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ORIGINAL ARTICLE

An In Vitro Study to Identify a Ceramic Polishing Protocol Effecting Smoothness Superior to Glazed Surface

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Abstract Polishing is taken up as an alternative to reglazing after adjustments of glazed ceramic prosthesis. An in vitro study was carried out to evaluate three different ceramic polishing systems and their combinations to identify a method that would achieve surface smoothness superior to the glazed surface. 77 glazed feldspathic porcelain disc surfaces, of diameter 12.5 mm and thickness 2 mm were constituted into seven groups of 11 specimen surfaces each. The glazed surfaces in the first group served as control (C). They were not subjected to deglazing or polishing. The remaining 66 surfaces underwent deglazing. The deglazed surfaces in the second group (D) were retained as such and did not undergo polishing. The deglazed surfaces in the third group (Wh), were polished using a polishing wheel (CeraMaster). In the fourth group (K), an adjustment kit (Porcelain Adjustment kit) was used for polishing the deglazed surfaces. The fifth group (Wx) was polished with diamond particle-impregnated wax (Dura-Polish Dia). In all these three groups, polishing was done for 40 s. The deglazed surfaces of the sixth group (WhWx) were polished initially with polishing wheel for 40 s and then with diamond particle-impregnated wax for 40 s. In the seventh group (KWx), the deglazed surfaces were polished with an adjustment kit (Porcelain Adjustment kit) for 40 s followed by diamond particle-impregnated wax (Dura-Polish Dia) for 40 s. In the sixth and seventh groups, the total polishing time was 80 s each. From each group, one specimen was set aside for scanning electron microscopy (SEM). The remaining ten specimens in each group underwent colorimetry and profilometry. Colorimeter (Minolta CR-200b ChromaMeter; Minolta, Osaka, Japan) was used to measure parameters according to CIE L*a*b* colour system and colour difference (ΔE) between control and other groups were calculated. Profilometer (Talysurf CLI 2000) was used to measure the surface roughness (Ra). The data were statistically analysed by one way ANOVA and Tukey HSD tests. The colour differences were well within the acceptable range of 3.3 units in groups subjected to polishing. Polishing with porcelain adjustment kit alone, diamond particle-impregnated wax alone or polishing wheel followed by diamond wax created surfaces with smoothness comparable to the glazed surfaces. The group polished by adjustment kit followed by diamond particle-impregnated wax showed surface roughness significantly less than the glazed surfaces. The SEM observations were corroboratory. It can be concluded that polishing with porcelain adjustment kit followed by diamond particle-impregnated wax, created surfaces significantly smoother than the glazed specimens with no significant negative effect on colour and thus can be a technique superior to glazing.

Keywords Feldspathic porcelain · Ceramic polishing · Reglazing · Porcelain adjustment kit · Diamond-particle impregnated wax

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Introduction

The potential of porcelain enamels to imitate the colour of teeth and gingival tissues was recognized and the first successful porcelain dentures were fabricated in eighteenth century [1]. The aesthetics, durability, biocompatibility and universal availability of dental porcelain provide a major advance in aesthetic restorative dentistry [2]. Ceramics exhibit the least amount of bacterial and glucan adhesion compared to amalgam, resin, composites and casting alloys.

A glazed ceramic surface increases the fracture resistance and reduces the potential abrasiveness by sealing the open pores in the surface of the fired porcelain [1]. It is a common clinical practice to adjust the glazed surface of porcelain restorations before insertion by grinding [3], for correcting occlusal interferences and inadequate contours. Adjustment procedures break the glaze layer and create a rougher surface promoting plaque formation, gingival inflammation and adverse soft tissue reaction or may increase the wear of the opposing dentition or restorative material [4–11]. Glazing or polishing after the adjustment procedures, is necessary to improve the flexural strength [12–14] and appearance of the restoration [15]. Several reports described different polishing techniques for ceramic restorations and supported the use of polishing as an alternative for glazing [16–24].

The purpose of this in vitro study was to investigate the efficacy of the individual porcelain polishing systems and to assess the effects of sequential combination of polishing systems on feldspathic porcelain in terms of colour difference (ΔE) and surface roughness (Ra).

Materials and Method

77 feldspathic porcelain (Vintage Halo, Shofu Inc., Kyoto 605-0983, Japan; Lot No. 010719) surface specimens of diameter 12.5 mm and thickness 2 mm were prepared using a vinyl polysiloxane (VPS) (Elite H-D+ Putty, Zermack, Italy) mould. The VPS mould consisted of two VPS pieces, each piece corresponding to one half of the disc specimen, which when placed opposingly over a glass slab formed the complete mould of diameter 17 mm and depth 2.9 mm, the larger dimensions being necessary to allow for firing shrinkage and losses during finishing. The porcelain powder and liquid were mixed in a fixed ratio (in a volume ratio of 4:1). The specimens were placed in a porcelain-firing oven (Programat P 100, Ivoclar-Vivadent) and fired according to manufacturer's instructions (approximately 900–920 °C at operational voltage of 220–240 V).

Specimens were finished with medium-grit diamond rotary instrument with a handpiece rotating at 10,000 rpm. Overglaze (Porcelain Glazing powder, Shofu Inc. Kyoto 605-0983, Japan) was applied and the specimens were fired with a starting temperature of 650 °C and increase of 50 °C/min. and, on reaching 910 °C, holding the specimens at that temperature for 1 min, as per manufacturer's instructions.

These 77 specimens were divided into seven groups of 11 specimen surfaces each. The glazed surfaces in the first group served as control (C) and were not subjected to deglazing or polishing. The remaining 66 surfaces underwent deglazing using a medium-grit diamond rotary instrument (DFS, SIDIA, Sintered diamond, Germany, Model No. 59181) with a slow-speed handpiece, rotating at approximately 10,000 rpm, with water coolant to simulate clinical procedures. The bur was applied over the specimen surface producing linear contact and moved from left to right, in multiple strokes, while rotating the disc gradually, to cover the entire disc surface evenly, for 75 s. The glaze removal was visually assessed with naked eye and using a magnifying glass of power 10 diopters in incandescent, fluorescent and natural light.

The deglazed surfaces in the second group (D) were retained as such and did not undergo polishing. The remaining 55 deglazed surfaces were polished using a single polishing system or a combination of systems, as shown in Tables 1 and 2, using a slow-speed handpiece rotating at approximately 10,000 rpm, as advised by the manufacturer. Polishing was performed by the same person in the same sitting. The deglazed surfaces in the third group (Wh), were polished using a polishing wheel (CeraMaster, Shofu Dental GmbH, Ratingen, Germany) for 40 s. In the fourth group (K), an adjustment kit (Porcelain Adjustment kit, Shofu Dental GmbH, Ratingen, Germany) was used for polishing the deglazed surfaces. It consisted of a 4-step process: white stone and three different polishers of decreasing particle sizes were used, one at a time, for 10 s each, with a total duration of 40 s. The fifth group (Wx) was polished with diamond particle-impregnated wax (Dura-Polish Dia,Shofu Dental GmbH, Ratingen, Germany) using a brush (Verankover, Germany). The rotating brush was first applied over the wax and then the specimen surface was polished for 40 s. The deglazed surfaces of the sixth group (WhWx) were polished initially with polishing wheel for 40 s and then with the diamond particle-impregnated wax for 40 s. In the seventh group (KWx), the deglazed surfaces were polished initially with the Porcelain Adjustment kit for 40 s as described above, and then with the diamond particle-impregnated wax for 40 s. In the sixth and seventh groups, the total polishing time was 80 s each. The total duration of polishing was not a test parameter in the present study.

All the specimens were boiled for 15 min for removing wax and wax-like substances that may give the specimens

Table 1 Materials used in the study

Material	Product	Code	Manufacturer
Adjustment kit	Porcelain adjustment kit	K	Shofu Dental GmbH, Ratingen, Germany
Polishing wheel	CeraMaster polishing wheel	Wh	Shofu Dental GmbH, Ratingen, Germany
Polishing wax	Dura-Polish Dia diamond particle-impregnated wax	Wx	Shofu Dental GmbH, Ratingen, Germany

Table 2 Polishing methods employed

	Study group	Polishing system/s	Manufacturer	No.of surfaces	Polishing time
1	C	Nil (Glazed surface)		11	
2	D	Nil (Deglazed surface)		11	
3	Wh	CeraMaster polishing wheel	Shofu Dental GmbH, Germany	11	40 s
4	K	Shofu porcelain adjustment kit	Shofu Dental GmbH, Germany	11	40 s
5	Wx	Dura-Polish Dia diamond wax	Shofu Dental GmbH, Germany	11	40 s
6	WhWx	CeraMaster polishing wheel + Dura-Polish Dia diamond wax	Shofu Dental GmbH, Germany Shofu Dental GmbH, Germany	11	40 + 40 s
7	KWx	Shofu porcelain adjustment kit + Dura-Polish Dia diamond wax	Shofu Dental GmbH, Germany Shofu Dental GmbH, Germany	11	40 + 40 s

smoothness by a waxy coat. The specimens were then ultrasonically cleaned (Spurby Industrial Company Ltd., Taiwan) with distilled water and dried with a blast of air for 30 s before the measurements.

To evaluate the effects of polishing systems on the ceramic surfaces microscopically, one specimen surface from each of the seven groups was analysed under Scanning Electron Microscope (5600LV, SEM, JEOL, Tokyo, Japan / EVO HD 15/25 SEM, Carl Zeiss Microscopy, LLC, Germany) at 15.0 kV, after sputter-coating with a thin film of gold using a sputter coater. The SEM photomicrographs were taken with 500× magnification and 2000× magnification for visual inspection.

There were 10 specimens remaining in each group and they underwent colorimetry and profilometry. Colour measurements were made using a Colorimeter (Minolta CR-200b ChromaMeter; Minolta, Osaka, Japan) according to the CIE L*a*b* colour system recommended by the Commission Internationale de l'Eclairage or International Commission on Illumination (CIE) in 1976. This instrument has a measuring head that uses diffuse illumination and 0-degree viewing angle geometry (specular component included) for colour measurements of surfaces, with light provided by a pulsed xenon arc lamp. The CIE L*a*b* colour system is an approximately uniform colour scale organized in a cube form. The L* value is a measure of lightness, the maximum for L* is 100 which represents a perfect reflecting diffuser. The minimum for L* is zero, which represents black. The a* value is a measure of redness (positive +a*) or greenness (negative −a*), and the b* value denotes yellowness (positive +b*) or blueness (negative −b*). These coordinates, obtained with a spectrophotometer, provide a numerical description of the colour position in a three-dimensional colour space.

The ΔL*, Δa*, and Δb* indicate how much a standard and sample differ from each other in L*, a*, and b* values, respectively. The total colour difference is denoted as ΔE. It mathematically expresses the amount of difference between the CIE L*a*b* coordinates of different specimens or the same specimen at different instances. The human eye cannot perceive colour difference (ΔE) values less than 1 [25]. ΔE values between 1 and 3.3 represent a perceptible and clinically acceptable range. ΔE values of 3.3 and higher are reported to be unacceptable under clinical conditions [26] and 3.3 has been used as the upper limit in several studies concerning the perceptibility of colour differences [27–31]. To position the tip of the colorimeter in the same location on each specimen, a nylon mould was prepared. The colorimeter was calibrated according to the manufacturer's instruction. The quantitative ΔE values between the specimens of group C and the experimental groups were calculated with the following formula [31]

$$\Delta E = \left[(L^*E - L^*C)^2 + (a^*E - a^*C)^2 + (b^*E - b^*C)^2 \right]^{1/2}$$

where (L*E − L*C), (a*E − a*C), and (b*E − b*C) are the differences in L*, a*, and b* values respectively; E represents the experimental specimens, and C represents the control specimens.

Surface roughness (Ra) of the specimens was evaluated using a profilometer (Talysurf CLI 2000, Taylor-Hobson Ltd., Leicester, England) equipped with confocal profilometric technology. The instrument is calibrated using a standard reference specimen. The measurement was done at three different locations for each specimen to obtain the general surface characteristics. The average values of these measurements are considered to be the Ra values.

The test parameters of the study, namely Ra and colour difference (ΔE) were analysed using computer software, Statistical Package for Social Sciences (SPSS) version 10. Data were expressed as mean and standard deviation. One way ANOVA was performed as parametric test to compare different treatments. Tukey's HSD was employed as post hoc analysis to elucidate individual multivariate comparisons. For all statistical evaluations, a two-tailed probability of value, <0.05 was considered significant.

Results

The mean colour difference values (ΔE), their standard deviations and results of one way ANOVA of test specimens are given in Table 3. The mean Ra values, their standard deviations and results of one way ANOVA of test and control specimens are given in Table 4.

The results of the present study showed significant differences in Ra and colour difference values (ΔE) among the groups studied. The Ra of the control group (C) i.e., the glazed surfaces, was 0.29 µm and that of the deglazed group (D) was 0.88 µm. The difference in Ra between the control and deglazed surfaces was significant statistically.

The group polished by polishing wheel (Wh) was the roughest among the groups that underwent polishing (Ra of Wh = 0.50 µm). The difference in roughness between this group and the control group (C) was significant statistically. Polishing by adjustment kit (K) (Ra of K = 0.44 µm) alone, diamond wax (Wx) (Ra of Wx = 0.40 µm) alone or polishing wheel followed by diamond wax (WhWx) (Ra of WhWx = 0.22 µm) results in surfaces with smoothness comparable to the glazed surface (control). The differences in values between the specimens of these three groups (K, Wx and WhWx) and control specimens were not statistically significant.

The group polished by porcelain adjustment kit followed by diamond wax (KWx) (Ra of KWx = 0.13 µm) had mean surface roughness less than the control group quantitatively and the difference between their values was statistically significant. Thus, polishing deglazed surfaces by porcelain adjustment kit followed by diamond wax results in surfaces smoother than and definitely superior to the glazed surface (control).

The difference between the roughness of deglazed specimens and each group of polished specimens was statistically significant, indicative of marked decrease in roughness by polishing.

The respective L*, a* and b* values of each group were as follows: C—73.0, 0.89 and 11.96. D—74.08, 0.31 and 8.88. Wh—73.55, 0.36 and 10.59. K—72.87, 0.76 and 11.25. Wx—73.15, 0.6 and 10.65. WhWx—72.78, 0.79 and11.73. KWx—72.52, 0.85 and 11.94.

Deglazed specimens had an average ΔE value of 3.402 which is perceivable by naked eye and more than the 3.3, the upper limit of clinically acceptable range of colour difference. Colour difference (ΔE) values were lower in the groups polished with (i) the adjustment kit followed by diamond wax (KWx) (ΔE 1.06), (ii) adjustment kit (K) alone

Table 3 Analysis of variance (one way ANOVA) of colour difference (ΔE) comparing different groups

Group	Mean	±SD	F value
Deglazed (D)	3.40^c	0.59	37.585**
Wheel (Wh)	1.67^b	0.28	
Kit (K)	1.07^a	0.57	
Wax (Wx)	1.57^b	0.44	
Wheel + Wax (WhWx)	1.07^a	0.48	
Kit + Wax (KWx)	1.06^a	0.36	

Values with same superscript (a, b, c) do not differ from each other—Tukey's HSD

** $p < 0.001$

Table 4 Analysis of variance (one way ANOVA) of surface roughness (Ra) in μm, comparing different groups

Group	Mean	±SD	F value
Control	0.29^{bc}	0.09	53.002**
Deglazed (D)	0.88^{e}	0.08	
Wheel (Wh)	0.50^{d}	0.15	
Kit (K)	0.44^{cd}	0.04	
Wax (Wx)	0.40^{cd}	0.20	
Wheel + Wax (WhWx)	0.22^{ab}	0.04	
Kit + Wax (KWx)	0.13^{a}	0.03	

Values with same superscript (a, b, c, d, e) do not differ from each other—Tukey's HSD

** $p < 0.001$

(ΔE 1.07) and (iii) the polishing wheel followed by diamond wax (WhWx) (ΔE 1.07); ΔE values were relatively higher with the use of (iv) polishing wheel alone (Wh) (ΔE 1.67) and (v) diamond wax alone (Wx)(Δ E 1.57). None of the polishing methods produced Δ E of 3.3 or more.

SEM photomicrographs (500× and 2000× magnification) of specimens demonstrated the surface texture exceptionally well and constituted a corroboratory assessment of the surface roughness. Examination of these images revealed surface appearance paralleling the mean surface roughness of study groups. The SEM photomicrograph of deglazed surface appears to be the roughest of all. The descending order of degree of irregularity and visual appearance of roughness was as follows: D, Wh, K, Wx, WhWx, KWx. The SEM photomicrograph of the surface polished with combination of adjustment kit and diamond particle-impregnated wax (KWx) is the smoothest of all the test specimens. Though this surface shows a few smoothened grooves, the overall surface appearance is markedly better than the SEM picture of the glazed surface (C). It may be noted that the glazed surface shows fine granularity in general and occasional "pebble-like" irregularities of varying size; they are clearly absent on surface polished with kit followed by diamond particle-impregnated wax (KWx) (Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9).

Discussion

The glazed surfaces of ceramic restorations become roughened during adjustment procedures for correcting occlusal interferences and inadequate contours. The roughened areas of restorations have been traditionally smoothened by reglazing. The increasing availability of newer polishing systems has evoked a keen interest in the studies comparing effects of polishing to glazed surface [4, 23, 24]. A few studies found polishing by combinations of systems producing surfaces as smooth as glazed surface [23, 24].

Many of the polishing systems that became commercially available over the years and tested by many researchers, have become unavailable later and new ones have been introduced. The most noteworthy and recent among them are polishing systems containing diamond particles. In 2006, Sarac et al. [23] concluded that the most efficient individual polishing system among those studied by them was porcelain adjustment kit. Porcelain adjustment kit is a combination of four components (adjusting, prepolishing, polishing and superpolishing). Further, they noted that other polishing systems, including diamond paste when used after adjustment kit, could provide only slight improvement and such an improvement was not statistically significant.

It is against this background that, the diamond particle-impregnated wax, which was introduced after diamond polishing paste, was studied. The differences in methodology, between the study of Sarac et al. and the present one, are to be emphasized. The present study used larger discs, longer total polishing time and longer polishing time per unit area. The disc diameter, surface area and duration of polishing per unit area were 10 mm, 78.54 mm^2 and 0.2547 s/mm^2 in the study by Sarac et al. and 12.5 mm, 122.71 mm^2 and 0.3260 s/mm^2 in the present study, respectively. Instead of polishing paste used by Sarac et al., diamond particle-impregnated wax was used in the present study.

In the study by Sarac et al. [23], the smoothness achieved by polishing with adjustment kit followed by polishing paste was similar to that of glazed surface. The present study achieved surface smoothness better than the glazed surface (the difference being statistically significant) by the use of porcelain adjustment kit followed by diamond particle-impregnated wax. The better result was thought to be due to the difference in the second polishing system and increase in the polishing time from 20 s (0.2547 s/mm^2) in the study by Sarac et al., to 40 s (0.3260 s/mm^2) or roughly $^1/_3$ s/mm^2 in the present study. As the area of deglazed surface on an adjusted restoration

Fig. 1 *Bar diagram* depicting the mean Delta E (ΔE) of different groups

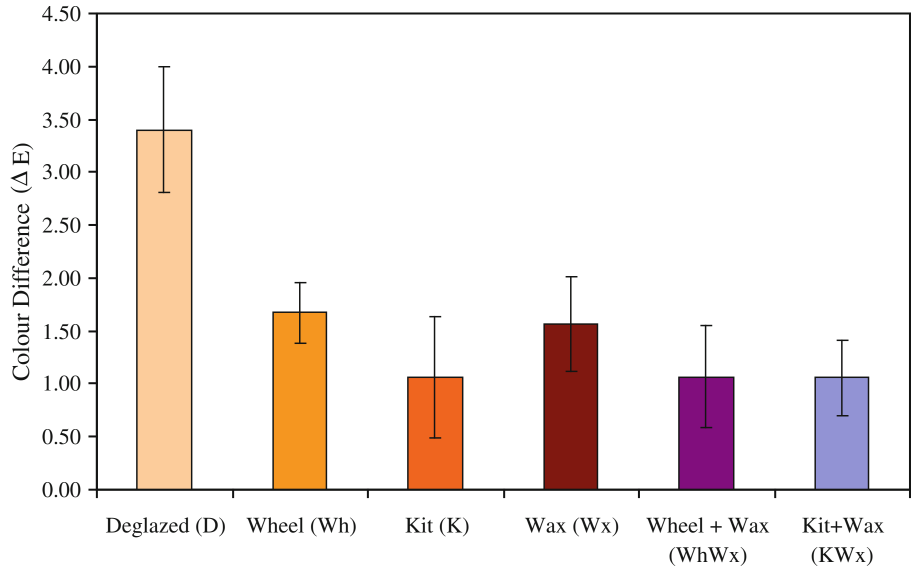
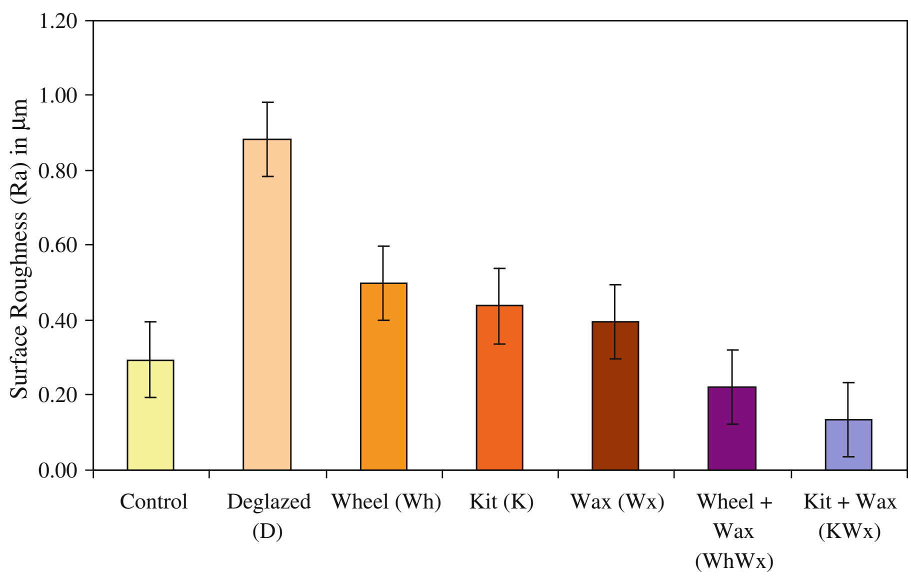


Fig. 2 *Bar diagram* depicting the mean surface roughness of different groups (in µm)



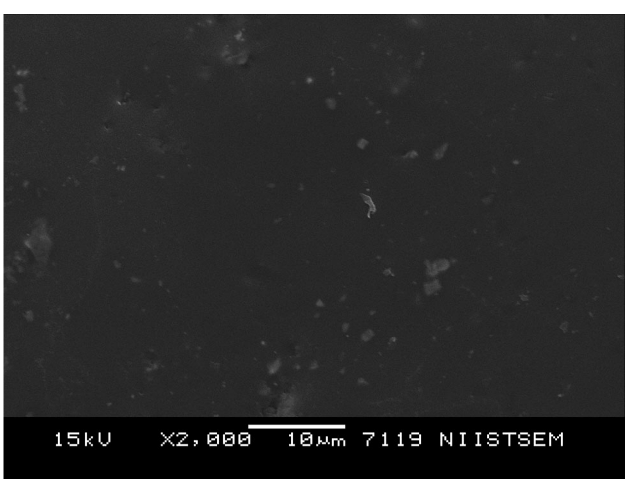


Fig. 3 SEM of glazed surface (Original ×2000)

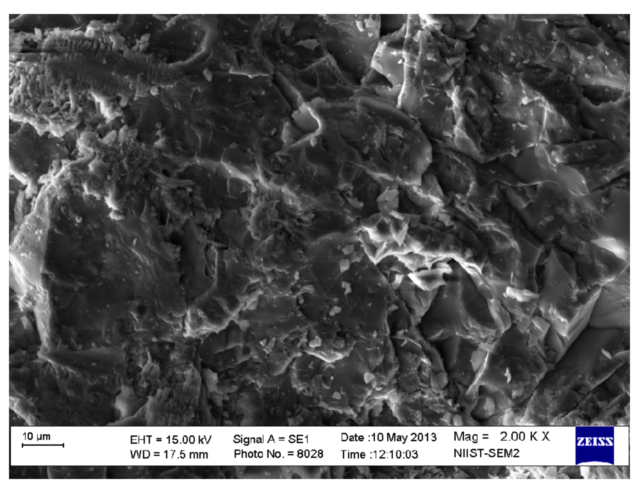


Fig. 4 SEM of deglazed surface (Original ×2000)

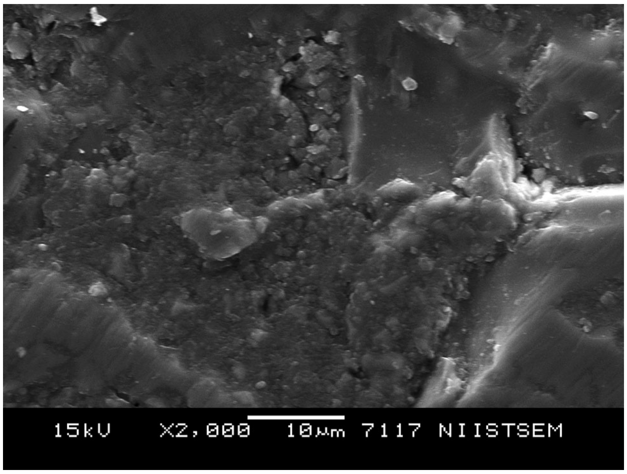


Fig. 5 SEM of surface polished with polishing wheel (Original ×2000)

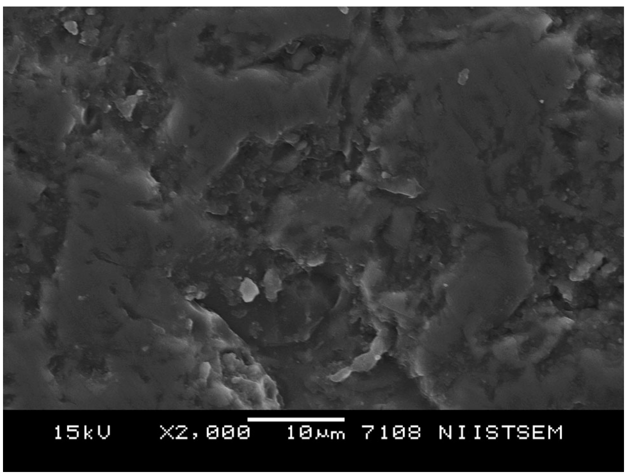


Fig. 6 SEM of surface polished with adjustment kit (Original ×2000)

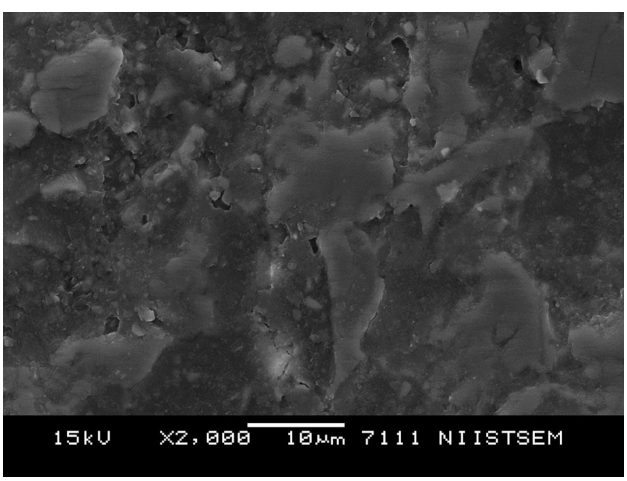


Fig. 7 SEM of surface polished with diamond wax (Original ×2000)

is minimal, the increase in the duration of polishing in the present study would not imply any significant increase in the total time spent by a clinician on a restoration.

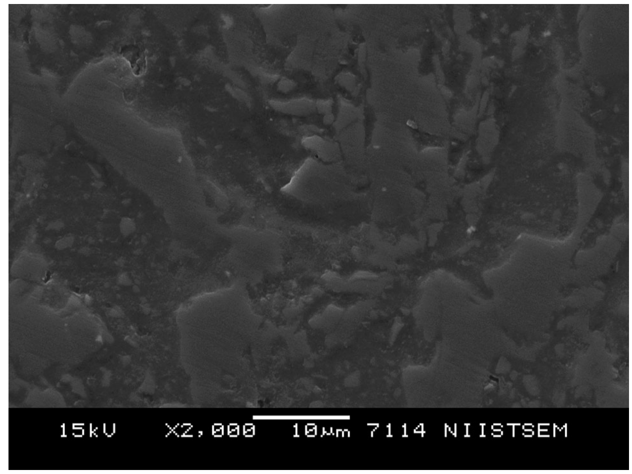


Fig. 8 SEM of surface polished with wheel + diamond wax (Original ×2000)

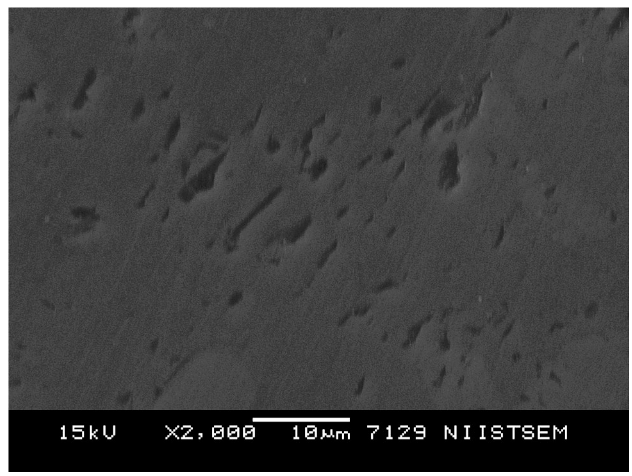


Fig. 9 SEM of surface polished with adjustment kit + diamond wax (Original ×2000)

The diamond wax could provide marked improvement in Ra values when used after the porcelain adjustment kit. The diamond wax contains a high density of pure diamond particles. The theoretical possibility of the wax base remaining on the surface pores, thereby bringing down the Ra values, was considered and investigated. The readings were done before and after dewaxing the specimens polished with diamond wax, by immersing in boiling water for 15 min and they were found to be similar.

Interestingly diamond wax, when used alone, could not produce surfaces smoother than the glazed surface. Thus it is logical to conclude that, to bring about the best effects within an acceptable polishing time of 40 s, the diamond wax needs the surface roughness to be "pre-reduced" to some extent, from the level of deglazed surface roughness to that produced by polishing with porcelain adjustment kit alone or polishing wheel alone.

Some of the limitations of the present study and areas requiring further research need elaboration. Different firing protocols with varying temperature settings and duration, multiple firings, application of vacuum during firing, varying quantity of liquid mixed with unit amount of porcelain powder etc can alter the porosity of the ceramic discs and restorations and hence their roughness when glaze layer is removed. These variables were not studied here. The polishing of ceramic prostheses which have curved surfaces is more laborious than that of a ceramic disc with planar surface. Furthermore, the area of surface where the glaze is lost during adjustment procedures of a ceramic restoration may not be equal to the surface area of a specimen disc. A study on experimental groups consisting of actual ceramic prostheses will be more informative. An analytical study on the abrasive particles of different polishing systems with particular reference to their hardness, size and chemical composition, is beyond the scope of the present study.

Conclusions

Within the limitations of this in vitro study, the following conclusions were drawn, keeping duration of polishing as 0.33 s/mm^2.

1. Polishing deglazed ceramic discs with the porcelain adjustment kit alone (K), diamond particle-impregnated wax alone (Wx) or polishing wheel followed by diamond particle-impregnated wax (WhWx) produced smoothness statistically comparable to glazed specimens (C).
2. Polishing deglazed ceramic discs with porcelain adjustment kit followed by diamond particle-impregnated wax (KWx), produced surfaces, significantly smoother than glazed specimens (C).

An implication of the present study in the clinical practice is that the adjusted areas of porcelain restorations may be polished with polishing wheel followed by diamond particle- impregnated wax to achieve smoothness comparable to reglazing. More importantly, the sequence of polishing with porcelain adjustment kit followed by diamond particle-impregnated wax, each for $^1/_3$ s/mm^2 can be superior to reglazing of restorations.

Conflict of interest None.

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