 Representative SEM image of a polished sample (PT1).

SEM has been used in various areas of dentistry, as well as for the microscopic examination of ceramic materials. This method provides an excellent method for high-resolution imaging once the original magnification has been set to a certain level. However, the samples may have to be coated with gold before being inserted into the chamber of the microscope.

CLSM is routinely used to analyze surface texture, to determine the actual profile, and to actually profile the numerical roughness parameters.[11] It has also been used along with atomic force microscopy to access the surface roughness of fiber posts, as well as to access the surface topography of dental implants.[12] The determination of surface roughness using CLSM is described in the literature.[3,13] It allows the optical serial sectioning of thick samples, which allows both visualization and quantification analysis.[14] Although it can describe the topology of the surface, its applications are restricted to magnifications similar to those of light microscopy and laser reflection of the materials under examination is required.[15]

Confocal microscopy is an imaging method that has been shown to be consistent during the various stages of gathering data, and the scans are very similar[16]; however, the accuracy may be affected because there are resolution limitations to CLSM, which might underestimate the surface.[14] Resolution is a function of the optical properties of the objective lens and the pinhole. In the current study, the pinhole was optimized to an arbitrary value (1 unit) to reflect the lens used. This was kept constant during all of the scans of this study and was not changed. Because the diameter of the pinhole was not decreased, the resolution was unaffected (decreasing the diameter increases the resolution).

Table 1 Statistical differences in terms of surface roughness parameters between the different study groups.

Group	Ra (μm)	Rq (μm)	Rv (μm)	Rp (μm)
Rough	11.48 (3.02)	15.55 (4.62)	27.43 (4.01)	89.70 (11.24)
PT1	7.62 (2.01)	9.65 (2.38)	23.25 (3.68)	54.59 (7.78)
PT2	7.47 (0.98)	9.68 (1.24)	22.96 (2.42)	55.15 (8.58)

The material used in current study was VITA VMK 95, which is a fine-grain feldspathic porcelain that requires sufficient time and force to grind and polish its surface. The results of the current study showed that there was a significant reduction in the surface roughness after polishing with Sof-Lex discs. All the surface roughness parameters demonstrated significant reductions in both the polished and roughened samples.

Gomis et al[6] concluded that Sof-Lex discs produce the best results on ceramics. The surface roughness parameters analyzed in their study included Ra, Rz, Rpm, and Rz:Rpm; Rz was defined as the sum of the largest profile peak and the largest profile valley,[7] and Rpm was defined as the mean value of the leveling depths of five consecutive sampling lengths. These parameters provide reliable information about the shape of the profile. The Rz:Rpm ratio also provides reliable information about the profile shape. A Rz:Rpm ratio > 5 indicates a sharp ridge, and a ratio < 5 indicates a rounder profile shape.[17] In the study by Gomis, Sof-Lex discs of three grits—coarse, medium, and fine—were used with an Ivoclar IPS Classic (metal-ceramic porcelain type, Ivoclar Vivadent, Liechtenstein) under moderate pressure and dry conditions for 30 seconds each (90 seconds total). While they did not use superfine grit in the polishing sequence, the sequence they used is still comparable to the current investigation of VITA VMK 95 in which all four grits were used for 20 seconds each (80 seconds total). The use of all four grits, including super fine, is indicated to achieve the best possible results and is recommended by the manufacturers. In the current study, the manufacturer's recommendations were followed. Polishing was carried out at a moderate speed, not very high, because high polishing speeds produce specimens that are weaker than those polished at lower speeds.[18]

The current investigation can be directly compared with the study by Al-Shammary et al[3] in which Sof-Lex discs were used on an experimental and a commercially available CAD/CAM restorative material. Their experimental material was a glass ceramic that consisted of crystals of barium/potassium fluormica in an aluminosilicate glassy matrix, while VITA VMK II consists of homogenous, fine-grained, feldspathic porcelain. Their experimental material demonstrated higher resistance to fracture and, thus, more force was required to reduce the surface roughness by removing material from the surface. They used all four grit sizes of Sof-Lex discs (i.e., coarse, medium, fine, and superfine), and they polished the surfaces of five samples of each material for 1 minute with each Sof-Lex grit (4 minutes total), travelling across the samples in one direction. Evaluations were carried out using CLSM, and the surface roughness parameters that were investigated included Ra, Rp, Rv, and Rq. Their results also confirmed that Sof-Lex significantly reduces the surface roughness of both commercially available and experimental ceramics. Their investigation was performed on a smaller sample size ($n = 5$ per group) compared with the current study on VITA VMK 95, which was conducted on a larger sample size ($n = 22$ per group). A larger sample size is advisable because a larger sample size yields a more powerful study.

In the above mentioned studies and in the current investigation on VITA VMK 95, Sof-Lex discs were used under dry conditions. Dry finishing with Sof-Lex discs has been proven to produce a superior finish compared with the surfaces produced using wet finishing with Sof-Lex discs.[19] There is also some variation in terms of the loads, speeds, and times used by different practitioners during polishing, and they often finish materials in an arbitrary manner. Although Sof-Lex discs significantly reduce surface roughness, their use may still be limited to areas with deep pits and fissures. Although the study design of this study is not similar to those of the studies by Al-Shammary et al[3] or Gomis et al,[6] who used ceramic materials other than VITA VMK 95, both of their studies support the findings that Sof-Lex discs have a reasonable effect on the reduction of surface roughness.

It is also clear from the results of the current study that prophylaxis paste has no significant effect on the surface roughness parameters of the ceramic. Prophylaxis pastes have been shown to provide anticaries effects when used in combination with fluoride gels or fluoride solutions,[20] and they are also frequently used after regular periodontal procedures to smooth tooth surfaces in clinical practice. However, its use as a polishing agent on ceramics has not been widely documented.

Referring to Table 1, the Rq values of PT2 are slightly higher. In addition, the mean Rv values are lower and the Rp values and higher for PT2 compared with PT1. However, these results are not statistically significant. This indicates that the use of a prophylaxis paste on ceramics may lead to an increase in surface roughness instead of decreasing surface roughness.

The factors that influence surface roughness may be related to the composition of the paste, the application force, and the applied duration of the paste.[21] Other factors may include the structure and composition of the restoration itself. The paste used in the current study is a conventional, coarse-grade, pumice-based paste. It may be that the coarse grain of the paste resulted in a slight increase in two of surface roughness parameters, namely Rq and Rp. Prophylaxis paste is acceptable for various clinical applications; however, its effect on the surface roughness of ceramics requires further investigation.

Reduction in surface roughness is always desirable because a rough surface on a restoration will attract more plaque and may result in periodontal problems. It is also necessary that the surface roughness be reduced in order to avoid wear of the opposite dentition. In addition, a smooth porcelain restoration is essential for clinical success because a smooth surface will resist fractures that can result in surface flaws. The results of this study suggest that a significant decrease in the surface roughness of the feldspathic porcelain, VITA VMK 95, can be achieved in a reasonable time using Sof-Lex discs.

Conclusion

Following the use of CLSM and SEM to evaluate the surface roughness of a standard porcelain, VITA VMK 95, the following conclusions were reached:

1. Compared with the rough group, the use of Sof-Lex aluminum oxide discs significantly reduced surface roughness after a certain polishing sequence was used.
2. The subsequent use of prophylaxis paste with polishing brushes on the surface of a ceramic that had already been polished with Sof-Lex discs did not produce a statistically significant better finish. Their use for polishing ceramics should be further investigated.

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