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# Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature

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## ABSTRACT

*Objectives.* The roughness of intraoral hard surfaces can influence bacterial plaque retention. The present review evaluates the initial surface roughness of several intraoral hard materials, as well as changes in this surface roughness as a consequence of different treatment modalities.

*Methods.* Articles found through Medline searches were included in this review if they met the following criteria: 1) stated threshold surface roughness values and reputed change in surface roughness due to different manipulation techniques; or 2) included standardized surface conditions that could be compared to the treated surface.

*Results.* Recently, some *in vivo* studies suggested a threshold surface roughness for bacterial retention ($R_a$ = 0.2 µm) below which no further reduction in bacterial accumulation could be expected. An increase in surface roughness above this threshold roughness, however, resulted in a simultaneous increase in plaque accumulation, thereby increasing the risk for both caries and periodontal inflammation. The initial surface roughness of different dental materials (*e.g.,* teeth, abutments, gold, amalgam, acrylic resin, resin composite, glass ionomer or compomer and ceramics) and the effect of different treatment modalities (*e.g.,* polishing, scaling, brushing, condensing, glazing or finishing) on this initial surface roughness were analyzed and compared to the threshold surface roughness of 0.2 µm. The microbiological effects of these treatment modalities, if reported, are also discussed and compared to recent *in vivo* data.

*Significance.* Based on this review, the range in surface roughness of different intraoral hard surfaces was found to be wide, and the impact of dental treatments on the surface roughness is material-dependent. Some clinical techniques result in a very smooth surface (compressing of composites against matrices), whereas others made the surface rather rough (application of hand instruments on gold). These findings indicated that every dental material needs its own treatment modality in order to obtain and maintain a surface as smooth as possible.

## INTRODUCTION

The oral cavity is constantly contaminated by many diverse microbial species. Most of these microorganisms, especially those which are responsible for caries (*e.g., Streptococcus mutans* and *Lactobacillus spp.*) and periodontitis (*e.g., Actinobacillus actinomycetemcomitans* and *Porphyromonas gingivalis*), can only survive in the mouth when they adhere to non-shedding surfaces. The surface roughness of intraoral hard surfaces is of clinical importance in the process of bacterial retention. Changes in this variable might, therefore, facilitate the prevention of caries and periodontitis. The surface free energy can also play a role in bacterial adhesion and retention; however, several studies (*e.g.,* Quirynen *et al.,* 1990; Quirynen and Bollen, 1995) suggested that the influence of the surface roughness overrules the influence of the surface free energy.

Studies by Quirynen *et al.* (1990) showed that an increase in the surface roughness of resin strips above an $R_a$ value of 2 µm resulted in a dramatic increase in the bacterial colonization of these surfaces in comparison to smooth strips ($R_a$ = 0.12 µm), whereas a change in the surface free energy had almost no impact. Recent studies on abutments of intraoral two-stage implants (Quirynen *et al.,* 1996; Bollen *et al.,* 1996) indicated that an increase in surface roughness (up to 0.8 µm) of these intraoral hard surfaces had a significant effect on the *in vivo* rate of plaque formation (supra- and subgingivally) only if the initial surface had a minimum $R_a$ value of 0.2 µm (see profile images, Fig. 1). Therefore, a "threshold $R_a$" was suggested, which can be located at an $R_a$ score of 0.2 µm.

This $R_a$ score is supported by the theory of bacterial adhesion and retention. Physically, bacterial adhesion and

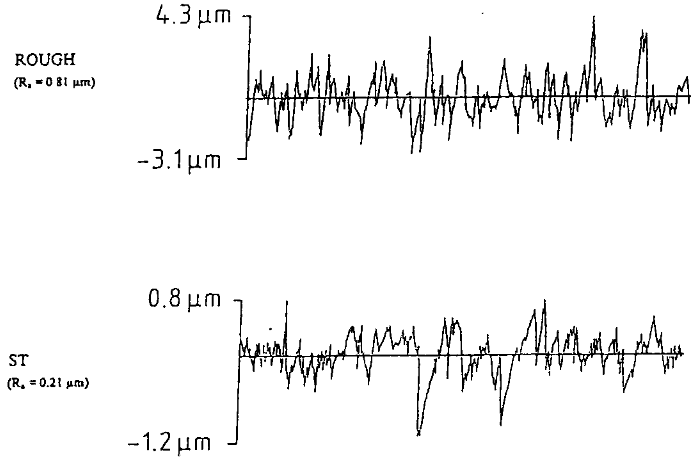


*Fig. 1.* **Profile images of 2 test abutments over the same assessment length (ROUGH = roughened standard abutment, ST = standard abutment). The length of the profiles is 0.12 µm. The surface roughness ($R_a$: arithmetic mean of the departures of the profile from the mean line) was measured with the Talysurf (Taylor-Hobson, Leicester, England).**

retention occur in four phases: transport of the bacterium toward the surface, initial bacterial adhesion, attachment by specific interactions, and finally, colonization of the surfaces (Quirynen and Bollen, 1995). Initial bacterial adhesion and retention are physico-chemically possible because a bacterium and a surface interact with each other from a certain distance (approximately 50 nm) through a combination of van der Waal's attractive forces and electrostatic repulsive forces.

Preferential retention occurs on rough surfaces since bacteria on such surfaces are more protected against shear forces and can, thereby, have the necessary time to reach direct contact or to bridge the distance. Initial colonization of enamel surfaces was indeed shown to start from surface irregularities (*e.g.,* pits, grooves or abrasion defects) where bacteria are strongly protected (Nyvad and Fejerskov, 1987). At these locations, the attachment may be more strongly established (Quirynen and Bollen, 1995). Furthermore, several studies stated that proliferation of the initially adhering microorganisms accounts for the major part of the microbial mass increase during early plaque formation (Brecx *et al.,* 1983) which may explain the importance of surface roughness in initial plaque formation.

Subgingivally, the impact of surface roughness is much smaller. The pocket by itself offers a shelter, which limits the possible impact of surface roughness on the subgingival plaque composition. Moreover, different means are available in this environment for bacterial survival: adhesion to root cementum, adhesion to the desquamating pocket epithelium, immersion in the crevicular fluid, invasion of the soft tissue and invasion of the hard tissue *via* the dentin tubuli (Quirynen and Bollen, 1995).

The aim of this literature review was to compare the surface roughness of different materials and the change in surface roughness by different manipulation techniques in relation to the stated threshold surface roughness of 0.2 µm.

## MATERIALS AND METHODS

The articles included in this review were selected using a Medline search (U.S. National Library of Medicine). The inclusion criterion was the presence of data on surface roughness. The following intraoral materials were studied: natural teeth (9 studies), implant abutments (5 studies), amalgam (8 studies), gold (6 studies), resin composites (17 studies), acrylic resin (7 studies), glass ionomers and compomers (3 studies), and ceramics (4 studies). If microbiological changes in relation to the roughness were available, they were included.

## RESULTS

*Tooth: Enamel and dentin / cementum.* The mean $R_a$ values, before and after professional therapies, are depicted in Table 1. Von Mierau *et al.* (1982) measured the surface roughness *in vivo* of crowns of natural teeth in 16 patients using a specially designed roughness probe. They reported that roughness depended on the tooth type (canines were the roughest) and on the location in the oral cavity (teeth in the upper jaw were rougher). All $R_a$ values were above 3.5 µm.

The effect of scaling on roots was examined by Rosenberg and Ash (1974). Fifty-eight teeth were divided into three groups before extraction: 20 teeth were scaled by curettes, 20 teeth were scaled by cavitron and the remaining 18 teeth served as controls. The initial surface roughness of 18.30 µm decreased after curette scaling (to 9.51 µm), whereas the cavitron scaling had no significant effect on the tooth roughness (17.21 µm). In an earlier study, Green and Ramfjord (1966) found almost the same results Lekness and Lie (1991) reported that the scaling of roots followed by polishing with chalk and pumice could decrease the surface roughness to nearly 1.3 µm, which is still high compared to the 0.2 µm threshold roughness.

Oral hygiene implements have almost no influence on the initial roughness of crowns. Smith *et al.* (1986), as well as Slop and Arends (1987), showed that the application of floss or toothbrushes did not change the $R_a$ value, whereas the use of wooden toothpicks resulted in an increase in the surface roughness. The difference of the latter roughness values from the $R_a$ values reported by Von Mierau *et al.* (1982) can be explained by the different device that was used to measure the surface roughness. Whereas Slop and Arends (1987) and Smith *et al.* (1986) used a computer- guided profilometer on extracted teeth, Von Mierau *et al.* (1982) had to use a manual probe for measuring the surface roughness on teeth in the oral cavity.

Polishing teeth has different effects on roughness, depending on the paste used. A recent study (Lutz *et al.,* 1995) showed that polishing dentin (with an initial $R_a$ of 0.03 µm) with different materials resulted in an increase in roughness up to 0.31 µm (pumice). Only the application of CCS 40 (Clean Chemical AB, Upplands Väsby, Sweden) stabilized the $R_a$ value at 0.03 µm. When enamel (initially 0.03 µm) was polished, only pumice led to an increase in roughness (up to 0.16 µm); none of the other materials influenced the $R_a$ value (Table 1).

No studies concerning microbiological effects and results were available.

**TABLE 1: THE EVOLUTION OF THE SURFACE ROUGHNESS OF TEETH**

| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
|---|---|---|---|---|
| Green and Ramfjord, 1966 | - | Scaling (sickles) | | 9.12 ± 2.67 |
| | | Scaling (curettes) | | 10.05 ± 2.29 |
| | | Scaling (files & curettes) | | 10.54 ± 2.45 |
| | | Scaling (hoes) | | 12.89 ± 2.16 |
| | | Scaling (files) | | 13.95 ± 3.69 |
| Rosenberg and Ash, 1974 | 18.30 | Scaling (curette) | | 9.51* |
| | | Scaling (cavitron) | | 17.21* |
| Heath and Wilson, 1976 | - | Brushing | (Enamel) | 0.10* |
| | | Polishing (rubber cup) | | 0.50* |
| | | Finishing (white stone) | | 0.50* |
| | | Polishing (prophylactic paste) | | 0.80* |
| | | Polishing (Zr discs) | | 0.80* |
| | | Finishing (diamond bur) | | 0.90* |
| Von Mierau *et al.*, 1982 | - | | Incisor / lower jaw | 3.50* |
| | | | Molar / lower jaw | 3.50* |
| | | | Premolar / upper jaw | 3.50* |
| | | | Molar / upper jaw | 3.75* |
| | | | Premolar / lower jaw | 3.75* |
| | | | Incisor / upper jaw | 3.85* |
| | | | Canine / lower jaw | 4.50* |
| | | | Canine / upper jaw | 4.50* |
| Smith *et al.*, 1986 | 0.06 | Flossing (superfloss) | | 0.07 ± 0.01 |
| | | Flossing (waxed floss) | | 0.07 ± 0.01 |
| | 0.07 | Toothpick application (wood) | | 0.18 ± 0.05 |
| | | Toothpick application (plastic) | | 0.22 ± 0.16 |
| Slop and Arends, 1987 | 0.15 | Brushing (500 x) | (Enamel) | 0.16 ± 0.02 |
| | | Brushing (10,000 x) | | 0.16 ± 0.02 |
| | | Brushing (30,000 x) | | 0.16 ± 0.01 |
| | | Brushing (50,000 x) | | 0.16 ± 0.01 |
| Lekness and Lie, 1991 | - | Scaling | | 1.54 ± 0.29 |
| | | + Polishing (pumice) | | 1.26 ± 0.19 |
| | | + Polishing (chalk) | | 1.10 ± 0.22 |
| | | Scaling | | 1.68 ± 0.40 |
| | | + Polishing (air powder) | | 1.41 ± 0.32 |
| | | + Polishing (chalk) | | 1.19 ± 0.26 |
| McGuckin *et al.*, 1992 | 1.9 | Bleaching (Proxigel, pH = 4.7) | | 0.60* |
| | | Bleaching (Superoxol, pH = 3.0) | | 0.60* |
| | | Bleaching (White & Brite, pH = 6.2) | | 0.90* |
| Lutz *et al.*, 1995 | 0.03 | Polishing (CCS 40) | (Dentin) | 0.03* |
| | | Polishing (Détartrine Z) | | 0.08* |
| | | Polishing (Zircate) | | 0.11* |
| | | Polishing (Cleanic) | | 0.15* |
| | | Polishing (CCS 250) | | 0.23* |
| | | Polishing (Nupro Coarse) | | 0.25* |
| | | Polishing (pumice) | | 0.31* |
| | 0.03 | Polishing (CCS 40) | (Enamel) | 0.03* |
| | | Polishing (Cleanic) | | 0.03* |
| | | Polishing (Détartrine Z) | | 0.05* |
| | | Polishing (CCS 250) | | 0.06* |
| | | Polishing (Nupro Coarse) | | 0.06* |
| | | Polishing (Zircate) | | 0.08* |
| | | Polishing (pumice) | | 0.16* |

*No standard deviations mentioned in original article.

*Artificial abutment on top of implants.* The $R_a$ values of abutments in different studies are shown in Table 2. There is a highly significant similarity between oral implants and teeth, indicated by the presence of crevicular fluid, the similarity in pocket epithelium or a comparable reaction toward plaque (Aspe *et al.*, 1989; Sanz *et al.*, 1991). Recently, Adonogianaki *et al.* (1995) even proved that the inflammatory and immune events in the peri-implant mucosa and the gingiva around natural teeth are similar. Therefore, the observations made of artificial abutments can be extrapolated to the root surfaces of natural teeth.

When six commercially available systems were compared, only the Steri-Oss (Denar Corp., Anaheim, CA, USA) and the IMZ abutments (AG Sparte Medizin Technik, Mannheim, Germany) seemed to have an $R_a$ value below 0.2 µm (Quirynen *et al.*, 1994). Recently it was shown that electro- and mechano-polishing of standard Brånemark abutments (Nobelbiocare, Götenborg, Sweden) also led to a surface roughness of less than 0.2 µm (0.13 µm and 0.11 µm, respectively) (Quirynen *et al.*, 1996). Ceka (Alphadent, La Chaux-de fonds, Switzerland) and Prozyr abutments (FBC Int. NV, Dessel, Belgium) even had $R_a$ values below 0.1 µm (0.05 µm and 0.06 µm, respectively) (Bollen *et al.*, 1996) (Table 2).

Considering the treatment of artifical abutments, special care should be taken when titanium instruments (Speelman *et al.*, 1992), air powder abrasive systems (Eliades *et al.*, 1991) or prophylactic agents, such as fluoride gels or gels containing hydrofluoric acid (Pröbster *et al.*, 1992), are used. These products lead to a tremendous increase in the initial surface roughness of the abutments.

*Microbiology.* When roughened ($R_a$ = 0.81 µm) abutments were compared to smooth ones ($R_a$ = 0.35 µm) (Quirynen *et al.*, 1993), it was shown that the rough abutments harbored 20 times more bacteria subgingivally, with a clearly higher proportion of spirochetes and motile organisms, which can be considered pathogenic (Theilade *et al.*, 1966). When the $R_a$ value was decreased below 0.2 µm, no significant further changes in the total amount nor in the pathogenicity of the adhering bacteria could be detected (Quirynen et al., 1996; Bollen *et al.*, 1996). Therefore, it was stated that 0.2 µm is the threshold surface roughness below which no impact on the bacterial retention could be expected.

*Amalgam.* The mean roughness values, before and after different treatment modalities, are depicted in Table 3.

When different brands of amalgam were compared, Smales (1981) found that the amalgams had a two-fold

**TABLE 2: THE EVOLUTION OF THE SURFACE ROUGHNESS OF ABUTMENTS**

| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
|---|---|---|---|---|
| Quirynen *et al.*, 1993 | 0.21 | Brånemark standard | | 0.21* |
| | | Brånemark sandblasted | | 0.81* |
| Quirynen *et al.*, 1994 | - | | Steri-Oss | 0.10 ± 0.01 |
| | | | IMZ | 0.13 ± 0.02 |
| | | | Brånemark | 0.21 ± 0.04 |
| | | | ITI-Bonefit | 0.23 ± 0.09 |
| | | | Astra-Tech | 0.27 ± 0.02 |
| | | | Corevent | 0.29 ± 0.03 |
| Quirynen *et al.*, 1996 | - | | CEKA | 0.05* |
| | | | Brånemark mechano-polished | 0.11* |
| | | | Brånemark electro-polished | 0.13* |
| | | | Brånemark standard | 0.21* |
| Bollen *et al.*, 1996 | - | | Prozyr | 0.06* |
| | | | Brånemark standard | 0.21* |

*No standard deviations mentioned in original article.

higher $R_a$ value than the threshold surface roughness, ranging from 0.43 ± 0.03 µm for Sybraloy (Sybron/Kerr, Romulus, MI, USA) to 0.49 ± 0.04 µm for Indiloy (Shofu Inc., Tokyo, Japan).

Moreover, the finishing procedures were also found to have a dramatic impact on the surface roughness. A study by Roulet and Roulet-Mehrens (1982) showed that, when initially smooth amalgam (0.05 µm) was polished with different materials, the surface roughness remained below 0.2 µm. Some polishing pastes had no influence on the initial $R_a$ value: Fluor-O-Clean (Hawe Neos Dental, Gentilino, Switzerland), Zircate (L.D. Caulk Co., Dentsply Int., Milford, DE, USA), Superpolish (Hawe Neos Dental) and Cleanpolish (Hawe Neos Dental). By contrast, polishing of smooth amalgam (0.16 µm) with Clinomyn and Colgate (Proctor and Gamble) toothpastes, resulted in a two- to three-fold increase in the surface roughness (up to 0.56 µm) (Johannsen *et al.*, 1989). When initially rough amalgam ($R_a$ = approximately 4.5 µm) was treated with consecutive polishing and finishing procedures, a ten-fold reduction in the surface roughness could be detected (Eide and Tveit, 1987). Davidson (1979) showed that polishing of amalgam with pumice and $SnO_2$ resulted in the smoothest surfaces and that the threshold roughness of 0.2 µm could be reached. Other studies confirmed these findings. The use of white stone (AD Trade Dist. Ltd., London, England, UK) or Nupro-paste (Nupro-gold, Janar Co., Grand Rapids, MI, USA), polishing with 240-grit discs and tiny strips, are procedures that enormously increase the surface roughness (Table 3).

No microbiological data were available. However, one can state that the amounts of copper (for $\gamma_2$-amalgam: from 1.4 to 5.3%; for non $\gamma_2$-amalgam: from 8.6 to 29.7%) (Vrijhoef *et al.*, 1980) and mercury in the different amalgams have an antibacterial function. Nourallahi and Meryon (1989) showed that when released from dental restorative materials, copper and mercury, have an antibacterial activity on bacterial plaque.

*Gold.* The results of different treatment modalities on the surface roughness of gold are summarized in Table 4. Roulet and Roulet-Mehrens (1982) showed that polishing of gold with different pastes did not have any effect on the surface roughness. Some pastes (Superpolish and Clean-polish) even smoothed the gold surface from 0.04 µm to almost 0.02 µm. Nupro red (Johnson & Johnson, East Windsor, NJ, USA) and Nupro green (Johnson & Johnson) seemed to have an adverse effect on the $R_a$ value, but the roughness still remained below 0.2 µm.

Heath and Wilson (1976), in contrast, showed that polishing of initially smooth gold surfaces with rubber cups, zirconium discs or a prophylactic paste (Kemdent Brand, Associated Dental Products, London, England, UK) increased the surface roughness clearly above the threshold $R_a$ value. Brushing had no effect on gold. The latter findings were confirmed by Johannsen *et al.* (1989; 1992) who also reported that brushing gold with toothpastes such as Clindomyn or Colgate did not have a severe effect on the roughness. The application of scalers and other oral hygiene instruments on gold increased the $R_a$ value from 3 µm (use of curettes) to 20 µm (use of cavitron) (Cutler *et al.*, 1995) (Table 4).

No microbiological data were available.

*Resin composite.* Many studies examined the surface roughness of resin composites (Table 5). When different brands were studied *in vitro*, Willems *et al.* (1992) found that almost 30% of the 60 composites tested had an $R_a$ value below the threshold of 0.2 µm after mechanical polishing. Heliosit (Vivadent, Schaan, Liechtenstein), Certain (Johnson & Johnson) and Heliomolar (Vivadent) were the smoothest (0.07 µm, 0.08 µm and 0.09 µm, respectively), whereas Estilux Posterior CVS (Kulzer Friedrichsdorf, Germany), Opalux (GC Int., Tokyo, Japan) and Litefil A (Shofu Inc.) were initially the roughest (1.48 µm, 1.50 µm and 1.56 µm, respectively). Smales (1981) detected higher *in vitro* values for Isopast (Vivadent) (0.93 ± 0.12 µm) and Concise (3M Dental Products, St. Paul, MN, USA) (2.09 ± 0.08 µm), whereas Willems *et al.* (1992) scored them as 0.13 µm and 1.44 µm, respectively.

Possible explanations for these differences could be the finishing procedures of the composites in the different studies and the different equipment used to perform the surface roughness measurements. When finishing and polishing procedures are considered, it is concluded that compressing a composite against a matrix creates a very smooth surface. All studies showed $R_a$ values far below the threshold level of 0.2 µm, ranging from 0.03 µm (Restodent (Lee Pharmaceutics) (Davidson, 1979) up to 0.2 µm (Adaptic (Johnson & Johnson, New Brunswick, NJ, USA) (Weitman and Eames, 1975). However, when conventional and microfilled composites were polished with different prophylactic pastes, an increase in surface

**TABLE 3: THE EVOLUTION OF THE SURFACE ROUGHNESS OF AMALGAM**

| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
|---|---|---|---|---|
| Heath and Wilson, 1976 | - | Brushing with dentifrice | | 0.30* |
| | | Polishing (pumice) | | 0.50* |
| | | Polishing (rubber cup) | | 0.50* |
| | | Polishing (prophylactic paste) | | 0.60* |
| | | Polishing (Zr Silicat discs) | | 1.00* |
| | | Polishing (white stone) | | 1.20* |
| Smales and Creaven, 1979 | - | Polishing (15 µm AlO) | | 0.22 ± 0.08 |
| | | Polishing (600-grit) | | 2.18 ± 0.87 |
| | | Polishing (240-grit) | | 4.42 ± 1.27 |
| | | Stripping | | 5.47 ± 2.51 |
| Davidson, 1979 | - | Carving | | 4.60* |
| | | Condensing against matrix | | 0.60* |
| | | Finishing bur | | 0.55* |
| | | Polishing (pumice) | | 0.20* |
| | | Polishing ($SnO_2$) | | 0.20* |
| | | SiC sandpaper | | 0.60* |
| Creaven *et al.*, 1980 | - | Polishing (silex and SnO) (proximal) (Tytin / Shepaloy) | | 0.25 ± 0.10 / 0.23 ± 0.15 |
| | | Condensing against matrix (prox) (Ty / Sp) | | 0.64 ± 0.08 / 0.75 ± 0.09 |
| | | Finishing with bur (occlusal) (Ty / Sp) | | 0.64 ± 0.15 / 0.62 ± 0.24 |
| | | Polishing with silex and SnO (occ) (Ty / Sp) | | 0.70 ± 0.18 / 0.54 ± 0.11 |
| | | Polishing (Nupro-paste) (prox) (Ty / Sp) | | 0.80 ± 0.46 / 0.90 ± 0.53 |
| | | Carving + burnishing (occ) (Ty / Sp) | | 1.84 ± 0.45 / 1.22 ± 0.13 |
| | | Polishing (Nupro-paste) (occ) (Ty / Sp) | | 2.18 ± 0.54 / 1.56 ± 0.45 |
| | | Carving (occ) (Ty / Sp) | | 3.74 ± 0.22 / 3.20 ± 0.58 |
| Smales, 1981 | - | | Sybraloy (Ternary alloy) | 0.43 ± 0.03 |
| | | | New True Dentalloy (Fine lathe-cut alloy) | 0.45 ± 0.03 |
| | | | Indiloy (Quaternary alloy) | 0.49 ± 0.04 |
| Roulet and Roulet-Mehrens, 1982 | 0.05 | Polishing (Nupro red) | | 0.16* |
| | | Polishing (Nupro green) | | 0.12* |
| | | Polishing (Nupro gold) | | 0.10* |
| | | Polishing (Coral II) | | 0.08* |
| | | Polishing (Colgate fluoride prophylactic paste) | | 0.10* |
| | | Polishing (Fluor-O-Clean) | | 0.06* |
| | | Polishing (Zircate) | | 0.05* |
| | | Polishing (Superpolish) | | 0.05* |
| | | Polishing (Cleanpolish) | | 0.05* |
| | | Polishing (Prophyprep) | | 0.10* |
| Eide and Tveit, 1987 | 4.00 | Green stone | | 1.70* |
| | | + Finishing bur | | 1.40* |
| | | + Polishing (pumice) | | 0.40* |
| | | + Polishing (chalk) | | 0.35* |
| | | + Polishing ($SnO_2$) | | 0.30* |
| | 4.20 | Green stone | | 1.70* |
| | | + Finishing bur | | 1.40* |
| | | + Coarse polisher | | 0.50* |
| | | + Fine polisher | | 0.20* |
| | | + Polishing (pumice) | | 0.50* |
| | | + Polishing (chalk) | | 0.40* |
| | | + Polishing ($SnO_2$) | | 0.40* |
| | 5.00 | Medium sandpaper | | 1.40* |
| | | + Fine sandpaper | | 0.80* |
| | | Polishing (fine white disc) | | 0.40* |
| | | + Polishing (pumice) | | 0.45* |
| | | + Polishing (chalk) | | 0.40* |
| | | + Polishing ($SnO_2$) | | 0.40* |
| Johannsen *et al.*, 1989 | 0.26 | Polishing (Clinomyn) (ANA 68) | | 0.70* |
| | | Polishing (Colgate) (ANA 68) | | 0.30* |
| | 0.16 | Polishing (Clinomyn) (ANA 2000) | | 0.56* |
| | | Polishing (Colgate) (ANA 2000) | | 0.30* |

* No standard deviations mentioned in original article.

roughness was detected, even up to 4 times (Roulet and Roulet-Mehrens, 1982). Chung (1994) saw the opposite result: polishing Herculite (Kerr Mfg. Co., Romulus, MI, USA) (0.35 ± 0.07 µm) and Heliomolar (0.52 ± 0.17 µm) decreased the surface roughness below the threshold $R_a$ (0.18 µm and 0.14 µm, respectively).

In studies where, unfortunately, no initial roughness was mentioned, it can be concluded that only the polishing of

**TABLE 4: THE EVOLUTION OF THE SURFACE ROUGHNESS OF GOLD**

| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
|---|---|---|---|---|
| Heath and Wilson, 1976 | 0.08 | Brushing | | 0.07* |
| | | Polishing (prophylactic paste) | | 0.30* |
| | | Polishing (rubber cup) | | 0.50* |
| | | Polishing (Zr discs) | | 0.50* |
| | | Finishing (white stone) | | 0.90* |
| Davidson, 1979 | - | Polishing (rouge) | | 0.04* |
| | | Polishing (discs) | | 0.10* |
| | | Polishing (sea-foam fine) | | 0.20* |
| | | Electrolysis | | 0.30* |
| | | Etching | | 0.40* |
| | | Polishing (sea-foam medium) | | 0.50* |
| | | Finishing (sand paper) | | 0.90* |
| Roulet and Roulet-Mehrens, 1982 | 0.04 | Polishing (Superpolish) | | 0.02* |
| | | Polishing (Cleanpolish) | | 0.03* |
| | | Polishing (Fluor-O-Clean) | | 0.03* |
| | | Polishing (Prophyprep) | | 0.03* |
| | | Polishing (Zircate) | | 0.03* |
| | | Polishing (Coral II) | | 0.04* |
| | | Polishing (Nupro gold) | | 0.04* |
| | | Polishing (Colgate fluor prophylax paste) | | 0.05* |
| | | Polishing (Nupro green) | | 0.06* |
| | | Polishing (Nupro red) | | 0.08* |
| Johannsen *et al.*, 1989 | 0.16 | Brushing (Colgate) | (Herador G) | 0.08* |
| | | Brushing (Clindomyn) | (Herador G) | 0.16* |
| | 0.16 | Brushing (Colgate) | (Sjödings C) | 0.06* |
| | | Brushing (Clindomyn) | (Sjödings C) | 0.22* |
| | 0.08 | Brushing (Colgate) | (Sjödings M) | 0.06* |
| | | Brushing (Clindomyn) | (Sjödings M) | 0.08* |
| Johannsen *et al.*, 1992 | 0.12 | Brushing (Clindomyn) | | 0.20* |
| | | Brushing (Colgate) | | 0.30* |
| Cutler *et al.*, 1995 | 2.83 | Application of curette | | 7.87 ± 3.30 |
| | | Application of explorer | | 13.70 ± 5.20 |
| | | Application of scaler | | 15.90 ± 3.70 |
| | | Application of cavitron | | 55.50 ± 25.2 |
| | 2.67 | Application of curette | | 6.67 ± 4.50 |
| | | Application of scaler | | 10.60 ± 4.20 |
| | | Application of explorer | | 16.50 ± 3.90 |
| | | Application of cavitron | | 37.50 ± 9.70 |

* No standard deviations mentioned in original article.

microfilled composites with alumina discs or with rubber wheels (O'Brien *et al.*, 1984), the polishing of Isomolar with diamond paste or Sof-lex discs (3M Dental Products) (Van dijken and Ruyter, 1987), and the polishing of Herculite with Sof-lex discs (Tjan and Chan, 1989) resulted in surface roughness below 0.2 µm. All the other manipulations led to a value above this threshold surface roughness (Table 5).

*Microbiology.* Only the study by Skjorland *et al.* (1982) mentioned some microbiological data: it was shown that bacteria adhered in similar amounts to the different materials and that there did not appear to be any predilection for the bacteria (*Streptococcus sanguis* ATCC 10556) to accumulate in the voids or on the filler or matrix surface of the composite. The absence of a relationship between surface roughness and plaque formation and retention might be explained by the high $R_a$ values of the examined surfaces (ranging from 0.8 to 1.4 µm).

The cytotoxicity of monomers can also have an antibacterial effect on the flora on this material.

*Acrylic resin.* The results of the treatment of acrylic resin are not clear-cut (Table 6). Busscher *et al.* (1984) stated that polishing this material leads to a surface roughness below the threshold $R_a$, depending on the polishing grit (from 0.03 µm to 0.75 µm). Most other studies found an increase in the roughness after polishing procedures: Loney *et al.* (1994) recently showed that treatment of resin with different procedures leads to a two- to five-fold increase of the surface roughness. Others found a 10-fold increase when No. 400 emery paper was used (Verran *et al.,* 1991). Similar to composites, compressing acrylic resin against glass results in a very low $R_a$ value (0.10 µm; Heath and Wilson, 1976) (Table 6).

*Microbiology.* Verran *et al.* (1991) showed that *Candida albicans* cells adhered in significantly higher numbers to rough acrylic than to smooth acrylic, but maximal adhesion was achieved on acrylic surfaces roughened with medium grit size emery paper ($R_a$ from 0.01 to 1.20 µm).

The roughness of a denture-fitting surface can help to determine its colonization by different microorganisms. Repeated aggressive brushing of dentures with abrasive cleansers will scratch even smooth denture surfaces (Anon, 1983; De Navarre, 1975). These findings were confirmed by Yamamuchi *et al.* (1990), who showed that *Streptococcus sanguis*, *Bacteroides gingivalis* C-101 and *Candida albicans* adhered in greater amounts to the roughest surfaces in comparison to the smooth surfaces.

*Glass ionomers and compomers.* Only three studies concerning glass ionomer and compomer cements could be found (Table 7). Recently, Gladys *et al.* (1997) summarized data on the surface roughness of these materials. Hotta *et al.* (1995) showed that only compressing Fuji Ionomer II (GC Int.) against glass resulted in an $R_a \leq 0.2$ µm. All the other manipulations of these cements, such as polishing and glazing, showed higher surface roughness values, even up to 1.5 µm (polishing of Chelonfil (ESPE Fabrik, Seefeld, Germany) (Table 7).

No microbiological data were available. The fluoride included in these materials resulted in antibacterial activity, although less important than the activity of copper, mercury and zinc in other dental restorative materials (Nourollahi and Meryon, 1989; Cimasoni, 1972). The fluoride release has a specific bactericidal effect on *mutans streptococci*, but only for a relatively short period of time (Forss *et al.*, 1991).

*Ceramics.* The results for this material are summarized

| TABLE 5: THE EVOLUTION OF THE SURFACE ROUGHNESS OF COMPOSITES | | | | |
|---|---|---|---|---|
| **Study** | **Initial Ra** | **Treatment** | **Situation-Material** | **Final Ra** |
| Weitman and Eames, 1975 | - | Compressing (Mylar strip) | | 0.20* |
| | | Polishing (AlO) | | 0.71* |
| | | Finishing (white Arkansas stone) | | 0.82* |
| | | Polishing (Zr paste) | | 1.01* |
| | | Polishing (pumice) | | 1.44* |
| Heath and Wilson, 1976 | - | Compression against glass matrix | | 0.09* |
| | | Compression against mylar matrix | | 0.15* |
| | | Polishing (Zr discs) | | 1.22* |
| | | Polishing (rubber cup) | | 1.37* |
| | | Finishing with white stone | | 1.49* |
| | | Brushing | | 1.86* |
| | | Polishing (prophylactic paste) | | 2.02* |
| | | Finishing with diamond bur | | 2.20* |
| Horton *et al.*, 1977 | - | Compressing (Mylar strip) | | 0.04 ± 0.01 |
| | | Polishing (discs) | | 0.58 ± 0.11 |
| | | Polishing (discs + Justi paste) | | 1.00 ± 0.10 |
| | | Polishing (discs + Precise paste) | | 1.02 ± 0.15 |
| | | Polishing (discs + 3M paste) | | 1.11 ± 0.12 |
| Davidson, 1979 | - | Compressing against matrix | (Concise) | 0.12* |
| | | Glazing | | 0.49* |
| | | Polishing (Precise paste) | | 0.83* |
| | | Finishing (Ruwa x fine) | | 0.90* |
| | | Finishing (3M strip) | | 0.90* |
| | | Polishing (Zircate) | | 0.99* |
| | | Finishing (Ruwa xx fine) | | 1.01* |
| | | Finishing (Arkansas) | | 1.02* |
| | | Finishing (Ruwa fine) | | 1.48* |
| | - | Compressing against matrix | (Restodent) | 0.03* |
| | | Glazing | | 0.37* |
| | | Finishing (Ruwa x fine) | | 0.48* |
| | | Finishing (Ruwa xx fine) | | 0.59* |
| | | Finishing (3M strip) | | 0.59* |
| | | Polishing (Zircate) | | 0.79* |
| | | Finishing (Ruwa fine) | | 1.16* |
| | | Finishing (Arkansas) | | 1.91* |
| Smales and Creaven, 1979 | - | Stripping | | 0.30 ± 0.13 |
| | | Polishing (600-grit) | | 1.42 ± 0.58 |
| | | Polishing (AlO) | | 1.85 ± 0.86 |
| | | Polishing (240-grit) | | 3.05 ± 0.89 |
| De Wet, 1980 | - | Compression against glass | | 0.10* |
| | | Finishing (tungsten + Arkansas + Sof-lex) | | 6.00* |
| | | + Application of Adaptic glaze | | 0.50* |
| | | + Application of Concise Enamel Bond Glaze | | 0.25* |
| | | + Application of Nuva-Seal Glaze | | 1.00* |
| | | + Application of Finite Glaze | | 2.50* |
| | | Finishing with diamond bur | | 15.00* |
| Smales, 1981 | - | | Isopast (Microfilled) | 0.93 ± 0.12 |
| | | | Concise | 2.09 ± 0.08 |

(continued)

in Table 8. Lee *et al.* (1995) recently found that the use of ultrasonic scalers or hand scalers had no influence on the roughness of initially smooth surfaces. Both treatment modalities kept the roughness (< 0.14 µm) below the threshold roughness, although when SEM photographs were subjectively evaluated, it was indicated that the integrity of the glazed surface was altered in the form of deep scratches on the ultrasonic-scaled surfaces and numerous smaller scratches on the hand-scaled porcelain. These scratches could not be detected with the profilometer. Most finishing techniques were found to render initially rough ceramic surfaces smoother, below the threshold $R_a$.

When ceramics with an initial $R_a$ value of nearly 3.0 µm were subjected to finishing with Sof-lex discs, or carbide burs or polishing with ET diamonds, with Flex-discs or two striper diamonds, the roughness decreased below 0.1 µm. Ward *et al.* (1995) showed that these findings were true for different ceramic materials, such as Ceramco II (Ceramco Inc., Burlington, NJ, USA), Vinytage (3M Dental Products), Opal 58 (3M Dental Products) and Duceram (Ducera Dental, GmBh, Rosbach, Germany). Polishing with different consecutive materials, such as tungsten, Shofu points (Shofu Int.), diamond strips (Premier Dental Co., Norristown, PA, USA) or Sof-lex discs resulted in little surface roughness, but not below the threshold surface roughness (Whitehead *et al.*, 1995) (Table 8).

No microbiological data were available.

In summary, the roughness of intraoral hard surfaces had a major impact on the retention of oral microorganisms. Supra- as well as subgingivally, an increase in surface roughness was found to result in a faster colonization of the surfaces and a faster maturation of the plaque, thereby increasing the risk for caries and periodontal inflammation. Therefore, the roughness of all intraoral hard surfaces should approximate an Ra value of 0.2 µm or lower.

Whereas a lot of publications deal with the supragingival aspect of surface roughness, the technical difficulty of altering the surface roughness of subgingival surfaces without surgical intervention explains the small number of publications concerning this subject. Furthermore, the majority of the articles are of relative importance since only one roughness parameter is mentioned (Ra, surface roughness). It would have been more valid to compare Rtm (mean of maximum peak to valley heights of a profile over the assessment length) or Sm (mean spacing between the profile peaks at the mean line) values since they give a better idea of the size of the irregularities on the surface. The Rtm value gives an idea of the depth of the defect, whereas the Sm value describes the width of the defect. Bollen *et al.* (1996) and Quirynen *et al.* (1996) explained

| TABLE 5: THE EVOLUTION OF THE SURFACE ROUGHNESS OF COMPOSITES (CONTINUED) | | | | |
|---|---|---|---|---|
| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
| Roulet and Roulet-Mehrens, 1982 | 0.28 | Polishing (Superpolish) | (Conventional) | 0.45* |
| | | Polishing (Zircate) | | 0.65* |
| | | Polishing (Cleanpolish) | | 0.70* |
| | | Polishing (Fluor-O-Clean) | | 0.80* |
| | | Polishing (Nupro gold) | | 0.85* |
| | | Polishing (Coral II) | | 1.00* |
| | | Polishing (Prophyprep) | | 1.00* |
| | | Polishing (Nupro green) | | 1.05* |
| | | Polishing (Colgate fluoride prophylactic paste) | | 1.10* |
| | | Polishing (Nupro red) | | 1.15* |
| | 0.05 | Polishing (Superpolish) | (Microfilled) | 0.08* |
| | | Polishing (Zircate) | | 0.11* |
| | | Polishing (Fluor-O-Clean) | | 0.12* |
| | | Polishing (Nupro gold) | | 0.12* |
| | | Polishing (Cleanpolish) | | 0.14* |
| | | Polishing (Coral II) | | 0.15* |
| | | Polishing (Colgate fluoride prophylactic paste) | | 0.22* |
| | | Polishing (Prophyprep) | | 0.22* |
| | | Polishing (Nupro green) | | 0.24* |
| | | Polishing (Nupro red) | | 0.28* |
| Skjorland *et al.*,1982 | - | | Epoxylite | 0.84 ± 0.37 |
| | | | Epolite | 0.90 ± 0.30 |
| | | | Adaptic | 1.42 ± 0.32 |
| | | | Sevitron | 1.42 ± 0.25 |
| O'Brien *et al.*, 1984 | - | Polishing (rubber wheel) | (Conventional) | 0.30* |
| | | Polishing (Silicate disc) | | 0.32* |
| | | Polishing (Alumina disc) | | 0.38* |
| | | Polishing (12-fluted bur) | | 1.50* |
| | - | Polishing (rubber wheel) | (Microfilled) | 0.08* |
| | | Polishing (Alumina disc) | | 0.14* |
| | | Polishing (Silicate disc) | | 0.45* |
| | | Polishing (12-fluted bur) | | 0.98* |
| Cooley *et al.*, 1986 | 3.78 | Polishing [$Na(CO_3)_2$ + air powder] (5 min) | (Silar) | 66.33 ± 11.4 |
| | | Polishing [$Na(CO_3)_2$ + air powder] (15 min) | | 91.89 ± 21.9 |
| | | Polishing [$Na(CO_3)_2$ + air powder] (30 min) | | 108.00 ± 15.9 |
| | 14.60 | Polishing [$Na(CO_3)_2$ + air powder] (5 min) | (Concise) | 138.30 ± 19.6 |
| | | Polishing [$Na(CO_3)_2$ + air powder] (15 min) | | 154.30 ± 16.4 |
| | | Polishing [$Na(CO_3)_2$ + air powder] (30 min) | | 173.00 ± 20.3 |
| Vandijken and Ruyter,1987 | - | Polishing (SiC paper) | (Isomolar) | 0.04 ± 0.02 |
| | | Polishing (Diamond paste 2.5 µm) | | 0.10 ± 0.09 |
| | | Polishing (Diamond paste 0.1 µm) | | 0.11 ± 0.19 |
| | | Polishing (Diamond paste 1 µm) | | 0.11 ± 0.05 |
| | | Polishing (Diamond paste 7 µm) | | 0.17 ± 0.09 |
| | | Polishing (Sof-lex, superfine) | | 0.19 ± 0.06 |
| | | Polishing (Sof-lex, fine) | | 0.29 ± 0.09 |
| | | Brushing | | 0.30 ± 0.18 |
| | | Polishing (Sof-lex, medium) | | 0.39 ± 0.13 |
| | | Polishing (Sof-lex, coarse) | | 1.04 ± 0.31 |

(continued)

that the Rtm value of all the artificial abutments they used was always less than 1 µm, which means that vertically, bacteria which normally are several µm in size are protected against shear forces. The Sm values of the abutments ranged from 26 to 6 µm, so only horizontally is some shelter offered to the bacteria, but only if the bacteria adhere to the surface parallel to the long axis of the abutments. In addition, very few publications could be found that included microbiological data related to the changes in surface roughness. From this point of view, a lot of research still must be done.

Materials with an initial low surface roughness should, therefore, be selected as the first choice. Amalgams with a low Ra value are Sybraloy, ANA 68 or ANA 2000. Smooth gold surfaces can be obtained with Herodor G, Sjödings C, Primor and Try-cast soft. The large review of composites by Willems *et al.* (1992) showed that several products are below the threshold level, such as Heliosit, Certain and Heliomolar. From the glass ionomer cements (Gladys *et al.,* 1997) only Fuji Ionomer seems to have an acceptable surface roughness. Several acrylic resins have an appropriate initial Ra value: Ivoclar Sr Isosit PE, Ivoclar SR Isosit N. Of the ceramic materials, only Vita VMK 68 porcelain had a surface roughness reaching 0.2 µm.

As for finishing procedures, the best way to achieve a smooth amalgam surface is to polish it with pumice or $SnO_2$, whereas if one starts with an initially smooth surface, most polishing pastes do not increase the roughness very much. Gold polishing can best be performed with rouge. The optimal way to make resin composites, acrylic resin and glass ionomer cements smooth is to compress them against a polyester strip. Also polishing with alumina discs, Sof-lex discs, rubber wheels or with diamond pastes (from 7 to 0.1 µm) can result in a smooth composite surface. Ceramics can preferably be finished with Sof-lex or carbide burs.

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**TABLE 5: THE EVOLUTION OF THE SURFACE ROUGHNESS OF COMPOSITES (CONTINUED)**

| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
|---|---|---|---|---|
| Vandijken and Ruyter,1987 | - | Polishing (SiC paper) | (Concise 1985) | 0.25 ± 0.06 |
| | | Polishing (Sof-lex, superfine) | | 0.26 ± 0.10 |
| | | Polishing (Sof-lex, fine) | | 0.35 ± 0.10 |
| | | Polishing (Sof-lex, medium) | | 0.48 ± 0.16 |
| | | Brushing | | 1.05 ± 0.29 |
| | | Polishing (Sof-lex, coarse) | | 1.11 ± 0.20 |
| | | Polishing (Diamond paste 0.1 µm) | | 1.33 ± 0.33 |
| | | Polishing (Diamond paste 2.5 µm) | | 1.41 ± 0.20 |
| | | Polishing (Diamond paste 7 µm) | | 1.78 ± 0.30 |
| Pratten and Johnson, 1988 | - | Compressing (Mylar matrix) | (Bisfil-I) | 0.14 ± 0.03 |
| | | Polishing (Shofu yellow) | | 0.26 ± 0.03 |
| | | Polishing (Shofu red) | | 0.32 ± 0.05 |
| | | Polishing (White stone) | | 1.36 ± 0.11 |
| | | Polishing (Brasseler ET diamond, fine, high-speed) | | 1.47 ± 0.18 |
| | | Polishing (Brasseler ET diamond, fine, low-speed) | | 1.73 ± 0.08 |
| | - | Compressing (Mylar strip) | (Bisfil-M) | 0.18 ± 0.04 |
| | | Polishing (Shofu red) | | 0.32 ± 0.06 |
| | | Polishing (Kerr polishing paste) | | 0.35 ± 0.6 |
| | | Polishing (3M Sof-lex, coarse) | | 1.42 ± 0.42 |
| | | Polishing (Brasseler ET diamond, fine, low-speed) | | 1.60 ± 0.13 |
| | | Polishing (Brasseler ET diamond, fine, high-speed) | | 1.73 ± 0.39 |
| Tjan and Chan, 1989 | - | Polishing (Luster paste) | (Herculite) | 0.11 ± 0.02 |
| | | Polishing (3M Sof-lex superfine) | | 0.11 ± 0.03 |
| | | Polishing (3M Sof-lex fine) | | 0.16 ± 0.04 |
| | | Polishing (3M Sof-lex medium) | | 0.25 ± 0.08 |
| | | Polishing (white stone) | | 0.43 ± 0.15 |
| | | Polishing (coarse) | | 0.84 ± 0.19 |
| | - | Polishing (Luster paste) | (P-30) | 0.26 ± 0.03 |
| | | Polishing (3M Sof-lex superfine) | | 0.28 ± 0.03 |
| | | Polishing (3M Sof-lex fine) | | 0.32 ± 0.0 |
| | | Polishing (3M Sof-lex medium) | | 0.47 ± 0.06 |
| | | Polishing (white stone) | | 0.70 ± 0.20 |
| | | Polishing (coarse) | | 1.10 ± 0.33 |
| Willems *et al.*, 1991 | - | Brushing (180 min) | (Heliosit) | 0.07 ± 0.01 |
| | | Polishing (Zr discs) | | 1.22* |
| | | Polishing (prophylactic paste) | | 2.02* |
| Willems *et al.*, 1992 | - | | Heliosit | 0.07* |
| | | | Certain | 0.08* |
| | | | Heliomolar | 0.09* |
| | | | Estilux Posterior CVS | 1.48* |
| | | | Opalux | 1.50* |
| | | | Litefil A | 1.56* |
| Chung, 1994 | 0.35 | Compressing against mylar strips | (Herculite) | 0.09 ± 0.05 |
| | | Polishing (Sof-lex) | | 0.17 ± 0.04 |
| | | Polishing (Enhance) | | 0.18 ± 0.04 |
| | | Polishing (Premier MPS) | | 0.25 ± 0.06 |
| | 0.52 | Compressing against mylar strips | (Heliomolar) | 0.10 ± 0.05 |
| | | Polishing (Enhance) | | 0.14 ± 0.04 |
| | | Polishing (Sof-lex) | | 0.14 ± 0.04 |
| | | Polishing (Premier MPS) | | 0.17 ± 0.05 |

* No standard deviations mentioned in original article.

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**TABLE 6: THE EVOLUTION OF THE SURFACE ROUGHNESS OF ACRYLIC RESIN**

| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
|---|---|---|---|---|
| Heath and Wilson, 1976 | - | Compressing against glass | | 0.10* |
| | | Compressing against mylar strip | | 0.30* |
| | | Polishing (rubber cup) | | 0.30* |
| | | Brushing | | 0.40* |
| | | Polishing (prophylactic paste) | | 0.50* |
| | | Polishing (pumice) | | 0.50* |
| | | Polishing (white stone) | | 1.00* |
| | | Polishing (Zr discs) | | 1.00* |
| Busscher *et al.*, 1984 | - | Polishing (0.25 µm) | | 0.03 ± 0.003 |
| | | Polishing (1 µm) | | 0.03 ± 0.003 |
| | | Polishing (3 µm) | | 0.04 ± 0.003 |
| | | Polishing (6 µm) | | 0.04 ± 0.002 |
| | | Polishing (0.05 µm) | | 0.06 ± 0.004 |
| | | Polishing (1200-grit) | | 0.26 ± 0.01 |
| | | Polishing (400-grit) | | 0.75 ± 0.02 |
| Johannnsen *et al.*, 1989 | 0.16 | Polishing (Colgate) | (Isosit PE) | 0.14* |
| | | Polishing (Clinomyn) | | 0.64* |
| | 0.16 | Polishing (Colgate) | (Isosit N) | 0.44* |
| | | Polishing (Clinomyn) | | 0.90* |
| Quirynen *et al.*, 1990 | - | | Strips (smoothed) | 0.12 ± 0.00 |
| | | | Strips (roughened) | 2.01 ± 0.09 |
| Yamamuchi *et al.*, 1990 | - | Polishing (No. 2000 emery paper + buff polishing) | | 0.09* |
| | | Polishing (No. 2000 emery paper + Perma cure polishing) | | 0.22* |
| | | Polishing (No. 2000 emery paper) | | 1.12* |
| Verran *et al.*, 1991 | 0.01 | Polishing (No. 2000 emery paper) | | 1.20* |
| Loney *et al.*, 1994 | 1.20 | Prolstc Wheel (+ polishing with SnO / + polishing with pumice) | | 3.3 ± 0.7 / 2.3 ± 0.2 / 1.4 ± 0.2 |
| | | E-cutter (+ polishing with SnO / + polishing with pumice) | | 3.8 ± 0.4 / 3.4 ± 0.3 / 1.9 ± 0.0 |
| | | Moloplast St (+ polishing with SnO / + polishing with pumice) | | 4.0 ± 0.4 / 2.6 ± 0.2 / 1.4 ± 0.2 |
| | | Moloplast C+S (+ polishing with SnO / + polishing with pumice) | | 4.2 ± 0.1 / 1.9 ± 0.1 / 1.7 ± 0.0 |
| | | Green (+ polishing with SnO / + polishing with pumice) | | 4.6 ± 0.4 / 1.9 ± 0.1 / 1.5 ± 0.4 |
| | | G)cutter (+ polishing with SnO / + polishing with pumice) | | 5.6 ± 0.4 / 1.8 ± 0.4 / 1.2 ± 0.1 |
| | | Moloplast cutter (+ polishing with SnO / + polishing with pumice) | | 5.7 ± 0.6 / 3.9 ± 0.3 / 1.2 ± 0.1 |
| | | Sandpaper (+ polishing with SnO / + polishing with pumice) | | 7.2 ± 0.6 / 2.3 ± 0.2 / 1.4 ± 0.1 |

* No standard deviations mentioned in original article.


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**TABLE 7: THE EVOLUTION OF THE SURFACE ROUGHNESS OF GLASS IONOMERS AND RESIN REINFORCERS**

| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
|---|---|---|---|---|
| Smales, 1981 | - | | Aspa | 2.35 ± 0.11 |
| Hotta *et al.*, 1995 | - | Glazed | Chelonfil | 0.60 ± 0.3 |
| | | | Chemfil | 0.70 ± 0.3 |
| | | | Fuji Ionomer II | 0.70 ± 0.3 |
| | | Polishing (Super snap) | Chemfil | 1.00 ± 0.1 |
| | | | Fuji Ionomer II | 1.00 ± 0.1 |
| | | | Chelonfil | 1.50 ± 0.3 |
| | | Compressing against glass | Fuji Ionomer II | 0.20 ± 0.0 |
| | | | Chemfil | 0.30 ± 0.3 |
| | | | Chelonfil | 0.40 ± 0.2 |
| Gladys *et al.*, 1996 | | Polishing procedures | Ionosit | 0.09 ± 0.01 |
| | | | Ketac-Fil | 0.29 ± 0.04 |
| | | | HIFI Master Palette | 0.52 ± 0.10 |
| | | | Photac-Fil | 0.84 ± 0.39 |
| | | Abrasion | Ketac-Fil | 1.07 ± 0.14 |
| | | | Ionosit | 1.39 ± 0.07 |
| | | | HIFI Master Palette | 1.80 ± 0.18 |
| | | | Photac-Fil | 3.10 ± 0.40 |


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| TABLE 8: THE EVOLUTION OF THE SURFACE ROUGHNESS OF CERAMICS | | | | |
|---|---|---|---|---|
| Study | Initial Ra | Treatment | Situation-Material | Final Ra |
| Fehér and Mörmann, 1995 | 3.30 | Finishing (Sof-lex extra fine) | | 0.03* |
| | | Finishing (Sof-lex fine) | | 0.04* |
| | | Finishing (Sof-lex medium) | | 0.05* |
| | | Machine finishing | | 0.10* |
| | | Finishing (Sof-lex rough) | | 0.15* |
| | | Finishing (proxoshape 8 µm) | | 0.20* |
| | | Finishing (proxoshape 4 µm) | | 0.30* |
| | | Finishing (proxoshape 15 µm) | | 0.40* |
| | | Finishing (4 µm diamond) | | 0.50* |
| | | Finishing (8 µm diamond) | | 0.80* |
| | | Finishing (15 µm diamond) | | 1.30* |
| Lee *et al.*, 1995 | 0.13 | Ultrasonic scaling | | 0.12 ± 0.13 |
| | 0.13 | Handscaling | | 0.14 ± 0.15 |
| Ward *et al.*, 1995 | 3.18 | Polishing (Flexi-disc system) | (Ceramco II) | 0.10 ± 0.04 |
| | | Polishing (Two striper diamonds) | | 0.14 ± 0.04 |
| | | + fluted carbide bur | | 0.06 ± 0.02 |
| | | Polishing (ET diamonds) | | 0.19 ± 0.04 |
| | | + finishing with carbide bur | | 0.07 ± 0.02 |
| | | Over-glazing | | 0.39 ± 0.11 |
| | | Polishing (Porcelain laminate polishing) | | 0.44 ± 0.10 |
| | | Self-glazing | | 0.52 ± 0.10 |
| | | Enhance finishing | | 0.70 ± 0.13 |
| | | Intraoral porcelain polishing | | 0.79 ± 0.12 |
| | 2.96 | Polishing (Flexi-disc system) | (Vinytage / Opal 58) | 0.09 ± 0.05 |
| | | Polishing (Two striper diamonds) | | 0.10 ± 0.04 |
| | | + fluted carbide bur | | 0.05 ± 0.02 |
| | | Polishing (ET diamonds) | | 0.14 ± 0.05 |
| | | + finishing with carbide bur | | 0.07 ± 0.02 |
| | | Polishing (Porcelain laminate polishing) | | 0.37 ± 0.08 |
| | | Self-glazing | | 0.43 ± 0.08 |
| | | Over-glazing | | 0.44 ± 0.09 |
| | | Enhance finishing | | 0.60 ± 0.14 |
| | | Intraoral porcelain polishing | | 0.77 ± 0.16 |
| | 2.60 | Polishing (ET diamonds) | (Duceram) | 0.05 ± 0.02 |
| | | + finishing with carbide bur | | 0.05 ± 0.02 |
| | | Enhance finishing | | 0.06 ± 0.10 |
| | | Polishing (Flexi-disc system) | | 0.06 ± 0.03 |
| | | Polishing (Two striper diamonds) | | 0.11 ± 0.04 |
| | | + fluted carbide bur | | 0.07 ± 0.03 |
| | | Over-glazing | | 0.37 ± 0.10 |
| | | Polishing (Porcelain laminate polishing) | | 0.38 ± 0.11 |
| | | Self-glazing | | 0.44 ± 0.09 |
| | | Intra-oral Porcelain polishing | | 0.78 ± 0.10 |
| Whitehead *et al.*, 1995 | | Polishing (tungsten / Shofu / diamond strips) | | 0.21* |
| | | Polishing (diamond strips / Sof-lex) | | 0.24* |
| | | Polishing (tungsten / Shofu / diamond paste) | | 0.31* |
| | | Polishing (tungsten / Shofu / diamond paste) | | 0.32* |
| | | Polishing (diamond strip / Shofu / diamond paste | | 0.40* |
| | | Polishing (Baker bur / diamond paste) | | 0.53* |

* No standard deviations mentioned in original article.

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