Abstract

Objectives:

To compare the surface gloss and surface roughness of three contemporary composites when polished with reduced-step polishing systems or a conventional multiple-step technique.

Methods:

Fifty Discs (8mm ø x 2mm) were each fabricated from three composites; Essentia (ES), BRILLIANT EverGlow (EG), and Filtek Universal, (FU). 5 different polishing systems were randomly assigned 10 specimens from each composite group. The 'gold standard' multiple-step system consisted of Sof-Lex XT discs followed by DiaPolisher diamond paste (GC) (P1). The two-step systems were Polishettes (P2) and DIATECH ShapeGuard (P3) and the one-step systems used were; Opti1Step (P4) and OneGloss (P5). Surface gloss was measured using a glossmeter and surface roughness was measured by a profilometer. Statistical analysis was conducted using one-way ANOVA and Pearson correlation tests. Samples were also imaged across different length scales using scanning electron microscopy and macro-lens photography.

Results:

The highest gloss was obtained when P2 and P3 were used in all composite groups ($p<0.05$). EG composite showed the lowest Sa (0.08 µm) when polished with P3 and highest gloss when polished with P2 (96.7 GU). Polishing with P5 resulted in highest Sa and lowest surface gloss in all composite groups ($p<0.05$). A high correlation was found between Sa and gloss, r = 0.73 ($p<0.05$). Both SEM and macro-lens photography supported quantitative data.

Conclusion: Both two-step composite polishing systems produced superior gloss compared to the traditional multiple-step polishing system. Mean surface roughness (Sa) and surface gloss are highly correlated with each other.

Clinical significance: Some reduced step composite polishing systems tested in this study produced superior gloss outcomes compared to the traditional gold-standard multi-step polishing system. This may enable significant clinical chair-time reduction and faster polishing protocols.

1. Introduction

A restoration's surface texture is essential for its clinical success and longevity [1]. The advancement of filler technology and the incorporation of nanosized fillers in modern resin composites has resulted in materials with superior optical properties and surface polish [2]. Reduced surface roughness and increased gloss are necessary to achieve superior aesthetic outcome, improved soft tissue health and restoration marginal integrity [3,4]. In contrast, rough surfaces negatively influence the aesthetics due to the reduced ability to reflect light, susceptibility to external stains and increased plaque retention [5–7]. *In vivo* studies showed that the mean surface roughness threshold for bacterial plaque retention is above 0.2 µm [6]. Furthermore, it is reported that patients can detect with the tip of their tongue a surface roughness of 0.3 µm [8]. Therefore, it is widely reported that a surface roughness value below 0.2 µm is considered the acceptable threshold for dental restoratives [6]. Thus, the finishing and polishing protocol is considered a critical step to achieve a favourable aesthetic outcome and increase the longevity of the restoration [9,10].

Surface gloss is an important factor to consider when restoration aesthetics are evaluated. Correlations between surface gloss and the surface roughness parameter (Ra) have been found and it is generally accepted that the by reducing the surface roughness the gloss is increased [11,12]. However, the relationship remains somewhat non-linear as various filler properties have a significant influence on the surface gloss and the optical properties of the material [2]. Evidence is also limited and there is lack of consensus on the required threshold levels of surface roughness that would provide acceptable surface gloss [13].

A wide range of instruments and protocols have been advocated for polishing resin composites. Conventionally, multi-step systems, typically Soflex discs and diamond paste, are routinely used by dental professionals and their effectiveness has been well established [14–17]. More recently, single- and two-step polishing instruments and protocols have been introduced by several manufacturers. Ideally, these should be less time consuming and more cost effective whilst at least maintaining comparable aesthetic results. Some positive evidence is emerging in relation to reduced step and one step polishing systems [12,18]. However, several variables can influence the surface roughness and the gloss of the material such as the type of resin composite, polishing system, polishing time and whether polishing is conducted under wet or dry conditions.

The aim of this study is to conduct a comprehensive analysis on a representative proportion of the market's reduced step composite polishing systems used on three contemporary resin composites.

The null hypotheses for this study were that there are no differences in (1) surface roughness and (2) surface gloss following the use of different polishing systems on three contemporary composites.

2. Materials and Methods

2.1 Specimen preparation

150 disc-shaped composite specimens 8mm ø x 2mm thickness (n=50 for each composite material) were prepared using a custom made steel mould. Specimens were fabricated from three commercial hybrid composites, as detailed in Table 1, by placing the material into a mould as a single increment, which was then covered with a cellulose acetate strip and a glass microscope slide and a mass of 1 kg was applied for 20 s to ensure consistent and reproducible packing of the specimens. Specimens were light irradiated using a light emitting diode (LED) light curing unit (LCU) Elipar^{TM} DeepCure-S, 3M,UK) with spectra range of 450-470nm and an irradiance of 1,470mW/cm^2. The irradiance was checked prior to use by employing a checkMARK (Bluelight Analytics Inc., Canada). Specimens were made in 5 sessions and irradiance output was checked prior to each session. Specimens were light irradiated for 20 seconds from both sides following the ISO 4049 specimen manufacture protocol by placing the tip of the light guide in direct contact with the cellulose acetate strip in the centre of the specimen [19]. Specimens were then stored in an airtight container prior to testing.

Table 1: Manufacturers' details of resin based composite materials tested

Resin Composite	Type	Manufacturer	Resin	Filler type/size	Load Vol%	Batch #
Filtek^{TM} Universal (FU)	Nano-hybrid	3M Oral Care, St. Paul, MN, USA	AUDMA, AFM, Diurethane-DMA 1,12 Dodecane-DMA	Silica, Ytterbium trifluoride, Zirconia/silica cluster 0.004-0.1 µm	58.4%	NA166625
Essentia Enamel (ES)	Microfilled hybrid	GC Corporation, Tokyo, Japan	UDMA, Bis-MEPP, Bis-EMA, Bis-GMA, TEGDMA	Pre-polymerised fillers, barium glass, fumed silica 0.01-10 µm	65%	GCE2642A
BRILLIANT EverGlow^{TM} (EG)	Nano-hybrid	Coltene, NJ, USA	Bis-GMA; Bis-EMA; TEGDMA	Pre-polymerised filler with glass and nano-silica 0.02-1.5 µm	56%	60019700

2.2 Finishing and polishing

Five commercially available composite polishing protocols were selected including multiple step, two step and one step systems as shown in Table 2.

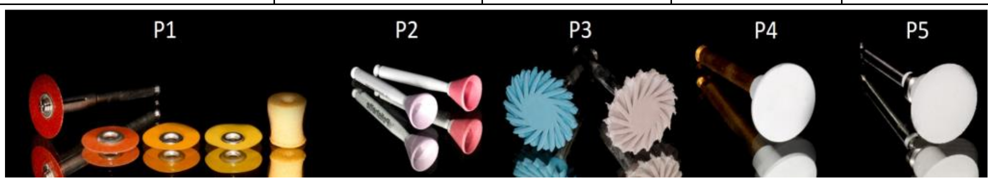
Table 2: Manufacturers' details of composite polishing systems used for the five tested protocols.

Polishing protocol	Polishing system	Matrix	Abrasives	Grit size	Manufacturer
Protocol 1 (P1)	Sof-Lex-XT discs (Red, Dark orange, Light orange, Yellow)	Discs	Aluminium oxide	Coarse 92-98 µm Medium 25-29 µm Fine 16-21 µm Superfine 2-5 µm	3M Oral Care
	Enhance polishing felt cup DiaPolisher diamond paste	Cup Paste	N/A Diamond	N/A 1 µm	Dentsply GC
Protocol 2 (P2)	Polishettes™	Silicone rubber	Diamond, silicon carbide, aluminum oxide.	Not available	KENDA
Protocol 3 (P3)	Diatech™ Shapeguard Spiral	Silicone rubber	Diamond	Pink 32-69 µm Blue 4-8 µm	Coltene
Protocol 4 (P4)	Opti1Step	Silicone rubber	Silicon carbide, aluminium oxide, Silicon oxide, diamond.	Not available	Kerr Corp.
Protocol 5 (P5)	OneGloss™ Disc	Synthetic rubber (Polyvinylsiloxane)	aluminium oxide, Silicon oxide	mean alumina particle size 85 µm	Shofu

Specimens were removed from their moulds and visually checked for surface imperfections with use of x 5 magnification dental loupes (Bryant Dental, UK). One side of each specimen was manually finished by P1200 grit silicon carbide (SiC) abrasive papers (Struers, Copenhagen, Denmark) under copious water irrigation by a single operator to remove the resin rich layer. P1200 grit SiC paper was chosen to simulate clinical finishing as the grit has a mean diameter of 18.3 µm, which is equivalent to fine high-speed composite finishing diamond burs (8-25 µm) [20]. Each composite groups' specimens were then randomly allocated (n = 10) to a polishing protocol as outlined in Table 3. Protocol 1 was considered as the control where Sof-Lex™ XT coarse grain to ultrafine were used followed by Enhance Polishing Cup (Dentsply, DE, USA) with DiaPolisher diamond paste (GC Corporation,Tokyo, Japan).

Table 3: Details of each individual step for the polishing protocols used and total time taken for each protocol.

Step	(P1)	(P2)	(P3)	(P4)	(P5)
1st	Sof-Lex™ XT Coarse grain (Red)	Polishettes™ Cup (Red)*	Diatech™ Shapeguard Spiral Wheel (Pink)*	Opti1Step Disc	OneGloss™ Disc
2nd	Sof-Lex™ XT Medium grain (Dark orange)	Polishettes™ Cup (Violet)*	Diatech™ Shapeguard Spiral Wheel (Blue)*		
3rd	Sof-Lex™ XT Fine grain (Light orange)				
4th	Sof-Lex™ XT Ultra fine grain (Yellow)				
5th	DiaPolisher diamond paste used with Enhance Polishing Cup				
Total time (s)	**150**	**60**	**60**	**30**	**30**



*systems that included use of water irrigation

Polishing was manually performed on one side of each specimen for 30 seconds at each step over the entire surface of the specimen following manufacturers' instructions. All polishers were used in a circular brushing motion simulating clinical use to reduce the risk of scratching or grooving specimens. A brand new polisher was used for each specimen for single use polishers (P1,P2 and P5) and a new polisher was used for each 10 specimens for re-useable polishers (P3 and P4). Polishing was performed at 10,000 rpm in a rate controlled motorized slow speed handpiece (KaVo Dental, Germany). Water irrigation was used when it was recommended by the manufacturers (P2 and P3).

2.3 Surface Roughness measurements

Surface roughness was measured with a white light profilometer (Proscan 2000, Scantron, UK) with a scan speed of 2 mm/s and step size of 10 µm in the x-direction and 20 µm in the y-direction. The probe was sensitive to record a minimum of 0.01 µm and a maximum of 150 µm in the z-direction. The central square area (6 x 6 mm) of each specimen was analysed and three-dimensional profiles were then generated using proprietary analysis software (Proform 2000, Scantron, UK). Measurements were taken from 4 different 2mm x 2mm area regions of interest (ROI) within the scanned specimen and the mean reading was recorded. The following roughness parameters were recorded:

- Sa (arithmetical mean of the surface deviations from the centre line = mean roughness),
- Sq (the root mean square of the surface over the centre line),
- Sp (vertical distance between the maximum surface height and the centre line = maximum surface peak height) and
- Sv (the distance between the deepest valley of the surface and the centre line = maximum surface valley depth).

2.4 Surface Gloss measurements

Surface gloss was measured with Novo-Gloss 60 degrees glossmeter (Rhopoint Instruments, UK). The instrument measured the intensity of the specular reflected light from the surface at a 60° angle to the normal and compared it to a reference value. Using a standard measurement angle of 60° is appropriate for all gloss levels. The glossmeter was calibrated prior to testing each group by comparing the results with the calibration plate, which has a reference value of 93.7 gloss units (GU) as well as by checking the zero point to exclude negative values. To perform the measurements, each specimen was placed on a custom-made steel plate with 10 mm Ø x 2 mm window centered directly over the device aperture. This allowed readings to be taken at the centre of each specimen whilst excluding external light during the tests. Three readings were recorded for each specimen and the mean gloss value was recorded. The glossmeter had a manufacturer claimed reproducibility / resolution of 0.5 GU / 0.1GU respectively across the GU range of 10-100.

2.5 Scanning Electron Microscopy (SEM)

SEM was used to evaluate the surface morphology of the polished composite specimens. Representative specimens were selected from each group and mounted on aluminium stubs and sputter coated with approximately 5 nm of gold using an argon sputter coating unit (Agar Scientific, Stansted, UK). The specimens were then imaged using a Hitachi-S-3400N, variable pressure scanning electron microscope (Hitachi High-Tech Technologies, Japan) under low vacuum.

2.6 Macro-lens Photography

Qualitative macroscale assessment of the specimen surfaces was conducted using macro-lens photography. Photographs were taken using a DSLR camera (D750, Nikon, Japan) with a 105 mm Macro lens (AF-S VR Micro-Nikkor, Nikon, Japan) and ring flash (140DG, Sigma, USA) placed perpendicular to each specimen, shutter speed 200, Aperture F32, 1:1 magnification ratio, custom white balance and shot in RAW. This was conducted by a single operator in a single session.

2.7 Statistical Analysis

Statistical analysis was conducted using IBM SPSS 25. Data sets were assessed for normality using the Kolmogorov– Smirnov test and Shapiro–Wilk test. Data were then analysed with one-way ANOVA and post-hoc Tukey test, with a significance level of $p<0.05$. The Pearson correlation test was used to test the strength of any correlation between the measured roughness parameters and gloss.

3. Results

3.1 Surface roughness

Exemplar roughness profiles are presented in Figure 1 for FU composite for the entire 6 mm x 6 mm scanned area (Figure 1A-C) and a 2 mm x 2 mm region of interest (Figure 1D-F). P5 shows clear evidence of surface scratches not removed by polishing. Table 4 shows surface roughness data presented as mean Sa, Sq, Sp and Sv values (µm) for the combination of the three composite resin and the five polishing protocols.

Table 4: Surface roughness parameters (Sa, Sq, Sp, Sv) mean (µm) ± standard deviation for the three composite resin materials and five polishing protocols

Sa					
Group	**P1**	**P2**	**P3**	**P4**	**P5**
FU	0.19 ± 0.01$^{A/a}$	0.19 ± 0.05$^{A/a}$	0.15 ± 0.02$^{A/a}$	0.18 ± 0.03$^{A/a}$	0.29 ± 0.06$^{B/a}$
ES	0.15 ± 0.03$^{A/a}$	0.13 ± 0.01$^{A/b}$	0.16 ± 0.03$^{A/a}$	0.17 ± 0.06$^{A/a}$	0.25 ± 0.04$^{B/a}$
EG	0.16 ± 0.04$^{A/a}$	0.11 ± 0.02$^{AB/b}$	0.09 ± 0.01$^{B/b}$	0.17 ± 0.03$^{AC/a}$	0.25 ± 0.05$^{D/a}$
Sq					
Group	**P1**	**P2**	**P3**	**P4**	**P5**
FU	0.25 ± 0.02$^{A/a}$	0.24 ± 0.03$^{A/a}$	0.20 ± 0.04$^{A/a}$	0.26 ± 0.04$^{A/a}$	0.38 ± 0.09$^{B/a}$
ES	0.22 ± 0.05$^{A/a}$	0.19 ± 0.02$^{A/a}$	0.27 ± 0.15$^{A/a}$	0.26 ± 0.10$^{A/a}$	0.40 ± 0.12$^{B/a}$
EG	0.22 ± 0.04$^{A/a}$	0.14 ± 0.02$^{AB/a}$	0.12 ± 0.02$^{AB/ab}$	0.31 ± 0.06$^{AC/a}$	0.36 ± 0.11$^{C/a}$
Sp					
Group	**P1**	**P2**	**P3**	**P4**	**P5**
FU	1.21 ± 0.49$^{A/a}$	1.38 ± 0.57$^{A/a}$	1.39 ± 0.97$^{A/a}$	1.26 ± 0.42$^{A/a}$	1.51 ± 0.60$^{A/a}$
ES	1.17 ± 0.55$^{A/a}$	1.19 ± 0.36$^{A/a}$	1.14 ± 0.55$^{A/a}$	1.82 ± 0.86$^{AB/a}$	2.34 ± 0.91$^{BC/a}$
EG	1.09 ± 0.37$^{A/a}$	0.65 ± 0.13$^{AB/a}$	0.62 ± 0.17$^{AB/a}$	1.71 ± 0.80$^{AC/a}$	2.02 ± 1.21$^{AC/a}$
Sv					
Group	**P1**	**P2**	**P3**	**P4**	**P5**
FU	0.98 ± 0.30$^{A/a}$	1.20 ± 0.58$^{A/a}$	1.34 ± 0.93$^{A/a}$	1.11 ± 0.27$^{A/a}$	1.57 ± 0.51$^{A/a}$
ES	1.28 ± 0.65$^{A/a}$	1.44 ± 0.47$^{AB/a}$	1.40 ± 0.59$^{AB/a}$	1.93 ± 1.28$^{AB/a}$	2.62 ± 1.29$^{BC/a}$
EG	1.17 ± 0.31$^{A/a}$	0.70 ± 0.17$^{A/a}$	0.54 ± 0.15$^{A/a}$	1.93 ± 1.07$^{AB/a}$	2.45 ± 1.63$^{BC/a}$

Values with the same superscript are not significantly different ($p>0.05$). Uppercase superscripts refer to the rows (i.e. polishing system within composite material). Lowercase superscripts refer to the columns (i.e. composite material within polishing system).

The first null hypothesis was rejected as data showed that there were statistically significant differences in roughness between the groups (p <0.05). Polishing systems were ranked based on the highest average surface roughness (Sa) obtained as follows: P5 > P4 > P1 > P2 > P3. Polishing with OneGloss (P5) resulted in the highest surface roughness for each composite, (p<0.05). Significant differences in Sq, Sp and Sv values were also found amongst the polishing systems and composite materials combinations, (p<0.05), as shown in Table 4.

3.2 Surface Gloss

Surface gloss group comparisons are shown in Table 5**Error! Reference source not found.**. The second null hypothesis was rejected as P2 and P3 resulted in highest gloss in all composite groups (p<0.05). The highest gloss value was obtained when EG composite was polished with P2 (96.70 GU). Polishing with P5 resulted in the lowest surface gloss in all composites groups (p<0.05).

Table 5: Surface gloss (GU) ± standard deviation for the three composite resin materials and five polishing protocols.

Group	P1	P2	P3	P4	P5
FU	$67.63 \pm 6.04^{A/a}$	$84.67 \pm 7.16^{B/a}$	$89.71 \pm 6.14^{BC/a}$	$82.39 \pm 7.74^{BC/a}$	$36.27 \pm 6.24^{D/a}$
ES	$73.32 \pm 5.00^{A/a}$	$86.64 \pm 6.11^{B/ab}$	$85.74 \pm 9.40^{B/a}$	$75.32 \pm 6.30^{AB/a}$	$44.39 \pm 5.20^{C/ab}$
EG	$73.35 \pm 11.25^{A/a}$	$96.70 \pm 3.54^{B/b}$	$90.68 \pm 6.0^{BC/a}$	$80.08 \pm 14.50^{AC/a}$	$50.71 \pm 4.36^{D/b}$

Values with the same superscript are not significantly different (p>0.05). Uppercase superscripts refer to the rows (i.e. polishing system within composite material). Lowercase superscripts refer to the columns (i.e. composite material within polishing system).

3.3 Correlation between surface roughness and gloss

Correlation between roughness and gloss was analysed for all composite groups together and separately for each material using Pearson's correlation test. Figure 2 shows that a general negative correlation was observed between surface roughness and gloss. The Pearson's correlation coefficient (r) was calculated for each test. Significant negative correlations were found between surface roughness parameters and gloss amongst all composite groups (pooled data), Table 6. A high correlation was found between gloss and surface roughness parameter Sa (r = 0.73) followed by a moderate correlation for Sq (r = 0.6), whereas Sp and Sv showed low correlations (r = 0.35).

Table 6: Pearson's correlations between gloss and surface roughness parameters of the individual composite groups and the pooled data for all composite groups

	FU	ES	EG	Pooled data
Sa	-0.80	-0.70	0.73	-0.73
Sq	-0.77	-0.48	-0.60	-0.60
Sp	-0.11	-0.51	-0.40	-0.35
Sv	-0.25	-0.43	-0.42	-0.35

3.4 Scanning Electron Microscopy

SEM images taken from representative specimens in each group are shown in Figure 3. The surface finish amongst the groups varied based on the finishing protocol and the composite material. Directional surface scratches and grooves were observed, voids were also observed corresponding to filler particles which have been removed from the surfaces by the finishing process. It is evident that (P3) showed a homogenous appearance across all composite groups with only shallow scratching visible on ES composite. This appearance was similar to the control protocol (P1) with superficial scratching seen only on EG composite. In contrast, P5 which was the worst performing protocol in terms of surface roughness and gloss yielded deep multi-directional grooves and scratches within all composite groups as shown in Figure 3 and Figure 4. Occasional pull-out of filler particles alongside the grooves was also seen, this was mostly evident when P5 was used, examples shown in Figure 4. In contrast, examples of superior polished surfaces, as observed by SEM, are shown in Figure 5.

3.5 Photographic Analysis

Analysis of the photographic images taken of the polished composite surfaces showed detectable visual differences between the polishing systems, examples are shown in Figure 6. Superficial scratching relating to abrasive elements of the polishing protocols can be seen in P5. Voids, due to filler pull out were seen relatively uniformly across all polishing protocols in both composites containing pre-polymerised fillers (ES and EG). This phenomenon is most obvious in the worst performing protocol (P5) when used on ES composite, Figure 6.

4. Discussion

A comprehensive analysis on a representative proportion of the market's reduced-step composite polishing systems was conducted in this study looking at gloss and at surface amplitude parameters as a measure of roughness.

The most common roughness parameter measured in similar studies is Ra, but this has significant limitations in describing the topography of a surface. Ra is the arithmetic mean deviation of the assessed profile, defined on a sampling length. Ra is used as a global evaluation of the roughness amplitude on a line profile but it does not say anything about the spatial frequency of the irregularities or the shape of the line profile [21] or indeed provide this information over a surface area. Accordingly, a range of area roughness amplitude parameters were recorded in the present study to provide a better representation of the effect of each polishing system over a polished area and mimicking more closely the surface 'window' used in gloss measurement in order to better assess any correlations between the two.

Table 4 shows that satisfactory surface roughness outcomes could be achieved with both two-step and one of the one-step polishing systems on all three composite resins tested. The lowest surface roughness (Sa 0.08 µm) was obtained from EG composite polished with a two-step system DIATECH ShapeGuard (P3), (p<0.05). Each composite group polished with Polishettes (P2) and Opti1Step (P4) systems also showed Sa values below that 0.2 µm resulting in an acceptable outcome which was comparable to the multiple-step system (P1), (p>0.05). However, polishing with the one-step system OneGloss (P5) resulted in highest surface roughness on all tested composites (p<0.05), and this was higher than the 0.2 µm threshold. Although all polishing protocols were conducted by a single experienced operator under the same conditions, OneGloss (P5) produced the largest roughness parameters, driven by the fact that the grooves introduced by the finishing regime were not polished away when compared to the other polishing protocols. The Onegloss system combines both finishing and polishing with the same disc, the difference between the two steps being a difference in pressure applied, with the polishing step needing approximately 30% of the pressure used in the finishing step. This would be incredibly difficult to achieve using a regular handpiece, even for an experienced dentist. High roughness parameters are in accordance with previous experimental findings on OneGloss polishing system where it produced higher surface roughness parameters when used on nanofilled and naohybrid composites [12,22].

It is worth noting that although a surface roughness (Ra) of 0.2 µm is generally accepted to be the cut-off value below which no correlation between surface roughness and biofilm formation can be found [23], oral environmental factors as well as morphological features of bacterial cells can influence the effects of surface roughness on bacterial adhesion and biofilm formation processes [24]. Therefore the simple correlation between surface roughness and biofilm formation remains debatable.

Resin composite composition has been shown to play an important role in restoration surface roughness [25]. The inorganic filler particle size influences the resultant surface roughness following polishing as dislodgment of the filler particles could leave smaller or bigger defects dependant on their size [26]. Therefore the final surface quality depends on the size of the filler particles and the choice of optimal matching polishing protocol [27]. Furthermore, surface roughness and materials' chemical composition play a crucial role in bacterial adhesion and biofilm formation [28]. Additionally, it is proposed that having higher amounts of inorganic components on the polished composite surfaces results in less biofilm formation and improved biological performance [29]. Composite materials selected in this study had comparable inorganic filler loading but different filler sizes; FU and EG are considered nanohybrid composites whilst ES is a microhybrid. EG and ES also differ from FU in that they contain 'pre-polymerised' fillers. Despite these filler differences, no differences were found between the materials when the multi-step polishing systems were used. However higher peak/valley parameters (Sp and Sv) were observed when OneGloss (P5) was used on ES (0.01-10 µm) and EG (0.02-1.5 µm) composites which both contain a fraction of larger pre-polymerised fillers.

Resin composites with smaller filler particles are able to obtain higher gloss and lower surface roughness when polishing with various polishing systems [30,31]. Closely situated small filler particles protect the resin matrix from abrasives and therefore are less susceptible to lose particles caused by contact with the abrasive material of polishing systems. On the other hand, nanohybrid composites with pre-polymerised fillers are susceptible to disruption of the filler-matrix interface due to the loss of the pre-polymerised fillers resulting in higher surface roughness than nanofilled composites [32,33]. In this study, higher surface roughness was observed in ES and EG composites which both contain a fraction of pre-polymerised fillers however only when OneGloss system (P5) was used. Dislodgement of nanoclusters from a nanofill resin composite has also been previously reported [6], however this was not observed in this study in FU (0.004-0.1 µm) composites which contain zirconia/silica agglomerate fillers. Similar findings were reported by Senawongse and Pongprueksa who did not observe nanoclusters dislodgments from nanofilled resin composites [33].

Gloss has been defined as '*the attribute of surfaces that causes them to have shiny or lustrous, metallic appearance*'[34]. Simply put, surface gloss is a measure of the quality of a surface and can be greatly influenced by a number of factors; the perception of gloss relates to finish (the magnitude, frequency, randomness and scale of curvatures), texture (changes in reflecting properties over the surface) and how a specimen is illuminated and viewed [35]. Instrumentally measured gloss is commonly used to evaluate the surface shine and the ability of a composite restoration to specularly reflect light which ultimately influences the aesthetic outcome [11]. It has been used as a suitable method to evaluate the polishability of resin composites due to the ease of use, quick data acquisition and low equipment costs [11]. In this study, the highest surface gloss was obtained when two-step systems P2 and P3 were used in all composite groups. The highest gloss values were obtained when EG composite was polished with P2 (96.70 GU) and P3 (90.68). By comparison, the least glossy surfaces were obtained when OneGloss (P5) was used in all composites groups with gloss values (36.2-50.7 GU), this is significantly lower compared to the other polishing protocols (p<0.05). The findings of this study is consistent with Pala et al [12] where OneGloss system was found to produce low surface gloss values when used on nanofilled and nanohybrid resin composites. Surfaces gloss values between 60 and 70 GU is considered acceptable surface finish for resin composites [36]. According to this, all three composite materials used in the study exhibited acceptable gloss values (67.60-96.70 GU) when multi-step and reduced step polishing systems were used except for OneGloss (P5).

Correlations between surface roughness and gloss of resin composites have been reported in the literature [11,37,38]. Generally when the surface roughness increases, the degree of random reflection of light will also increase, resulting in decreased gloss [39]. However researchers have also reported that the improvement of surface roughness may not directly result in similar improvement of surface gloss, and this could differ from material to material [14,32]. The findings of this study showed significant negative correlations between surface roughness parameters and gloss amongst all composite groups (pooled data) with Pearson's correlation coefficient r = 0.7 (p<0.05). Similar negative correlation was also observed when each composite material was analysed separately whereby Pearson's correlation coefficient (r) for FU and EG is 0.7 and ES is 0.8 (p<0.05).This is consistent with previous reports revealing a negative correlation between surface roughness (Ra) and gloss [11,37,38]. Given the high correlation between surface roughness parameter (Sa) and gloss, it was concluded that assessment of surface roughness using Sa or Sq was more appropriate than Sp or Sv.

The lowest surface roughness and highest surface gloss were achieved when the composite material was matched with the same manufacturer's polishing system; EG with DIATECH ShapeGuard (P3). This could be due to corresponding composite filler size and silicone diamond particle on the polishing wheels. Nevertheless, reduced step systems Polishettes (P2) and Opti1Step (P4) also showed comparable satisfactory outcomes when compared to more time consuming Sof-Lex-XT discs multi-step system. The one-step system OneGloss (P5) did not achieve satisfactory surface topography, roughness and gloss values on the tested resin composites in this study. The findings of this study could allow reduced clinical chair time whilst achieving the desired outcome with some of the reduced step-step systems mentioned earlier. Additionally, it could significantly reduce clinical waste as the majority of the elastomer based reduced-step polishing systems can be sterilised and used multiple times unlike the conventional multi-step polishing discs.

SEM image analysis showed variable surface topography of the polished composite surfaces based on the polishing protocol used. SEM images of the polished composite surfaces supported the surface profilometric findings amongst all materials/polishing protocols tested, Figure 3. It is evident that the two-step polishing protocol (P3) showed regular surfaces across all composite groups with very few shallow grooves that were visible on ES composite. In contrast, the one-step (OneGloss, Shofu) polishing protocol (P5) resulted in a more ploughed surface topography with deep multi-directional grooves and scratches within all composite groups as shown in Figure 3 and Figure 4. Similar observations were reported on nanofilled and nanohybrid composites when OneGloss polishing system was used resulting in higher roughness parameters and irregular surface topography [12,22]. Nevertheless, the control multi-step protocol (P1) showed homogeneous uniform surfaces with few superficial grooves seen on EG composite. The remaining reduced step protocols (P2 and P4) produced less homogenous surfaces but shallow uni-directional grooves were evident.

Interestingly, the differences between the various polishing systems observed by SEM were also apparent using macro-lens photography, Figure 6, a technique available to many dental practitioners, suggesting that this imaging method was appropriate for measuring the efficacy of polishing systems.

Polishing-disc composition has been found to influence the surface roughness and gloss outcome, this includes hardness, size and shape of the abrasive particles as well as the physical properties of the imbedding matrix [40,41]. Several studies concluded that flexible aluminium oxide discs are considered the best polishing tools for removing surface irregularities and producing smooth resin composite surfaces [10,16,42].

Aluminium oxide particles are harder than the majority the fillers used in resin composites, therefore they are able remove equal amounts from both inorganic filler particles and the resin matrix, forming smooth surfaces without dislodgement of the filler particles [43]. Additionally polishing discs containing diamond elements have been found to achieve better performance by reducing surface roughness and increasing the gloss [25]. Furthermore, it has been suggested that the shape and the design of the polishing discs also affect the outcome, discs with elastomeric bristles that are uniformly impregnated with abrasives can adapt easily to every surface within the restoration, this will minimise heat formation and unwanted pressure [12].

The findings of this study supported that disc composition and characteristics influence the surface roughness, gloss and topography of resin composites. The best performing systems (P2) and (P3) contain the desired features for improved surface finish, (P3) also has a flexible wheel design with elastomeric bristles containing aluminium oxide and diamond particles which can adapt to most surfaces of the restoration resulting in improved polish. Similar improved performance of DIATECH ShapeGuard (P3) was reported by other researchers [44]. In contrast, the worst performing polishing system OneGloss (P5) contains abrasive 85 µm alumina particles which is significantly larger than the final polishing discs in the other systems tested. (P5) system was also the only protocol that did not contain diamond particles which are suggested to improve the polishing performance by reducing surface roughness and increasing the gloss [25].

Conventional multi-step polishing systems such as P1 used in this study follows the concept of application of progressively finer grits of abrasives to polish resin composite restorations [45]. Manufacturers recommend using all grits in a sequence to achieve the best surface polish. However clinicians now have the choice of a wide range of reduced steps polishing systems that could achieve similar/superior outcomes.

The authors found that employing a comprehensive methodology including 3D surface roughness analysis, surface gloss measurements and surface topography analysis using the SEM and macro-lens photography, provided a robust understanding of the effect of the polishing systems on surface characteristics of resin composites.

5. Conclusion

Both two-step systems can produce superior gloss outcomes ($p<0.05$) within a significantly shorter period of time compared to the traditional multiple-step polishing system. Final surface properties of resin composites are influenced by the polishing method used. This has a significant impact on the surface roughness, surface gloss, surface topography and macro appearance of the polished restorations. Surface characteristics of polished resin composites remain complex to analyse and are influenced by the type of resin composite material, polishing system composition and the surrounding oral environmental. Therefore, the authors recommend using a range of micro- and macro- methods when analysing polished resin composite surfaces in order to obtain a meaningful understanding of the materials' behaviour and polishing systems' performance.

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