EFFECT OF FINISHING INSTRUMENTATION ON ENAMEL AND COMPOSITE SURFACE MORPHOLOGY AND MARGINAL INTEGRITY OF RESIN-BASED COMPOSITE RESTORATIONS

by

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ABSTRACT

Cristina Maresca: Effect of Finishing Instrumentation on Enamel and Composite Surface Morphology and Marginal Integrity of Resin-Based Composite Restorations
(Under the direction of Dr. André Ritter)

This study evaluated the effect of different finishing instruments on enamel and composite surface morphology, and the effects of different finishing instruments on marginal integrity of resin-based composite restorations. Bovine incisors (n=75) embedded in epoxy resin had the facial enamel ground and polished to 1200-grit. A standardized Class V cavity was prepared on each specimen and restored with composite (Z250). Specimens were randomized into fifteen groups (n=5) according to finishing instruments: positive control (coarse diamond), negative control (1200-grit), fine crosscut burs (CC), straight cut burs (StC), spiral cut burs (SpC), and finishing diamonds (FD). StC, SpC, and FD were tested individually as fine, extra-fine, and ultra-fine, and sequentially as a series (cumulative effect). A high-speed, water-cooled handpiece under standardized conditions {(pressure (0.5N) and time (40 s)} was used. Specimens were analyzed for Ra with a mechanical profilometer and observed using scanning electron microscopy (SEM) at x500 magnification for marginal integrity (gap measurement). Data were analyzed using two-way ANOVA and the Duncan test. Statistically significant differences ($p<0.05$) were detected among the finishing instruments.

The positive control surface created by the diamond medium band bur generated the roughest surface, while the negative control surface created with the mechanically polished enamel generated the smoothest surfaces. When compared with the negative control group, StC all series, SpC all series, and FD fine were observed to have a statistically significant difference in surface roughness. These three groups presented higher Ra values when compared with the other groups.

For the marginal integrity, there was no statistically significant difference between FD and the negative control. However, the positive control exhibited significantly larger gaps when compared to the other finishing instruments. Intermediate results were observed for CC, StC and SpC. FD (fine, extra-fine and ultra-fine) generated smaller gaps compared to carbides and regular-grit diamonds.

Finishing diamonds: fine, extra-fine and ultra-fine, generated smaller gaps compared to carbides and regular-grit diamonds.

To my husband Mark, thank you for your support, love and bringing so much happiness into my life.

I would not have accomplished this without you

Love you.

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AFM	Atomic Force Microscope
ANOVA	Analysis of Variance
CC	Crosscut burs
DSD	Dunnett's method
FD	Finishing diamonds
Min	Minute
mm	Millimeter
N	Newton
Ra	Roughness unit
Ra max	Ra maximum
Rpm	Revolutions per minute
SD	Standard deviation
SEM	Scanning electron microscope
SpC	Spiral cut burs
StC	Straight cut burs
μm	Micrometer

CHAPTER I

Introduction and Literature Review

Proper finishing and polishing (collectively described herein as *finishing*) are important steps that enhance both the esthetics and longevity of dental restorations (Jefferies, 1998; Goldstein, 1989). Directly placed resin-based composite (composite) restorations have to be finished to reduce possible gingival irritation, surface discoloration, patient discomfort, and secondary caries (Larato DC, 1972). The smoothest surface of a resin composite restoration is attained when the material is polymerized against a smooth matrix band (Halim N., *et al*., 2003). However, the composite surface layer cured in such conditions is rich in the resin's organic binder (Yatabe M *et al*., 2001). Furthermore, if a matrix band is not used, polymerization of the outer layer is oxygen-inhibited resulting in a surface prone to discoloration and wear. In either case, removal of that outermost layer of composite by finishing instruments produces a harder, more wear resistant, and more esthetically stable surface (Lutz F, *et al*., 1983; Schmid O 1991).

The finishing instruments recommended in the literature vary considerably. Many instruments have been advocated for finishing composite restorations including burs (Johnson, Jordan & Lynn, 1971; Scoot & Roydhouse, 1968; Gray & Gavin, 1975), diamond stones and green stones (Denison & Craig, 1972), white Arkansas stones (Gray & Gavin, 1975; Dennison & Craig, 1972; Weitman & Eames, 1975), diamond disks, (Chandler, Bowen & paffenbarger, 1971), cut disk (Scoot & Roydhouse, 1968; Gray & Gavin, 1975), Sandpaper disks (Scoot & Roydhouse, 1968), zirconium silicate disks (Kanter, Koski & Graham, 1976; Mclundie and Murray, 1974), silicon carbide disks (Dennison and Craig, 1972), abrasive rubber wheels (McLean & Short, 1969), Emery or cerium oxide paste (scoot & Roydhouse, 1968), aluminum oxide slurry (Weitman & Eames, 1975), and abrasive-free disks (Elias-son & others, 1976). Resin glazes also have been advocated to improve the surface finish of composite restorations (Kun & Paameijer, 1975; Heath & Wilson, 1976), but they are generally short - lived because of abrasion (Pameijer, 1975; Calatrava, Dennison, 1976).

The development of micro-filled and hybrid composite resins in the late 1970s promoted a change in the finishing instruments. Tungsten carbide burs and finishing stones were observed to cause an unacceptable degree of subsurface damage and aluminum oxide disks were recommended (Reinhardt *et al*., 1983). Subsequent advances in abrasive bonding technology led to the development of micro-fine diamond burs which quickly gained popularity for the finishing of margins and surfaces of small particle, hybrid and microfilled composite resins These burs were found to cause less surface and subsurface damage on marginal fractures in restorations than 12-fluted tungsten carbide burs or stones (Lutz *et al*., 1983). However, through improvements in design, multi-blade tungsten carbide burs can be manufactured to operate with the minimum of run out (eccentricity) and compared with microfine diamonds in respect to the surface finish of composite resins and the degree of enamel damage at the margin restorations (Boghosian *et al*., 1987). However, the blades of such burs are susceptible to damage which may limit service life.

Different finishing instruments and devices are available for the different categories of resin-based composite materials and types of restorations. Barbosa and colleagues (Barbosa *et al.*, 2005) examined the average surface roughness of two microfilled (Durafill and Perfection), one hybrid (Filtek Z250) and two packable composites (Surefil and Fill Magic), before and after eight different finishing instruments using carbide burs, fine/extra-fine diamond burs, aluminum oxide discs, rubber polishing points, and fine/extra-fine polishing pastes. It was determined that for all composites, the use of diamond burs resulted in the greatest surface roughness (Ra: 0.69 to 1.44 μm). The lowest Ra means were obtained for the specimens treated with Sof-Lex discs (Ra: 0.11 to 0.25 μm). The Ra values of Durafill were lower than those of Perfection and Filtek Z250, and these in turn had lower Ra than the packable composite resins. Overall, the smoothest surfaces were obtained with the use the complete sequence of Sof-Lex discs. In areas that could not be reached by the aluminum oxide discs, the carbide burs and the association between rubber points and polishing pastes produced satisfactory surface smoothness for the packable and hybrid composite resins, respectively.

Studies have evaluated the effect of different finishing instruments on surface characteristics of various restorative materials (Mitchell CA *et al*., 2002; Ashe MJ *et al*., 1996; Reis AF., *et al*., 2002; Jung M, 1997, Barbosa SG *et al*,. 2005). However, limited data are available regarding the problem of marginal quality of resin composite restorations with enamel margins (Schmidlin PR, Gohring TN, 2004). Aggressive finishing instruments may lead to damage of the composite-tooth margin, gap formation and marginal discoloration as a result of internal enamel or composite micro fractures.

Many different rotary instruments for finishing restorations are available, and it is clinically important to determine the finishing instruments that results in the smoothest surface (Lutz F *et al.,* 1983; Herrgott A *et al.,* 1989; Joniot SB *et al*., 2000). However, little research has attempted to quantify iatrogenic trauma of the enamel margins that may occur during finishing procedures (Mitchell CA and Pintado MR, 2002). Some knowledge of enamel trauma may be derived from the orthodontic literature in which surface loss has been quantified during resin composite clean-up procedures after bracket removal (Thompson RE and Way DC, 1981).

Dentists have a plethora of finishing instruments at their disposal which are used for refinishing and polishing, eliminating excess material, worn out feather edges and marginal imperfections, as well as marginal and superficial discolorations. However, polishing itself may lead to crevice formation and marginal disintegration. Enamel and/or restoration fractures may occur and result in white margins and subsequent discoloration (Fukushima, Setcos & Phillips, 1988; Bryant, Marzbani & Hodge, 1992). Microleakage may thus occur (Ferracane & Condon, 1990). Also, there is increased risk of developing secondary caries (Han, Okamoto & Iwaku, 1992; Wilder *et al.*, 2000).

Fitzpatrick and Way, 1978, reported that the loss of enamel during resin composite removal from enamel with a fluted bur at high speed was 55.6 μm. Push and Way, 1980, reported a mean loss of enamel of 17.2 μm when rotary instruments were used to remove residual cement after bracket removal. Gwinnet and Gorelick, 1977, compared tooth abrasion when lightly filled and heavily filled composites were removed from enamel surfaces. They found that the most damage occurred around the heavily filled composite, as a greater force was required to remove deep scratch marks that could not be eliminated by polishing. Arcuri and colleagues (Arcuri *et al*., 1993), compared enamel abrasion when excess composite was removed with coarse and fine diamond burs or 12 and 40 fluted tungsten carbide finishing burs. They found that the striations and irregularities produced by the carbide burs were less prominent than those produced by the diamonds burs.

Mitchell and colleagues (Mitchell *et al*., 2002), quantified the loss of surface enamel and dentin surrounding Class V restorations during resin composite shaping and finishing instrumentation procedures. They found that there was no significant difference in the loss of surrounding tooth substance based on composite type (low or high viscosity).

Schmidlin and colleagues (Schmidlin *et al*., 2004), correlated the smooth-surface polishing efficacy of different instruments with their potential for destructive effects on restoration margins and enamel finish lines. They reported that 8-μm diamond burs and 40-fluted tungsten carbide finishers produced smoother surfaces and less finishing-line destructions than the other instruments under evaluation.

Given the controversial nature of the existing published data and the lack of information available on the effect of finishing instruments on enamel-composite margins, this study evaluated the enamel and composite surface morphology and enamel-composite marginal integrity produced by different finishing instruments.

The aims of the present research were: (1) to evaluate the effect of different finishing instruments on enamel surfaces; (2) to evaluate the effect of different finishing instruments on composite surfaces; and (3) to evaluate the effect of different finishing instruments on the marginal integrity of resin composite restorations with enamel margins. The results of theses studies are reported in Chapter II and Chapter III. General conclusions are presented in Chapter IV.

CHAPTER II

Effect of Finishing Instrumentation on Enamel and Composite Surface Morphology.

Introduction

The aim of any restoration is to replace the missing natural tooth substance with a material that restores the original contour and surface finish of dental enamel. To achieve this goal, the restoration is shaped by a matrix or sculpted freehand to restore the correct contour, and the surface is polished. The effects of finishing instrumentation on the enamel and composite surfaces have been frustrating problems to clinicians. Plaque accumulation, gingival irritation, and increased staining of the restoration result from the surface roughness (Weitman RT, 1975; Eliasson *et al.,* 1970; Bagheri R, *et al.,* 2004).

Little research is found regarding the effects of polishing instrumentation on the enamel. Some knowledge of enamel abrasion may be derived from the orthodontic literature, in which surface loss has been quantified during composite cleanup procedure after bracket removal (Fitzpatrick and Way, 1977; Brown and Way, 1978; Push and Way 1980; Gwinnet AJ and Gorelick, 1977; Krell and Courey, 1993; Acurri *et al.,* 1993).

Brown and colleagues (Brown and Way, 1978) used destructive methods of embedded steel markers to quantify the loss of surface enamel during the debonding of filled resin after orthodontic treatment with an unspecified finishing bur. The loss of material ranged from 0 to 46.8 μm, with a median value of 25μm.

Krell and colleagues (Krell and others, 1993) described different methods used to quantify tooth surface abrasion after bracket removal. These methods include examination of the perikimata patterns on the enamel surface, the insertion of steel markers in the enamel surface as reference points, the use of impressions to record surface contours before and after debonding procedures, the use of model fabrication of enamel surface, and the measurements of enamel loss with scanning electron microscopy. The author used high speed hand pieces and 12-flutet carbide burs followed by aluminum oxide disk. They reported a mean loss of enamel of 149 μm.

Previous work on finishing anterior restorative materials showed that a very smooth surface could be obtained when composite restorations were allowed to set in contact with the matrix strips (Dennison JB *et al.*, 1981; Gedick R *et al.,* 2005). It was therefore recommended that as little finishing as possible is carried out after the insertion. However, other investigators suggest that the surface of composite resins allowed to set against matrix strips is limited by a "resin-rich layer" which must be removed to expose a more abrasion resistance surface (Hannah and smith, 1973). Also, it is usually necessary to reduce some excess filling and resurface the restoration, leaving a much rougher surface regardless of the method of polishing. The ultimate surface of a composite restoration should be non-porous and extremely smooth, with a maximum amount of the hard particles of filler at the surface to resist the abrasion.

The finishing instrumentation recommended in the literature varies considerably. Many instruments have been advocated for finishing restorations of composite resin and with the appearance of different kinds of finishing instruments and the development of newer composite resin materials using small fillers; many studies on the best method for polishing composite resin restoration have been reported. However, the results have been contradictory.

Tungsten carbide and diamond burs afford the opportunity for finishing those areas of complex anterior inaccessible restorations which are inaccessible to discs. For the precise finishing of small delineated areas, and for concave and occlusal surfaces, rigid rotary instruments are necessary**.** Questions still exist regarding the finishing indications of diamonds vs. carbide burs. Phillips, 1983, showed that diamond burs produce less disrupted surfaces than tungsten carbide burs on various composites. Studies evaluating diamonds and carbide burs efficacy advocate their use under an air-water spray (Lutz *et al*., 1983; Boghosina *et al*., 1987). In addition to the physiological benefits derived from the cooling effect of the spray upon the tooth, it may also prevent dehydratation of the composite, increase the efficiency of the rotary instrument by keeping the cutting surfaces free from debris, and contribute to a smother restoration by preventing the surface from being scored by particles as they dislodge (Dodge W *et al.,* 1991).

Frequently, by the time a study is completed, the resin and/or the polisher have been replaced by newer, different materials, which then require continued research. The purpose of this study was to evaluate the effect of different finishing instruments: carbide, straight cut (Fig 2.1), spiral cut (Fig 2.2), and crosscut blue/yellow band (Fig 2.3), and finishing diamonds (Fig 2.4) (Brasseler USA) on enamel and composite surface texture.

Figure 2.1

Brasseler Straight Cut Series: fine (red bad), extra-fine (yellow band), and ultra-fine white band).

Figure 2.2

Brasseler Spiral Cut Series: fine (red bad), extra-fine (yellow band), and ultra-fine white band).

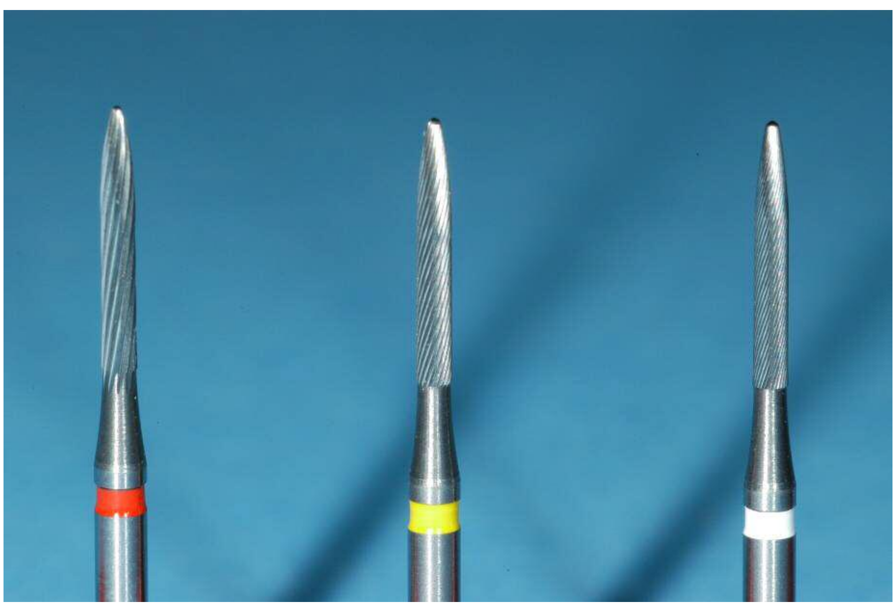


Figure 2.3

Brasseler Crosscut: extra-fine (yellow-blue band).

Figure 2.4

Brasseler Finishing Diamond Series: fine (red bad), extra-fine (yellow band), and ultra-fine white band).

Materials and Methods

Enamel:

Seventy-five crowns from bovine incisors were obtained, and stored in 0.5% chloramine T for disinfection. The specimens were embedded in epoxy resin (Epothin, Buehler Ltd., Lake Bluff, IL) using 1'' thermosetting phenolic rings (Ring forms, Buehler Ltd.) with the facial enamel surface slightly protruding from the cast. The exposed facial surfaces of the specimens were ground flat with 320, 400, and 600-grit abrasive paper (CarbiMet discs, Buehler, Ltd.) under running water (1 minute, light pressure for each cycle). Care was taken not to expose dentin. Specimens were then polished with 1200-grit abrasive paper under running water and fine polished with a 5-micron diamond paste to generate a highly polished enamel surface (baseline). Technical profiles of the materials and finishing instrument tested are shown in Table 2.1, and 2.2.

The specimens were randomized into six treatments of five teeth in each group as shown in Table 2.3. Group 1, was the ***negative control,*** which was the control mechanically-polished enamel, the smoothest surface, (Fig 2.5) and Group 2 was the ***positive control*** which was the surface created by the diamond medium band bur, the roughest surface (Fig 2.6). The rest of the Groups, 3, 4, 5 and 6, corresponded to the straight cut, crosscut, spiral cut and finishing diamonds respectively. Because most of the finishing treatments comprise a sequence of instruments, the individual effect of each instrument was tested as well as the cumulative effects of the series. A total of five specimens were assigned to each group. Revolutions per minute (RPM) were standardized according to 30,000 rpm for electric high-speed instruments, (*NSK Ti-Max, NI400*). The handpiece was used with light stroking action along the enamel specimen. A standardized pressure of 0.5 N was applied. Pressure was standardized by using a "Pressure Device" shown in Figure 2.7, and Video1. Pressure standardization was determined by asking different operators to polish a sample and determined what the usual pressure when polishing a sample is.

The pressure device consists of a load cell, a bridge amplifier, and a data acquisition unit connected to an IBM compatible PC through a USB port. The device measured the pressure applied by the hand while polishing tooth samples. The software collected the data of the pressure values in N in a Microsoft Excel spreadsheet. The single input value was saved in the spreadsheet for every second, for the total of the forty seconds finishing cycle. So, a total of forty values per sample were acquired. Also, the pressure value for each second was the result of the average of pressure release for every second during the entire cycle.

Diamond medium bur 100 μm was included as positive (course) control because it is clinically widely used. The mechanically polished enamel served as a negative control. Controls facilitated interpretation and discussion of the results.

Enamel surface roughness (Ra) was measured with the help of a two dimensional profilometer (Federal Surfanalyzer System 5000, Federal Products Co, Providence, RI) to measure step heights and roughness of surfaces. A stylus, radio *0.0002 μm*, was placed in contact with the enamel surface, and then scans were recorded perpendicular to the finishing scratch directions; Mesial to distal direction over a length of 2.5 mm on sample surface, all the specimens were scanned by placing them in the same orientation position. The average surface roughness for each specimen was determined by three scan readings. Each reading was 1mm apart, and the average roughness of each group was determined by the averages of each specimen of the group (five).

Three measurements were recorded: the average roughness (Ra, μm), maximum roughness (Ra max, μm), and minimum roughness (Ra min, μm). The mean specimen roughness was the average of the three scans for each specimen, and all the mean averages (n=5 specimens per group) were averaged to generate a total average for each Group. The specimens were kept hydrated when they were not being measured.

Composite

Finishing instrumentation procedures and roughness measurements were carried out as described for enamel with few differences:

A standardized Class V-like (box-shaped) preparation was prepared in the facial aspect of each specimen with a No. 271 carbide bur using a water-cooled electric high-speed handpiece. Each specimen received one cavity measuring approximately 3 X 3 X 2 mm (mesiodistally, incisogingivally, and depth wise respectively). A template was used to standardize the tooth preparations, and the dimensions of all preparations were verified with a digital caliper.

The enamel and dentin of the preparation were etched with 37.5% orthophosphoric acid (Scotchbond Etchant Plus 3M ESPE) for 15 seconds, rinsed with water for 5 seconds, and light dried for 5 seconds. An ethanol- and water-based dental adhesive (Adper Single Bond, 3M ESPE) was applied in two consecutive coats, air thinned, and light-polymerized for 20 seconds with a halogen light-curing unit in normal mode (Optilux 501, Kerr-Demetron).

Before restoration, a 1mm x 1mm point mark was placed with a waterproof felt pen on the enamel immediately adjacent to the restoration. This mark helped to determine the amount of finishing instrumentation used (fig 2.9).

Next, cavities were restored with Filtek Z-250 resin composite, shade A2 (3M ESPE). The resin composite was inserted in one increment to challenge the adhesive interface, and light-polymerized for 40 seconds with a light curing unit in normal mode (Optilux 501, Kerr-Demetron). The curing light unit was tested for light output using a curing radiometer (Model 100, Demetron Research Corp., Kerr), which showed an intensity of 600 mW/cm^2 before the samples were light cured. After curing, the specimens were stored in deionized water at 37^oC for 1 week (fig 2.10).

For the negative control group cavities were restored and polymerized against an appropriate matrix strip, to obtain the smoothest surface.

The rest of the specimens were randomized into five treatments. Each specimen was evaluated according to its individual effect as well as the cumulative effect of the series as described for enamel, and shown in Table 2.3

Composite surface roughness (Ra) was measured as described for enamel with the difference that the stylus, was placed in contact with the composite surface, Mesial to distal direction over a length of 2.5 mm on sample surface. Care was taken that the stylus did not go over the interface of the enamel-composite restoration. Three measurements were recorded: the average roughness (Ra, µm), Ra max, and Ra Min. The mean roughness was the average of the three scans for each specimen, and all the mean averages (n=5 specimens per group) were averaged to generate a total average for each group. The specimens were kept hydrated when they were not being measured.

Statistical analysis: Composite and enamel:

One-way analysis of variance (ANOVA) was used to determined signicant interactions between the finishing instruments. To compare the negative control to all other treatment groups, excluding the positive control, Dunnett's method (DSD) was initially employed, and Fisher's test was used to identify differences among all groups.

Table 2.1 Technical profile of the materials tested.

Material	Product Name	Lot No., Exp. Date, shade	Manufacturer
Epoxy resin	Epo-thin resin	20-8142-016	Buehler Ltd., Lake Bluff, IL
	Epo-thin hardener	20-8142-016	
1’’ thermosetting phenolic rings	Ring forms	20-8151-010	Buehler Ltd., Lake Bluff, IL
Abrasive paper 320,400,600 and 1200	CarbiMet® Discs, 8″		Buehler Ltd., Lake Bluff, IL
high-speed instruments	NSK Ti-Max, NI400	4800883	NSK
Resin composite	Filtek Z-250	shade A2	3M ESPE St. Paul, MN, USA
The curing light unit	Optilux 501		Kerr-Demetron Orange Calif.
Vinyl polysiloxane	Flexitime	180296	Heraeus Kulzer, Dormagen, Germany

Table 2.2 Technical profile of the finishing instruments tested.

Instrument		Band	Grit	Usage	Handpiece speed	Lot No	Manufacturer
Diamond	Medium	No band	100 µm	Light stroking action for 40seconds at 0.5N	30,000 rpm	856542	Brasseler USA,Savanna GA.
Straight Cut	Fine	Red band	8 blades	Light stroking action for 40seconds at 0.5N	30,000 rpm	ET9 678799	Brasseler USA,Savanna GA.
	Extra-fine	Yellow band	16 blades			ETF621188	
	Ultra-fine	White band	30 blades			ET9UF132791	
Crosscut	Fine	Blue/yellow band	16 blades	Light stroking action for 40seconds at 0.5N	30,000 rpm	ET9Q263777	Brasseler USA,Savanna GA.
Spiral Cut	Fine	Red band	12 blades	Light stroking action for 40seconds at 0.5N	30,000 rpm	H48L670299	Brasseler USA,Savanna GA.
	Extra-fine	Yellow band	20 blades			H48LF677999	
	Ultra-fine	White band	30 blades			H48LUF139799	
Finishing diamonds	Fine	Red band	30 µm	Light stroking action for 40seconds at 0.5N	30,000 rpm	DET9F04048	Brasseler USA,Savanna GA.
	Extra-fine	Yellow band	15 µm			DET9EF01001	
	Ultra-fine	White band	8 µm			DET9UF34023	

Figure 2.5

Negative Control: control mechanic-polished enamel (the smoothes surface).

Figure 2.6

Positive control: Surface created by the diamond medium band bur (the roughness surface).

Figure 2.7
Force device.

Table 2.3

Group description for effect of finishing instrumentation on enamel and composite surface morphology and marginal integrity.

Groups	Systems Description				n
Group 1	**Negative Control**	Mechanically-polished enamel or restoration			5
Group 2	**Positive Control:** Diamond	Medium	No band	100 μm	5
Group 3	Straight Cut	Fine	Red band	8 blades	5
		Extra-fine	Yellow band	16 blades	5
		Ultra-fine	White band	30 blades	5
		All Series		**Sequence**	5
Group 4	Crosscut	Fine	Blue/yellow band	16 blades	5
Group 5	Spiral Cut	Fine	Red band	12 blades	5
		Extra-fine	Yellow band	20 blades	5
		Ultra-fine	White band	30 blades	5
		All Series		**Sequence**	5
Group 6	Finishing diamonds	Fine	Red band	30 μm	5
		Extra-fine	Yellow band	15 μm	5
		Ultra-fine	White band	8 μm	5
		All Series		**Sequence**	5
		Total			**75**

Results

Enamel

The mean and standard deviation of surface roughness (Ra, µm) are listed in Table 2.4, and graphically depicted in Figure 2.8. Clearly, the positive control (diamond medium band bur) created the roughest surface with a mean Ra = 2.89±0.68. Overall, the smoothest initial surfaces were attained with the negative control, mechanically-polished enamel (Ra = 0.49±0.23). When compared with the negative control group, StC all series (mean Ra = 1.61±0.52), SpC all series (mean Ra = 1.69±0.52), and finishing Diamonds fine burs (mean Ra = 1.83±0.85) were observed to have a statistically significant difference in surface roughness. These three groups presented the roughest values when compared with the rest of the groups (Table2.4). All other groups were observed to have no statistically significant differences in roughness compared with the Negative Control group. Comparisons of the all-series methods (groups: StC, CC, SpC, and FD) showed not statistically significant differences with a p-value of 0.1521.

Table 2.4

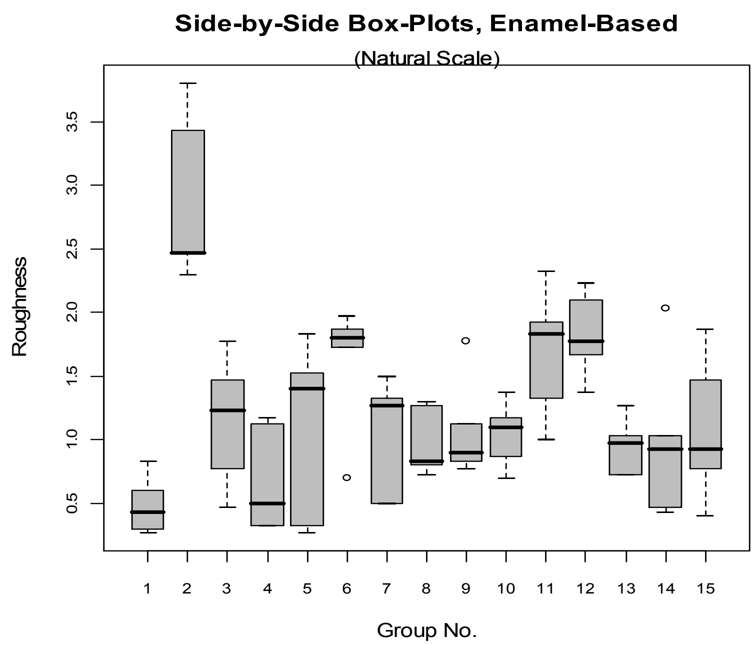
Mean and standard deviation of enamel surface roughness.

Groups		Type	Band	Mean Ra µm	SD
Group 1	**Negative Control**	Polished enamel		0.49[a]	0.23
Group 2	**Positive Control:** Diamond	Diamond Medium	No band	2.89[b]	0.68
Group 3	Straight Cut	Fine	Red	1.14[a]	0.52
		Extra - Fine	Yellow	0.69[a]	0.42
		Ultrafine	White	1.07[a]	0.72
		All Series		1.61[b]	0.52
Group 4	Crosscut	Fine	Yellow	1.02[a]	0.48
Group 5	Spiral Cut	Fine	Red	0.99[a]	0.27
		Extra - Fine	Yellow	1.08[a]	0.41
		Ultrafine	White	1.04[a]	0.26
		All Series		1.69[b]	0.52
Group 6	Finishing diamonds	Fine	Red	1.83[b]	0.35
		Extra - Fine	Yellow	0.95[a]	0.22
		Ultrafine	White	0.98[a]	0.65
		All Series		1.09[a]	0.58

Means not statistically different share superscript letters.

Figure 2.8

Box-plots of enamel study.



Composite

Mean and standard deviation of surface roughness (Ra, μm) for composites are listed in Table 2.5, and graphically depicted in Figures 2.9. The positive control (diamond medium band bur) created the roughest surface (mean Ra = 3.43±0.68). Overall, the smoothest initial surfaces were attained with the negative control group (mean Ra = 0.51±0.46), created against a Mylar strip. When compared with the negative control group, SpC all series (mean Ra = 1.81±0.43) and finishing Diamonds fine burs (mean Ra = 1.82±0.34) were observed to have a statistically significant difference in surface roughness. These two groups presented higher mean Ra values when compared with all other groups. All other groups were observed to have no statistically significant differences in roughness compared with the negative control group.

Comparisons of the all-series methods (groups: StC, CC, SpC, and FD) showed statistically significant differences among clusters of groups, linking groups StC and SpC in one cluster and Cc and FD in another. Groups StC and SpC are different from groups Cc and FD with a p-value of 0.0061.

The rest of the groups did not show statistically significant differences when compared to the Negative Control group.

Table 2.5

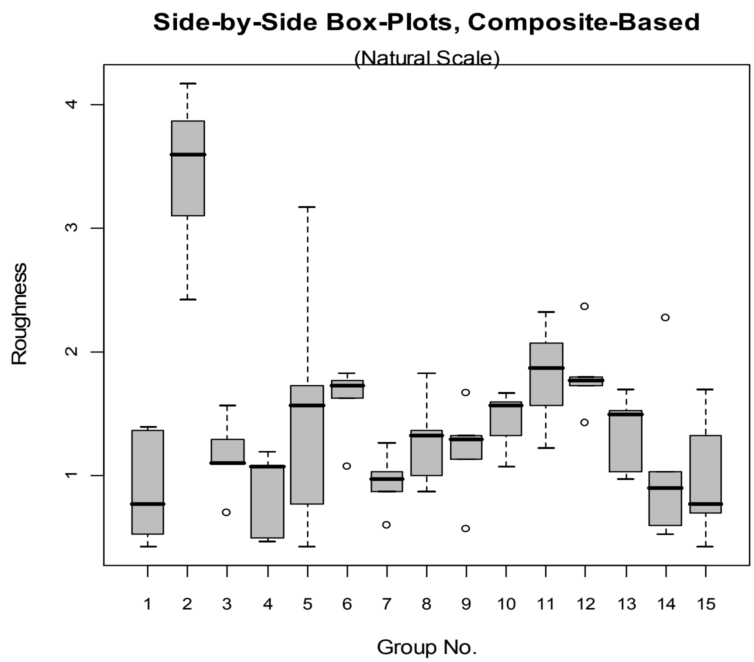
Mean and standard deviation of composite surface roughness.

Groups		Type	Band	Mean Ra µm	SD
Group 1	Negative Control	Polished enamel		0.51[a]	0.46
Group 2	Positive Control:	Diamond Medium	No band	3.43[b]	0.68
Group 3	Straight Cut	Fine	Red	1.15[a]	0.32
		Extra - Fine	Yellow	0.86[a]	0.35
		Ultrafine	White	1.53[a]	1.06
		All Series		1.61[a]	0.3
Group 4	Crosscut	Fine	Yellow	0.95[a]	0.24
Group 5	Spiral Cut	Fine	Red	1.28[a]	0.38
		Extra - Fine	Yellow	1.20[a]	0.4
		Ultrafine	White	1.45[a]	0.25
		All Series		1.81[b]	0.43
Group 6	Finishing diamonds	Fine	Red	1.82[b]	0.34
		Extra - Fine	Yellow	1.35[a]	0.33
		Ultrafine	White	1.07[a]	0.7
		All Series		0.99[a]	0.52

Means not statistically different share superscript letters.

Figure 2.9

Box-plots of composite study



Discussion

The effectiveness of finishing procedures on contemporary composite surfaces is an important consideration in the restorative process. In this study, the smoothest surfaces for enamel were obtained by polishing the enamel at 1200-grit, and the smoothest surfaces for composite were obtained by curing against a matrix strip. This finding was in agreement with previous studies on resin composites (Lutz *et al*., 1983; Halim N., *et al*., 2003; Dennison JB *et al*., 1981; Gedick R *et al*., 2005; Yap AU *et al*., 2004). The surface roughness (Ra, μm) of both polished enamel and the Mylar formed surfaces increased by the use of finishing diamonds and carbide burs.

Diamond and carbide burs are necessary for contouring anatomically structured and concave surfaces such as the lingual surfaces of anterior teeth or occlusal surfaces of posterior teeth. With hybrid composites, finishing diamonds have been shown to produce rough, trough-like surfaces compared to carbide burs (Jung M, 1997). Jung suggested that finishing diamonds were best suited for gross removal and contouring due to their high cutting efficiency of composite surfaces, while carbide finishing burs would be best suited for smoothing and finishing as a result of their low cutting efficiency. Roeder LB *et al*., 2000, found that carbide finishing burs produced surfaces with Ra values that averaged three times as smooth when compared to surfaces finished with finishing diamonds. Ferracane JL., *et al* 1992 also found that finishing diamonds were more efficient in removing material from the composite surface, though they tend to leave a more irregular surface when compared to finishing carbide. Berastegui *et al*., 1992, suggested that both diamond and carbide finishing burs should be used not as instruments for finishing and polishing, but instead as instruments for modeling of the restoration

On the other hand Felix *et al*., 1983, concluded that diamond burs 40 and 15 μm produced a surface roughness on composite or enamel comparable to the widely accepted 12 and 40 fluted carbide burs. They also stated that carbide burs produced surface and subsurface damage caused by a hammering effect. They also tend to plough through restorative materials rather than abrade them. The hardness of traditional composite macrofillers, or the microfilled complexes, does not permit the flutes to cut them clean without damage. Therefore, when traditional and hybrid composites are finished with carbide burs, the macrofillers are more likely to be dislodged than grown down, causing detectable surface irregularities. With microfilled composites, the particles are rocked loose and destroyed. Consequently, when such restorations are finished with carbide burs, they do not have the same luster-like surface that is possible when finished with fine and superfine diamond burs.

Jung M, 2003, concluded that the use of a 30 μm diamond caused a large amount of detrimental effects, and did not recommend its use for finishing packable composites. He also concluded that the subsequent use of two finishing diamonds, or a finishing diamond followed by a carbide 16 blade extra-fine, reduced the initial roughness significantly to more than half the amount on all composites. Joniot *et al.,* in 2000 stated that 30 μm and a 15 μm diamond burs produced a better surface than finishing carbides. Joniot further stated in this study that Raskinn and Vreven (1996) came to the same conclusion, finding that tungsten carbide burs caused more surface damage. Felix, Jung and Joniot's results are in agreement with the results of this study.

Kaplan and colleagues (Kaplan BA *et al*., 1996), using hybrid composites, observed that diamonds caused a greater degree of gouging. However, the gouges were not as deep as those produced with carbides and could therefore be brought to a smother polish. These results agree with the results of this study for the all-series. Joniot *et al*., 2000, stated that finishing with burs alone produced a rougher surface and therefore recommended using subsequent finishing instruments to improve the surface quality. Finishing instruments like Sof-Lex discs or aluminum oxide discs can be used to minimize the defects and removed the surface scratches caused by the use of the diamond burs or carbide burs. They also provide the smoothest composite/enamel surface, similar to those produced by Mylar strips, in accordance with Pedrini D *et al*., 2003; Ozgunaltay G *et al*., 2003; Berastegui E *et al*.,1992; Neme AL *et al*., 2003.

In this study, statistically significant differences were found among Ra values of the finishing diamond burs when compared to finishing carbides burs. The 30µm fine finishing diamond produced the roughest surfaces on enamel and composite, with Ra values of 1.83 µm and 1.82 µm for enamel and composite respectively, compared with the 1.14 µm (enamel) and 1.15 µm (composite) produced by the fine StC, and the 0.99 µm (enamel) and 1.28 µm (composite) for the SpC (Tables: 2.4 and 2.5) Jung M, 1997, Roeder LB *et al*., 2000, and Ferracane JL., *et al.,* 1992, agree that finishing diamonds have been shown to produce rough, trough-like surfaces when compared to carbide burs. However, the aforementioned studies only compared the effects of the fine finishing diamonds (30 µm) versus the ultra-fine carbides (30 blades), instead of comparing carbides versus the equivalent grit diamond (ultra-fine 8 µm).

In this study the individual effect of each instrument (fine, extra-fine, and ultra-fine) was tested, as well as the cumulative effects for the StC, SpC, and FD. The findings demonstrate that the subsequent use of a 15 µm and 8 µm finishing diamonds reduced roughness significantly, and the cumulative effect of the all series for the diamonds resulted in the smoothes surfaces (Ra 0.99 µm).

On the other hand, the effect of the all series for the carbide finishing burs showed roughness Ra values of 1.61 µm (StC), and 1.81 µm (SpC). It is possible that a small number of deep grooves created by the blades of the fine carbide burs remained after the initial polishing burs (fine) that could not be removed effectively by the extra-fine and ultra-fine burs. It could further be theorized that the presence of small numbers of deep grooves correlated with the greatest Ra values found in the enamel and composite of all series specimens.

The smoothness obtained with mechanically polished enamel and the matrix strips could not be reproduced by any of the diamond or carbide finishing systems.

Composite resin fillers appear to play an intrinsic role in how well a composite finishes (Berastegui *et al*., 1992; Mitchell CA *et al*., 2002; Joniot SB *et al.,* 2000; Yap AU 1994 and 2004). In composites where the filler particles are significantly harder than the matrix or resin phase, the latter may suffer a preferential loss during finishing. The larger the particle size, the greater the surface roughness (Toledano *et al*., 1994; Yap AU *et al*., 1997). In addition, the effectiveness of the finishing instruments is material-dependent. Yap *et al*., 2004, investigated the surface texture of composite and compomer after treatment with different one-step finishing instruments and found that for the composite material (Z100), no significant difference in surface roughness was observed between one-,two and multi-step finishing instruments. Stoddard and Johnson (1991) suggested that, because of the variation in filler particles and types of resins, it is important to pair a resin composite with a matching polishing system, and according to Weinstein 1988, by systematically decreasing the particle size of the abrasive, a superior surface can be achieved. The grit in the polishing material should be smaller than the particle size of the restorative material that is being polished in order to produce better results. Weinstein further stated that additional factors affecting polishing results may include the amount of pressure utilized during polishing, the orientation of the abrading surface, and the amount of time spent with each finishing bur. However, in this study, each of these factors was closely controlled.

Another variable of the study is that different Ra measurement instruments can show different roughness values. The controversy surrounding whether carbide or diamond finishing burs produce a smoother surface can be affected by the fact that different instruments can be used to measure Ra. Berastegui (1992) utilized a mechanical profilometer in determining that carbide burs produced a smoother surface than diamonds. The roughness values obtained by the

Berastegui study cannot be compared with the results of Joniot et at, 2000, who obtained better result with the diamonds when measuring with an optical profilometer. Also, Teixeira and colleagues (Teixeira EC *et al*., 2005), found significant differences when comparing the Ra results of the same sample using an AFM and a profilometer. Ra values can vary significantly, especially when measurements are conducted at different levels of dimensional resolution. The size of convolutions, special frequency, and distribution of features should be considered. AFM techniques can be used to measure surface features and can develop accurate images of the surface topography and texture even to the atomic scale, differing from the measurement scale of a standard mechanical surface profilometer. Features that can be clearly resolved with AFM, such as an individual filler particle in a composite, are not always seen in a mechanical profilometer trace. Additionally, features such as troughs created in a dental composite surface by finishing instruments are too large to be characterized with AFM. For this reason we did not use an AFM instrument in this study.

When attempting to fully characterize surface morphology, multiple analytical techniques (AFM, surface profilometry, optical profilometry, etc.) should be considered as they can obtain information over a broad dimensional range. Optical profilometry permits a touch free scanning of the composite surface and enable the sample surface to be studied more precisely, as the optical beam is less limiting than the recording head. The size of the stylus tip, which is commonly used for mechanically profilometry, is regarded as being too large to penetrate the irregularities of finished surfaces (Joniot *et al*., 2000; Jung, 1997; Whitehead *et al*., 1999).The laser stylus is focused to a diameter of 1 μm, thus providing a great accuracy for the profilometric evaluation.

The roughness parameters used by the profilometer utilized in this study, (Federal Surfanalyzer System 5000, Federal Products Co, Providence, RI), are vertical parameters since they describe surface irregularities only by their amplitudes. Also, this kind of profilometer does not reflect both the vertical (height of profile elements) and the horizontal (number of surfaces irregularities) dimensions of surface irregularities. The shortcomings of those parameters have been pointed out in the dental literature (Jung, 1997; Whitehead *et al*., 1999; Teixeira *et al*., 2005).

The complex structure of a surface cannot be fully characterized solely by the surface roughness measurements. Therefore, it is not appropriate to draw definitive conclusions on the clinical suitability of a finishing instrument based exclusively on roughness averages.

The “smear layer” is another variable affecting the results of this study. Samples were not cleansed using an ultrasonic bath before roughness was measured. It is indeed possible that the smear layer created during instrumentation could have affected the roughness values, especially for the all series methods, when a great deal of instrumentation polishing is performed on the sample.

An additional variable is the natural and substantial variation in the quality and height of the enamel for the bovine teeth.

According to the results of this study, finishing diamonds have a tendency to produce smoother surfaces when compared to finishing carbides, except for the fine finishing diamond (red band). Among the finishing carbides, there is a tendency of the all series group to show the higher roughness values.

CHAPTER III

Effect of Finishing Instrumentation on Marginal Integrity of Resin-Based Composite Restorations.

Introduction:

Proper finishing of restorations is desirable not only for aesthetic considerations but also for oral health. The primary goal of finishing is to obtain a restoration that has good contour, occlusion, healthy embrasure forms and a smooth surface. Ideally, a filler rich, enamel like, glossy polished surface should be achieved. In addition, perfect marginal adaptation and seal are desired. Many different rotary instruments are available for finishing restorations. However, finishing instrumentation may lead to crevice formation and marginal disintegration (Schmidlin *et al*., 2004). It is also possible that cavity preparations with dental burs can easily produce micro-fractures in the enamel. The degree of the generation of the enamel damage induced during cavity preparation can be influenced by the diamond grit size and type of bur (Xu HH *et al*,. 1997). Cavity preparation with minimal mechanical damage at the cavosurface margin may be an important factor for preventing enamel cracking at the side of resin composite restoration (Kozo *et al.,* 2005).

Significant attention has been paid to which instruments provide the smoothest restoration surfaces, but little research has attempted to quantify iatrogenic marginal defects, which may occur during the finishing instrumentation. These defects will result in microleakage, which can be defined as the passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material (Kidd, 1976). Clinically, it may lead to staining, postoperative sensitivity and/or recurrent caries. Variations in finishing instrumentation techniques have been shown to affect the ability of composite restorations to resist leakage. Brackett *et al*., 1997 evaluated the effect of three finishing instruments on the microleakage of Class V hybrid resin composite and found that the greatest incidence of leakage was observed in restorations finished with carbide finishing burs.

Yu and others, 2000, evaluated the possible influence of finishing instrumentation on microleakage. Results indicated that finishing instruments affects the ability of the restorative system to resist microleakage. Under the conditions of this study, the best results were achieved with a 30-fluted bur followed by a short wet polish. Samples finished dry with polishing disks demonstrated considerable microleakage.

The finishing periods serve as another factor that may influence the sealing ability around restorations. M Irie and colleagues (M Irie *et al*., 2003), evaluated the effect of the initial polishing period through 30 minutes, 3 hours, 12 hours, 24 hours and 1 week after setting on the gap formation around Class V restorations. The authors used three resin-modified glass ionomers, one compomer, one conventional glass ionomer and one microfilled composite. When specimens were polished immediately after the setting procedure, this study showed 100-140 gaps around the X-section of the restorations. In contrast, only 10-40 gaps around the Class V restoration were observed when the specimens were polished after 12 hours of storage. Significant differences were observed between polishing immediately and polishing after 12 hours of storage. However, delayed polishing did not improve gap formation for a compomer. Due to the structure of the glass ionomer and its hydrophilic nature, water absorption and subsequent swelling may lead to partial compensation of the shrinkage.

Only limited data are available on the influence of finishing instrumentation on marginal quality of composite restorations. This study evaluated the effect of different finishing instruments on the enamel-composite marginal integrity of the restorations.

Materials and Methods

Seventy-five crowns from bovine incisors were obtained, and stored in 0.5% chloramine T for disinfection. The specimens were embedded in epoxy resin using 1’’ thermosetting phenolic rings with the facial enamel surface slightly protruding from the cast. The exposed facial surfaces of the specimens were ground flat with 320, 400, and 600-grit abrasive paper under running water (1 minute, light pressure for each cycle). Care was taken not to expose dentin. Specimens were then polished with 1200-grit abrasive paper under running water and fine polished with a 5-micron diamond paste to generate a highly polished enamel surface (baseline).

A standardized Class V like preparation was prepared in the facial aspect of each specimen with a No. 271 carbide bur using a water-cooled electric high-speed handpiece. Each specimen received one cavity measuring approximately 3 X 3 X 2 mm (mesiodistally, incisogingivally, and depth wise respectively). A template was used to standardize the tooth preparations, and the dimensions of all preparations were verified with a caliper. The enamel and dentin of the preparation was etched and then restored as described for composite in the materials and methods section of the previous chapter. II

The specimens were randomized into six treatments of five teeth in each group as shown in Table 2.3. Group 1 was the ***negative control,*** which was the control mechanically restoration, the smoothest surface, and Group 2 was the ***positive control*** which was the surface created by the diamond medium band bur, the roughest surface (Fig 2.6). The rest of the groups, 3, 4, 5, and 6, corresponded to the straight cut, crosscut, spiral cut and finishing diamonds respectively. Because most of the finishing instruments comprise a sequence of instruments, the individual effect of each instrument was tested as well as the cumulative effects of the series. A total of five specimens were assigned to each group. Revolutions per Minute (RPM) were standardized according to 30,000 rpm for electric high-speed instruments, (*NSK Ti-Max, Nl400*). The handpiece was used with light stroking action along the enamel specimen. A standardized pressure of 0.5 N was applied as described for composite in the materials and methods section of the previous chapter II.

Evaluation of enamel-composite marginal integrity

Samples were submerged in an ultrasonic bath for 15 min, to remove the debris over the margins. Vinyl polysiloxane impressions (Flexitime, Heraeus Kulzer) of the 75 specimens were taken. Impressions were poured with Epo-thin, low viscosity epoxy, (Buehler). All the specimens were mounted on aluminum stubs with carbon tape and were sputter coated with gold 250Å for 60 seconds. Specimens were observed under Scanning electron microscopy (SEM) at an accelerating voltage of 12 k V at 90^o angle and working distance of 28mm . The enamel-composite marginal interface was observed initially at 20x magnification for localization of the all margins of the restoration, and then magnification was set at 300x to examine the entire periphery of the margin restoration. The two biggest gaps of the restoration were selected. Images of the gaps were taken at 500x. Two images per each sample were taken, creating a total of 150 images. Special care was taken in the selection of the two biggest gaps, to be sure that they were localized in different axis of the restoration.

The two largest gaps in different axis of the restoration were selected and the largest portion of the gap was measured using Image J 1.34 software. (National Institutes of health, USA). The gap measurements were averaged for each specimen. The group average was obtained by averaging the five values for each group.

Correlation between the location of the gaps and the orientation of the finishing striations was determined by observation of all SEM images. The hypothesis was that more gaps are found on enamel-composite margins that are perpendicular to the orientation of the finishing instrumentation, when compared to parallel margins.

Statistical analysis

The Analysis of variance (one-way ANOVA) was used to determine significant interactions between the finishing instruments and marginal integrity. A Duncan test was also used to identify differences among all groups. A significance level of 0.05 was used for all statistical analysis.

Results

Gap mean values and standard deviations for the evaluation of enamel-composite marginal integrity are presented in Tables 3.1 and Figures 3.1.

When observing marginal integrity, there was no statistically significant difference between all the finishing diamonds and the negative control (mean gap= 0.73±0.25). The worst marginal integrity result was obtained with the positive control (medium-grit diamond bur) (mean gap= 16.23±5.87), which produced a statistically significant difference compared to other finishing instruments. Intermediate results were observed for CC, StC and SpC. SEM evaluation correlated well with the quantitative data.

There was no correlation between the location of the gaps and the orientation of the finishing striations. Gap formation was influenced primarily by the type of bur used, and not by the orientation of the finishing striations.

Table 3.1

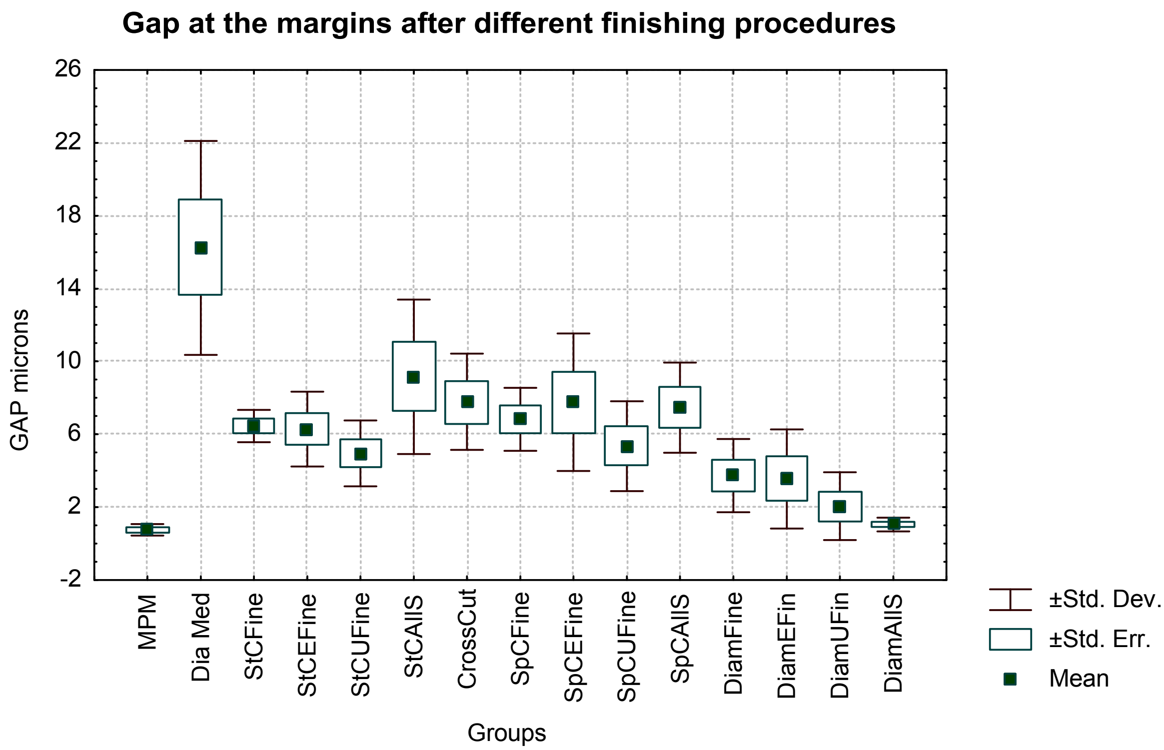
Gap Summary Table

Groups		Type	Band	Mean Gap µm	SD	p < 0.05
Group 1	Negative Control	Polished enamel		0.73	0.25	a
Group 2	Positive Control	Diamond Medium	No band	16.23	5.87	f
Group 3	Straight Cut	Fine	Red	6.45	0.89	cde
		Extra - Fine	Yellow	6.28	2.06	cde
		Ultrafine	White	4.94	1.81	bcd
		All Series		9.15	4.24	e
Group 4	Crosscut	Fine	Yellow	7.78	2.64	de
Group 5	Spiral Cut	Fine	Red	6.82	1.73	cde
		Extra - Fine	Yellow	7.82	3.68	de
		Ultrafine	White	5.34	2.48	bcde
		All Series		7.46	2.48	cde
Group 6	Finishing diamonds	Fine	Red	3.73	2.01	abc
		Extra - Fine	Yellow	3.54	2.73	abc
		Ultrafine	White	2.05	1.86	ab
		All Series		1.04	0.38	a

Means not statistically different share superscript letters.
Duncan test; GAPS (gap data finishing procedures.sta)
Probabilities for Post Hoc Tests
$F(14,60)=5.57$; $p<.0000$

Figure 3.1

Gap at the margins after different finishing procedures.



Discussion

Dentists are responsible for the patient’s care and need to discern and avoid new caries and periodontal disease and ensure the long term quality of tooth restorations. The longevity of the latter varies significantly (Downer & others, 1999), and the reported mean survival time for resin restoration is five years or less. The primary reasons for replacements are tooth or restoration fractures and secondary caries diagnosed visually or on radiographs. Gaps in the enamel-composite margin may result in microleakage and introduction of further caries (Roberson T *et al*., 2002; Xu *et al*., 1997). Enamel cracking is initiated by the damage caused during preparation with burs and is likely to be furthered by the contraction of the polymerizing resin composite (Watson TF *et al*., 1998). In this study, the effects of the various bur grits on the marginal integrity of the resin restorations were evaluated using SEM by selecting the two largest gaps in different axes of the restoration.

The worst marginal integrity result was observed with the positive control (medium-grit diamond, Figure 3.2.), which produced statistically significant differences when compared to all groups. Kanemura *et al*., 1998, reported that cavity preparation using a regular grit diamond or carbide bur produced irreversible damage to superficial enamel.

The finishing diamond burs generated the smallest gaps of all the groups, and there were no statistically significant differences between the finishing diamonds and the negative control group (Fig 3.3. and 3.8 a-c). These results are in general agreement with previous literature (Lutz *et al*., 1983; Nishimura K *et* *al*., 2005). Lutz *et al*., 1983, showed that marginal quality of restorations was significantly superior when diamond finishing burs were used. Lutz stated, "It is to be assumed that the gentleness of the finishing diamond burs to the margins of the restorations has practical clinical consequences."

In this study, among the finishing diamonds, the *all series method* afforded the best results in terms of gap formation, followed by the ultra-fine, extra-fine, and fine methods respectively. Xu *et al*., 1990, reported that cracks produced by course diamonds burs were effectively removed by finishing with finer diamonds.

No statistically significant differences were noted among the straight cut, crosscut and spiral cut groups (fig 3.4, 3.5, and 3.6). However, when comparing the straight cut and spiral cut groups, a tendency can be noted: large gaps develop when the all series methods were used, leading to an interpretation that the more instrumentation in a restoration, the more likely to increase the gap, which is in contrast with the diamond group. The results of this study were comparable with previous investigations. Neme *et al*., 2002, suggested that even fine and ultra-fine instruments may negatively influence the integrity of the enamel and, to a lesser extend, restoration margins. Therefore, every additional step in a polishing sequence may increase the risk of further finish-line destruction.

According to the results of this study, polishing with finishing diamond burs is recommended to improve the marginal integrity of resin restorations. In addition, as Lutz observed, the gentleness of the finishing diamond burs to the margins of the restorations has practical clinical consequences.

One significant variable is the composite used in this study (Z-250). In general, microfills and minifills undergo more extensive marginal degradation than the more heavily filled midifills composite. Ferracane *et al*., 1999, reported that the differences between the midifills and microfills were significant, and midifills has significantly lower breakdown. This suggests that the effects of finishing instruments on the marginal integrity are material dependent.

More in vitro test are needed to investigate the influence on surface and margin characteristics in order to improve the future management of adhesive restorations after placement and during maintenance. The use of finishing instruments should be minimized to avoid marginal destruction, while guaranteeing good performance of the restorations.

Restorations that are properly finished should have a superior esthetic quality. They should show less opaque areas of marginal enamel, as the result of fractures, and less marginal discoloration over time. However, the guidelines for use of diamond finishing burs should be heeded.

The finishing diamonds in this study were used with 0.5N pressure (light pressure) in a constant wiping motion, and under generous water spray. The continuous wiping motion is recommended to avoid formation of grooves. Under the conditions of this in-vitro study: Finishing diamonds: fine, extra-fine and ultra-fine generated smaller gaps compared to carbides and regular-grid diamonds.

Figure 3.2

A representative SEM image (500x) of marginal integrity result observed with the positive control (Group 2).

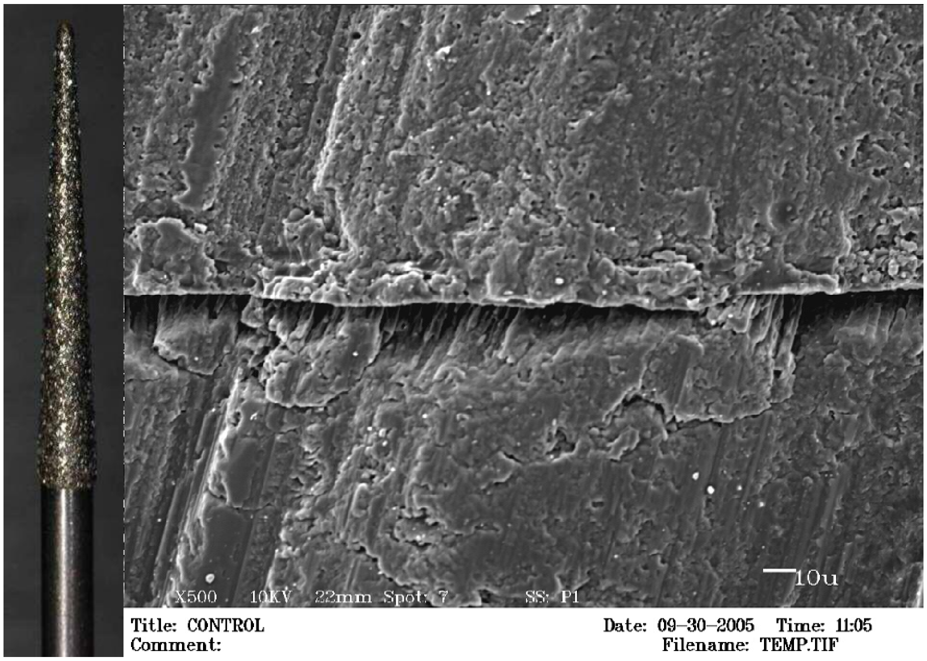


Figure 3.3

A representative SEM image (500x) of marginal integrity result observed with the negative control (Group 1).

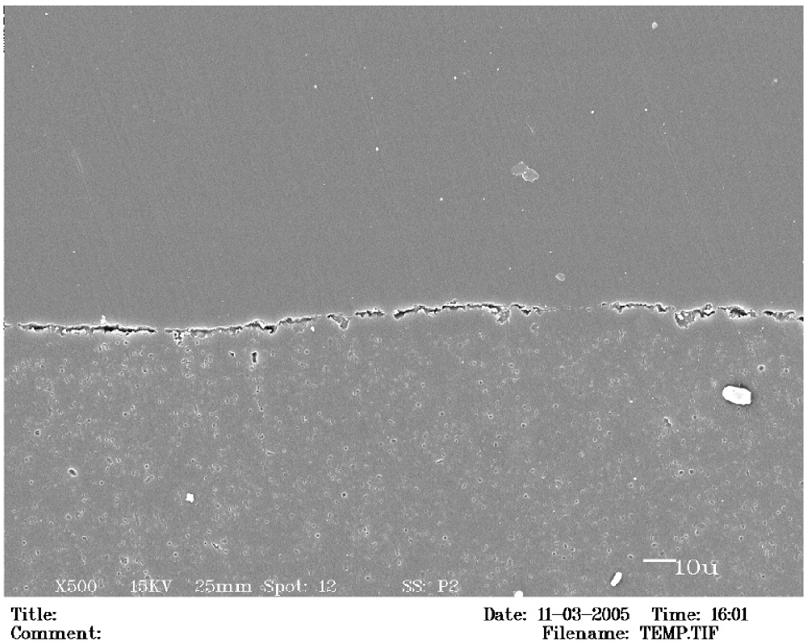
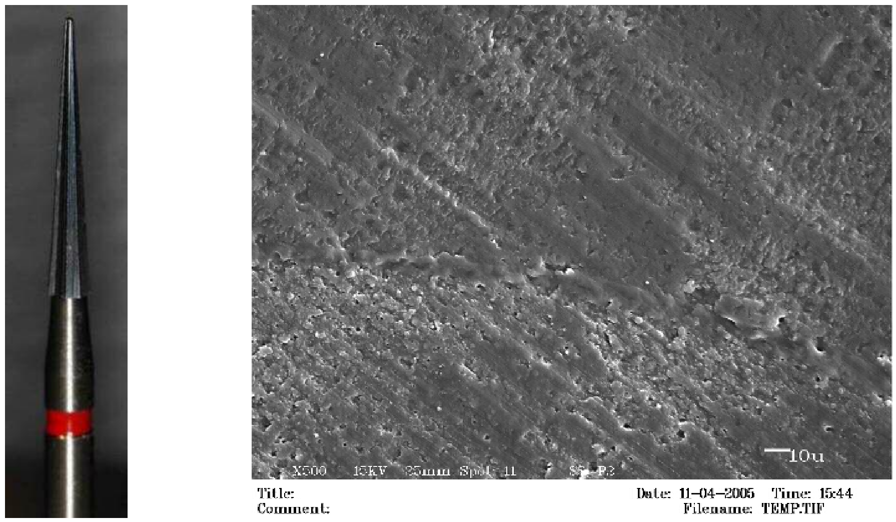


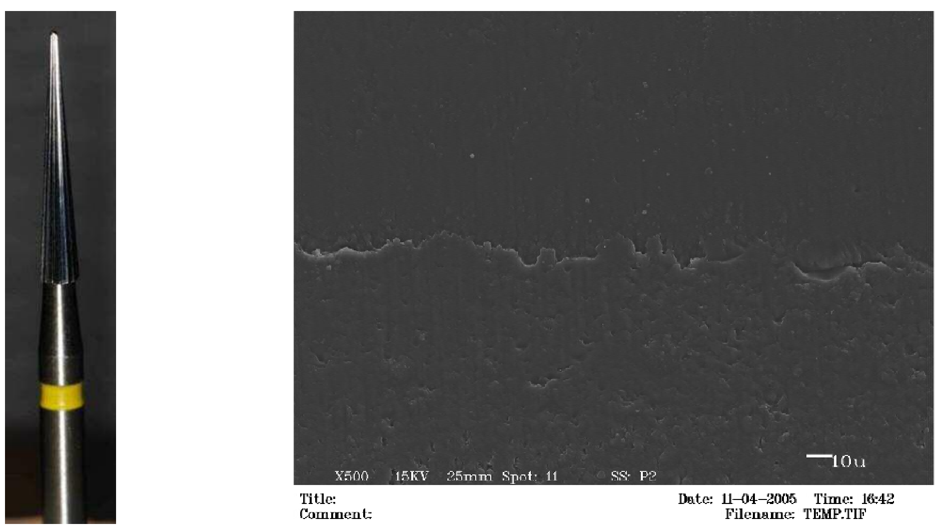
Figure 3.4

Representative SEM images (500x) of marginal integrity result observed with the Straight Cut (Group 3).

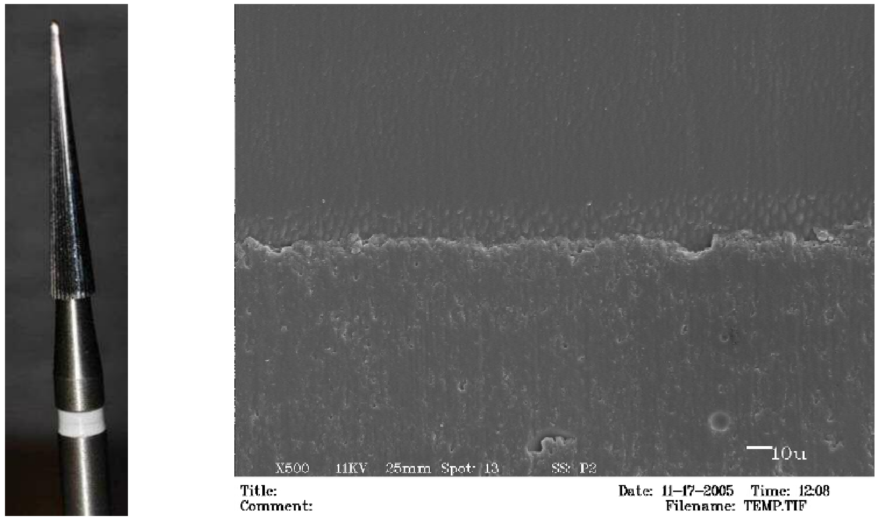
a. Fine



b. Extra-fine



c. Ultra-fine



d. All series

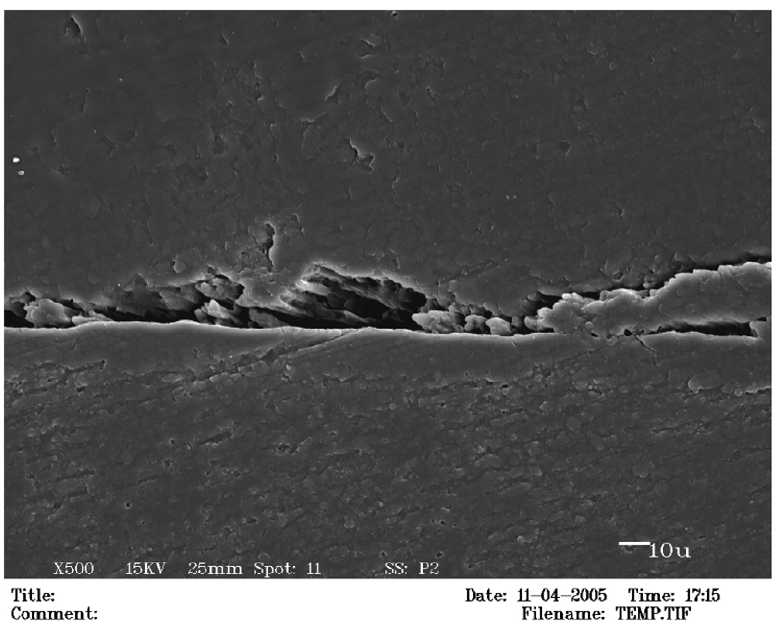


Figure 3.5

A representative SEM image (500x) of marginal integrity result observed with crosscut (Group 4).

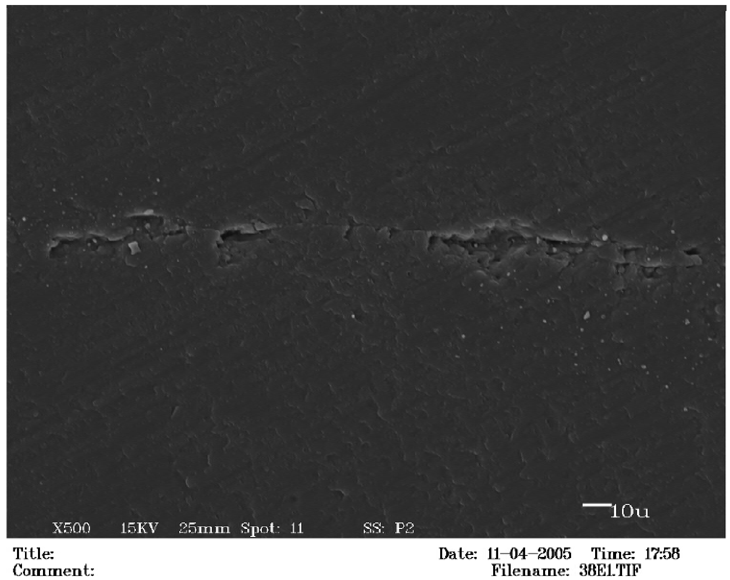
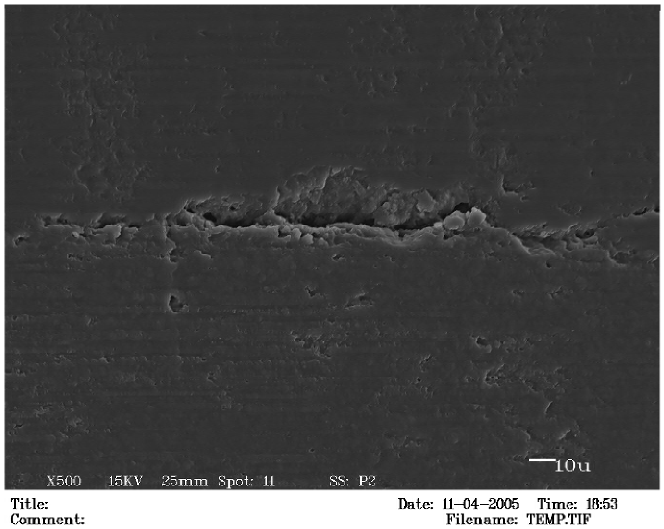


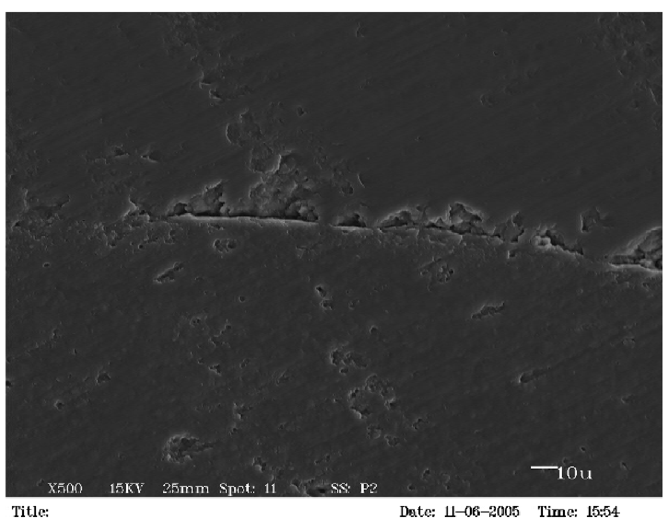
Figure 3.6

Representative SEM images (500x) of marginal integrity result observed with the Spiral Cut (Group 5).

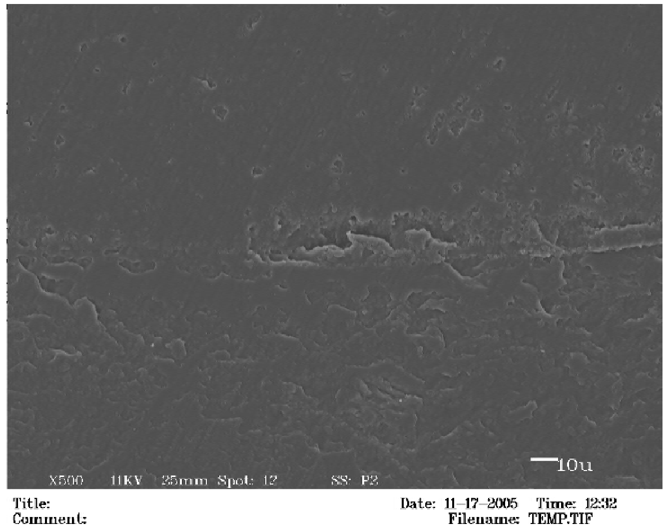
a. Fine



b. Extra-fine



c. Ultra-fine



d. All series

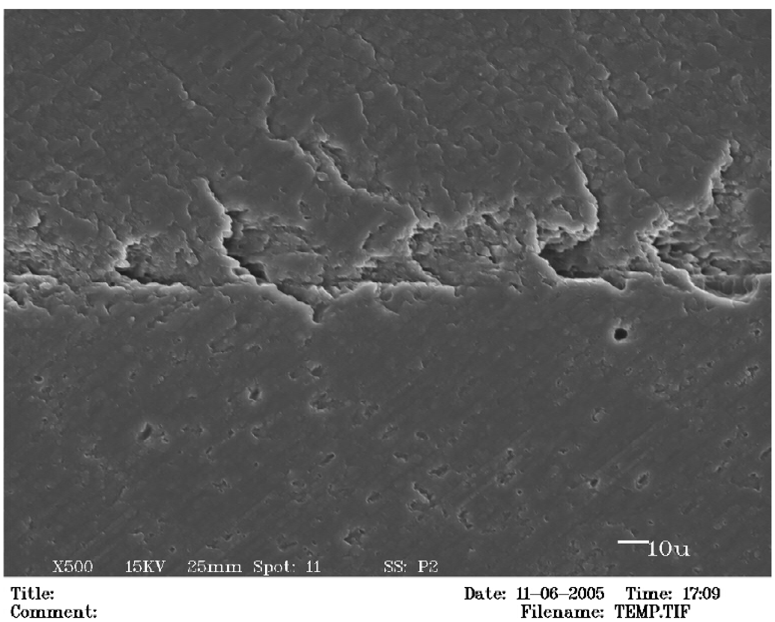
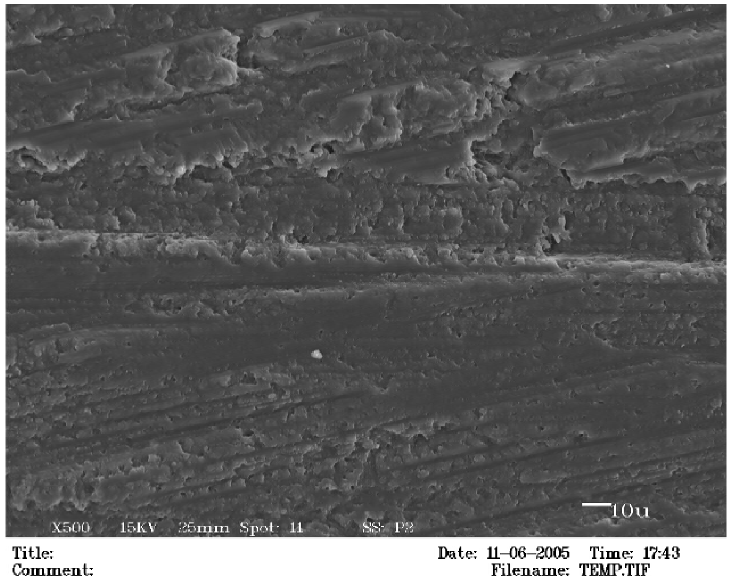


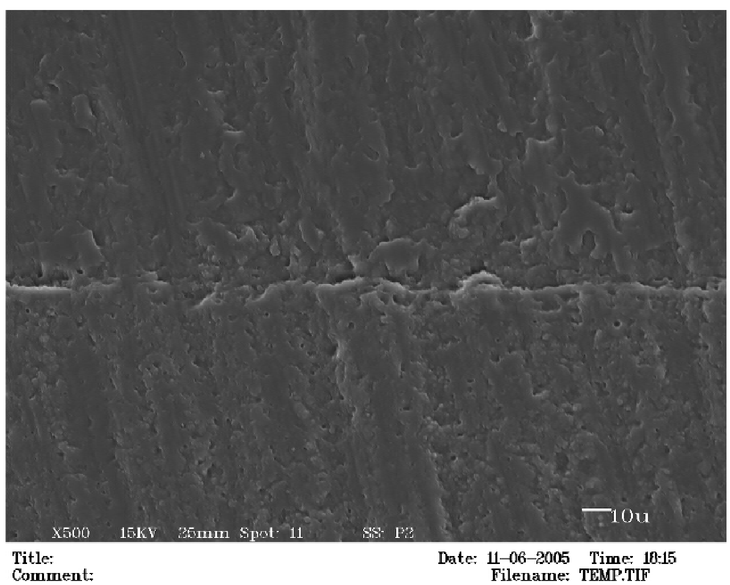
Figure 3.7

Representative SEM images (500x) of marginal integrity result observed with the Finishing diamonds Cut (Group 6).

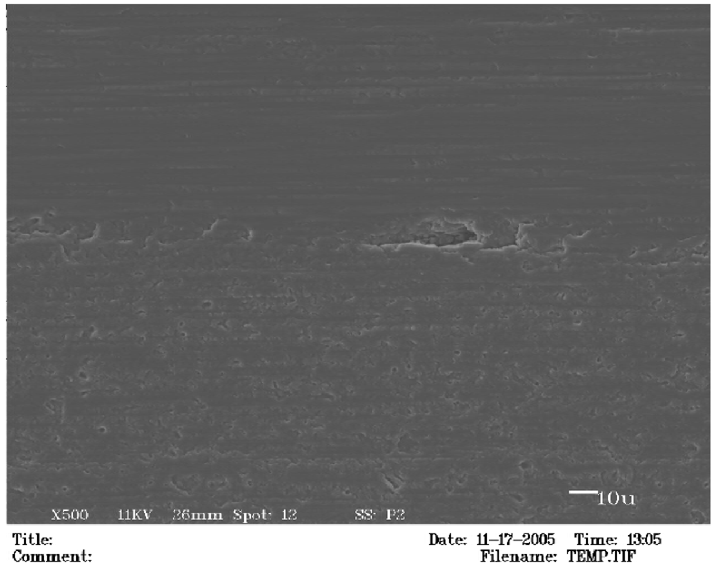
a Fine



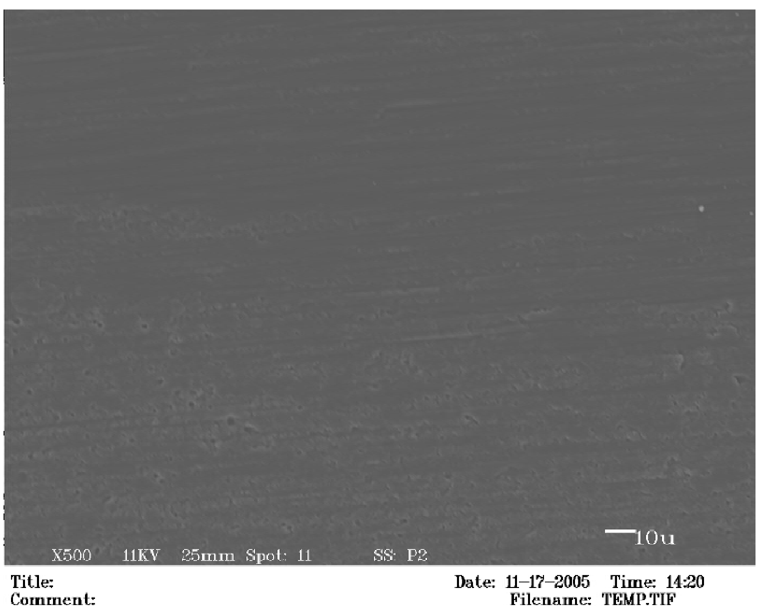
b. Extrafine



c. Ultra-fine



d. All series



Chapter IV

Summary and Conclusion

Summary

Tungsten carbide and diamonds burs afford the opportunity for finishing those areas of complex anterior restorations which are inaccessible to discs. For the precise finishing of small delineated areas and for concave and occlusal surfaces, rigid instruments are necessary. However, literature varies in recommending either diamond or carbide burs.

In the present investigation, the smoothest surfaces for enamel were obtained by polishing the enamel at 1200-grit, and the smoothest surfaces for composite were obtained by curing against a matrix strip. The surface roughness (Ra, µm) of both polished enamel and the Mylar formed surfaces increase by the use of finishing tungsten carbide and diamonds burs.

The roughness surface in this study was created by the fine (30 µm) finishing diamonds and the all series carbide. The roughness values of the carbide may be due to the surface and subsurface damage caused by a hammering affect of the carbide burs as Felix and colleagues mentioned (Felix et al., 1983). Also, the cumulative instrumentation when the carbide all series instruments are used may tend to plough through restorative material rather than abrade them. The hardness of traditional composite macrofillers, or the microfilled complexes, does not permit the flutes to cut them clean without damage. Therefore, when composites are finished with carbide burs, the macrofillers are more likely to be dislodged than ground down, causing detectable surface irregularities. Also, the diamond's degree of gouging is not as deep as those produced with carbide. Consequently, when such restorations are finished with carbide burs, they do not have the same luster-like surface that is possible when finished with extra-fine and ultra-fine diamonds. A fine diamond (30μm) caused a large amount of detrimental effects and is not recommended for finishing composites. However, the subsequent use of extra-fine (15μm) and ultra-fine (8μm) finishing diamonds reduced roughness significantly, and the cumulative effect of the all series for the diamonds resulted in the smoothes surface.

On the other hand, the effect of the all series for the carbide finishing burs showed the roughest values. It is possible that a small number of deep groves created by the blades of the fine carbide burs could not be removed affectively by the extra-fine and ultra-fine burs. It could be further theorized that the presence of small numbers of deep grooves correlated with the greatest Ra values found in the enamel and composite of all series specimens.

Additional factors affecting polishing results may include the amount of pressure utilized during polishing, the orientation of the abrading surface, and the amount of time spent with each finishing bur. Other factors affecting the roughness values may include the smear layer created during instrumentation that may affect the profilometer reading, and the different Ra measurements that instruments can show. A mechanical profilometer roughness value can vary significantly from AFM or Optical profilometer roughness values since measurements are conducted at different levels of dimensional resolution. The complex structure of a surface can not be fully characterized solely by the surface roughness measurements. Therefore, it is not appropriate to draw definitive conclusions on the clinical suitability of a finishing instrument based exclusively on roughness values.

In addition to smooth surface, a perfect marginal adaptation and seal are desired. However, finishing instrumentation may lead to crevice formation and marginal disintegration. In the present investigation, it was noted that the worst marginal result was observed with the medium-grit diamond (100 μm), and all the finishing diamond burs generated the smallest gaps of all groups. These burs included fine (30 μm), extra-fine (15 μm) and ultra-fine (8 μm). The all series methods afforded the best results in terms of gap formation, followed by the ultra-fine, extra-fine, and fine methods respectively.

Among the finishing carbide burs, no differences were noted among the straight cut, crosscut and spiral cut groups. However, when comparing the straight cut and spiral cut, a tendency can be noted: large gaps develop when the all series methods were used, leading to an interpretation that the more instrumentation in a restoration, the more likely to increase the gap, which is in contrast with the diamond finishing group.

It is to be assumed that the gentleness of the finishing diamonds burs to the margins of the restoration has practical clinical consequences.

Conclusions

Within the limitations of these experiments, the following can be concluded:

1. The smoothest surface for composite was obtained when cured in contact with the Mylar strip.
2. The smoothest surface for enamel was obtained mechanically polished at 1200 grit.
3. The worst Ra results were obtained with the fine diamond and the use of the SpC and StC all series.
4. Finishing diamonds: fine, extra-fine and ultra-fine generated the smallest gaps compared to carbides and regular-grit diamonds.

APPENDICES

The following appendices contain tables describing the individual experimental sample data for the Effect of Finishing Instrumentation on Enamel and Composite Surface Morphology (Chapter II), and Effect of Finishing Instrumentation on Marginal Integrity of Resin-Based Composite Restorations (Chapter III). The data was summarized in the Results section.

Table A1

Complete Description of Enamel Roughness Values.

Controls

	Control mechanically-polished enamel.						Diamond, Medium (no band): 100 µm					
	1	2	3	4	5	Average	11	12	13	14	15	Average
Ra µm	0.30	0.60	0.40	0.30	0.80		3.30	4.10	2.30	2.20	2.80	
	0.30	0.60	0.40	0.30	0.90	0.49	3.60	3.20	2.20	2.40	2.40	2.89
	0.20	0.60	0.50	0.30	0.80		3.40	4.10	2.90	2.30	2.20	
Average	0.27	0.60	0.43	0.30	0.83		3.43	3.80	2.47	2.30	2.47	
Ra Max µm	0.30	1.00	0.50	0.40	1.00		4.40	6.80	3.00	3.30	4.80	
	0.30	0.90	0.50	0.40	1.10	0.68	5.00	4.70	3.30	3.40	5.40	4.51
	0.20	0.90	0.80	0.40	1.50		5.00	6.20	4.40	3.70	4.30	
Average	0.27	0.93	0.60	0.40	1.20		4.80	5.90	3.57	3.47	4.83	
Ra Mn µm	0.20	0.30	0.20	0.20	0.30		0.70	0.30	0.40	0.40	0.30	
	0.20	0.20	0.20	0.20	0.30	0.23	0.60	0.50	0.40	0.50	0.20	0.43
	0.20	0.30	0.20	0.20	0.30		0.70	0.50	0.40	0.40	0.20	
Average	0.20	0.27	0.20	0.20	0.30		0.67	0.43	0.40	0.43	0.23	

Straight Cut

	Straight Cut (ET9), Fine (Red band).						Straight Cut (ET9), Extra - Fine (yellow band)					
	16	17	18	19	20	Average	21	22	23	24	25	Average
Ra µm	1.20	0.50	0.80	1.60	1.50		1.10	0.80	0.30	0.50	0.40	
	1.10	0.40	0.80	1.40	1.90		1.10	1.20	0.30	0.50	0.30	
	1.40	0.50	0.70	1.40	1.90		1.30	1.40	0.40	0.50	0.30	
Average	1.23	0.47	0.77	1.47	1.77	1.14	1.17	1.13	0.33	0.50	0.33	0.69
Ra Max µm	2.00	0.90	1.30	2.80	3.50		1.60	1.10	0.50	0.90	0.60	
	1.80	0.60	1.40	2.40	2.90		1.90	2.20	0.50	0.90	0.30	
	2.30	0.70	1.10	2.50	3.20		2.00	2.70	0.60	0.90	0.40	
Average	2.03	0.73	1.27	2.57	3.20	1.96	1.83	2.00	0.53	0.90	0.43	1.14
Ra Mn µm	0.30	0.20	0.30	0.40	0.30		0.30	0.50	0.20	0.20	0.20	
	0.30	0.30	0.40	0.40	0.40		0.20	0.30	0.20	0.20	0.20	
	0.40	0.30	0.30	0.40	0.40		0.70	0.40	0.20	0.20	0.20	
Average	0.33	0.27	0.33	0.40	0.37	0.34	0.40	0.40	0.20	0.20	0.20	0.28

	Straight Cut (ET9), Ultrafine (white band)						Straight Cut (ET9), All Series					
	26	27	28	29	30	Average	31	32	33	34	35	Average
Ra µm	1.50	1.40	0.30	0.30	1.80		2.00	2.00	2.10	1.70	1.20	
	1.50	1.40	0.20	0.30	1.50		1.80	1.90	1.70	1.70	0.60	
	1.60	1.40	0.30	0.40	2.20		1.60	2.00	1.80	1.80	0.30	
Average	1.53	1.40	0.27	0.33	1.83	1.07	1.80	1.97	1.87	1.73	0.70	1.61
Ra Max µm	3.20	2.60	0.40	0.50	3.30		3.70	3.80	4.00	3.10	2.00	
	2.80	2.60	0.30	0.40	3.00		3.40	3.70	3.80	3.10	1.10	
	3.00	2.60	0.40	0.60	3.70		3.10	3.90	3.40	3.20	0.30	
Average	3.00	2.60	0.37	0.50	3.33	1.96	3.40	3.80	3.73	3.13	1.13	3.04
Ra Mn µm	0.60	0.20	0.20	0.20	0.50		0.40	0.30	0.50	0.40	0.30	
	0.40	0.40	0.20	0.20	0.40		0.30	0.40	0.50	0.40	0.20	
	0.40	0.40	0.20	0.20	0.70		0.30	0.40	0.50	0.40	0.20	
Average	0.47	0.33	0.20	0.20	0.53	0.35	0.33	0.37	0.50	0.40	0.23	0.37

Crosscut (ET9Q), Fine (blue/yellow band).						
	36	37	38	39	40	Average
Ra µm	1.50	1.70	0.40	1.50	0.50	1.02
	1.30	1.30	0.50	1.30	0.50	
	1.20	1.50	0.60	1.00	0.50	
Average	1.33	1.50	0.50	1.27	0.50	
Ra Max µm	2.40	3.00	0.60	2.60	0.80	1.67
	2.10	2.10	0.60	2.70	0.70	
	1.70	2.40	0.90	1.60	0.90	
Average	2.07	2.50	0.70	2.30	0.80	
Ra Mn µm	0.30	0.30	0.20	0.30	0.20	0.28
	0.30	0.30	0.30	0.30	0.20	
	0.30	0.40	0.30	0.30	0.20	
Average	0.30	0.33	0.27	0.30	0.20	

Spiral Cuts

	Spiral cut (48L), Fine (Red band)						Spiral cut (48L), Extra - Fine (yellow band)					
	41	42	43	44	45	Average	46	47	48	49	50	Average
Ra µm	0.70	0.80	0.70	1.40	1.40		0.80	0.80	1.30	0.80	3.00	
	0.80	0.80	0.70	1.30	1.10		0.80	0.70	1.20	0.90	1.20	
	0.90	0.90	0.80	1.10	1.40		0.90	0.80	0.90	1.00	1.10	
Average	0.80	0.83	0.73	1.27	1.30	0.99	0.83	0.77	1.13	0.90	1.77	1.08
Ra Max µm	1.40	1.20	0.90	2.60	2.50		1.00	1.30	2.60	1.70	2.60	
	1.40	1.10	0.60	2.10	1.90		1.20	1.20	2.20	1.60	2.80	
	1.80	1.40	1.30	1.50	0.80		1.80	1.30	1.30	1.70	2.50	
Average	1.53	1.23	0.93	2.07	1.73	1.50	1.33	1.27	2.03	1.67	2.63	1.79
Ra Mn µm	0.20	0.20	0.30	0.30	0.30		0.30	0.20	0.40	0.20	0.40	
	0.30	0.30	0.20	0.40	0.30		0.30	0.20	0.30	0.30	0.40	
	0.20	0.40	0.30	0.30	0.30		0.30	0.30	0.50	0.30	0.30	
Average	0.23	0.30	0.27	0.33	0.30	0.29	0.30	0.23	0.40	0.27	0.37	0.31

	Spiral cut (48L), Ultrafine (white band)						Spiral Cut (48L), All Series.					
	51	52	53	54	55	Average	56	57	58	59	60	Average
Ra µm	0.80	1.20	1.50	1.20	0.50		1.90	1.60	1.20	2.00	0.70	
	0.80	1.30	1.70	1.10	1.10		1.90	2.00	1.50	2.60	0.80	
	1.00	1.00	0.90	1.00	0.50		2.00	1.90	1.30	2.40	1.50	
Average	0.87	1.17	1.37	1.10	0.70	1.04	1.93	1.83	1.33	2.33	1.00	1.69
Ra Max µm	1.40	2.20	2.40	2.20	0.90		3.50	2.60	2.10	3.50	1.00	
	0.90	2.20	2.40	1.60	1.60		3.70	3.60	2.40	4.80	1.20	
	1.50	1.50	1.00	1.60	0.70		3.60	3.10	2.20	4.60	2.10	
Average	1.27	1.97	1.93	1.80	1.07	1.61	3.60	3.10	2.23	4.30	1.43	2.93
Ra Mn µm	0.20	0.40	0.50	0.20	0.20		0.50	0.40	0.40	0.60	0.20	
	0.30	0.30	0.30	0.60	0.20		0.50	0.50	0.20	0.70	0.20	
	0.30	0.30	0.50	0.30	0.30		0.60	0.50	0.40	0.50	0.90	
Average	0.27	0.33	0.43	0.37	0.23	0.33	0.53	0.47	0.33	0.60	0.43	0.47

Finishing Diamonds

	Finishing diamonds (ET9), Fine (Red band)						*Finishing diamonds (ET9, Extra-Fine (yellow band)*					
	61	62	63	64	65	Average	66	67	68	69	70	Average
Ra µm	1.70	2.40	1.50	2.30	1.40		0.80	0.70	0.60	1.50	1.10	
	1.40	2.40	2.20	2.00	1.50		0.70	0.70	1.20	1.20	1.00	
	1.90	1.90	1.60	2.00	1.20		0.70	0.80	1.10	1.10	1.00	
Average	1.67	2.23	1.77	2.10	1.37	1.83	0.73	0.73	0.97	1.27	1.03	0.95
Ra Max µm	2.50	4.10	2.90	3.50	2.50		1.10	1.10	0.90	2.50	1.50	
	2.00	3.70	5.20	3.00	2.10		1.10	1.20	1.90	2.10	1.60	
	2.80	2.90	3.10	3.10	2.00		1.00	1.20	0.80	1.50	1.50	
Average	2.43	3.57	3.73	3.20	2.20	3.03	1.07	1.17	1.20	2.03	1.53	1.40
Ra Mn µm	0.30	0.40	0.40	0.30	0.30		0.30	0.20	0.30	0.40	0.50	
	0.40	0.60	0.20	0.40	0.40		0.20	0.20	0.30	0.50	0.30	
	0.50	0.60	0.20	0.40	0.20		0.20	0.30	0.40	0.30	0.30	
Average	0.40	0.53	0.27	0.37	0.30	0.37	0.23	0.23	0.33	0.40	0.37	0.31

	Finishing diamonds (ET9), Ultrafine (white band)						*Finishing diamonds (ET9), All Series*					
	71	72	73	74	75	Average	76	77	78	79	80	Average
Ra µm	1.00	0.40	1.00	2.00	0.40		2.10	0.70	1.00	1.70	0.40	
	1.10	0.50	0.80	1.70	0.50		1.80	0.70	0.90	1.40	0.40	
	1.00	0.50	1.00	2.40	0.40		1.70	0.90	0.90	1.30	0.40	
Average	1.03	0.47	0.93	2.03	0.43	0.98	1.87	0.77	0.93	1.47	0.40	1.09
Ra Max µm	1.70	0.60	1.70	4.50	0.80		4.40	1.20	2.00	3.60	0.50	
	2.10	0.70	1.50	3.70	0.70		3.70	1.10	1.80	2.70	0.50	
	2.00	0.80	1.80	4.90	0.50		3.20	1.70	1.60	2.00	0.40	
Average	1.93	0.70	1.67	4.37	0.67	1.87	3.77	1.33	1.80	2.77	0.47	2.03
Ra Mn µm	0.40	0.20	0.30	0.50	0.30		0.60	0.20	0.30	0.50	0.30	
	0.40	0.20	0.30	0.50	0.30		0.50	0.20	0.40	0.60	0.30	
	0.40	0.30	0.30	0.50	0.40		0.50	0.30	0.40	0.50	0.30	
Average	0.40	0.23	0.30	0.50	0.33	0.35	0.53	0.23	0.37	0.53	0.30	0.39

Table A.2

Complete Description of Composite Roughness Values

Controls

	Control: Restoration against matrix band						Diamond, Medium (no band): 100 µm					
	1	2	3	4	5		6	7	8	9	10	
Ra µm	0.60	0.56	0.60	0.50	0.50		3.30	3.30	2.40	2.50	3.30	
	0.40	1.00	0.60	0.40	0.50	0.51	3.90	3.50	3.60	2.30	2.80	3.43
	0.50	0.30	0.40	0.50	0.30		3.60	5.70	5.60	2.50	3.20	
Average	0.50	0.62	0.53	0.47	0.43		3.60	4.17	3.87	2.43	3.10	
Ra Max µm	2.40	2.40	1.10	2.40	0.90		5.10	6.10	3.20	4.40	6.80	
	2.50	1.90	0.90	0.70	1.10	1.51	6.30	5.60	6.20	3.80	5.60	6.09
	2.10	2.50	0.60	0.60	0.60		5.90	9.70	13.00	3.90	5.80	
Average	2.33	2.27	0.87	1.23	0.87		5.77	7.13	7.47	4.03	6.07	
Ra Mn µm	0.30	0.30	0.30	0.30	0.20		0.70	0.40	0.40	0.30	0.20	
	0.30	0.30	0.30	0.20	0.20	0.26	0.90	0.40	0.40	0.40	0.20	0.41
	0.30	0.30	0.20	0.20	0.20		0.70	0.30	0.30	0.30	0.30	
Average	0.30	0.30	0.27	0.23	0.20		0.77	0.37	0.37	0.33	0.23	

Straight Cut

	Straight Cut (ET9), Fine (Red band).						Straight Cut (ET9), Extra - Fine (yellow band)					
	16	17	18	19	20	Average	21	22	23	24	25	Average
Ra µm	1.10	0.70	1.00	1.30	0.90		1.80	1.00	0.50	0.80	0.50	
	1.10	0.80	1.10	1.50	1.70		0.80	1.30	0.50	1.10	0.50	
	1.10	0.60	1.20	1.10	2.10		0.60	1.30	0.50	1.30	0.40	
Average	1.10	0.70	1.10	1.30	1.57	1.15	1.07	1.20	0.50	1.07	0.47	0.86
Ra Max µm	1.80	1.20	1.60	2.00	1.50		2.60	1.80	0.80	1.40	0.70	
	1.80	1.10	1.60	2.30	2.70		1.20	2.20	0.80	2.60	0.80	
	1.70	0.80	2.40	2.00	3.80		1.00	2.10	0.60	2.30	0.60	
Average	1.77	1.03	1.87	2.10	2.67	1.89	1.60	2.03	0.73	2.10	0.70	1.43
Ra Mn µm	0.30	0.30	0.30	0.40	0.20		0.60	0.30	0.30	0.20	0.30	
	0.30	0.20	0.50	0.40	0.30		0.20	0.30	0.30	0.20	0.30	
	0.30	0.30	0.30	0.30	0.30		0.20	0.40	0.20	0.20	0.30	
Average	0.30	0.27	0.37	0.37	0.27	0.31	0.33	0.33	0.27	0.20	0.30	0.29

	Straight Cut (ET9), Ultrafine (white band)						Straight Cut (ET9), All Series					
	26	27	28	29	30	Average	31	32	33	34	35	Average
Ra µm	1.50	2.10	0.40	0.70	3.40		1.90	1.70	1.70	1.60	0.60	
	1.60	1.70	0.50	0.80	3.00		1.80	1.70	1.80	1.70	1.90	
	1.60	1.40	0.40	0.80	3.10		1.80	1.80	1.80	1.60	0.70	
Average	1.57	1.73	0.43	0.77	3.17	1.53	1.83	1.73	1.77	1.63	1.07	1.61
Ra Max µm	2.80	3.50	0.70	1.40	6.30		3.60	3.70	2.90	2.70	0.90	
	3.00	2.80	0.80	1.30	5.80		3.50	3.70	3.00	2.60	4.00	
	3.00	2.60	0.60	1.40	5.60		3.40	3.50	3.00	2.80	1.10	
Average	2.93	2.97	0.70	1.37	5.90	2.77	3.50	3.63	2.97	2.70	2.00	2.96
Ra Mn µm	0.30	0.50	0.20	0.30	0.80		0.40	0.50	0.40	0.30	0.30	
	0.40	0.40	0.30	0.30	0.80		0.40	0.40	0.40	0.30	0.20	
	0.30	0.30	0.30	0.30	0.70		0.50	0.40	0.40	0.30	0.30	
Average	0.33	0.40	0.27	0.30	0.77	0.41	0.43	0.43	0.40	0.30	0.27	0.37

Crosscut

	Crosscut (ET9Q), Fine (blue/yellow band).					
	36	37	38	39	40	Average
Ra µm	1.20	0.80	0.90	1.00	0.50	
	1.40	0.80	0.80	1.10	0.50	
	1.20	1.00	1.20	1.00	0.80	
Average	1.27	0.87	0.97	1.03	0.60	0.95
Ra Max µm	0.70	1.20	1.30	1.60	0.60	
	2.60	1.30	1.10	0.80	0.70	
	2.10	1.80	1.80	2.00	1.00	
Average	1.80	1.43	1.40	1.47	0.77	1.37
Ra Mn µm	0.30	0.30	0.30	0.30	0.30	
	0.30	0.30	0.30	0.30	0.30	
	0.20	0.30	0.30	0.20	0.50	
Average	0.27	0.30	0.30	0.27	0.37	0.30

Spiral Cut

	Spiral cut (48L), Fine (Red band)						Spiral cut (48L), Extra - Fine (yellow band)					
	41	42	43	44	45	Average	46	47	48	49	50	Average
Ra µm	1.10	1.00	1.10	1.50	2.00		0.90	0.40	1.60	1.30	1.20	
	1.60	0.80	1.20	1.40	2.20		2.00	0.60	0.90	1.30	2.00	
	1.30	0.80	0.70	1.20	1.30		0.50	0.70	1.40	1.40	1.80	
Average	1.33	0.87	1.00	1.37	1.83	1.28	1.13	0.57	1.30	1.33	1.67	1.20
Ra Max µm	1.90	1.80	1.90	2.60	2.30		1.30	0.70	3.10	2.10	2.30	
	2.20	1.60	2.30	2.20	4.60		6.60	0.90	1.30	2.90	3.20	
	2.70	1.60	0.90	2.00	2.00		0.80	0.90	2.70	2.30	2.40	
Average	2.27	1.67	1.70	2.27	2.97	2.17	2.90	0.83	2.37	2.43	2.63	2.23
Ra Mn µm	0.20	0.30	0.30	0.40	0.60		0.30	0.20	0.20	0.30	0.40	
	0.20	0.40	0.30	0.50	0.30		0.20	0.30	0.30	0.20	1.10	
	0.20	0.30	0.30	0.30	0.20		0.20	0.20	0.40	0.30	1.00	
Average	0.20	0.33	0.30	0.40	0.37	0.32	0.23	0.23	0.30	0.27	0.83	0.37

	Spiral cut (48L), Ultrafine (white band)						Spiral Cut (48L), All Series.					
	51	52	53	54	55	Average	56	57	58	59	60	Average
Ra µm	1.30	2.00	2.00	1.80	1.40		2.60	2.50	1.00	2.50	1.00	
	1.10	1.50	1.40	2.10	1.30		1.60	2.60	1.50	1.60	1.40	
	0.80	1.30	1.30	1.10	1.30		2.00	1.90	2.20	1.50	1.30	
Average	1.07	1.60	1.57	1.67	1.33	1.45	2.07	2.33	1.57	1.87	1.23	1.81
Ra Max µm	2.40	3.50	2.90	3.10	2.80		5.50	4.20	1.70	4.70	1.80	
	1.60	2.50	2.40	2.20	2.00		2.60	5.00	2.60	3.10	2.10	
	1.20	2.40	2.10	1.50	2.90		3.60	2.70	3.90	2.60	2.20	
Average	1.73	2.80	2.47	2.27	2.57	2.37	3.90	3.97	2.73	3.47	2.03	3.22
Ra Mn µm	0.40	0.50	0.30	0.30	0.20		0.40	0.60	0.30	0.60	0.30	
	0.30	0.50	0.40	0.70	0.30		0.40	0.30	0.40	0.50	0.60	
	0.20	0.50	0.50	0.30	0.30		0.40	0.40	0.50	0.40	0.30	
Average	0.30	0.50	0.40	0.43	0.27	0.38	0.40	0.43	0.40	0.50	0.40	0.43

Finishing Diamonds

	Finishing diamonds (ET9), Fine (Red band)						Finishing diamonds (ET9, Extra-Fine (yellow band)					
	61	62	63	64	65	Average	66	67	68	69	70	Average
Ra µm	2.00	1.90	1.30	2.50	1.90		1.30	1.60	1.00	1.70	1.10	
	1.60	1.30	1.60	2.50	1.80		1.60	1.70	1.00	1.40	1.00	
	1.70	2.00	1.40	2.10	1.70		1.70	1.80	0.90	1.40	1.00	
Average	1.77	1.73	1.43	2.37	1.80	1.82	1.53	1.70	0.97	1.50	1.03	1.35
Ra Max µm	3.20	3.10	2.30	3.90	3.60		2.10	2.70	1.40	2.30	1.40	
	2.80	2.30	3.00	3.90	3.00		2.50	2.80	1.50	2.20	1.40	
	3.10	2.50	2.30	3.10	2.70		2.70	3.00	1.40	2.20	1.50	
Average	3.03	2.63	2.53	3.63	3.10	2.99	2.43	2.83	1.43	2.23	1.43	2.07
Ra Mn µm	0.30	0.40	0.30	0.40	0.30		0.30	0.30	0.20	0.40	0.30	
	0.30	0.50	0.40	0.60	0.60		0.40	0.40	0.30	0.40	0.30	
	0.40	0.90	0.40	0.40	0.40		0.40	0.50	0.30	0.40	0.30	
Average	0.33	0.60	0.37	0.47	0.43	0.44	0.37	0.40	0.27	0.40	0.30	0.35

	Finishing diamonds (ET9), Ultrafine (white band)						Finishing diamonds (ET9), All Series					
	71	72	73	74	75	Average	76	77	78	79	80	Average
Ra µm	1.10	0.50	1.50	2.10	0.60		1.70	0.60	0.90	1.30	0.40	
	0.80	0.50	0.90	2.60	0.70		1.70	0.70	0.70	1.30	0.50	
	0.80	0.60	0.70	2.10	0.50		1.70	0.80	0.70	1.40	0.40	
Average	0.90	0.53	1.03	2.27	0.60	1.07	1.70	0.70	0.77	1.33	0.43	0.99
Ra Max µm	2.20	0.80	3.00	4.60	1.00		3.80	1.00	1.50	2.70	0.50	
	1.30	0.90	1.30	5.00	0.80		3.70	1.20	1.10	2.70	0.80	
	1.60	1.00	1.20	4.70	1.00		3.70	1.20	1.00	2.90	0.50	
Average	1.70	0.90	1.83	4.77	0.93	2.03	3.73	1.13	1.20	2.77	0.60	1.89
Ra Mn µm	0.30	0.40	0.30	0.60	0.20		0.40	0.30	0.40	0.30	0.30	
	0.30	0.30	0.50	0.50	0.50		0.40	0.40	0.30	0.30	0.20	
	0.30	0.30	0.30	0.70	0.30		0.50	0.50	0.30	0.50	0.30	
Average	0.30	0.33	0.37	0.60	0.33	0.39	0.43	0.40	0.33	0.37	0.27	0.36

Table A.3

Complete Description of Gap Values

Mechanically polished margin µm						Spiral cut (48L), Fine (Red band) µm					
6	7	8	9	10	Average	41	42	43	44	45	Average
1.34	1.30	1.30	0.45	0.75	0.73	6.36	3.18	13.64	6.82	6.82	
0.56	0.97	0.21	0.21	0.18		6.82	5.47	4.55	8.19	6.38	
0.95	1.14	0.76	0.33	0.47		6.59	4.33	9.10	7.51	6.60	6.82
Positive Control: Diamond, Medium (no band): 100 µm						Spiral cut (48L), Extra - Fine (yellow band) µm					
11	12	13	14	15	Average	46	47	48	49	50	Average
18.63	12.73	29.55	8.18	22.73	16.23	5.45	15.00	10.00	8.64	4.09	
23.18	14.54	13.18	6.38	13.19		1.87	10.45	10.91	4.12	7.63	
20.91	13.64	21.37	7.28	17.96		3.66	12.73	10.46	6.38	5.86	7.82
Straight Cut (ET9), Fine (Red band) µm						Spiral cut (48L), Ultrafine (white band)µm					
16	17	18	19	20	Average	51	52	53	54	55	Average
8.64	7.27	8.64	4.57	5.93		1.82	12.45	7.27	5.45	5.45	
7.27	5.02	4.12	6.64	6.36		2.76	5.45	5.00	2.76	5.00	
7.96	6.15	6.38	5.61	6.15	6.45	2.29	8.95	6.14	4.11	5.23	5.34
Straight Cut (ET9), Extra - Fine (yellow band)µm						Spiral Cut (48L), All Series µm					
21	22	23	24	25	Average	56	57	58	59	60	Average
8.01	9.02	10.00	4.12	7.74		5.47	6.43	5.91	11.36	9.09	
5.93	5.25	7.28	2.27	3.21		2.67	6.36	8.18	8.65	10.45	
6.97	7.14	8.64	3.20	5.48	6.28	4.07	6.40	7.05	10.01	9.77	7.46
Straight Cut (ET9), Ultrafine (white band) µm						Finishing diamonds (ET9), Fine (Red band)µm					
26	27	28	29	30	Average	61	62	63	64	65	Average
5.47	3.66	4.57	2.45	2.61		4.76	4.55	3.66	9.83	0.50	
9.26	9.09	2.27	5.47	4.55		3.45	4.57	1.82	2.76	1.36	
7.37	6.38	3.42	3.96	3.58	4.94	4.11	4.56	2.74	6.30	0.93	3.73
Straight Cut (ET9), All Series µm						Finishing diamonds (ET9, Extra-Fine (yellow band)µm					
31	32	33	34	35	Average	66	67	68	69	70	Average
9.52	10.91	15.45	5.02	7.67		0.50	0.45	4.29	3.21	5.00	
4.55	18.64	7.27	2.17	10.32		1.44	0.50	6.82	10.00	3.21	
7.04	14.78	11.36	3.60	9.00	9.15	0.97	0.48	5.56	6.61	4.11	3.54
Crosscut (ET9Q), Fine (blue/yellow band) µm						Finishing diamonds (ET9), Ultrafine (white band)µm					
36	37	38	39	40	Average	71	72	73	74	75	Average
8.64	6.83	7.27	2.73	10.45		0.91	0.45	4.57	0.45	0.45	
15.00	4.55	7.72	7.74	6.82		9.09	1.87	0.91	0.45	1.36	
11.82	5.69	7.50	5.24	8.64	7.78	5.00	1.16	2.74	0.45	0.91	2.05

Table A.4

Summary Table of Force Applied to Each Specimen.

Summary Table of Force Applied to Each Specimen				
Groups		Type	Band	Mean Force N
Group 1	**Negative Control**	Polished enamel		
Group 2	**Positive Control**: Diamond	Diamond Medium	No band	0.30
Group 3	Straight Cut	Fine	Red	0.43
		Extra - Fine	Yellow	0.52
		Ultrafine	White	0.66
		All Series		0.53
Group 4	Crosscut	Fine	Yellow	0.32
Group 5	Spiral Cut	Fine	Red	0.32
		Extra - Fine	Yellow	0.35
		Ultrafine	White	0.43
		All Series		0.31
Group 6	Finishing diamonds	Fine	Red	0.31
		Extra - Fine	Yellow	0.51
		Ultrafine	White	0.46
		All Series		0.36

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