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Use of Two Surface Analyzers to Evaluate the Surface Roughness of Four Esthetic Restorative Materials After Polishing

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Clinical Relevance

All esthetic restorative materials do not have the same polishing characteristics. Nanofilled composites and fluid materials containing microfiller give the best surface states. Results with posterior composites and compomers are less effective.

SUMMARY

This study had two aims: determine how well four esthetic restorative materials lent themselves to polishing and compare the results obtained using two different techniques for evaluating surface roughness.

The four materials used were two composites modified by the addition of resin, Dyract AP (Dentsply) and Dyract Flow (Dentsply); one composite designed for posterior restorations, SureFil (Dentsply) and one universal micromatrix composite, Esthet-X (Dentsply). Five test pieces were made with each product by inserting the material into cylindrical molds and polymerizing it layer by layer. A single operator polished the specimens on the same day using the Enhance system (Dentsply) and two aluminum oxide pastes. The surfaces were studied successively by means of two surface analyzers: a high-resolution optical profilometer (Nanosurf 488, SAS Technology) and a mechanical profilometer (Mitutoyo Surftest-SV 402). These measurements gave the mean roughness of the surface (Ra). Ten zones were examined for each specimen, and the specimens were observed under an optical microscope (PMG3 inverted metallographic microscope) at 50x magnification.

The qualitative and quantitative analyses of the results showed good surface states for all materials. However, the composites based on nano- and micro-filler technology gave the smoothest surfaces after polishing. A comparison of the values obtained with each method of observation

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showed that mechanical profilometry tended to show roughness caused by polishing, while optical profilometry brought out roughness due to the structure of the material itself.

INTRODUCTION

Esthetic restorative materials are essentially composed of an organic phase (the resin matrix) and mineral particles intended, among other things, to improve their mechanical resistance (Braem & others, 1989; Ferracane, Antonio & Matsumoto, 1987; Condon & Ferracane, 1997).

Such materials can be classified into several categories, according to the structure and composition of each phase. In terms of the textures most frequently used, more fluid or more compact materials designed for different uses can be added.

"Flow" products have a more fluid consistency, which makes insertion easier and adapts better to the tooth structures. The mechanical properties of the first generation of these materials are not as good as those of conventional composites (Bayne & others, 1998) but can be considered acceptable. However, improvement is needed in their mineral filler content, and the trend is toward a second generation, which shows better mechanical performance while remaining just as fluid.

The number of condensable composites has also been increasing in the continuing search for an alternative to metallic materials. Their firmer consistency with respect to conventional composites comes from changes to the filler or matrix (Leinfelder, Radz & Nash, 1998). According to Suzuki (2001), the clinical performance of condensable composites is not significantly different from conventional ones. Nevertheless, Kyoung and others (2000) compared the mechanical properties of certain condensable composites and found that SureFil (Dentsply/Caulk, Milford, DE, USA) gave good results for resistance to flexion (1000 MPa) and for hardness (35 kg/mm^2).

Currently, nanofiller technology is in the process of adapting to dental composites and, according to Bayne (2000), the use of this type of filler enhances their adhesion to the matrix, thus leading to better resistance to wear.

Among the qualities required of a composite or compomer, good polishability is of prime importance, since this property influences not only the esthetics but also the durability of the obturation by preventing bacterial plaque from attaching to it.

The effect of polishing on esthetic qualities has long been under study, including as early as 1979, when Lietha-Elmer and Kratky concluded that the shine of a material depended essentially on the microgeometry of its surface. When microrelief presents highs and lows of corrugations greater than the wavelength of visible light, the light scatters in the grooves and pits and the material appears mat. To give the material a shine and to improve its esthetic aspect, the restoration must be polished in such a way that the microgrooves are reduced to dimensions smaller than the wavelength of light (about 0.5 µm), which is then reflected by the surface (Chandler, Bowen & Paffenberger, 1971).

Plaque is known to accumulate on the rough surfaces of restorations, thus favoring the development of periodontal disease (Waerhaug, 1975; Weitman & Eames, 1975; Bollen, Lambrechts & Quirynen, 1997) defined as a critical roughness threshold beyond which bacteria were likely to adhere to the surface. The value of this threshold is 0.2 µm.

The microrelief of the surface depends on the equipment used for polishing and also on the structure of the material to be polished.

Many polishing systems have been proposed to help with the last step of material insertion, eliminate defects and thus obtain a high quality surface state. Earlier studies have shown that the best finishing system is one recommended by the manufacturer (Jefferies, Barkmeier & Gwinnet, 1992; Joniot & others, 2000; Türkün & Türkün, 2004), adding that, when the material and polishing system come from the same manufacturer, its compatibility is better. Ritter (2001) showed that condensable composites are easier to polish if polishing paste is used.

However, the surface quality at the end of polishing also depends on the shape and size of the filler included in the material and the proportion it represents in the overall composition. Ryba, Dunn and Murchison (2002) showed that the larger the size of the filler particles, the rougher the surface after polishing. They also showed that too small a quantity of matrix relative to the amount of filler can mean that the largest particles may be rubbed off during polishing. In contrast, composites containing small particles are easier to polish.

This study determined how the matrix and filler compositions of restorative materials influenced the ease with which they could be polished using the same finishing system ((Enhance, Dentsply/Caulk; Prisma-Gloss) with two aluminum-based polishing pastes. Two techniques were used to evaluate the roughness of the surfaces: mechanical profilometry and three-dimensional optical profilometry. Several authors have studied the former method (Briand, 1990; Grimonster & others, 1994; Berastegui & others, 1992; Warren & others, 2002), while the latter method has been used in studies of the polishing qualities of certain composites (Joniot & others, 2000). Both techniques are methods for characterizing the morphology of a surface so as to bring out its topography.

Mechanical profilometry is two-dimensional. It is a tactile method using a diamond-tipped stylus. The sensor moves along an X-axis, measuring variations in height along the perpendicular, vertical Z-axis, taking the machine's translation system as the reference. The parallelism between the surface under study and the translation axis of the sensor must therefore be adjusted very carefully (Bouchareine, 1999). In such mechanical contact methods, the shape of the tip acts as a low pass filter, and defects with dimensions that are small relative to the radius of the curvature of the sensor are neglected. The sensitivity of the technique is on the order of 0.01 µm. When roughness is minimal, the sensor resolution is insufficient and optical measurements are needed (Jung, Voit & Klimek, 2003).

Optical profilometry is a three-dimensional analysis method that provides both a qualitative and quantitative representation of the relief. It is a method without mechanical contact, and the measuring device is an optical beam. The principle of the method is as follows: a plane wave falling on a plane surface that is not totally absorbent undergoes reflection and propagates as a plane wave in the direction given by Descartes' law. This is known as specular reflection. If neighboring points of the surface are not at the same height, a local phase shift occurs in the plane wave, which is observed as diffusion of the light in directions other than that of specular reflection. If the surface is very rough, the light is uniformly diffused in all directions and no longer represents the topography of the surface. The measurements are, therefore, useful only on surface states of very high quality. The apparatus works by measuring the distance between an internal reference and the points of the surface. The characteristics of the optical components give a resolution of a few nanometers over an area of about 100 µm square (Cornet & Deville, 1998).

METHODS AND MATERIALS

For this study, two composites and two compomers were studied: a condensable composite intended for posterior restorations, SureFil (Dentsply); a universal composite with a micro-matrix, including certain fillers having sizes on the order of a nanometer, Esthet-X (Dentsply/Caulk); a compomer designed to fill all cavities in anterior and posterior teeth, Dyract AP (Dentsply, Konstanz, Germany) and Dyract Flow (Dentsply), which is also a compomer but has a fluidity that makes it ideal for small cavities, pits and crevices, shallow Class V and marginal repairs in anterior and posterior teeth not subjected to occlusal stresses. Table 1 shows the compositions of these four materials.

Five specimens of each material were produced. They were made in cylindrical molds 5 mm in diameter by polymerizing successive 2-mm thick layers for 30 seconds using a QHL 75 polymerizing lamp (Dentsply/Caulk), which provided a luminous intensity of 450 mW/cm^2 and generated a wavelength of 480 nm, compatible with the camphoroquinone contained in the materials. The specimens were then polished by the same operator using the Enhance system (Dentsply/Caulk) with polishing points, then two pastes. The points contained about 70% aluminum oxide particles of mean size 100 µm. The Prisma-Gloss pastes used also contain aluminum oxide powder in which the particle size is about 1 µm for Prisma-Gloss fine and 0.3 µm for Prisma-Gloss extra-fine. The specimens were first examined under optical microscope (inverted metallographic microscope PMG3) at a magnification of 50x to check the quality of the surface.

The materials were then observed with an optical profilometer (Nanosurf 488, SAS Technology), followed by a mechanical profilometer (Mitutoyo Surftest SV 402). The radius of curvature of the tip was 5 µm. Five zones

Table 1

Material	Manufacturer Time	Type Cure	Polymer	Fillers (µm)	Filler Size (% by volume)	Filler Content
Dyract Flow	Dentsply Detrey Konstanz, Germany	Minifill 20-40 seconds	Carboxylic acid modified macromonomers Ammonium salt of PENTA and N,N-dimethylaminoethylmethacrylate	Strontium-alumino-fluoro silicate glass	1.6	38%
Dyract AP	Dentsply Detrey Konstanz, Germany	20-40 seconds depending on the shade	UDMA TCB resin Alkanoyl-poly-methacrylate	Strontium-fluoro-silicate glass	0.8	47%
Esthet-X	Dentsply/Caulk Milford, DE, USA	Microhybride 20 seconds	Bis GMA, bis EMA, TEGDMA	Barium-aluminium-fluoroboro-silicate glass silica	0.6-0.8 10-20nm	60%
SureFil	Dentsply Caulk Milford, DE, USA	Minifill 30 seconds	Urethane modified bisGMA	Barium-aluminium-fluoroboro-silicate glass silica	0.8	65%

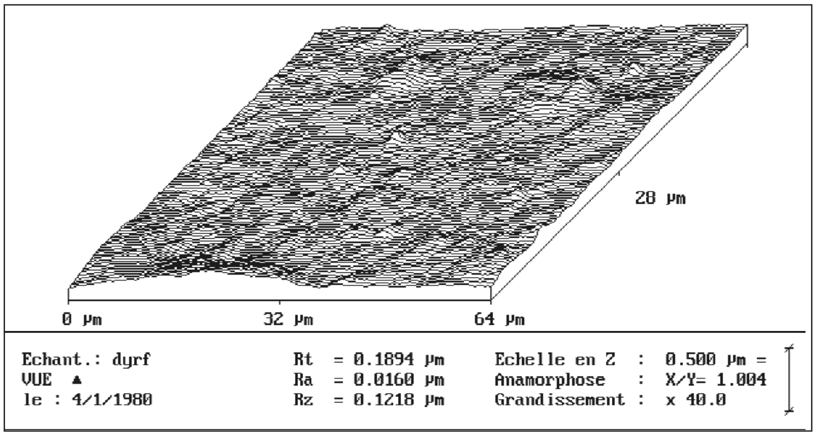

Figure 1. *Dyract Flow, three-dimensional profile obtained by optical profilometry.*

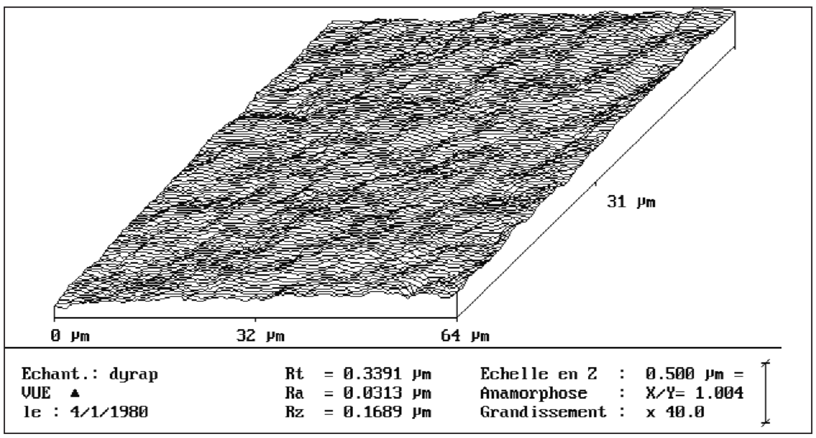

Figure 2. *Dyract AP, three-dimensional profile obtained by optical profilometry.*

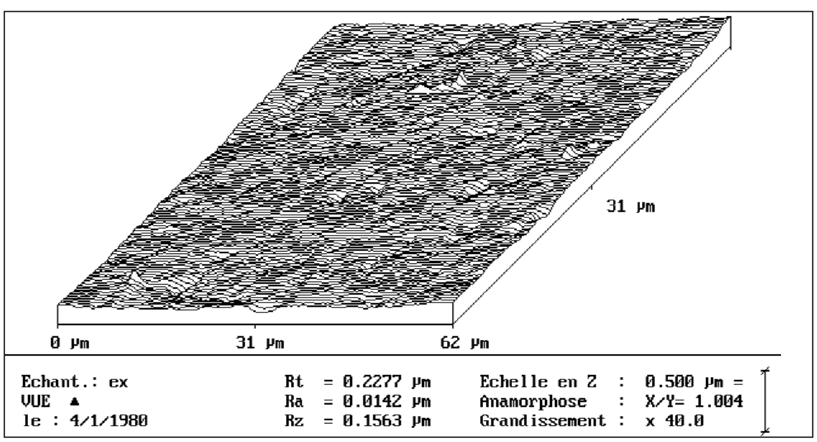

Figure 3. *Esthet-X, three-dimensional profile obtained by optical profilometry.*

chosen at random were examined for each specimen. This choice is in agreement with the work of Warren and others (2002). From a quantitative viewpoint, both investigation methods characterize the roughness of the surface using different parameters defined by the ISO 4287 standard. Ra, the mean roughness, is one of the most significant parameters, as is the arithmetic mean of all the values of roughness profile R over the evaluation length. This is the most frequently used parameter for surface characterization (Yap & Mok, 2002; Neme & others, 2002; Türkün & Türkün, 2004).

For each specimen, the mean of the five values of Ra was calculated and used as a criterion for the statistical evaluation of the results. For each method of measurement (mechanical and optical), the results obtained for the materials were compared using a Kruskal-Wallis non-parametric test (p=0.05) completed by Mann-Whitney tests (modified for multiple comparisons) to situate any differences found.

For each material, the results obtained by optical and mechanical profilometry were compared using a Wilcoxon test (p=0.05). A correlation was sought between the results obtained by the two methods, using the Kendall test (p=0.05).

RESULTS

Qualitative Evaluation

The three-dimensional profiles obtained by the optical method enabled a first appreciation of the surface states of each composite as shown in Figures 1, 2, 3 and 4. A rougher appearance is noticeable for SureFil and Dyract AP.

Observation under the metallographic optical microscope showed more numerous and bigger filler particles for SureFil (Figure 8) and a more granular surface state for Dyract AP (Figure 6). Esthet-X (Figure 7) and Dyract Flow (Figure 5) had a similar appearance (Figures 5, 6, 7 and 8).

Quantitative Evaluation

Table 2 and Figure 9 sum up the results obtained. The statistical analysis comparing the values of the four materials was performed with the same significance threshold (p=0.05). A Kruskal-Wallis test and a Mann-Whitney test (with Dunn-Bonferroni correction) were used for multiwise comparison. With mechanical profilometry, the analysis revealed the lowest values of Ra for Dyract-Flow, with Esthet-X in second position and SureFil and Dyract AP last.

The comparison of the results obtained using the two methods for each material was performed using a Wilcoxon test (significance threshold p=0.05), and the search for correlation between the results obtained by the two methods used Kendall's rank correlation (significance threshold p=0.05). No correlation was found (p=0.89), which implies that the two methods do not cover the same fields of investigation.

DISCUSSION

Discussion of Method

As Neme and others (2002) point out, the dentist's aim in placing restorative materials is to obtain the best possible surface state in order to reduce the retention of plaque and coloring agents to a minimum and also produce an esthetically satisfactory result.

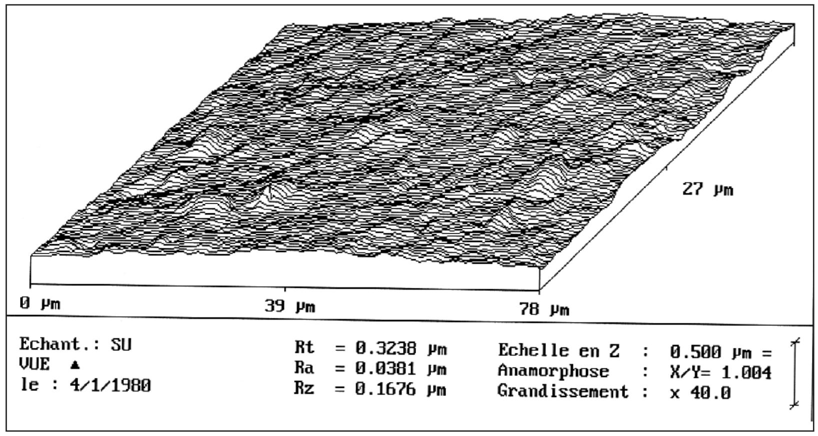

Figure 4. *SureFil, three-dimensional profile obtained by optical profilometry.*

Mechanical profilometry is widely used to assess surface states (Berastegui & others, 1992; Jung, 2002; Neme & others, 2002). Optical profilometry also measures the surface roughness of composites after polishing (Joniot & others, 2000). Both methods give quantitative evaluations of a surface by determining the same roughness parameters, for example, total roughness (Rt) and mean roughness (Ra). The latter parameter is the most frequently used, because it is among the most significant (Bouchareine, 1999). Both methods have their advantages but also their limits of resolution.

An important advantage is the absence of preparation of the specimen surface before observation. Thus, the same specimens can be re-used and possibly re-observed after successive time intervals.

As Cornet and Deville (1998) have shown, tactile methods have limits connected with their basic principle, such as errors in the size of small hollows, because of the radius of curvature of the stylus or problems with acutely concave surfaces. Moreover, the method is relatively slow and the force with which the stylus is applied may sometimes damage the surface. The optical methods do not have these disadvantages, as the beam penetrates all the nooks and crannies and, as Jung and others (2003) have shown, the resolution is finer. On the other hand, the optical methods require a surface state sufficiently smooth to avoid the apparition of artifacts due to diffusion of light in all directions, while the tactile methods can analyze the surface at each stage of polishing.

From a qualitative point of view, mechanical profilometry only gives a two-dimensional representation of the surface, which provides little information; whereas, optical profilometry shows the 3-D topography, allowing the materials to be classified according to the aspect of their surfaces.

Discussion of Results

Both mechanical and optical profilometry enable the arithmetic means (Ra) of surface roughness to be calculated. However, the results show higher values for this parameter in mechanical profilometry. This is due to the mechanical sensor not detecting all the small crevices that are recorded by the optical beam.

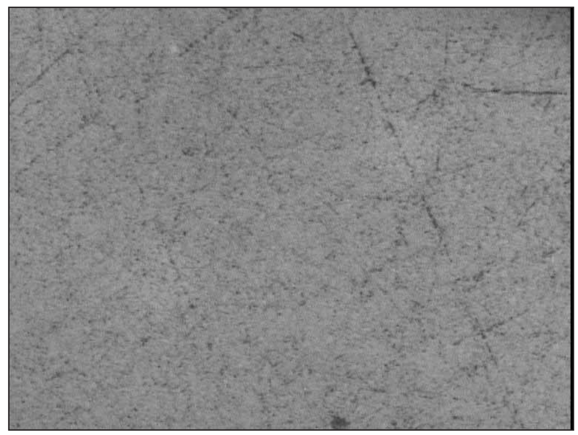

Figure 5. *Dyract Flow, observation under optical microscope (50x).*

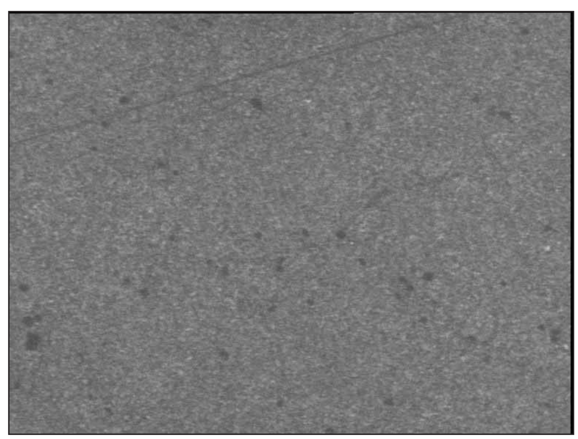

Figure 6. *Dyract AP, observation under optical microscope (50x).*

Whatever the method used, all four materials tested showed good esthetic qualities after finishing. All the recorded values of Ra were smaller than 0.5 µm, the wavelength of light. This is in agreement with the findings of Chandler and others (1971). All the results were

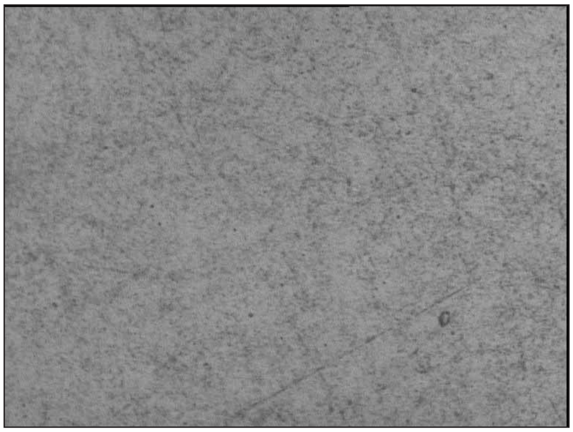

Figure 7. *Esthet-X, observation under optical microscope (50x).*

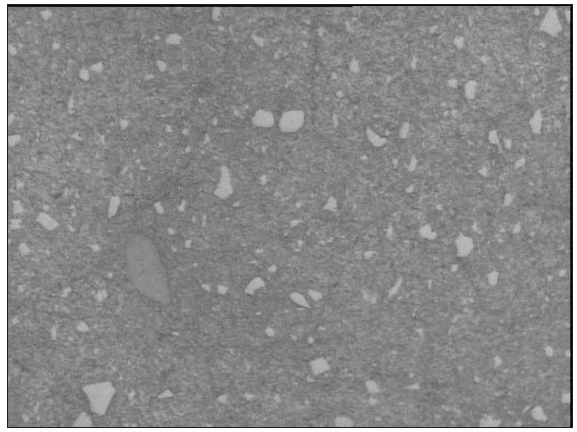

Figure 8. *SureFil, observation under optical microscope (50x).*

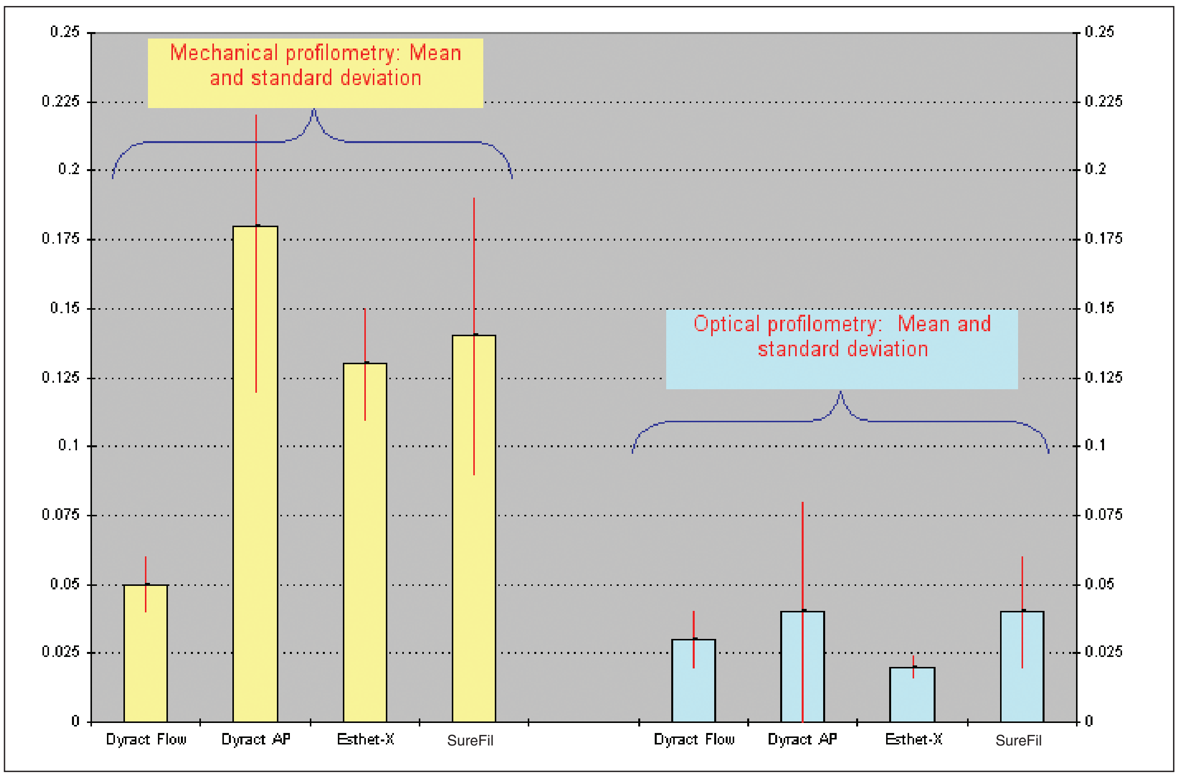

Figure 9. *Histogram showing the means and standard deviations of Ra obtained for the four materials using optical profilometry and mechanical profilometry.*

below 0.2 µm, the value that Bollen and others (1997) consider to be the threshold for the adhesion of bacteria, which demonstrates that the surface state of these materials is good when they have been polished with the Enhance system.

Mechanical profilometry gave the lowest values of mean roughness for Dyract Flow, whereas optical profilometry gave the lowest values for Esthet-X. However, both results were very close, on the order of 0.01 µm, and the variation can be explained by the fact that, since the scales are not the same, the roughness observed does not come from the same sources. Mechanical profilometry observations made by linear sweeps of the surface bring out roughness caused by polishing the materials; whereas optical profilometry observations made over areas with sides of about 100 µm chosen at random on the surface of the material tend to show roughness due to the structure of the material itself.

Table 2

Materials	Mechanical Profilometry: Mean and Standard Deviation	Optical Profilometry: Mean and Standard Deviation
Dyract Flow	0.05 (0.01)	0.03 (0.01)
Dyract AP	0.18 (0.04)	0.04 (0.04)
Esthet-X	0.13 (0.02)	0.02 (0.004)
SureFil	0.14 (0.05)	0.04 (0.02)

Thus, the observation of Esthet-X by mechanical profilometry showed a larger number of bur marks or polishing scratches than were detected on Dyract Flow, which was confirmed by the optical microscopy results. In contrast, the optical profilometry examination revealed a smoother surface for Esthet-X than Dyract-Flow. This could be explained by the presence of nanofiller in the matrix of Esthet-X. The same observations were made by Yap and others (2004), who studied the polishing qualities of composites based on nanofiller technology.

Dyract AP and SureFil showed very similar results for optical profilometry, with SureFil having a slight advantage. In particular, Dyract showed a greater standard deviation, signifying larger variations in polishability. In mechanical profilometry, as in optical, the highest mean roughness (Ra) values were found for Dyract AP.

A mechanical profilometry study by Neme and others (2002) showed that composites gave better polishing results than composites modified with the addition of polyacid. Yap and others (2004), also using mechanical profilometry, demonstrated that the Ra recorded for nanofilled composites were lower than those of microfilled composites and compomers. This study parallels previous ones, finding better surface states for composites than for compomers.

CONCLUSIONS

The interest of this research is twofold—it compares two surface analysis techniques, one tactile, the other optical, yielding a three-dimensional representation. Mechanical profilometry works on the scale of roughness regarding the texture of the surface, which can result from traces left by the polishing material; whereas optical profilometry detects micro-roughness, which generally reflects the structure of the material analyzed.

It also enables the materials to be ranked by surface state after polishing. The values of Ra observed for Dyract AP and SureFil were the least effective. Dyract Flow and Esthet-X showed good suitability for polishing. It has often been noted that the polish obtained depends on the use of the finishing system recommended by the manufacturer. The authors of this study can add that it also depends on the structure of the material.

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