ROUGHNESS AND WEAR RESISTANCE IN THE PROCESS OF SELECTING COMPOSITE RESINS

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Abstract. Due to the the multitude of composite materials available, choosing the most adequate ones is a difficult task. Apart from most relevant characteristics such as aesthetics and mechanical strength, it is just as important to obtain smooth restorations, given the negative effects of bacterial plaque retention on the stomatognathic system. We have considered four of the composite resins most frequently used by dentists in Romania and we used laboratory tests to analyse the wear resistance and surface roughness after applying 3 finishing systems. We show that finishing systems have a powerful impact on composite materials roughness, and the best results are obtained with a microhybrid composite. As for wear resistance, nanohybrid composites proved to be superior to microhybrid ones. The results of the study suggest that the structure of the composite material counter-balances its roughness. From a clinical perspective, the quality of the surface of dental restorations is important not only functionally, preventing their wear and bacterial plaque retention, but also from an aesthetical point of view.

Key words: composite resins, wear, finishing systems, roughness, surface properties.

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1. INTRODUCTION

Since their appearence on the market in 1950, composite materials improved continuously, while still keeping many of their initial characteristics [1]. Dentistry applications of composite resins has become increasingly widespread, as a result of the patients' increased aesthetic demands, improved chemical composition, and adherence of these materials to dental structures [2]. A composite material is defined as a three-dimensional compound composed of at least two different chemical components or, it can also be described as a mixture of strong inorganic particles bound to each other through a resin matrix. Initiation system and catalysts are present as well [3].

Early dental composites of the 1970es contained large filling particles (over 10 μm in diameter), and would wear out quickly when used on the occlusal surfaces of posterior teeth [4]. Significant improvements were made with the introduction of composites with medium-sized filling particles (*e.g.* 2,5 μm), in the mid-80es, and the more recent, much more wear-resistant micro/nano-hybrid composites. While wear may be of minimal importance for small and medium-sized restorations, failure rates are higher for larger restorations, especially those involving cuspid restoration [5].

Although the obvious advantages of composite resins led to the improvement of odonthal treatments, it is important to mention that these materials, depending on their chemical composition, still come with a number of significant disadvantages, such as contraction during photo-polymerisation; changing colour in time; dental sensitivity, and high wear rates, especially in lateral areas [6]. One solution to solving these shortcomings was the nanocomposites, which contain nano-fillings that form groups called nanoclusters. These composites are similar to the microfilling composites in terms of aesthetics, as they are easy to polish, but they can act similar to large particles, providing increased strength and small contraction upon polymerisation [7, 8]. The surface properties of restoration materials are critical for their success, as they mediate the interaction of these materials with the oral environment, including the build-up of dental biofilm [9, 10]. These surface characteristics are given by the chemical composition of the material, the nature of the substrate, the surface roughness, and wear resistance [11].

In terms of surface roughness, it was proven that the particle size in composite resins has a significant impact on the surface roughness of these materials [12]. Although studies have shown that the size and shape of the filling may affect the surface roughness in composite resins [13], one should not forget the importance of finishing systems. Abrasive particles must be relatively stronger than the filling materials in order to get efficient composite finishing; otherwise, the polishing agent will just remove the resin matrix, leaving the exposed filling particles behind [14].

Wear is defined as the process of change of the initial condition of the shear surfaces by materials detaching during the shearing, change of the size, shape, physical and mechanical properties, constructive and functional characteristics through mechanical, thermal, chemical, electrical, radioactive actions etc. [15]. Wear resistance of composites is given mainly by the composition of the resin and the distribution of the filling particles [16]. Various shapes and size combinations of filling particles are associated with the wear performance of composites. Studies have mentioned that increased loading of the filling content may help improve the wear resistance of composites. Smaller, sphere-shaped particles proved to have better mechanical strength and greater wear resistance. However, due to the agglomeration of inorganic particles, it is difficult for them to be properly incorporated in the resin matrix; therefore, researchers created hybrid composite resins [17].

Since the key desiderata in restoration dentistry is to obtain strong odonthal treatments, with as good finishing as possible, in order to obtain aesthetic restorations with low dental biofilm retention characteristics, we set to conduct a study to determine the roughness and wear resistance of 4 composite resins. For the analysis to be conclusive, we considered to be necessary to analyse four of the widest used composite resins in Romania. In terms of their inorganic structure, the 4 composites were microhybrids (G-aenial Posterior, Gradia Posterior), 2 nanohybrids (Valux ™ Plus Universal, Filteck Z550). All 4 composites were finished using 3 different systems: Sof Lex, Super Snap and TOR VM.

2. MATERIALS AND METHODS

For the first stage, we determined the surface roughness for the 4 composite resins. We selected the best results and then proceeded to determine wear resistance. Four of the most frequently used composite resins were proposed for analysis: their characteristics are given in Table 1.

Table 1

Analysed composite materials

No.	Name of composite material	Producer	Functionality	Resin tip	Filling time
1	Valux™ Plus Universal	3M Science Applied to Life	Universal composite for restorations	Bis-GMA and TEGDMA	The inorganic filling is 66% by volume
2	Filtek Z550	3M Science Applied to Life	Teeth anterior and posterior restorations	Bis-GMA, UDMA, BIS-EMA, PEGDMA and TEGDMA	The inorganic charge represents 82% by weight and 68% by volume
3	G-aenial Posterior	VITA Zahnfabrik H. Rauter GmbH & Co.KG	Posterior restorations	Methacrylate Monomers	2 types of pre-polymerized filler
4	Gradia Posterior composite	GC Europe N.V.	Posterior restorations	Bis-GMA	organic-inorganic filling

BIGMA: Bisphenol A diglycidal ether dimethacrylate;
TEGDMA: tri ethylene glycol dimethacrylate;
BISE-MA: Bisphenol A polyethylene glycol diether dimethacrylate;;
PEGDMA: poly ethylene glycol dimethacry-late;
UDMA: urethane di methacrylate.

Test samples were taken from each composite, which were properly labelled and documented. Samples were made using a stainless steel cuff, Porcelain Stampler, which allowed us to make composite disks with 10 mm diameter and 2.5 mm thickness. To make the samples, material was placed in the cuff, and to create level disks, we used a 4 mm thick glass plate on which we applied even pressure.

Composite materials were applied and compacted in one layer in the cuff, which allowed us to create samples of the sizes mentioned above. To eliminate potential influences of photo polymerisation on the results, we used the thickness of the glass plate as a reference to maintain a constant distance of the lamp from the samples, by putting the lamp end in direct contact with the glass plate. The photopolymerisation time was consistent with the specifications of each manufacturer [18–21], according to Table 2.

Table 2

Photo polymerisation time applied

No.	Material	MU	Photo polymerisation time
1	Valux™ Plus Universal	s	20
2	Filtek Z550	s	20
3	G-ænial Posterior	s	20
4	Gradia Posterior	s	20

Before testing, the samples were checked and then kept for 24 h in distilled water at a constant temperature of 37°C. The samples were finished with 3 finishing systems, namely: Sof Lex, Super Snap and TOR VM. The stages recommended by the manufacturer were followed for each finishing system. In the case of the Super Snap system, as this is a 4 stage system, we first proceeded to the out-lining using the Black disk; the finishing was made using the Purple disk; the polishing was made using the Green disk, and the super-finishing – using the Red disk. Similar to the Super Snap system, the TOR VM system indicates using 4 disks of various granulations, in the following sequence: blue disk for rough levelling; green for outlining; yellow for finishing, and white for polishing. Using the Sof Lex system required using the 2 disks: the Tan variant for the pre-polishing and the Pink one for the polishing itself.

To avoid any discrepancies caused by using different working techniques, all samples were made by the same operator. The samples were analysed in a speciality laboratory, using specific equipment. Thus, to test wear resistance, a TRB-0254 tribometer from CSM Instruments was used, as well as a Nikon Eclipse MA 100 microscope. This equipment was used to determine the shear coefficient in a wet and in a dry environment, and it works with samples of no more than 20 mm. To enable proper fastening of the samples in the device, the samples were incorporated in a silicone elastomer, then fastened in the equipment's device.

The roughness of the samples was studied using a Surtronic S25 Taylor Hobson profilometer with the following characteristics: calibration limit – 300 µm, resolution – 0.01 µm, examination length – 0.25–25 mm, examination speed – 1 mm/s. Since a surface with low roughness favourably influences wear resistance, for each composite system we selected the samples with best roughness results, which we then subjected to wear tests.

The samples were moistened using artificial saliva; the purpose of this lubricant was to ensure a testing environment as close to the oral cavity environment as possible. Two balls with a 6 mm diameter made of sapphire and alumina were used during the tests. The samples were subjected to shear operations using the two types of balls, with the artificial saliva as lubricant, using movements of 3 mm amplitude, a linear speed of 6 cm/s, 20000 cycles, 3 N pressing force. The traces resulted from the wear testing were studied through optic microscopy, using a Nikon Eclipse MA 100 microscope with image acquisition and processing software, NIS ELEMENTS BR.

3. RESULTS

In terms of surface roughness. Quantitative determination of roughness is done using roughness profile parameters. In the mean line system, two categories of profile parameters are used: physical parameters and statistic parameters [22]. The most important statistic parameter of roughness is the arithmetic mean depth of the roughness, Ra, or the arithmetic mean deviation of roughness. This represents the mean value of YR1, YR2,…, YRn values of the actual profile "P" up to the mean line "m", considered within the limits of the reference length "l" [23]. The study provided the following results summarised in Table 3.

Table 3

Mean roughness of composite resins by finishing system used

No.		Roughness – Ra [µm]		
	Composite	**SOF LEX**	**SUPER SNAP**	**TOR VM**
1	Valux™ Plus Universal	0.191	0.22	0.159
2	FILTEK Z550	0.527	0.487	0.112
3	G-ænial Posterior	0.11	0.29	0.994
4	Gradia Posterior composite	0.154	1.33	2.16

The results were obtained by measuring, taking photos of and documenting wear traces on each individual composite resin. As Table 3 shows, the composite resin with the lowest roughness was achieved with G-ænial posterior, finished with Sof Lex (0.11 µm). Closely similar values were seen with the Filtek Z550 nanohybrid composite, finished with TOR VM, (0.112 µm), and with the Gradia posterior microhybrid composite finished with Sof Lex (0.154 µm). At the other end of the range, the worst results were obtained when analysing Gradia posterior composite finished with TOR VM (2.16 µm) and Super Snap (1.33 µm).

In terms of wear resistance. Looking at the action of the finishing systems on the results obtained, we selected, from every composite, those samples with the smallest roughness. Therefore, we analysed the wear resistance for the following combinations of composite resins and finishing systems: Valux ™ Plus Universal and Filtek Z550 finished with TOR VM, and G-aenial posterior and Gradia posterior finished with Sof Lex. Thus, after performing 3 measurements of the wear traces for each composite a mean value was calculated, and the obtained results are summarised in Table 4.

Table 4

Wear trace summary

No.	Material resin used	Polishisng system used	Ball type	N1	N2	N3	Average width
1	Valux ™ Plus Universal	TOR VM.	alumina	277.06 µm	287.82 µm	269.01 µm	277.96 µm
2	Valux ™ Plus Universal	TOR VM.	sapphire	172.18 µm	172.18 µm	166.8 µm	170.39 µm
3	Filtek Z550	TOR VM.	alumina	332.9 µm	316.74 µm	314.73 µm	321.46 µm
4	Filtek Z550	TOR VM.	sapphire	217.89 µm	213.86 µm	211.84 µm	214.53 µm
5	G-aenial posterior	Sof Lex	alumina	248.15 µm	234.02 µm	232.01 µm	238.06 µm
6	G-aenial posterior	Sof Lex	sapphire	229.99 µm	227.98 µm	217.88 µm	225.28 µm
7	Gradia posterior	Sof Lex	alumina	255.56 µm	258.25 µm	244.8 µm	252.87 µm
8	Gradia posterior	Sof Lex	sapphire	225.95	223.28	234.04	227.76

The greatest trace width was obtained for the testing of Filtek Z550, finished with TOR VM and tested with the alumina ball, meaning the lowest wear resistance. The smallest value was obtained for Valux ™ Plus Universal, finished with TOR VM and tested with the sapphire ball, meaning that this composite resin proved to have the strongest wear resistance.

4. DISCUSSION

Given that numerous commercial variants of composite resins are present on the market, it is difficult to perform an even analysis in terms of wear resistance or roughness. The existing studies must be used very carefully as instruments for selecting composite resins, given the difficulties in simulating the movements of the lower jaw and the mouth environment. The existing studies only provide indicative values that can vary according to a multitude of factors.

A very polished odontal restoration is difficult to achieve because of the different amount of filling particles, their size, and the different strength of the filling particles and the composite resin matrix [24]. According to speciality literature, an average surface roughness (Ra) of 0.2 μm is a limit value for the roughness of composite restoration surfaces, beyond which bacterial retention is high enough to lead to cavities and/or periodontal disease [25].

Considering this finding, we note that the only composite resin-finishing system combinations with roughness values ranging below this value are:

– Valux ™ Plus Universal finished with Sof Lex and TOR VM;

– Filtek Z550 finished with TOR VM;

– Gaenial Posterior finished with Sof Lex.

It is easy to see that no composite resin finished with the Super Snap system offered results below this threshold.

Roughness differences by finishing and polishing techniques can be attributed to the distinct particle size models and their layout in the resin matrix. For a finishing system to be efficient, the cutting particles must be harder than the filling particles; otherwise, the finishing and polishing system can only work on the resin matrix. Paradoxically, this can lead to a greater surface roughness. Therefore, finishing and polishing procedures on the surface of the restoration material can be beneficial or, on the contrary, they can be harmful [26].

The results shown in Table 3 indicate the statistic average roughness for all 4 materials, taking into account the finishing systems applied for surface conditioning. Thus, differences can be seen depending both on the composite resin manufacturer and on the finishing system used.

According to the results obtained, the microhybrid composite G-ænial posterior finished with Sof Lex gave the lowest roughness of all the analysed composites. As mentioned earlier, for a finishing system to be efficient, the particles of the finishing disk must be harder than any component of the composite system. Although studies are available mentioning the criteria needed for achieving optimal finishing, namely the size and the hardness of the filling particles, for the finishing systems, manufacturers do not provide enough details on the hardness of the finishing particles compared to the hardness of the composite particles.

The influence of the finishing systems on the composite resins is best shown with the microhybrid composite Gradia Posterior, which showed significant differences between the samples finished with Sof Lex (0.154 μm) and samples finished with TOR VM (2.16 μm). Various combinations between composite resins and finishing systems may or may not have similar results.

Certain studies [27–30] showed that, from a clinical point of view, no significant differences were noted between the roughness values obtained for a composite resin finished with various finishing systems. On the other hand, studies are available claiming that the results of the efficiency of finishing and polishing systems differs, but they depend on the properties of the composite resin material and its compatibility with the finishing system [31–34].

It is important to note that the study we made has certain limitations, related to the fact that, as it was an *in vitro* study, the samples were even, which favoured better results compared to what could have been obtained on irregular, hollow or convex surfaces of teeth. The finishing systems used can significantly influence the mechanical properties of the composite resins. This aspect was noted in other specific studies as well, which studies revealed that finishing systems may have both a positive and a negative impact on the wear resistance of resins [35–40].

One cause for this phenomenon, which was identified by other authors as well [40], is the composition and the level of granulation of the finishing particles [41].

Some studies showed that unpolished restorations increase the shearing coefficient and, as a result, may increase the wear rates [42].

Since wear is the most frequent phenomenon seen in dental surfaces, wear resistance is one of the most important properties that composite materials used for restoring odontal lesions must possess. Wear resistance is necessary both for posterior restorations and for anterior ones [43]. One of the most frequently seen causes of failure in composite restorations is the wear that shows especially at the level of occlusal and proximal surfaces [44].

It is well know that good wear resistance brings about a number of significant benefits for composite restorations, such as:

– Colour stability;
– Prolonged life of the restoration;
– Functionality of the restoration.

On the other hand, weak wear resistance causes dental migrations, impact on the temporomandibular joint, periodontic pathology, and muscle fatigue [45-48]. Some of the most important factors influencing composite wear are the volume, size, and hardness of filling materials. The larger the filling volume, the lower the composite wear [49, 50].

In terms of wear resistance, in our study, best results were obtained with Valux ™ Plus Universal, finished with TOR VM and tested with the sapphire ball. Since this composite is a nanohybrid material, we can confirm that inorganic filling remains the defining element in influencing the mechanic properties of composites. This idea is strengthened by the fact that the next best result after Valux ™ Plus Universal was obtained with another nanohybrid (Filtek Z550). Similar results were shown in other studies as well [51, 52], where nanohybrid resins obtained more favourable results in wear tests, irrespective of the finishing system used. Ugur Erdemir *et al.* noticed no significant differences in their study between the wear behaviour of the micro- and nano-hybrid composite resins selected [53]. The same conclusion was obtained from the research of D. Angerame and M. De Biasi, who, after analysing several similar studies, reported in their review that there are no considerable differences between the wear behaviour of nano- and micro-hybrid resins [54].

In terms of resistance, odontal restoration can be considered ideal when it has the same wear rate as natural teeth. The average value of annual wear in a molar was shown by the Lambrechts P. *et al.* study to be 29 μm, while that of a premolar was 15 μm [52]. Previous research analysing the wear of universal composite resins revealed approximately 50–75 μm wear per year, while new composites displayed significantly lower wear values (10–20 μm per year) [55].

The dynamics of testing processes, together with the multitude of parameters that need to be analysed restrict the results of comparative studies of the various composite materials. The difficulty to simulate the circumstances and the movements of the dental and jaw system considerable, and therefore most *in vitro* studies produce indicative results [56, 57].

5. CONCLUSIONS

In terms of roughness analysis, the study showed that, besides the importance of the chemical structure of composites, finishing systems significantly influence surface roughness.

In terms of wear resistance, the study confirmed higher resistance of nanohybrid resins compared to microhybrid resins, which was also indicated by other speciality studies.

Given the correlation between surface roughness and wear resistance, normally, the composite with the lowest roughness value should have produced the best wear resistance. However, the study shows that the lowest roughness was obtained with a microhybrid composite, while the greatest wear resistance was obtained with a nanohybrid. This may suggest that the structure of the composite may compensate the deficiencies related to the surface roughness.

Given the limitations of *in vitro* studies in terms of simulating the circumstances of the oral environment, we consider that it is of utmost importance to conduct long term *in vivo* studies to identify the most efficient combinations of composite materials and finishing-polishing systems. Until exhaustive studies will become available, the responsibility of selecting such combinations lies with the dentist.

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