Effects of Different Polishing Protocols and Curing Time on Surface Properties of a Bulk-fill Composite Resin

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Objective: *To determine the effects of different polishing protocols and curing times on the surface roughness (SR), surface gloss (SG) and surface hardness (SH) of a bulk-fill composite resin (BCR).*

Methods: *A total of 30 block-shaped specimens (40 mm long × 10 mm wide × 2 mm thick) were made from Filtek Bulk-Fill composite resin and divided into two groups (n = 15) according to curing time (10 and 40 seconds). Each group was subdivided into five groups (n = 3) according to the polishing protocol: laboratory polishing with different silicon paper grits (G1:1200) → (G2:2400) → (G3:4000). Chairside polishing was performed using a series of Sof-Lex spiral (G4) and Jiffy Polisher (G5) points. The SR was measured by a surface profilometer. A Vickers indenter was used to test the SH, and a glossmeter was used to determine the SG at 60 degrees. The SR, SG and SH were quantified before and after polishing. A scanning electron microscopy (SEM) evaluation was then performed.*

Results: *The curing time did not affect the surface properties of the BCR ($P > 0.05$). Significant differences in SR (ranging from 0.1 to 2 μm) and SG (ranging from 20 to 90 GU [gloss unit]) were found according to the type of polishing protocol ($P < 0.05$). The SH values following different polishing protocols were significantly higher (ranging from 82 to 95 VH [Vickers hardness]) than the polishing values obtained before the polishing protocols ($P < 0.05$).*

Conclusion: *The tested chairside polishing protocols presented lower SG and higher SR values than the laboratory polishing protocols.*

Key words: *bulk-fill composite resin, curing time, polishing protocol, surface properties*

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Aesthetic concepts have been particularly important in driving the development of dental composite resins in the last few years. A glossy and perfectly smooth surface is a requirement for a desirable aesthetic appearance[1]. Such a surface also needs to remain smooth for a long period within the oral environment. The smooth surface, apart from enhancing the aesthetic result, prevents the formation of discolouring films and plaque retention due to the absence of micro-roughness[1]. Moreover, surface hardness and smoothness decrease the coefficient of friction and subsequently this may reduce the wear rate[2], which compromises the clinical performance of the composite restorations. Surface quality also affects the fracture resistance in brittle materials such as composite resins[3]. The quality of a polished composite resin

surface is related to intrinsic material properties and to the finishing/polishing procedure applied[4].

It has been thought that incremental filling techniques using conventional composite resins are time consuming and therefore new types of composite resins have been launched; these are called bulk-fill composite resins (BCRs)[5]. Unlike conventional composite resins, which are typically placed in maximum increments of 2 mm, BCRs are allowed to be placed in increments of 4 mm or thicker[5]. There are now several BCRs available, some being flowable (low viscosity) and some highly viscous. The latter, high viscous BCRs, do not require an additional surface layer of conventional composite resin, and may be used as a single-step bulk-filling material[5,6]. However, independent in vitro and in vivo studiesare limited, especially on the aesthetic appearance of high viscous BCRs in terms of their surface smoothness, hardness and gloss.

It is well known that the mechanical properties, and thus the clinical performance, of these BCRs are influenced by the degree of monomer conversion[5]. From this point of view, the increase in light cure exposure time is one of the several clinical approaches that have been investigated to prolong the clinical lifetime of the bulk-fill composite restorations[7]. It has been suggested that surface properties can be determined both by the intrinsic characteristics of the composite resin and by the finishing and polishing procedures[8]. Thus, a successful composite restoration requires care not only in the restorative material selection, with ideal aesthetics and mechanical strength characteristics, but also in the choice of the finishing and polishing protocol[1,9]. Several finishing and polishing protocols are available on the market, including diamond burs, rubber cups, discs and abrasive pastes[9-11]. Some studies have indicated that aluminium oxide discs produce smoother surfaces compared with diamond burs, tungsten carbide drills and rubber cups associated with polishing pastes[12-14]. However, Hoelscher et al[15] concluded that the use of finishing tips, followed by polishing pastes, does not provide the same surface smoothness as aluminium oxide. A limited number of studies have so far evaluated the effect of exposure time and polishing protocols on the surface properties of the new high viscous BCRs[16-18].

Therefore, the aim of the present in vitro study was to determine the effects of different polishing protocols and curing time on the surface roughness (SR), surface gloss (SG) and surface hardness (SH) of a high viscous BCR. The null hypothesis tested was that different polishing protocols and curing times do not have any effect on the surface properties (SR, SG, SH) of BCRs.

Materials and methods

Thirty block-shaped specimens (40 mm long × 10 mm wide × 2 mm thick) of BCR (Filtek Bulk-Fill, A2 Shade, 3M ESPE, St. Paul, USA) were made in half-split moulds between transparent Mylar sheets. A thin glass plate was placed on the free surface of the composite resin to remove the material excess. Specimens were divided into two groups (n = 15) according to the curing time used. Polymerisation of the BCR was performed using a hand light-curing unit (Elipar S10, 3M ESPE, Seefeld, Germany) for either 10 or 40 seconds, in five separate overlapping portions, from one side of the mould. The wavelength of the light was between 430 and 480 nm and the light intensity was 1600 mW/cm^2. The specimens were then subdivided into five groups (n = 3) according to the polishing protocols. Laboratory polishing was performed using different silicon paper grit sizes (G1:1200) → (G2:2400) → (G3:4000) at 300 rpm while water cooled using an automatic polishing machine (Struers RotoPol-11, Copenhagen, Denmark) for 3 minutes. The chairside polishing was performed using a series of Sof-Lex spiral (beige and pink, G4) (3M ESPE, St. Paul, USA) and Jiffy Polisher points (yellow, G5) (Ultradent Products, South Jordan, USA) with a low-speed hand piece (20 rpm) and water cooling (9 minutes). One side of the specimen surface facing the mould was polished and this side was named 'polished side'. The other side of the specimen facing the glass slide and the Mylar strip remained unpolished and was named 'unpolished side'. After polishing, the specimens were rinsed with water and stored dry at room temperature before testing.

In total, there were 10 groups (n = 3) involving three different laboratory polishing paper grits, and two chairside polishing protocols with two curing times. The surface properties were assessed for the polished and unpolished sides.

The SR of each group was measured using a surface profilometer (Mitutoyo surftest 301, Mitutoyo Corporation, Kanagawa, Japan), with a standard cut-off of 0.8 mm, a transverse length of 0.8 mm and a stylus speed of 0.1 mm/s. The roughness average (Ra) of a specimen was defined as the arithmetic average height of roughness component irregularities from the mean line measured within the sampling length. Five profilometer tracings were made for each specimen and the numerical average was determined for each group.

The SG was measured at a 60-degree incidence angle using a calibrated infrared Zehntner-Glossmeter (Zehntner Testing Instruments, Sissach, Switzerland)

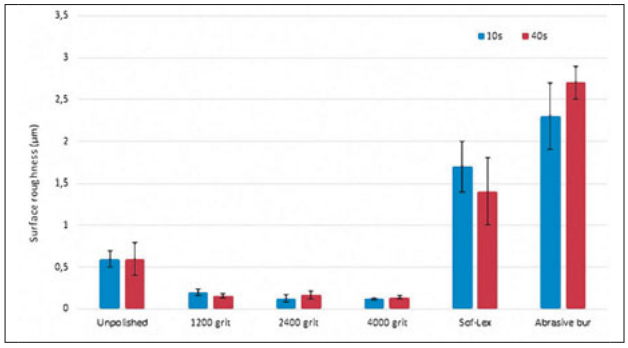

Fig 1 Surface roughness (Ra) values of specimens in relation to different curing times and polishing protocols. Vertical lines represent the standard deviation (Ra: roughness average).

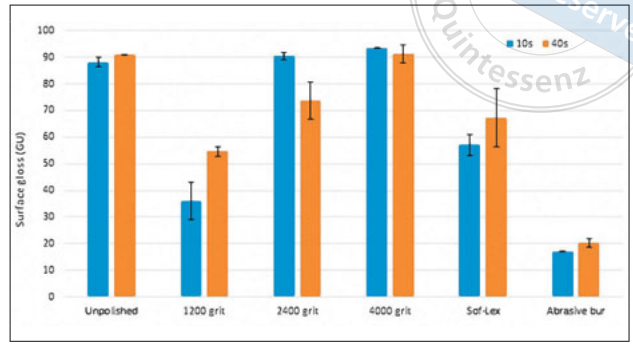

Fig 2 Surface gloss (GU) values of specimens in relation to different curing times and polishing protocols. Vertical lines represent the standard deviation (GU: gloss unit).

with a square measurement area of 6 mm × 40 mm. The average of five measurements was recorded per surface.

The surface hardness (SH) of each group was measured using a Duramin hardness microscope (Struers) with an objective lens x40 and a load of 1.96 N applied for 15 seconds. Each specimen's surface was subjected to five indentations. The diagonal length impressions were measured, and the Vickers values were converted into microhardness values by the machine. The microhardness was obtained using the following equation:

$$H = \frac{1854.4 \times P}{d^2}$$

where H represents the Vickers hardness in kg/mm^2, P is the load in grams and d is the length of the diagonals in µm.

Scanning electron microscopy (SEM) (JSM-5500, JEOL, Tokyo, Japan) was used to observe and capture images of the polished surfaces. Specimens (n = 2) from each of the polishing protocols were stored in a desiccator for 1 day. Subsequently, they were coated with a gold layer using a sputter coater in a vacuum evaporator (BAL-TEC SCD 050, Sputter Coater, Balzers, Liechtenstein) before the SEM examination. SEM observations were carried out at an operating voltage of 8 to 15 kV.

The data were analysed using SPSS version 23 (SPSS, IBM, Armonk, New York, USA) using analysis of variance (ANOVA) with $P < 0.05$ significance level, followed by a Tukey's HSD post-hoc test to determine the differences between the groups.

Results

The SR, SG and SH values of the tested high viscous BCR after various polishing protocols and curing times are shown in Table 1 and in Figures 1, 2 and 3, respectively. The ANOVA results revealed that curing time had no significant effect ($P = 0.112$) on the tested surface properties of the BCR. Significant differences in SR (ranging from 0.1 to 2 µm) and SG (ranging from 20 to 90 GU) were found according to the type of polishing protocol ($P < 0.05$). The specimens polished with the 4000 grit paper showed the lowest SR (0.1 µm) and the highest SG (93 GU) values among all the groups tested.

Regarding the analysis of the simple linear regression model between SR and SG, and as theoretically expected, these two variables demonstrated a linear correlation ($R^2 = 0.983$). As seen in Figures 1 and 2, the highest SR (2.7 µm) and lowest SG (17 GU) values were observed for specimens polished by Jiffy Polisher points. The chairside polishing protocols used in the present study increased the SR and decreased the SG

Table 1 Mean and standard deviation of surface roughness (SR), surface gloss (SG) and surface hardness (SH) for the tested bulk-fill composite resin (BCR) after various polishing protocols and curing times.

Groups	SR (µm)		SG (GU)		SH (VH)	
	10 s	40 s	10 s	40 s	10 s	40 s
Unpolished	0.6 (0.10)	0.6 (0.20)	88.2 (1.7)	90.9 (0.2)	59.6 (5.0)	67.2 (3.3)
1200 grit	0.2 (0.04)	0.1 (0.03)	36.1 (7.0)	54.6 (1.8)	95.4 (8.3)	95.5 (4.7)
2400 grit	0.1 (0.04)	0.1 (0.05)	90.4 (1.4)	73.8 (7.0)	84.1 (3.0)	93.3 (4.3)
4000 grit	0.1 (0.01)	0.1 (0.02)	93.3 (0.1)	91.3 (3.5)	85.8 (9.0)	87.3 (9.0)
Sof-Lex	1.7 (0.30)	1.4 (0.40)	57.1 (4.0)	67.3 (11.0)	81.6 (7.0)	92.9 (7.0)
Abrasive bur	2.3 (0.40)	2.7 (0.20)	17.1 (0.3)	20.3 (1.7)	83.9 (8.0)	87.1 (7.0)

GU: gloss unit; VH: Vickers hardness; s: seconds.

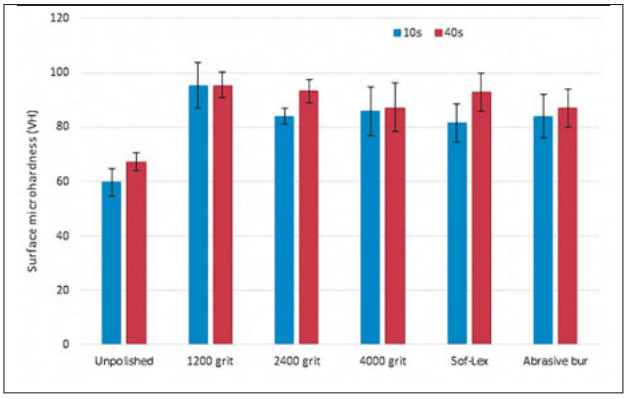

Fig 3 Surface microhardness (VH) values of specimens in relation to different curing times and polishing protocols. Vertical lines represent the standard deviation (VH: Vickers hardness).

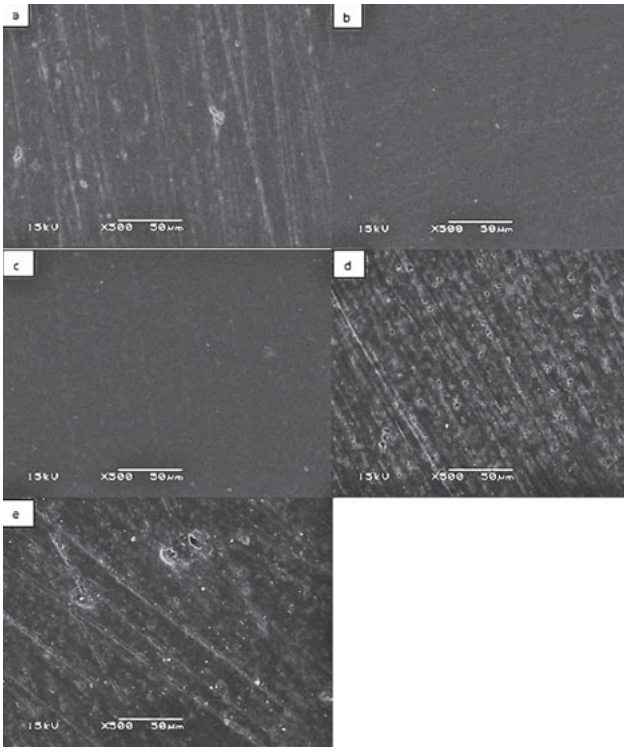

Fig 4 Scanning electron microscopy (SEM) images of the specimens after polishing using different protocols: **(a)** 1200 grit; **(b)** 2400 grit; **(c)** 4000 grit; **(d)** Sof-Lex spirals; **(e)** Jiffy points.

of the composite resin surfaces compared with the unpolished surfaces. The SH after different polishing protocols was significantly higher (ranging from 82 to 95 VH) than that before polishing (ranging from 60 to 67 VH) ($P < 0.05$), regardless of the polishing protocol used. The SEM images obtained after each polishing protocol are shown in Figure 4. Shallow scratches were observed on the surface of specimens following polishing with the 1200 grit paper (Fig 4a). However, after polishing with the 2400 and 4000 grit papers, the scratches disappeared and the surfaces became uniform and smooth (Fig 4b and c). Wide scratches and a large number of small pits resulting from filler particle exfoliation were observed after using chairside polishing protocols (Figs 4d and e).

Discussion

High viscous BCRs have been subjected to a number of studies aimed at evaluating their laboratory and clinical applications because they are recent materials used in dentistry[5-7]. One of the challenges presented by these BCRs is the quality of the polished surface, which is questionable since they do not require an additional surface layer of conventional composite resin and should be used as single-step bulk-filling materials[5,19]. Considering that polishing is an important factor potentially influencing the clinical performance of composite restorations[20,21], our null hypothesis was that different polishing protocols and curing times do not have any effect on the surface properties of high viscous BCRs. The evaluated material (Filtek Bulk-Fill) showed variable changes in SR, SG and SH as a result of different polishing protocols. For the first parameter, the null hypothesis was rejected. The level of SR and SG depended on the type of polishing protocol used. On the other hand, different curing times (10 or 40 seconds) with high curing irradiance (1600 mW/cm^2) had no significant effect on the tested surface properties. This is in accordance with a previous study[15], which found that high curing irradiance had no positive influence on the surface quality of the Filtek Bulk-Fill composite. Researchers and clinicians have reported that increasing the curing time can result in optimal clinical durability of composite resins[9,22,23]. However, manufacturers claim that curing times have been measured under ideal laboratory conditions, which may not necessarily represent clinical situations.

The SR of restorations may lead to plaque accumulation, surface discolouration and poor aesthetics, and this is directly related to the restorative materials and the polishing protocols used[1]. The finishing procedures for restorations are mostly essential for contouring and removing the excess material, although they lead to increased surface roughness, which eventually requires restoration polishing[21].

As recommended by Roeder et al[24], in this study we measured the surface properties of BCR before and after polishing to homogenise the specimens. It was observed that the average SR of the BCR against the Mylar sheet

(unpolished surface) was lower than after polishing using chairside protocols (Fig 1). Similar results were also observed in the studies by Hoelscher et al[15], Borges et al[25] and Cazzaniga et al[26]. Although the surfaces that were light cured against a Mylar sheet were smoother, in most cases, finishing the restoration was required to remove the excess material and to recontour; this reduced the surface smoothness and required a restoration polishing step[20,25]. Moreover, the polymerised surface against the Mylar sheet is rich in resin matrix (oxygen inhibition layer), is less resistant to abrasion and can contain bubbles[27]. By comparing the SR values obtained with different polishing protocols, it was clearly observed that the laboratory polishing with different silicon paper grits obtained smoother surfaces than the chairside polishing protocols. In addition, the Sof-Lex spiral resulted in a significantly smoother surface than polishing with Jiffy Polisher points. These differences can be explained by the hardness and type of the abrasive, and the geometry of the instruments employed[28]. According to Blank[29], the design of the Sof-Lex spiral wheels employs two parallel rows of 15 individually radiating elastomeric 'bristles', uniformly impregnated with abrasives. The flexible form can adapt to nearly every surface of a restoration, minimising heat formation and unwanted pressure during polishing. Several studies concluded that flexible aluminium discs are the best instruments for producing surface smoothness[30-32]. However, one could also recommend the Jiffy points, since points may be used clinically in areas that are not readily accessible to other polishing systems.

Overall, SR was satisfactory for all polishing protocols except for the Jiffy Polisher points (Ra ≈ 2 μm) because, according to Weitman and Eames[33] and Shintani et al[34], there was no appreciable difference in plaque accumulation between surfaces polished using different protocols, which resulted in Ra values ranging from 0.7 to 1.4 μm. On the other hand, Kaplan et al[35] stated that Ra values < 10 μm were clinically undetectable. Cazzaniga et al[26] showed that polishing procedures of the composite resin did not influence biofilm formation and the material characteristics, and that chemical composition played an important role in the biofilm formation processes. In the present study, the SEM results (Fig 4) were consistent with the SR results. SEM observations revealed that deeper and more frequent scratch lines (irregularities) were evident for the chairside polishing protocols.

Gloss is the ability of a surface to reflect light. In general, a high SR is associated with a smooth restoration surface[36]. In the present study, with respect to the polishing protocol, the least glossy surfaces were obtained when the BCR was polished with Jiffy Polisher points (Fig 2). Consistent with our study, Pala et al[30] reported that multi-step systems (Sof-Lex spiral) produced ahigher gloss, while the one-step system produced the lowest gloss. According to the American Dental Association's professional product review, 40 to 60 GU was identified as a typically desirable gloss based on observations from an expert panelist[10]. Cook and Thomas[37] reported that an improper polishing of restorations is generally considered to be below 60 GU, with an acceptable polishing being between 60 and 70 GU. According to this evaluation, only the laboratory polishing protocol up to a 2400 and 4000 grit size and the Sof-Lex spiral used in the present study exhibited successful gloss results (Fig 2).

Consistent with our results, Heintze et al[36] and Watanabe et al[38] revealed a correlation between SG and SR. The lower the SR, the higher the SG. Heintze et al[36] reported that the SG improved consistently during the polishing procedures. However, researchers also reported that the improvement of SR was not similar to the improvement of SG, and differed between type of materials[30,39]. In general, it has been stated that when the SR increases, the gloss decreases[1].

The SH has been used to predict the wear resistance of a material and its ability to abrade or be abraded by opposing dental structures or materials[2]. According to the SH results of our study, the level of SH seems to be related to the content of the composite resin and not to the polishing protocols. Contrary to the SR and SG results, the unpolished surfaces exhibited significantly lower SH values than the polished surfaces, regardless of the polishing protocol used (Fig 3). This observation may be due to the presence of an oxygen-inhibited gel-like layer on the surface of the composite material, as reported in previous studies[27,40]. This layer, of unreacted monomers, has a decreased degree of conversion and would thus be soft.

It is clinically significant to determine the performance of the restoratives as a consequence of polishing procedures and curing time because these phenomena could affect the mechanical and physical properties of materials and thelongevity of restorations.

The limitation of this study was that specimen preparation was performed by two investigators, which might have had an effect on the pressure exerted during the polishing procedures although the polishing time was controlled. A negative control group of BCRs, whose roughness could have been provided using a diamond finishing bur on the surface, is missing, but will be evaluated in the near future. Additional studies are also needed to evaluate the long-term surface characteristics of high viscous BCRs.

Conclusion

According to the research methodology used, both the SR and SG of the evaluated BCRs were influenced by the polishing protocol used. The smoothest and most glossy surfaces were obtained with the laboratory polishing protocol (4000 grit). The SH seems not to be related to the polishing protocols. A light curing time had no positive influence on the surface characteristics evaluated.

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Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Dr Lippo LASSILA designed the study and performed the statistical work; Drs Airald DUPONT and Karri LAHTINEN prepared and evaluated the specimens; Prof. Pekka K. VALLITTU contributed to the writing of the manuscript; Dr Sufyan GAROUSHI designed the study, analysed the results and wrote the manuscript.

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