The Effect of Various Debonding Burs on the Enamel Surfaces of Teeth After Debonding Metal Brackets

BY

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THESIS

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This thesis is dedicated to my mother and my father for their unconditional love and support.

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LIST OF ABBREVIATIONS

ADA	American Dental Association
AFM	Atomic Force Microscope
ANOVA	Analysis of Variance
ARI	Adhesive Remnant Index
CLSM	Confocal Laser Scanning Microscope
ESI	Enamel Surface Index
µm	Micrometers
Ra	Average Roughness
Rq	Root Mean Square Roughness
Rt	Maximum Roughness Depth
SD	Standard Deviation
SEM	Scanning Electron Microscopy

SUMMARY

The debonding stage of orthodontic treatment involves removal of attachments from the surface of teeth followed by removal of remaining adhesive resin. The adhesive resin removal process is often accomplished by different debonding burs which are believed to be safe to enamel surface while removing all remaining adhesive resin from the tooth surface. Different burs are used by different clinicians based on cost, experience, and convenience.

Several studies have shown that these burs can cause damage to the outer layer of enamel. The objective of this study was to evaluate the effects of four different commercially available burs on the enamel surface of teeth.

The null hypothesis tested was that there is no statistically significant mean difference between the enamel surfaces of teeth which have been debonded using one of four commercially available burs: 1) 12 fluted (universal) carbide, 2) 20 fluted carbide, 3) 30 fluted carbide, and 4) white stone.

Eighty human premolar teeth extracted for orthodontic reasons were randomly assigned to one of four groups. In each group, fifteen teeth were used for profilometric analysis and the remaining five teeth were used for scanning electron microscopy. Initial profilometric analysis and SEM imaging were performed. Five spots on each tooth were used for profilometric analysis.

The teeth were bonded using metal brackets according to the standard bonding protocol. During the debonding procedure, brackets were removed from the surface of teeth using bracket removing pliers. The amount of remaining adhesive on the surface of the teeth was evaluated using the ARI system. Remaining adhesive was removed using one of the four burs according to the group. Final profilometry was performed on the five previously specified points on each tooth and the final SEM images were also captured. One-way ANOVA and Post-Hoc Scheffé tests were utilized to statistically analyze the data. The Chi-Square test was used to compare the ARI values between groups.

There was a statistically significant difference in roughness value after debonding between groups 1 and 2 ($p = 0.000$), 1 and 3($p = 0.000$), 1 and 4 ($p = 0.000$), 2 and 4 ($p = 0.000$), and 3 and 4 ($p= 0.000$). However, no statistically significant difference was observed between groups 2 and 3 ($p= 0.063$). The ARI values between groups were comparable and no statistically significant differences were observed between groups in terms of amount of adhesive resin remaining on the tooth surface prior to using the debonding burs ($p= 0.925$).

The results of the study showed that the white stone bur caused the most damage to the surface of enamel, followed by the 12 fluted bur while the 30 fluted and 20 fluted carbide burs caused the least damage. Furthermore, there was no statistically significant difference in enamel surface roughness between the 20 fluted and the 30 fluted burs.

1. INTRODUCTION

1.1 <u>Background</u>

Orthodontic treatment sometimes involves the placement of attachments directly on the surface of teeth to enable the clinician to move the teeth in desired directions. Historically, metal bands were the common attachments used for this purpose. The process of placing bands around every tooth required interproximal spaces and was a tedious and time consuming process and not esthetically attractive, especially on the front teeth. As such, the industry focused on discovering simpler and smaller attachments to be used in conjunction with the bands and possibly replace them.

The introduction of acid etch technique in the 1950's revolutionized the practice of orthodontics. George Newman (1965) published the first article on using epoxy adhesives for orthodontic attachments. With later advancements and improvements in bonding adhesives, there was no further need to fit bands to every single tooth hence saving time and causing less patient discomfort. The advantages of such adhesive systems were 1) improved esthetics, 2) ease of hygiene, 3) not requiring interproximal spaces, and 4) decreased cost (Newman, 1965).

Various bonding materials have since been used to attach brackets to the surfaces of teeth. A recent survey, reporting that only second molars were banded routinely by a majority of U.S. orthodontists, shows the success of current bonding materials and techniques (Keim, 2002).

At the completion of orthodontic treatment, brackets and auxiliary attachments are removed from the enamel surface. The goal of the debonding procedure is to remove the attachments and all adhesive resin from the tooth and to return the tooth surface to its original condition without inducing iatrogenic damage (Zachrisson and Büyükyilmaz, 2005). In order to minimize damage to the enamel surface, it is more desirable for bond failure to occur at the bracket-adhesive interface or within the adhesive resin rather than at the enamel-adhesive interface (Bishara et al., 2001). However, this would result in more adhesive resin remaining on the tooth surface, requiring more clean up (Bishara et al., 1999). Hence, it seems to be a challenge to minimize damage to enamel during the adhesive removal process while maintaining efficiency.

The debonding process most commonly involves using a pair of bracket removing pliers to remove the bracket from the tooth, followed by different polishing burs to clean the remaining adhesive resin from the enamel surface. New instruments, such as burs, discs, and diamond or silicone coated polishers, which are advertised to be less aggressive, have been developed (Ulusoy, 2009).

Care must be taken at the time of polishing the tooth surface to minimize damage to the outer surface of enamel because it is believed that the outer most layer of enamel has a higher mineral content and more fluoride relative to deeper zones. As such, this layer potentially plays a big role in resisting decalcification (Øgaard, 2001). A localized loss of hard tissues can be caused by calcium loss from the enamel surface (Pont et al., 2010). Also, the rougher surfaces could contribute to plaque accumulation, stain, and demineralization through microbial activity

(Gwinnett and Gorelick, 1977). Despite the importance of the debonding stage, there is a lack of a universally accepted protocol for it (Eliades, 2004).

Practitioners use various debonding burs based on experience, cost, and ease of use. Many orthodontists have a set debonding protocol which has been developed throughout years of practice based on their experience. Commercial suppliers have provided a variety of polishing instruments, burs, etc. without any description of what their instruments do to the enamel surface (Gwinnett and Gorelick, 1977). The trend has not changed much over the years and there is still a lack of knowledge with regards to this subject. However, the effects of these burs on the enamel surface of teeth needs to be investigated since the alterations in the enamel surface caused by rotary instruments can be irreversible.

1.2 Purpose of the Study

The purpose of this study was to evaluate the effects of four different commercially available burs on the enamel surface of teeth. The four burs investigated were: 1) 12 fluted carbide, 2) 20 fluted carbide, 3) 30 fluted carbide, and 4) white stone.

1.3 Objectives

- To evaluate the effects of 4 different debonding burs on the enamel surface of teeth as manifested quantitatively by roughness (Ra) value.
- To evaluate the effect of these burs visually using Scanning Electron Microscopy (SEM).

1.4 Null Hypothesis

- The null hypothesis tested in this study is that there is no statistically significant mean difference between the enamel surfaces of teeth which have been debonded using one of four commercially available burs:

1) 12 fluted (universal) carbide
2) 20 fluted carbide
3) 30 fluted carbide
4) white stone

2. RELATED LITERATURE

2.1 <u>Orthodontic Bonding</u>

In 1955, when Buonocore introduced the acid etch technique a new window of opportunity was opened in the world of dental materials. During the following decades, the industry exploded with a wide range of materials and instruments. The acid etch technique utilizes phosphoric acid to alter enamel surface chemically thus allowing interlocking of the bonding material with tooth structure (Buonocore, 1955).

In 1966, the first documented direct bonding in orthodontics was performed by Cueto at the Eastman Dental Center Department of Orthodontics in Rochester, New York (Cueto, 1990). This *in vivo* experiment was performed on a few patients using a circular bracket base with an 0.018 x 0.025 slot which was bonded to the labial surfaces of four maxillary incisors. The purpose of the experiment was to determine the feasibility of attaching a bracket directly to the tooth without using orthodontic bands (Cueto, 1990). The results of the experiment were promising, with only a low percentage of brackets debonding in the following weeks.

Throughout the years manufacturers have worked on perfecting the bonding method. Some advantages of bonding include comfort to the patient, conservation of arch length, and ease of placement by the practitioner (Campbell, 1995). Gradually more and more orthodontists began to use bonding instead of banding. A 2002 survey of 8,812 orthodontists revealed that the only teeth that were routinely banded by a majority of orthodontists in 2002 were second molars, but all molars and premolars were banded less routinely than in the past (Keim et al., 2002).

An ideal bonding material to be used as an adhesive for bonding brackets to the teeth must be dimensionally stable, fluid in form to allow easy flow into the enamel surface, possess excellent inherent strength, and be easy to use (Proffit, 2007a). It should also be relatively easy to remove with the least amount of damage to the enamel surface at the completion of orthodontic treatment. The dental materials industry strives to perfect these criteria in their products.

2.2 Debonding Orthodontic Brackets: Clinical Procedure

Upon completion of orthodontic treatment, all attachments and appliances must be removed. This final stage of orthodontic treatment, appliance removal, can be divided into two main steps. The first step involves removal of brackets and attachments and the second step encompasses the removal of residual adhesive resin (Zachrisson and Büyükyilmaz, 2005).

The first step is usually accomplished by using orthodontic instruments such as "twin-beaked pliers" or ligature cutters. Bennett et al. (1984) performed a study in which they compared three different methods of removing metal brackets. The first technique consisted of squeezing the bracket wings with pliers, the second involved applying a shear force to the bracket base, and the last method applied a shear force at the level of the adhesive resin layer. The results of this study showed that the first method resulted in the least amount of stress transfer to the enamel.

The safest way to remove metal brackets is to distort the bracket base to induce bond failure between the base and the adhesive resin by squeezing the wings of the bracket with pliers

(Proffit, 2007b; Bennett et al., 1984). Subsequently, the remaining adhesive resin can be cleaned from the tooth surface using one of many commercially available debonding burs.

2.3 Potential Problems and Considerations in Debonding

The greater strength of the adhesive resins becomes a potential problem in debonding. The issue in adhesion of brackets to the enamel surface in orthodontics is that the bonding strength should be high enough to prevent failure during orthodontic treatment but also low enough so that there is negligible enamel damage during bracket removal (Pont et al., 2010).

Upon removal of a bracket from the tooth, bond failure must occur at one of three possible sites (Proffit, 2007a):

1) Between the bonding material and the bracket
2) Within the bonding material itself
3) Between the bonding material and the enamel surface

Failure at the junction of the enamel surface and the bonding material is generally undesirable since as the bracket is pulled away from the surface, “tearing” of enamel is likely to occur (Proffit, 2007a; Bishara et al., 2001). Bond failure at any other location other than the enamel surface is safer for the integrity of the tooth structure. However, it requires more time to remove the remaining adhesive resin from the tooth surface (Özer et al., 2010).

The amount of adhesive resin remaining on the tooth surface after debonding is variable. In 1984, Årtun and Bergland used an index to evaluate the amount of adhesive resin remaining on the tooth surface after debonding. The Adhesive Remnant Index (ARI) scoring system was defined as:

Score 0 = No adhesive left on the tooth.

Score 1 = Less than half of the adhesive left on the tooth.

Score 2 = More than half of the adhesive left on the tooth.

Score 3 = All adhesive left on the tooth, with distinct impression of the bracket mesh.

The ARI system has been used by many studies since then and modified versions of this scoring system are still being used. Although it is not a reliable means to estimate surface roughness by itself (Eliades et al., 2004), it allows for verifying the similarity of enamel surfaces before different debonding burs are used on teeth. Given the broad variability in amount of adhesive resin remaining, this method allows for calibration of all enamel surfaces before any attempt at removing or altering the enamel surface has been taken.

Pont et al. (2010) performed a combination of an *in vivo* and *in vitro* evaluation on the enamel surface lost after debonding. Thirty consecutive patients who completed orthodontic treatment with fixed appliances were included. Standard bonding protocol was followed. At the end of treatment, brackets were debonded and the $ARI_{Bracket}$ as well as the ARI_{Tooth} were recorded following removal of brackets. Adhesive remnants were removed with a tungsten carbide bur followed by a fine carbide bur. Zircate polishing paste was applied and rubber points were used as the last step. An impression of the labial surface of teeth was taken and poured with an epoxy resin material as a replica. The replicas were studied under a scanning electron microscope. The enamel surface index (ESI) used by Zachrisson and Årthun in 1979 was originally used to score the enamel surfaces of teeth. This scoring system will be further discussed in subsequent sections.

Energy dispersive x-ray spectrometry was used to measure the percentage of calcium from enamel that was present on the adhesive resin. This was performed on brackets with $ARI_{bracket}$ score of 1, 2, and 3 indicating presence of some adhesive resin on the bracket. Since none of the adhesive resin materials contained calcium, the calcium found on the resin was assigned to enamel loss. The ARI_{tooth} results showed that a score of 3 was the most frequent indicating adhesive failure between the bracket base and adhesive resin with a distinct impression of the bracket mesh on the tooth. The highest incidence of ARI_{tooth} score of 3 was observed in central incisors and the lowest percentage (score zero) on the first molars. Pont et al. concluded that all teeth had acceptable enamel surfaces.

The amount of enamel lost during debonding procedures has been the subject of many studies and depends on many different factors including instruments used for debonding and the type of adhesive resin used (Pus and Way, 1980; Thompson and Way, 1982; Van Waes et al., 1997; Zachrisson and Årthun 1979). Regardless of the method used to remove the excess adhesive resin from the enamel surface, some scarring of enamel is inevitable (Campbell, 1995; Zachrisson and Årthun, 1979; Retief and Denys 1979; Pont et al., 2010; Özer et al., 2010). An improper debonding technique can lead to esthetic problems, tooth sensitivity, and possible increasing the risk of caries (Ulusoy et al., 2009).

In a survey of orthodontists in 1995, 80% of the respondents recognized enamel scarring following debonding although only 50% felt that the original enamel was more esthetically pleasing (Campbell, 1995).

2.4 Characteristics of "Normal" Enamel Surface

Any discussion regarding the enamel surface of teeth warrants an understanding of the characteristics of intact enamel. Much of what is known about the appearance of normal enamel surface is related to classic studies of Mannerberg in 1960. The appearance of tooth enamel varies as an individual ages. In young teeth, horizontal ridges called perikymata run continuously around the crown in a circular pattern. The pattern of perikymata varies widely both between individuals and from one part of a tooth to another with more pronounced ridges closer to the cervical region of the tooth and shallower ridges more incisally (Mannerberg, 1960; Zachrisson, and Årthun, 1979).

With aging, this organized perikymata pattern is generally lost and gradually replaced by a scratched pattern. Tooth brushing habits, abrasive diets, and the normal everyday process of mastication leave footprints on the enamel surface. Mannerberg's study showed that in some individuals in middle and late teens the pattern of perikymata may be intact and present over the entire tooth surface while in others the surface might show perikymata and horizontal scratches, and others may show a severely horizontally scratched pattern (Mannerberg, 1960). Using replicas of enamel surface, Mannerberg found normal wear to be in the range of 0 to 2 μm per year. For comparison, when a sandpaper disk is used on the tooth surface, a contact of a fraction of a second will leave a groove as deep as 5 µm or more on the tooth surface (Zachrisson and Büyükyilmaz, 2005).

Enamel is composed of crystallites embedded in a sparse organic matrix. It is predisposed to many different abrasion phenomena throughout an individual's lifetime (Zarrinnia et al., 1995). In short, since the tooth surface is in a dynamic state, the normal structure of enamel changes as an individual ages (Zachrisson and Büyükyilmaz, 2005). A "normal" tooth surface is not an unequivocally defined condition which should always be taken into consideration with any study involving the enamel surface appearance. This makes the study of tooth surface changes more challenging and casts a shadow of doubt on any study which claims a definite conclusion.

2.5 Methods of Enamel Surface Evaluation

Evaluation of the enamel surface has been the focus of different studies since the 1950's. The methods used for this purpose range from strict visual evaluations to complex algorithmic measurements. The three most commonly used methods for the evaluation of enamel surface to date are scanning electron microscopy (SEM) (Gwinnett and Gorelick, 1977; Zachrisson and Årthun, 1979; Retief and Denys,1979; Campbell, 1995; Zarrinnia et al., 1995; Ulusoy, 2009) , Profilometry (Eliades et al., 2004; Özer et al., 2010) , and atomic force microscopy (AFM) (Karan et al., 2010). Other methods such as SEM in combination with X-ray microanalysis (Ruppenthal et al., 1992), as well as a confocal laser scanning microscope (CLSM) (Brauchli et al., 2011) have also been used in a number of the most recently published studies.

2.5.1 <u>Scanning Electron Microscopy</u>

A scanning electron microscope (SEM) is a type of electron microscope that uses a high-energy beam of electrons to generate an image from a sample. The collision of electrons with the atoms that make up the sample produces electrons and x-rays which are then used to produce the image (Purdue University website, 2011).

The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. It produces images of high resolution, which means that closely spaced features can be examined at a high magnification. Preparation of the samples to be examined is relatively easy since most SEMs only require the sample to be conductive allowing free movement of electrons through the material. The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most commonly used instruments in research areas today (University of California Berkeley website, 2011)

Scanning electron microscope images can show the enamel damage; however, they can provide only subjective information (Pont et al., 2010). Any procedure or process affecting the tooth surface morphology can be best examined under SEM (Ulusoy et al., 2009).

Classic studies on enamel surface roughness have used SEM as a visual means of evaluating the scarring and scratches on enamel surface caused by different debonding techniques. Since SEM cannot provide a quantitative mode of evaluation, this method cannot be used for comparative assessment of enamel roughness (Karan et al., 2010). However, SEM is still a valid supportive tool for quantitative evaluation methods because it affords a more subjective inspection and permits a better understanding of what happens to the treated enamel (Özer et al., 2010).

2.5.2 Profilometry

A profilometer uses a thin stylus to scan the surface of the object and measure its roughness. The tip of the stylus is about 20 microns in diameter. The stylus is typically made of metal or diamond and is drawn slowly across the sample surface to yield an image**.** (Sharma et al., 2010).

Contact profilometers are used in investigating most of the world's surface finish standards. One advantage of contacting the surface is that in dirty environments the contaminants will not be scanned. A very small stylus tip radius can be used which results in good resolution. A profilometer can work on the surface of the sample directly and there is no need to make duplicate models of the material (Engineers Edge Website, 2011).

The roughness parameters measured via profilometry include:

1) "Average roughness (R_a): This parameter describes the overall surface roughness and can be defined as the arithmetic mean of all absolute distances of the roughness profile from the center line within the measuring depth.
2) Root mean square roughness (R_q): This represents the height distribution relative to the mean line.
3) Maximum roughness depth (R_t): Which registers isolated profile features on the surface

4) Mean roughness depth (R_z): Which describes the average maximum peak to valley height of five consecutive sampling depths" (Eliades et al., 2004).

Using profilometer measurements allows for quantification of surface roughness in terms of parameters that can be analyzed statistically. Profilometry also allows for a standard means of comparison.

2.5.3 Atomic Force Microscopy

"The atomic force microscope (AFM) is the member of the family of scanning probe microscopes most capable of imaging soft, non-conducting surfaces. The imaging principle consists of a scanned tip attached to a cantilever. Bending of the cantilever due to forces on the tip is measured by the deflection of a laser pointer. Scanning action in the lateral and vertical directions is provided by piezoelectric devices" (Farina et al., 1999). Hard surfaces that exhibit micro irregularities can be analyzed using AFM (Karan et al., 2010).

AFM analysis is an alternative method that uses multiple scans in high resolution and can be used for analysis of such surfaces with nanoscale (microscopic, in the order of 10^{-9}) irregularities. Minimal sample preparation, simultaneous 2 and 3 dimensional image capturing, and the possibility of re-examination of the sample are a few of the advantages of this method (Karan et al., 2010).

2.6 Effects of Debonding Burs on Enamel Surface

In one of the first articles published on the subject, Gwinnett and Gorelick focused on different means of adhesive removal at debonding (Gwinnett and Gorelick, 1977). Even though not many studies had been done to describe enamel surface at that time, this particular study captured the attention of many clinicians and researchers as it demonstrated the amount of damage to the enamel surface at debonding. Human teeth were used for this study but the number and types of teeth used are not mentioned in the article. Following bracket removal using pliers, teeth were divided into different groups and the remaining adhesive resin was removed using different methods.

In each group one of the following methods was used in removing excess adhesive resin: Green stone followed by white stone, sand paper disks, green rubber wheel, and debonding burs. The burs used in the study consisted of a tungsten carbide finishing bur operated at high speed, a plain cut steel finishing bur at low speed, and an acrylic steel bur at low speed. SEM was used to compare the enamel surfaces.

The results of the study showed that although green stone followed by white stone removed adhesive resin remnants effectively, deep groves were cut into the enamel as resin was removed. The sand paper disks were not only inefficient, but also removed enamel in varying degrees. Green rubber wheel was most effective in removing the adhesive resin but it was noted that heat was generated in cases of bulk adhesive resin removal. Even though it did scratch the enamel surface, the scratches were removed to some extent with pumice. Finally, not much distinction has been made between the different types of burs used but the results show that loss of enamel occurred with all methods especially tungsten carbide bur operated at high speed. While none of these techniques resulted in an entirely smooth enamel surface, using the green rubber wheel was recommended as the method of choice.

In the classic article published in 1979 by Zachrisson and Årthun, fifty five extracted human premolar teeth were studied following different debonding techniques using SEM. The buccal surfaces of the teeth were etched with 37% phosphoric acid for 60 seconds and brackets were bonded with diacrylate adhesive resin. After 24 hours the brackets were removed and divided into different groups. Rotating instruments at low speed with no water cooling were used to finish the surface. The methods used included fine diamond burs, green rubber wheels, sand paper disks of different coarseness, plain cut tungsten carbide finishing burs, and spiral fluted tungsten carbide fissure burs. A scoring system named enamel surface index (ESI) was devised and utilized. An ESI score of zero to four was given to the surfaces based on the amount of scratches present and perikymata pattern of teeth. Hence, according to the SEM images, a score of zero was given to a perfect surface with no scratches and with a distinct perikymata pattern and a score of four was assigned to an unacceptable surface with coarse scratches.

The results of the study showed that all effective methods in removing the excess adhesive resin also abraded the enamel to varying degrees and none left a perfect surface with an ESI score of zero. The most damage to enamel and the highest ESI score correlated with the use of diamond burs. Regardless of the coarseness of sand paper disks, it was difficult to remove the adhesive resin remnants completely with these disks and the amount of enamel loss was slightly lower than occurred using diamond burs. The green rubber wheel was more efficient than the sand paper disks but the resulting scratches were similar to those made by sand paper disks. The smoothest surface was obtained with a tungsten carbide bur. Both the plain cut and spiral fluted burs received an ESI score of 1. Based on this study, Zachrisson et al. suggested the use of tungsten carbide bur in slow speed. Contrary to the study by Gwinnett and Gorelick (1977), they found the green rubber wheel to be abrasive to the enamel surface and not acceptable.

In 1979, Retief and Denys used 36 teeth which were divided into seven groups for multi-step polishing procedures. After teeth were bonded using standard protocol the brackets were removed with bracket removing pliers. The polishing sequences used included bracket removing pliers, scaler, finishing diamond bur, 12-bladed finishing carbide bur, finishing stainless steel bur, SofLex disks, and finishing rubber wheels. SEM analysis of all teeth was performed. The results of this study showed that damage to the enamel surface was inevitable regardless of the method used. The bracket removing pliers, scaler, and diamond burs resulted in a significant loss of enamel.

The sequence recommended in this study is removing the bulk of the remaining adhesive resin with a 12 bladed tungsten carbide bur operated at high speed with air cooling followed by polishing disks and pumice. None of the methods used was able to restore the tooth to the original enamel surface. The effectiveness of multi-step procedures in debonding such as those used in this study has been questioned by other authors. These procedures have shown to be too time consuming which brings about the question of practicality for everyday practice. (Zachrisson and Årthun, 1979).

A study by Campbell in 1995 compared a sharp band remover, green stone, a diamond bur, a 30 fluted carbide bur, a crosscut bur of an unknown number of flutes, and SofLex disks. Different types of teeth including central incisors, lateral incisors, and canines were used for the study. The sample size is not mentioned. The teeth were etched and bonded and one of the above methods was used to remove the remaining adhesive resin from the teeth. SEM analysis of the teeth was performed which showed that the 30 fluted bur resulted in the least amount of scarring and easy removal of adhesive resin. The crosscut bur left a grid-like pattern of scarring but was able to remove the remaining adhesive resin. Finally, the SofLex discs removed the excess remaining adhesive resin but were quite difficult to use. The scarring with these discs was less than that caused by crosscut burs but more than that caused by the 30 fluted carbide bur. A whole array of different pumicing and polishing steps following the use of these methods is evaluated in this study. These include pumice, polishing wheels and cups such as Enhance, green cups and brown cups.

The conclusion drawn was that a fine fluted tungsten carbide bur at high speed used with a light stroke is the most efficient and the safest method of removing the remaining bonding material. The final recommended protocol in this study is to use: 1) 30 fluted tungsten carbide bur at high speed while using food coloring on the adhesive resin pad to improve visibility, 2) Enhance points and cups to remove gross scarring, 3) Water slurry of fine pumice, and finally 4) Brown and green cups. Despite the statement made by Campbell that in a busy clinical practice, post debonding polishing must be effective, efficient, and comfortable to the patient, this protocol seems very complicated and time consuming. The disadvantages are similar to what is cited with other multi-step protocols.

In 1995, Zarrinnia et al. performed another scanning electron microscopy analysis of the enamel surface following different debonding protocols. Forty two extracted premolar teeth were divided into seven groups. SEM images before bonding were taken and the teeth were bonded according to standard protocol. Following bracket removal, different debonding procedures were performed on each group of teeth as follows: Group 1) Fine finishing diamond point bur operated at high speed, Group 2) 169L carbide bur, Group 3) 12 fluted carbide finishing bur, Group 4) A stainless steel finishing bur, Group 5) Moore disks used sequentially from coarse to fine, Group 6) SofLex disks used sequentially, and Group 7) Shofu wheels. Rubber cups and Zircate paste were used on all groups as the final step.

The diamond bur was shown to produce deep grooves on the enamel surface which persisted even after pumice was applied. This finding is in agreement with Zachrisson and Årthun (1979) and Retief and Denys (1979). The 169L carbide bur severely gouged the surface. The 12 fluted carbide bur was efficient but it was difficult to avoid enamel removal when using this bur. The stainless steel bur removed the residual resin with great difficulty since steel is softer than the resin filler particles. This is also consistent with findings by Retief and Denys in 1979. Sandpaper disks also removed the resin efficiently but at the expense of enamel removal. SofLex disks were found efficient in restoring the surface to a relatively smooth finish, as was found by Retief and Denys in 1979; however, this study found this technique to be relatively slow. The Shofu wheels were unable to remove the bulk of the remaining adhesive resin.

Based on their findings, Zarrinnia et al. (1995) recommend using a 12 fluted tungsten carbide as the first step following bracket removal followed by the SofLex disks and a final finishing with a rubber cup and Zircate paste. The small number of teeth per group (7 per group), and the use of SEM as the only means of comparison, makes these findings questionable. Also, the multistep procedure has its disadvantages in terms of clinicians' efficiency and their willingness to perform multi-step procedures.

Eliades et al. (2004) performed a study which used a quantitative measurement for the first time to evaluate enamel surface roughness after debonding. Thirty extracted premolar teeth were used for the study. The initial enamel surfaces were subjected to profilomtery and roughness values were obtained. Two recordings were made on the surface of each tooth. Following profilometric analysis, teeth were bonded with a chemically cured, no mix adhesive and debonded after one week. Teeth were divided into two groups and excess adhesive was removed using either an eight bladed carbide bur or an ultrafine diamond bur. SofLex disks were used to polish all teeth surfaces and a second profilometric analysis was performed. The duration of each adhesive resin removal protocol was also recorded.

The results of this study showed that all roughness parameters increased with the use of both burs but more so with the use of the ultrafine diamond bur. However, the diamond bur was two times faster than the eight bladed carbide bur in removing the excess adhesive. The use of quantifiable parameters in this study as opposed to subjective SEM analysis, allows for a more accurate comparison. However, given the wide range of roughness values for different parts of a tooth, the use of two recordings per specimen and using the average roughness of the two can lead to possible error.

Ulusoy in 2009 performed a study to compare the effects of eight different one step polishing procedures. According to the authors of this study, one step systems have become more popular and are used more often than multi-step procedures since they are less time consuming and result in less contact time between the polishers and the tooth surface, reducing enamel surface damage. Eighty five extracted premolar teeth were used for this study: 5 teeth were used as controls and the remaining 80 teeth were etched and bonded following the standard bonding protocol. Brackets were removed 24 hours after bonding and one of the following polishing methods were used to remove the excess adhesive resin: 12 fluted tungsten carbide bur, 30 fluted tungsten carbide bur, SofLex disc, Super snap disc, PoGo one step micropolisher, OptiShine brush, 30 fluted tungsten carbide bur followed by PoGo one step micropolisher, and finally a 30 fluted tungsten carbide bur followed by OptiShine brush. As with most of the studies done on this subject, SEM analysis was used to compare the enamel surfaces. The time required for each polishing procedure was also recorded.

The results of the study showed that the maximum clean up time was found with PoGo polisher system and the minimum clean up time was found with 30 fluted tungsten carbide bur. Although the 12 fluted bur resulted in fast removal of the remaining adhesive resin, enamel scarring was visible on SEM micrographs. This is similar to results found by Zarrinnia et al. in 1995.

The most effective residual adhesive resin removal was performed with PoGo micropolishers which produces surface roughness comparable to that of Mylar strips. PoGo micropolishers are single-use diamond impregnated polishing devices designed to use without water in the final polishing of composite resin restorations. However, this method was found to be very time consuming (maximum time recorded). The two multistep procedures (SofLex discs and Super Snap discs) also resulted in significant scarring of the enamel surface which is possibly attributed to the edges of these disks. All finishing systems were found to be "clinically acceptable" in removing the residual adhesive resin after debonding except for the OptiShine brush group without any pretreatment.

In a recent study by Karan et al. (2010), post debonding enamel surface roughness was studied using atomic force microscopy (AFM). In an attempt to circumvent the mere subjective analysis of SEM, this investigation was designed to quantitatively assess enamel roughness using roughness values. Twenty extracted maxillary premolars were scanned using AFM. Three different points were measured on the surface of each tooth. Roughness values for each surface were measured in terms of Average roughness (Sa), Root mean square roughness (Sq), and Maximum roughness depth (Smax). Brackets were bonded on the teeth according to the standard protocol and were removed after 24 hours. The two burs used in the study were the eight bladed tungsten carbide and the fiber reinforced composite bur. Following the removal of resin, teeth were scanned again under the AFM. The results of the study showed a significant increase in roughness values with the use of the eight bladed carbide bur but a decrease in roughness value compared to the original surface roughness with the use of the composite bur. The use of composite bur was more time consuming.

In 2010, Özer et al. performed a study in which they used profilomtery to evaluate enamel surface roughness. Ninety nine extracted human premolar teeth were used in the study.

Teeth were divided into 9 groups of 11 teeth. One tooth in each group was used for SEM analysis and the remainder for profilometry. After normal bonding and bracket removal, teeth were randomly assigned to one of the 9 groups: 1) tungsten carbide bur used with a high speed hand piece , 2) tungsten carbide used with a low speed hand piece, 3) a tungsten carbide bur with high speed hand-piece followed by SofLex disks, 4) a tungsten carbide bur with slow speed hand-piece followed by SofLex disks, 5) SofLex disks alone, 6) tungsten carbide bur with high speed hand piece and a fiberglass bur, 7) tungsten carbide bur with slow speed hand-piece followed by fiberglass bur, 8) fiberglass bur 9) intact enamel. The number of blades for each bur is not mentioned in this study. The ARI score was recorded for each tooth prior to removing the remaining adhesive resin. Profilometer measurements were taken on tooth surfaces after debonding was completed. Two recordings were made for each specimen and the results were averaged. One tooth in each group was scanned under SEM. The time spent during each debonding procedure was also recorded.

The results of the study showed that SofLex disks and fiberglass burs required more time than carbide burs to remove the remaining adhesive resin. Similar to previous studies, none of the procedures were able to restore the enamel surface to its original roughness. The SofLex disks were the most successful for restoring the enamel close to the original roughness value. The roughness values measured for this study were only recorded after debonding. Thus, comparison between the original and final roughness values was not possible.

In 2011, Brauchli et al. used the confocal laser scanning microscope (CLSM) for the first time to measure enamel surface roughness. Forty two bovine incisors were divided into three groups and abraded with either 37% phosphoric acid (the conventional etching method), air abrasion, or a combination of the two. Bonding and debonding was performed on the teeth similar to previous studies. After the ARI for each tooth was recorded, the remaining adhesive resin was removed with either a carbide bur (unknown number of blades) or via air abrasion. The enamel surface roughness was measured with CLSM and 3D images were visually inspected for surface structure and adhesive resin remnants.

The ARI scores revealed a significantly higher percentage of bond failure at the enamel-adhesive resin interface in teeth that were air abraded prior to bonding. Thus, air abrasion facilitates debonding but this advantage of a low ARI score is compromised by lower bond strength in a clinical situation. Air abrasion is not recommended because of the undesirable results of more brackets debonding throughout the course of treatment. The surface of teeth which were debonded with air abrasion was very smooth whereas the surface after use of a carbide bur showed a wavy pattern. Nonetheless, the difference in roughness values for both debonding procedures was not statistically significant. Due to a potential risk of inhaling increased amounts of ambient dust from air abrasion, removal with a carbide bur is recommended in this study.

3. MATERIALS AND METHODS

3.1 Study Design

The methods of analysis used in this study were profilometry and scanning electron microscopy. The SEM evaluation of an enamel surface is an excellent tool to demonstrate the surface topography. However, SEM is not quantitative and cannot be used as a sole means of comparison of surface roughness (Özer et al., 2010). Hence, profilometry was used to provide us with a means of quantitative comparison between the roughness values of individual teeth.

In order to perform profilometry on the curved surfaces of premolar teeth, a special set up needed to be manufactured which allowed proper mounting of the teeth. Also, the set up had to permit repeatable positioning of the teeth into the apparatus before and after the polishing procedure so that we could return to the same spots on the surface of the teeth before and after the procedure. The American Dental Association (ADA) laboratories assisted us with providing this set up which will be explained in detail in the subsequent sections.

3.2 Collection and Storage of Teeth

The required application form for this study, “Determination of Whether an Activity Represents Human Subjects Research”, was submitted to the UIC Office for the Protection of Research Subjects. It was determined that this research does not meet the definition of human subject research as defined by 45 CFR 46.102(f) under research protocol number 2010-0054.

The methods section was later modified to use profilometry in conjunction with the SEM. Due to this change, another application form, “Determination of Whether an Activity Represents Human Subjects Research”, was submitted to the UIC Office for the Protection of Research Subjects. Again, it was determined that this research does not meet the definition of human subject research as defined by 45 CFR 46.102(f) under research protocol number 2011-0307.

Eighty human maxillary and mandibular premolar teeth that had been previously extracted from orthodontic patients in the course of orthodontic treatment were collected over a four month period. The exclusion criteria included:

1) Teeth with caries or restorations on the buccal surface.
2) Teeth with enamel defects, hypo-calcifications, or fluorosis on the buccal surface.
3) Teeth with visible cracks on the buccal surface.

The teeth were rinsed with tap water and then stored in a neutral 10% formaldehyde solution at room temperature. This solution has proven to be antimicrobial and at the same time would not affect the microscopic features of teeth. This has been the storage protocol used in studies involving enamel surface evaluation (Campbell, 1995; Zachrisson and Årthun, 1979)

3.3 Study Groups

Teeth were randomly divided into 4 groups of 20 teeth.

Group 1: 12 fluted carbide bur (Brasseler, Savannah, GA, USA)

Group 2: 20 fluted carbide bur (Brasseler, Savannah, GA, USA)

Group 3: 30 fluted carbide bur (Brasseler, Savannah, GA, USA)

Group 4: White stone bur (Brasseler, Savannah, GA, USA)

In each of the above groups, fifteen teeth were tested using profilometry and five teeth were used for SEM.

3.4 Preparation and Mounting of Sample

The buccal surfaces of teeth were gently washed for 30 seconds. A precision sectioning saw (IsoMet, Buehler®, IL, USA) cooled by a steady stream of water was used to separate the anatomical root from the anatomical crown. Using the same saw, teeth were then sectioned occlusal-gingivally into one buccal and one lingual section.

Cylindrical garolite (fiberglass) mounting jigs 15 mm in diameter and 70 mm in height were used for mounting the buccal section of each tooth. In each solid garolite cylinder, a well was cut out on the upper base to a depth of 6 mm and an inner diameter of 8 mm. Each cylinder also had a key slot machined on one side allowing the jig to be mounted only in one configuration into the profilometer set up.

Each tooth was mounted using the same protocol ensuring reproducible placement into the profilometer set up (Figure 1). The mounting jig was placed inside the profilometer set up and secured using holding clips. The buccal section of the tooth was placed on a mounting stylus using a small piece of rope wax to temporarily hold the tooth in position. The stylus was brought down until the tooth was partially embedded in the mounting well. The position and orientation of the tooth was confirmed with a camera which produced an image on a monitor for visualization of accurate position of the tooth. To ensure accurate profilometer readings, emphasis was placed on mounting the premolar teeth with the buccal surface parallel to the floor and facing upward. Figure 1 shows a photograph of the set up.

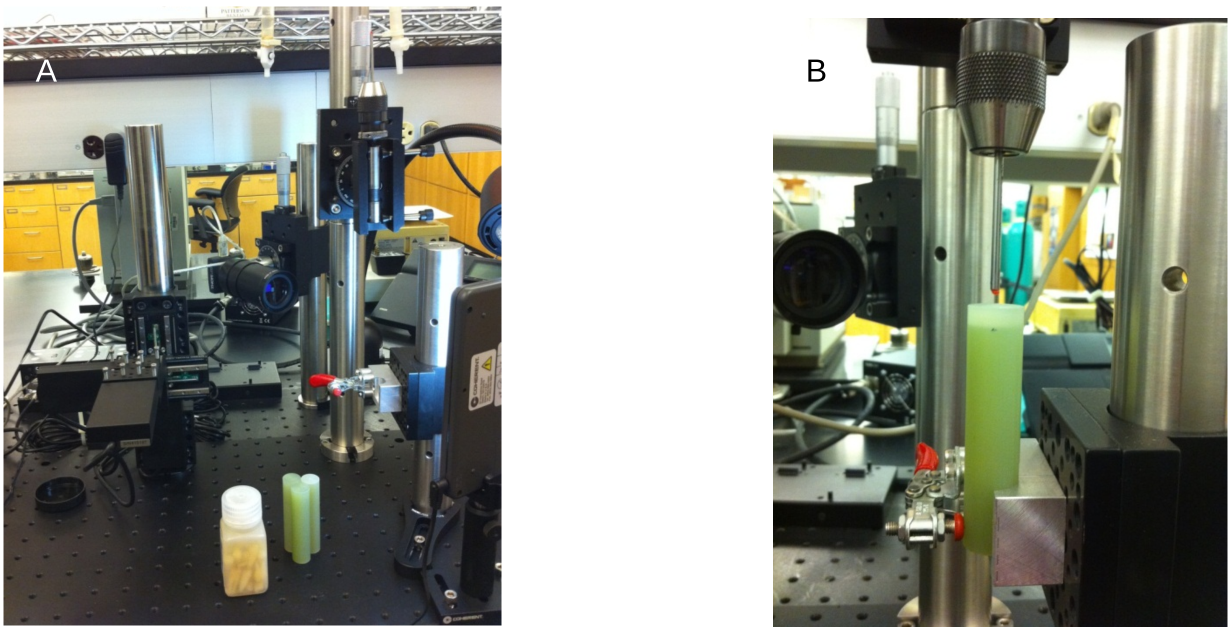

Figure 1. Profilometer set up: A) Overall set up; B) Close up of the mounting jig and the stylus used for mounting.

After proper orientation was confirmed, a flowable composite material (Tetric EvoFlow, Ivoclar Vivadent, Armherst, NY, USA.) was injected into the well. Enough material was injected until the material was flush with the surface of the well with the buccal surface of the tooth exposed above the material. The flowable composite material was light cured per manufacturer's instructions until completely set. The mounting stylus was then lifted up from the tooth surface with the tooth securely mounted in the well. The surface of the tooth was examined to confirm cleanliness. Any debris or remaining wax was removed from the tooth surface using a cotton pellet. The mounted teeth were then stored in water at room temperature until ready for use.

The remaining twenty teeth that required preparation for SEM were kept in water at room temperature following sectioning. These teeth were then mounted on standard stages that are routinely used for SEM imaging purposes.

3.5.1 Initial Profilometer Measurements

The buccal surface enamel of sixty teeth mounted for profilometry testing were surveyed using a profilometer (Sutronic, Taylor & Hubson, Leicester, United Kingdom). Each mounting jig containing the tooth was placed in the profilometer set up with the key slot facing the indexed counterpart on the mounting apparatus and secured using holding clips.

The profilometer was set on a motorized stage allowing the exact location of the probing tip to be recorded prior to each profilometer measurement. For each sample the original location of the profilometer tip was recorded and the first roughness value (Ra) was measured. Ra is the overall surface roughness of a material that can be defined as the arithmetic mean of all absolute distances of the roughness profile from the center line within the measuring length.

The motorized stage was then moved to a different location. The new X and Y coordinates were recorded and the initial Ra value was measured. This process was repeated on the surface of each tooth until the profilometer failed to report a value due to lack of contact with the tooth surface (due to the curved surface). At this point the initial profilometric survey of the tooth was considered complete. From the readings, five points on the surface of each tooth were then randomly selected (average distance between points 1-2 mm). The exact location of these five points was recorded as X and Y coordinates so that the roughness value at these same spots could be re-measured following debonding. Before each tooth was bonded, it was placed on the profilometer set up again and the Ra values for the 5 previously recorded spots was re-measured to ensure repeatable measurements of the same spot.

3.5.2 Initial Scanning Electron Microscopy Evaluation

The twenty buccal sections of premolar teeth set aside for SEM evaluation which were randomly assigned to one of the four debonding groups (five teeth in each group) were placed on standard SEM stages and secured with carbon tape applied to the base of the section. Scanning electron microscopy photographs were taken at 18X and 100X magnifications using S-3000N scanning electron microscope (Hitachi, Tokyo, Japan). The teeth were stored in water at room temperature until ready to use in bonding and debonding procedures for enamel surface evaluation.

3.6 Bonding Protocol

The bonding protocol was the same for all teeth regardless of whether profilometric measurements or SEM evaluation was going to be performed. All 80 teeth were cleaned prior to bonding with tap water. Following this step, 37% phosphoric acid (Ultradent Product, Inc., South Jordan, UT, USA) was applied to the enamel for 30 seconds. The teeth were then rinsed with tap water for 20 seconds and air dried. A chalky appearance of the enamel surface verified successful etching.

A thin coating of Transbond™ XT primer (3M Unitek, CA, USA) was painted on the surface and lightly air dried. The mesh pad of stainless steel, standard premolar brackets (American Orthodontics, Sheboygan, WI, USA) were coated with a single coating of Transbond™ XT adhesive (3M Unitek, Monrovia, CA, USA). Brackets were then placed on each tooth using bracket tweezers (Orthopli, Philadelphia, PA, USA). The brackets were placed in the middle of the tooth in occlusal-gingival and mesial-distal directions, and seated with firm pressure. Excess adhesive resin was carefully removed with an explorer. The bracket was cured with an Ortholux™ LED curing light (3M Unitek, Monrovia, CA, USA) for 5 seconds mesially, 5 seconds distally, 5 seconds occlusally, and 5seconds gingivally for a total of 20 seconds. Each tooth was stored in water at room temperature for one week prior to debonding.

3.7 Debonding Procedure

All teeth were debonded following the same protocol. A bracket removing plier (Orthopli, Philadelphia, PA, USA) was placed against the wings of the bracket and squeezed. Squeezing the bracket wings causes distortion of the bracket pad and induces bond failure between the pad and the adhesive resin. This method has been described as the safest way to remove metal brackets (Proffit, 2007b; Bennett et al., 1984).

Each tooth was then examined with 6.5x magnification under a light microscope to examine the amount of resin remaining on the tooth similar to the protocol used by Özer et al. (2010). The Adhesive Remnant Index System (Årtun and Bergland, 1984) was used to define the amount of adhesive remaining on the tooth and each tooth was scored as follows:

Score 0 = No adhesive resin left on the tooth

Score 1 = Less than half of the adhesive resin left on the tooth

Score 2 = More than half of the adhesive resin left on the tooth

Score 3 = All adhesive left on the tooth with a distinct impression of the bracket mesh

3.8 Residual Adhesive Resin Removal

The remaining adhesive resin on the enamel surface was removed using the same protocol for all groups. The only variable was the type of finishing bur used in each group. A unique polishing apparatus designed by the ADA laboratories (Chicago, IL, USA) was used with each bur to remove the residual adhesive resin from the enamel surface (Figure 2A). This apparatus enables application of a constant, programmed load by a polishing instrument in a standard repeatable manner. By keeping test parameters such as speed, applied force, and contact angle constant, human error is minimized (Figure 2B).

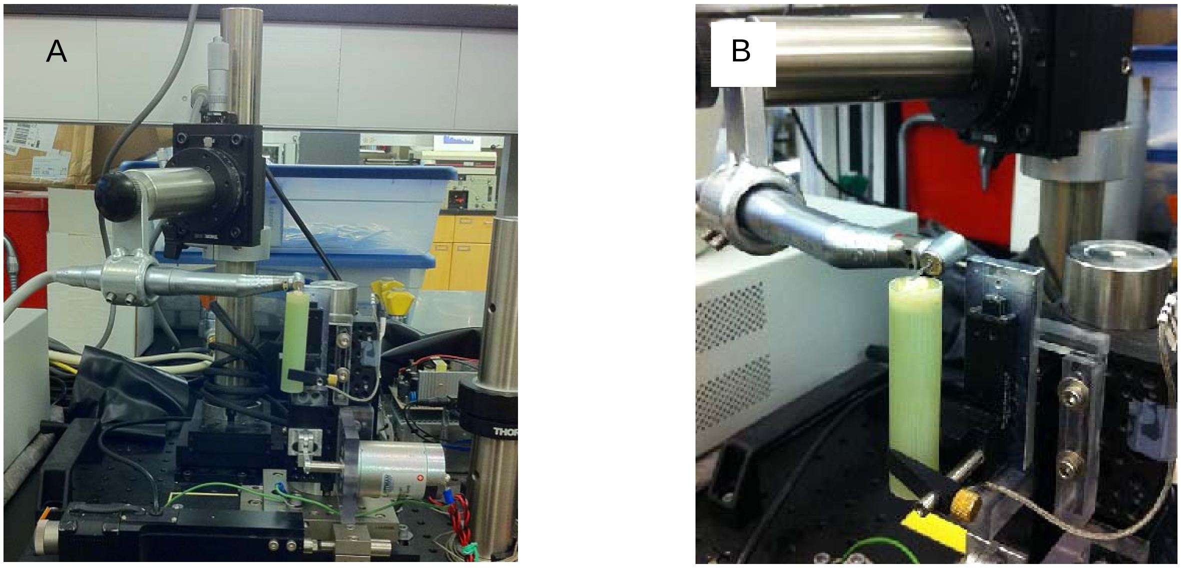

Figure 2. Polishing apparatus set up: A) Overall set up; B) Close up of bur in contact with the enamel surface.

All burs were used with a high speed hand-piece (Bien Air, Bienne, Switzerland) operating at 100,000 revolutions per minute. The direction of adhesive resin removal was mesial-distal on all teeth. A new bur was utilized for each sample to prevent any possible error caused due to inconsistencies in the quality of the bur.

Mounting jigs were secured in the specimen holder, and each tooth was polished with one of the four debonding burs until no residual adhesive resin was present on the tooth surface when visually inspected (Eliades, et al., 2004).

3.9.1 **<u>Final Profilometer Measurements</u>**

Following debonding and removal of residual adhesive resin, the sixty teeth in the profilometry groups were placed in the profilometry apparatus one at a time in the same orientation as the initial position for each tooth. According to the exact location of the original five spots which had been recorded, the motorized stage was adjusted so that the scanning probe was oriented at the same location (X, Y coordinates) as the initial recordings. The roughness values (Ra) for the original five spots on the surface of each tooth were measured with the profilometer and recorded.

3.9.2 Final Scanning Electron Microscopy Evaluation

The twenty teeth in the SEM group were photographed again after the removal of remaining adhesive resin. The same magnifications of 18X and 100X as were used for the initial SEM photographs were used.

3.10 Statistical Analysis

For the profilometric analysis , the calculation of the sample size for each study group was based on the descriptive statistics results from a published article that compared surface roughness of enamel using profilometry (Mathias et al., 2009). In the present study, using 15 units of analysis (teeth) in each of the four experimental groups made it possible to detect a large effect size with at least 80% of power. The data analysis on the Ra values before and after debonding was performed using One-Way ANOVA and Post-Hoc Scheffe. The Chi-Square test was used to compare the percentage of teeth in each group with each ARI value.

4. RESULTS

4.1 Surface Roughness Descriptives

The One-Way ANOVA results represented in Table I provide the descriptive statistics for the mean and the standard deviation for the Ra value initially and after polishing. Figure 3 illustrates the descriptive findings by means of a bar graph.

Teeth in groups 1 through 4 were polished using 12 fluted carbide, 20 fluted carbide, 30 fluted carbide, and white stone burs in this order. From the profilometer measurements of a single tooth, five spots were measured and the average roughness value was calculated for each tooth based on these five spots. The roughness values of fifteen teeth in each group were then calculated and reported as the mean roughness value for that particular group.

TABLE I

DESCRIPTIVE STATISTICS FOR INITIAL AND POST-POLISHING Ra VALUE (µm) BY GROUPS

	Group	N	Mean	SD
Initial Ra (µm)	1	15	1.099	0.055
	2	15	1.100	0.056
	3	15	1.098	0.043
	4	15	1.096	0.035
	Total	60	1.098	0.047
Ra After Polishing (µm)	1	15	1.707	0.056
	2	15	1.290	0.065
	3	15	1.233	0.038
	4	15	2.128	0.060
	Total	60	1.590	0.368

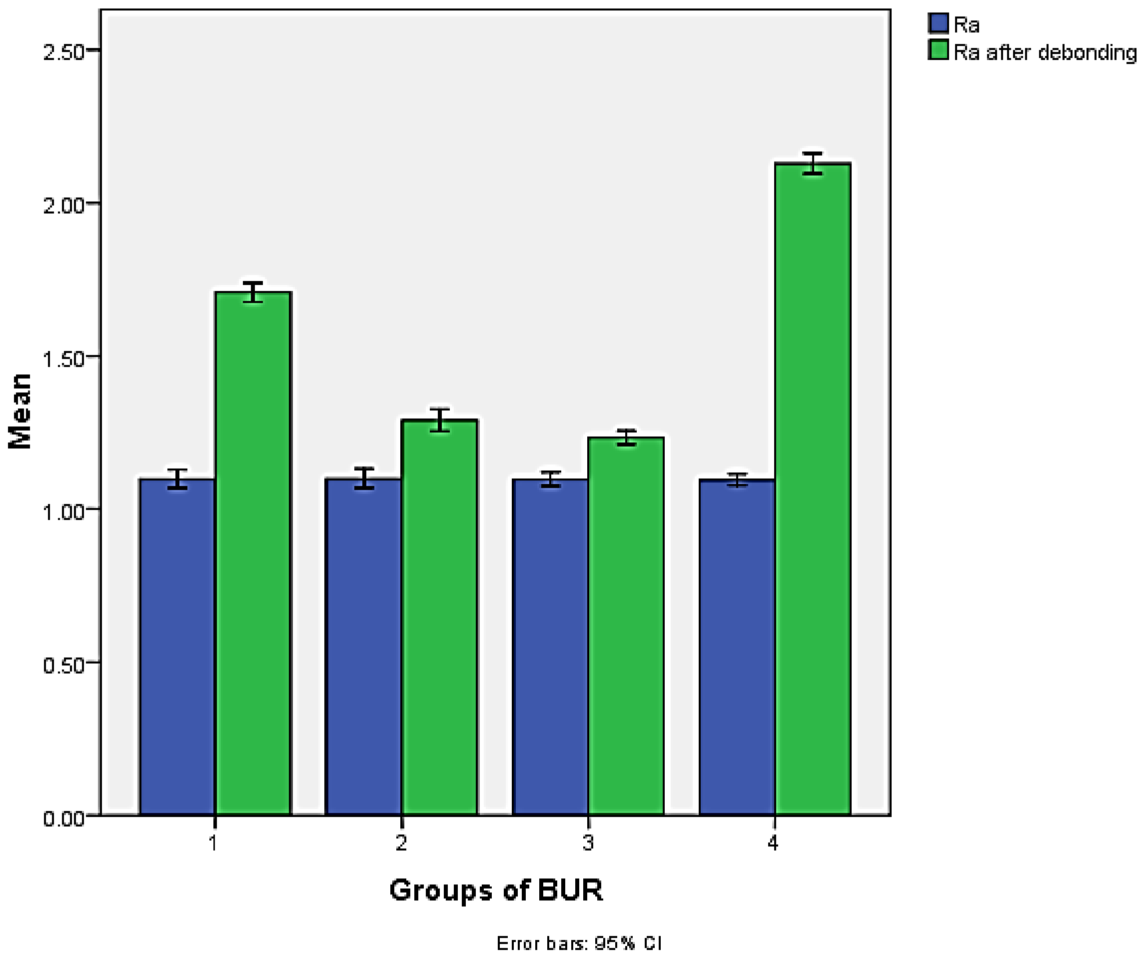

Figure 3. Descriptive statistics for initial and post- polishing Ra Value (µm) by groups

Table I shows that the means of the initial Ra values of all groups were approximately equal. In all groups, the Ra value increased after debonding. The highest post-debonding Ra value was found to be after using the white stone bur (Group 4) with a mean value of 2.13 (µm) ± 0.06 while the lowest was found to be after using the 30 fluted carbide bur (Group 3) at 1.23(µm) ± 0.04.

4.2 ANOVA and Post-Hoc Scheffé Tests

The One-Way ANOVA test was performed to evaluate whether there was a statistically significant difference between the Ra values of the four groups before and after the polishing procedure. A p-value less than or equal to 0.05 was considered to be significant. Table II summarizes the results of One-Way ANOVA.

TABLE II

ONE-WAY ANOVA- Ra VALUES

		Sum of Squares	df	Mean Square	F	p-Value*
Initial Ra (µm)	Between Groups	0.000	3	0.000	0.018	0.997
	Within Groups	0.129	56	0.002		
	Total	0.129	59			
Final Ra (µm)	Between Groups	7.806	3	2.602	836.179	0.000*
	Within Groups	0.174	56	0.003		
	Total	7.981	59			

* p-value statistically significant at ≤ 0.05

These results indicate that a statistically significant difference exists among the four groups after polishing. The Post-Hoc Scheffé test was then performed to compare pairs of means that are different. The results from the Post-Hoc Scheffé test are shown in Table III.

TABLE III

POST HOC SCHEFFÉ TEST FOR THE AFTER POLISHING Ra VALUE BY GROUPS

(I) Groups of Teeth	(J) Groups of Teeth	Mean Difference (I-J)	Std. Error	p-Value*
1	2	0.41733	0.02037	0.000*
	3	0.47400	0.02037	0.000*
	4	-0.42067	0.02037	0.000*
2	1	-0.41733	0.02037	0.000*
	3	0.05667	0.02037	0.063
	4	-0.83800	0.02037	0.000*
3	1	-0.47400	0.02037	0.000*
	2	-0.05667	0.02037	0.063
	4	-0.89467	0.02037	0.000*
4	1	0.42067	0.02037	0.000*
	2	0.83800	0.02037	0.000*
	3	0.89467	0.02037	0.000*

* p-value statistically significant at ≤ 0.05

The results of the Post-Hoc Scheffé test showed that there are statistically significant mean differences among the four different burs in Ra after debonding with the exception of results between groups 2 and 3 ($p>0.05$). The raw data can be found in Appendix C.

4.3 Chi-Square Test

The Chi-Square test was performed to evaluate whether there was a statistically significant difference between the four groups in terms of ARI score after removal of brackets and prior to using any polishing burs. Table IV shows the cross-tabulation of different groups of teeth and the proportion of teeth with each ARI score within each group.

It is verified from the frequencies shown in Table IV that the highest frequency of all ARI scores was found to be an ARI of 2. None of the samples showed an ARI score of zero indicating that when debonding the bracket from the surface of the teeth, there was always some residual adhesive resin left on the enamel surface. The Chi-Square test showed that ARI scores are not significantly different regardless of which bur was used during polishing ($\chi^2 = 6.944$, df = 6 , N= 60, p=0.925, ($p>0.05$). Figure 4 illustrates the ARI value frequencies within each group.

TABLE IV

CHI-SQUARE TEST FOR ARI VALUES PRIOR TO POLISHING BY GROUPS

			Groups of Bur				
			Group 1	**Group 2**	**Group 3**	**Group 4**	**Total**
ARI Value	1	Count	1	2	2	3	8
		% of Total	6.7%	13.3%	13.3%	20.0%	13.3%
	2	Count	10	8	10	8	36
		% of Total	66.7%	53.3%	66.7%	53.3%	60.0%
	3	Count	4	5	3	4	16
		% of Total	26.7%	33.3%	20.0%	26.7%	26.7%
	Total	Count	15	15	15	15	60
		% of Total	100.0%	100.0%	100.0%	100.0%	100.0%

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.944	6	0.925
Likelihood Ratio	1.997	6	0.920
Linear-by-Linear Association	0.549	1	0.459
N of Valid Cases	60		

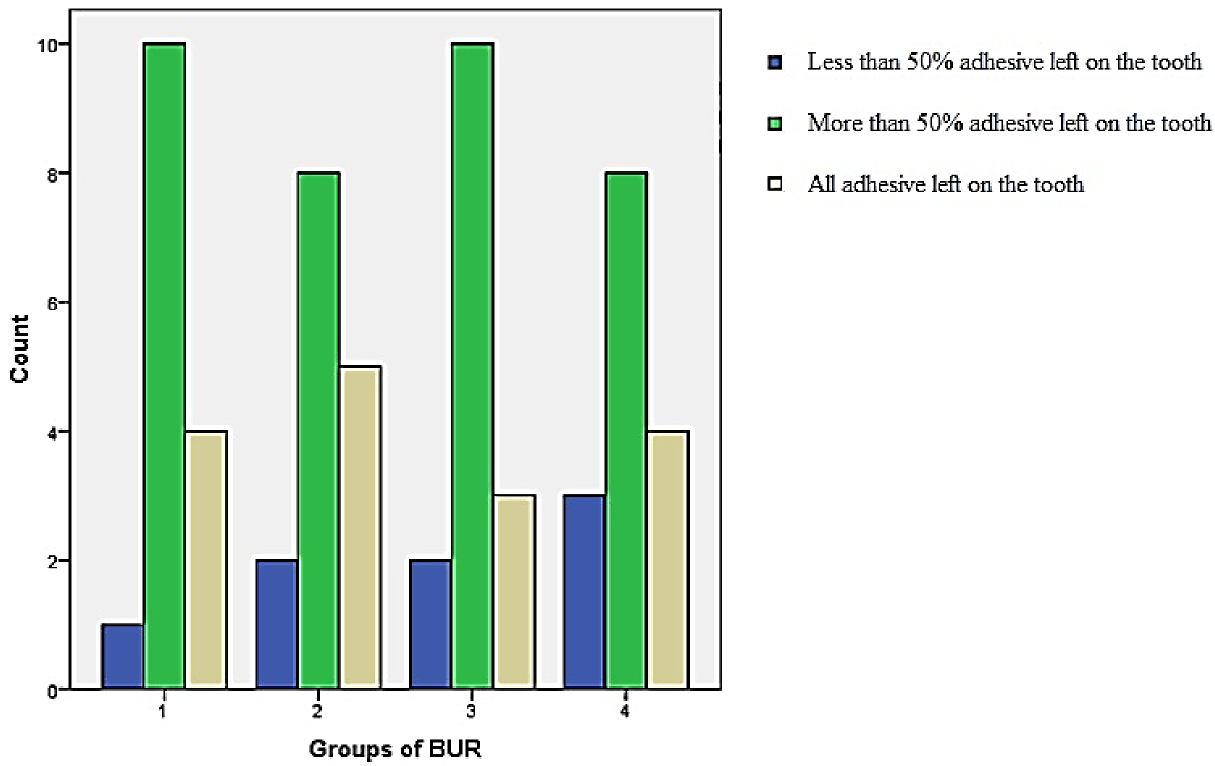

Figure 4. ARI value frequencies in each group

4.4 SEM Images

Figures 5 through 8 demonstrate the before and after SEM images for each bur used. The magnifications used in obtaining these images were 18x and 100x magnification. In each figure, the first row represents the original surface and the second row represents the surface after polishing. The SEM images show that no bur was able to restore the surface enamel to its original topography.

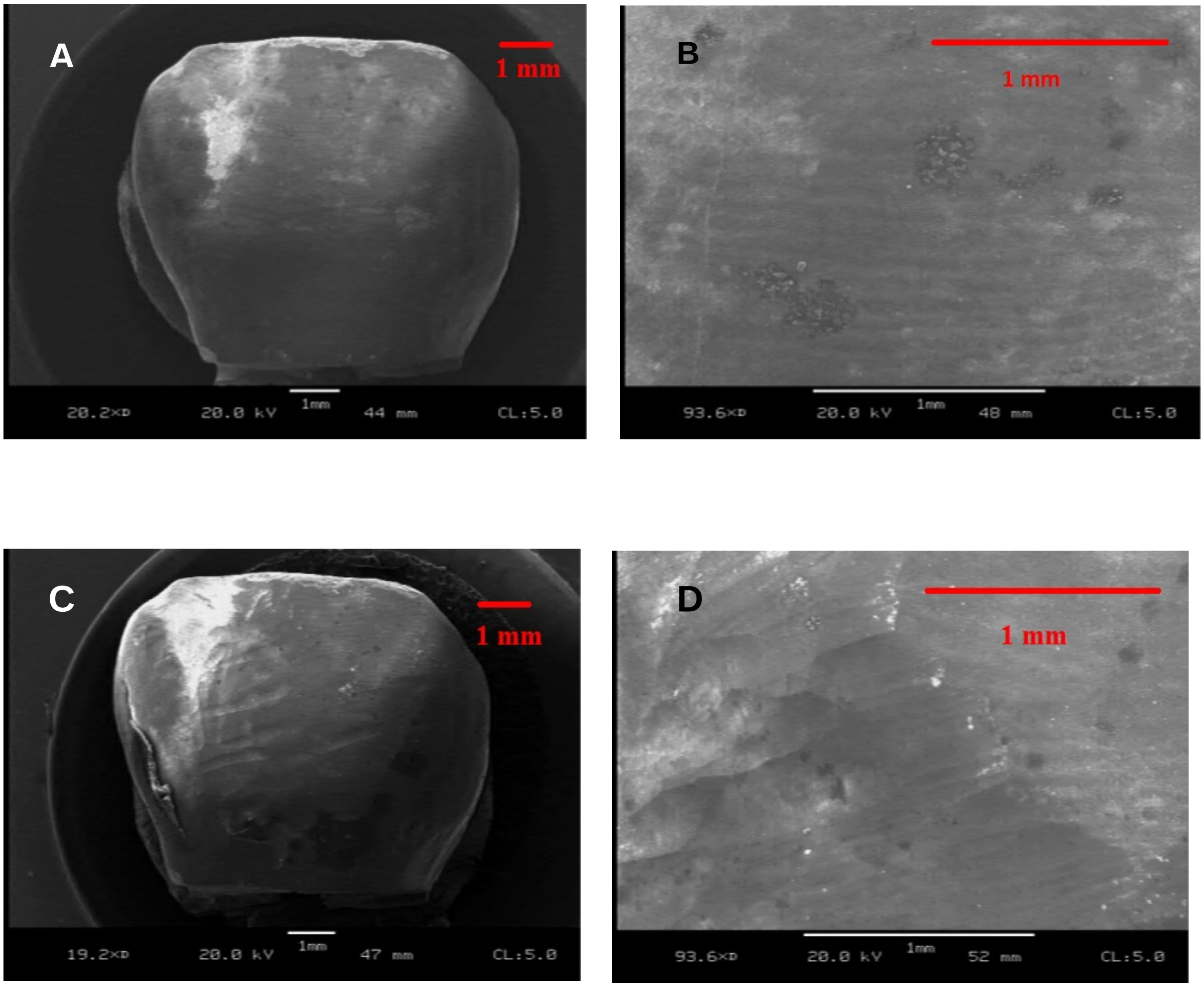

Figure 5. Group 1 representative SEM images of enamel surface: A) Original surface (18X); B) Original surface (100X); C) After using twelve fluted carbide finishing bur (18X); D) After using twelve fluted carbide finishing bur (100X). Note the presence of visible gouges.

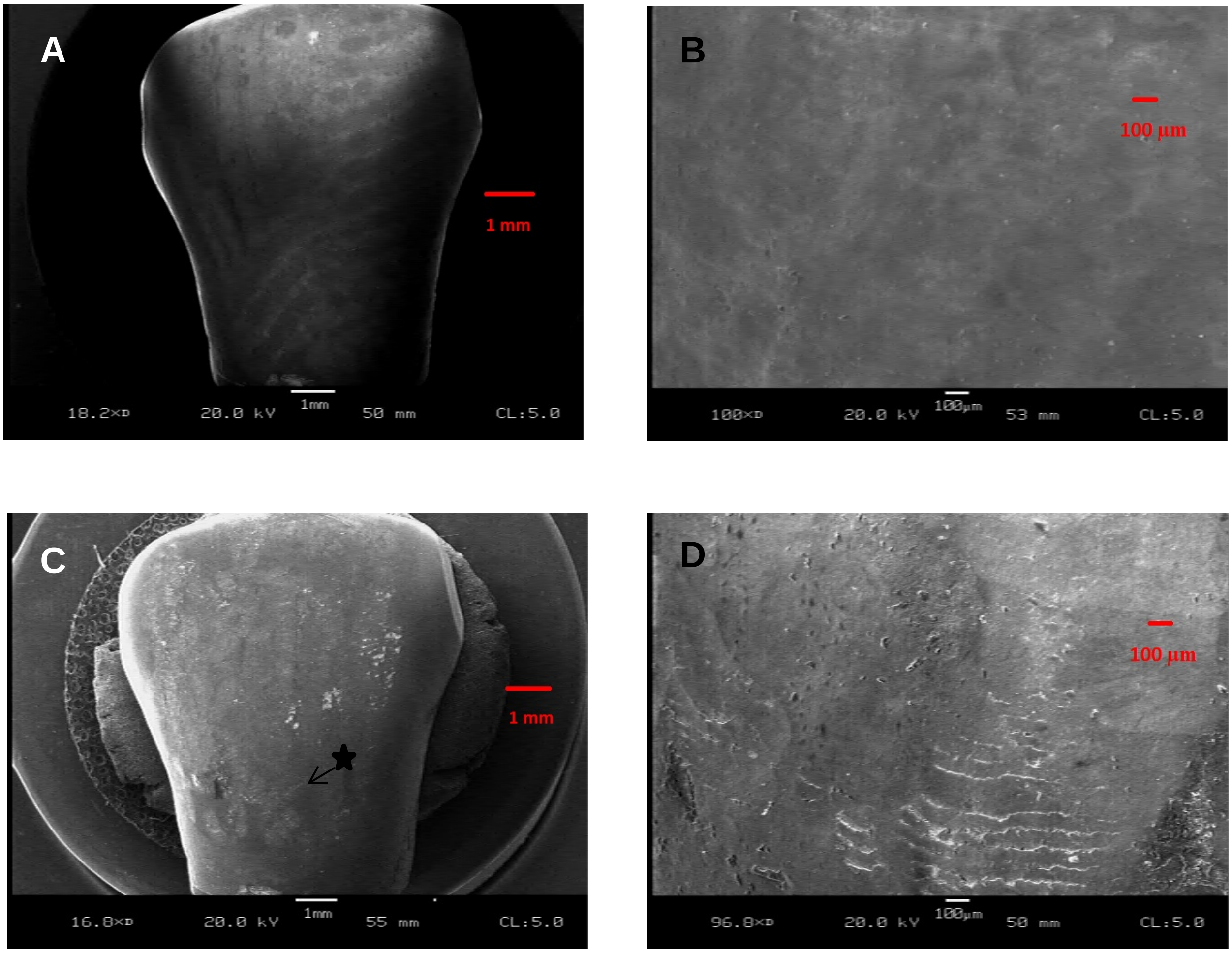

Figure 6. Group 2 representative SEM image of enamel surface: A) Original surface (18X); B) Original surface (100X); C) After using twenty fluted carbide finishing bur (18X); D) After using twenty fluted carbide finishing bur (100X).The surface shows loss of the prikymata pattern. Note the remaining islands of resin on the surface (asterisk).

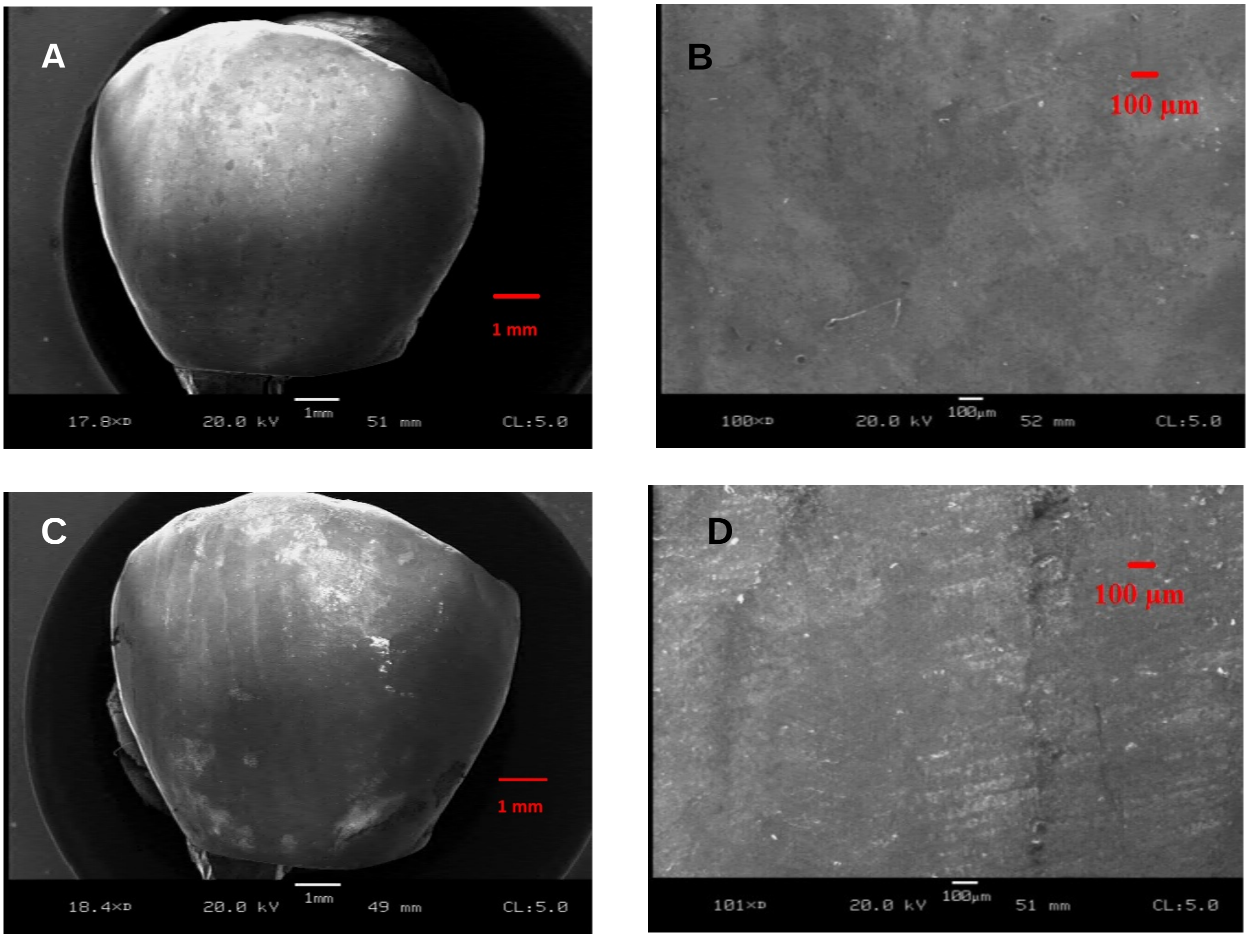

Figure 7. Group 3 representative SEM images of enamel surface: A) Original surface (18X);. B) Original surface (100X); C) After using thirty fluted carbide finishing bur (18X); D) After using thirty fluted carbide finishing bur (100X).The surface appears more irregular than the original enamel surface with scratches on the surface.

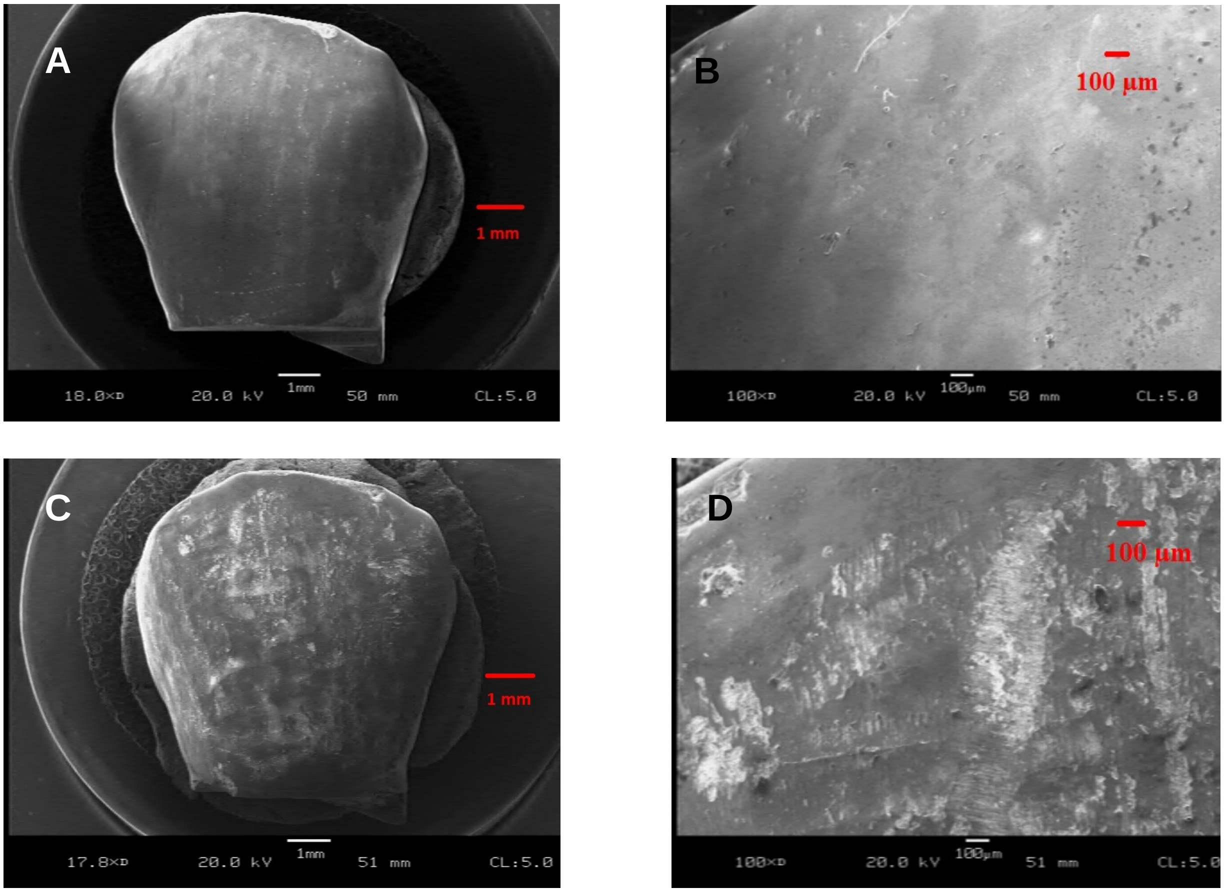

Figure 8. Group 4 representative SEM images of enamel surface: A) Original surface (18X); B) Original surface (100X); C) After using white stone finishing bur (18X); D) After using white stone finishing bur (100X). The surface appearance is completely different from the original surface with an extensive amount of grooves on the surface.

5. DISCUSSION

Clinical orthodontic treatment has been revolutionized during the past decades with the advent of direct bonding. Placement of orthodontic attachments on the surface of teeth can be accomplished by using bonding materials. These materials must be strong enough to withstand the daily forces exerted on these attachments throughout the duration of orthodontic treatment. However, unlike when used for restorative dentistry, these materials must be removable from the surface of enamel at the completion of orthodontic treatment. It has been shown in multiple studies that regardless of the method used to remove the excessive adhesive resin from the enamel surface, some scarring of enamel is inevitable (Campbell, 1995; Zachrisson and Årthun, 1979; Retief and Denys, 1979; Pont et al., 2010; Özer et al., 2010).

The search for an efficient and safe method to accomplish the debonding procedure has attracted the interest of many researchers. Most of the original studies have focused on SEM to compare the enamel surface before and after using different debonding burs (Gwinnett and Gorelick, 1977; Zachrisson and Årthun, 1979; Retief and Denys, 1979; Campbell, 1995; Zarrinnia et al., 1995; Ulusoy et al., 2009) with only a few studies incorporating other methods such as profilometry (Eliades et al., 2004; Özer et al., 2010), CLSM (Brauchli et al., 2011), and AFM (Karan et al., 2010).

The goal of this study was to compare the effects of four different debonding burs (12 fluted carbide, 20 fluted carbide, 30 fluted carbide, and white stone) on the enamel surface. To this date no study has compared the effects of these burs on the enamel surface in a controlled setting.

5.1 Analysis of Results

The surface roughness measurements showed that the initial mean roughness values of the enamel surface of teeth were very similar. The roughness value increased after polishing regardless of the bur used. This finding is in agreement with previous studies (Özer et al., 2010; Eliades et al., 2004; Karan et al., 2010). The SEM images also demonstrated that none of the final surfaces had the same appearance as the original surface of enamel. These findings support the Ra data that with current commercially available burs, some scarring of the enamel surface always occurs (Campbell, 1995).

The roughness value measurements showed that the white stone caused a significant increase in roughness (roughly double the original value) which is in agreement with what is seen on the SEM images in terms of presence of multiple scratches on the surface. The findings of this study show that the twenty fluted and thirty fluted burs are not significantly different from each other in terms of scarring of the enamel surface. These results verify the importance of using both qualitative (SEM) and quantitative (profilometry) data. None of the previous studies have compared the twenty fluted carbide with the thirty fluted carbide bur in terms of the resulting enamel roughness value.

The ARI values obtained at debonding showed that there was similar number of teeth in each group with similar amounts of adhesive resin left on their enamel surface. This was important to ensure an equal distribution of remaining resin in different groups for resin removal prior to using any burs. In this particular experiment, none of the brackets came off the enamel surface without leaving any trace of excess adhesive resin as demonstrated by none of the teeth exhibiting an ARI value of zero. This is possibly an intentional specification of the manufacturers to prevent damage to the enamel surface caused by the removal of the bracket and adhesive resin as one unit which would possibly damage the surface enamel.

In all groups, there were a larger number of teeth with ARI scores of 2 (more than half of the adhesive resin remaining on the tooth). This is similar to the findings of Özer et al. (2010). Pont et al. had slightly different results in 2010 with ARI score of 3 having the highest frequency. The differences in ARI values can be attributed to the debonding technique and the different mesh designs at the base of the brackets. The more retentive the mesh design of the bracket, the higher percentage of brackets that will be debonded without leaving any trace of adhesive resin on the enamel surface. Also, as it has been shown, different methods of debonding such as holding the pliers at the junction of the enamel-bracket interface or at the outer wings of the bracket can cause different modes of bond failure (Proffit, 2007a; Bennett et al., 1984). In this study, the debonding pliers were placed at the outer wings of the bracket which could have resulted in greater number of bond failures within the adhesive resin material.

5.2 **Strengths of Current Study**

Previous publications have focused on the effects of multiple different burs and debonding techniques on the enamel surface of teeth. Less attention has been given to the debonding procedure itself. In the current study, we focused on standardizing and controlling all variables, as much as possible, and only investigated four burs which were then used under the same conditions. Attention was given to the details of the set up to allow repeatable, reliable, and exact measurements. In none of the previous publications has the polishing apparatus been set up in such a way that human error is minimized.

Extracted human teeth are very difficult to collect, store, and standardize. The teeth used in this study were premolar teeth previously extracted for orthodontic purposes. Since the enamel surface was the focus of this experiment, great care needed to be taken to select the surfaces with the least amount of pre-existing damage and defect which was the basis for the exclusion criteria.

There are multiple challenges with using profilomtery on the enamel surface of teeth. Most profilometers are designed to work on flat surfaces. With human premolar teeth, the tooth surface is curved for the most part. Hence, it was very important to be able to mount the samples in such a way to have a relatively flat surface facing the profilometer tip. The set up designed by the ADA laboratories was specifically made for this purpose (Sarrett, 2010).

In order to maximize accuracy, during the mounting process, the exact placement of the teeth inside the mounting well was visualized with a camera projecting the image on a computer monitor. This method allowed the investigator to use the profilometer on the surface of natural teeth. If the sample is not set up in this manner, the roughness values recorded by the profilometer would not be accurate as the profilometer probe would “fall off” the sample as the surface curves during the scanning process. The profilometer used in this study (Surtronic, Taylor & Hobson, Leicester, United Kingdom) is the same instrument used by Özer et al. in their study published in 2010. However, it is not clear from their study how the curved enamel surfaces were measured using this profilometer and how they addressed this issue.

Since it was very important to have a large enough sample size, power analysis was performed based on a previously published article on enamel surface analysis (Mathias et al., 2009) and a sample size of 15 per group was found to be adequate to produce an 80% power. The sample size used in this study was larger than that in previously published studies. Five spots were utilized on the surface of each tooth which served two purposes: 1) it allowed returning to the same spot after polishing rather than returning to a broad area on the surface of the tooth which might be highly variable from one location to the next, 2) by averaging the 5 values, a more accurate representation of the roughness value for that tooth was obtained as compared to obtaining a single reading.

The removal of the excess adhesive resin on the tooth surface also needed to be very standardized and controlled to allow a relatively unbiased comparison of different burs. The only standardization performed in previous studies had been to use the same speed when using high speed or low speed handpieces. In the present study, the goal was to minimize the human error and keep the handpiece speed, pressure, and contact time constant.

The custom built polishing apparatus at the ADA laboratories was used for this purpose. The hand piece was held stable while the sample moved under the revolving bur at a constant speed using a motorized stage. By utilizing this set up, it was ensured that the removal of adhesive resin from the tooth surface was performed in a constant manner for all burs. This apparatus had previously been tested in a series of experiments comparing the available polishing systems for composite resins (Sarrett, 2010). A new bur was used for each tooth since a prior used bur could potentially cause more scarring than a new bur. Using a new bur for each tooth eliminated this potential source of error when comparing different teeth.

5.3 **Clinical Applicability**

Although there are no universally accepted standard protocols for debonding brackets (Eliades et al., 2004) the results of this study can make the clinicians more aware of what is actually happening iatrogenically to the enamel surface of teeth during this process. The use of a less expensive, more durable bur such as white stone might seem economically advantageous to the practicing orthodontist, but this might come at the price of inflicting more damage to the enamel. The fact that none of the original enamel surfaces were restored to their original surface after adhesive resin removal also calls for the need for safer debonding burs to be designed and manufactured by the industry.

5.4 **Limitations of Current Study**

We acknowledge several limitations in this study. The Ra value was used as the only parameter in comparing the profilometric analysis results. There are two fundamental deficiencies of Ra. It is unable to indicate the depth of the irregularity (differentiating between deep or shallow grooves) and also it lacks the information on the profile of the irregularity as peaks or valleys meaning the peaks and projections are registered in an identical manner (Eliades et al., 2004). However, additional parameters such as Rq and Rt can be used to overcome this problem. Rq is the root mean square roughness representing the height distribution relative to the mean line and Rt is the maximum roughness depth which registers isolated profile features on the surface. These parameters were not studied in this experiment due to the limitations of the profilometer set up. Accurate Rq and Rt values could not be obtained from the curved surfaces of teeth in a reproducible and accurate manner.

This study was an *in vitro* study which brings about all potential limitations of studying an *in vivo* phenomenon out of its natural setting. In all *in vitro* studies, data is obtained without considering intraoral factors such as saliva, masticatory forces, temperature, and pH changes (Pont et al., 2010). Saliva is not comparable to water in terms of storage of teeth. It has been suggested that increased enamel roughness following adhesive resin removal may be effectively diminished by masticatory loads (Eliades et al., 2004). Pumice was not used in this study to prevent any potential damage to the surface enamel which is contrary to what is generally done clinically.

The samples used for the roughness value measurements were not the same samples used in SEM imaging. This was due to the fact that the mounting methods required for each apparatus were different and once teeth were mounted for profilometry, they could not be removed and mounted for SEM analysis. Had this been done, it would have not been possible to return to the same five spots after the polishing was completed since the mounting would have been different. However, by keeping all procedures the same on all samples, the investigator tried to get as close of a representation of our samples as possible.

Another important factor that was not studied in this experiment is the time required to remove the excess adhesive resin from the surface of teeth. Time has been studied in a number of previous studies (Eliades et al., 2004; Özer et al., 2010; Ulusoy, 2009) and is a very important factor when making the clinical decision of which bur to use. In this study, after the sample went through a cycle of polishing, the operator had to re-initiate another cycle of polishing on the computer which would require extra time. Also, towards the end of the polishing stage, the operator needed to visually scan the surface to determine at what point the polishing was adequate which required another variable amount of time. These factors combined made it inaccurate to make any reliable, unbiased time measurements.

This study focused on a one-step polishing procedure using a single bur on the surface of each tooth. It is at the discretion of the clinician to use multi-step polishing methods to gain a smoother surface. Previous studies have shown that despite getting a smoother surface with the use of these multi-step polishers, to date no method has been able to restore the surface to its original roughness (Özer et al., 2010; Campbell, 1995; Retief and Denys, 1979). In addition, these multistep polishers are in general more time consuming which would make them undesirable for the clinician in a busy practice (Ulusoy, 2009; Zarrinnia et al., 1995). Nonetheless, this is another limitation of this study.

The amount of adhesive resin used in bonding the brackets to the surface of the teeth was not exactly the same for all teeth. This is similar to the clinical situation but can be a limitation to our experimental design. None of the previous studies have made any note of standardizing this step either. Utilizing the ARI value after debonding allowed the investigator to ensure similar frequency of teeth with similar amounts of remaining adhesive resin on their surface. Hence, the ARI value was used to rectify the problem of unequal initial amounts of adhesive resin to some extent.

The completion of the polishing stage was only determined with visual examination of the surface. Different clinicians can have different finishing goals for this stage. While some choose to leave some resin in order to prevent harm to the enamel surface, others choose to clean up any and all traces of it at the expense of more scarring of the enamel surface.

5.5 Future Studies

The design and manufacturing of the profilometer set up to examine the curved enamel surface as well as the polishing apparatus were the most important accomplishments of this investigation which makes it possible to conduct more studies of this nature under these standard conditions which did not exist previously. The most important indication for future studies is to use similar experimental designs to investigate the effects of other burs which are presently used and to evaluate the newly manufactured burs that are claimed to be superior to their predecessors.

As mentioned previously, other surface roughness parameters such as Rq and Rt can be incorporated in the analysis to provide a more comprehensive representation of the surface topography. This method has previously been attempted by Eliades et al. in 2004. Combining the standardized settings which were used in this study with the extra parameters can be helpful in future studies.

Long term follow up of orthodontically treated teeth which have been polished with these burs can be studied. Use of different fluoride pastes or other fluoridated products can affect the enamel surface and the effect of these products used after debonding can be investigated.

By programming the polishing apparatus to allow multiple cycles of polishing without the need to re-initiate each step manually and being able to stop the cycles when the investigator feels the polishing is complete, the time required to use each bur can also be investigated and compared to other burs. This would result in having additional information available in making any clinical decisions. Finally, since glass ionomer is also used to apply attachments to the enamel surface, the effect of different debonding burs on these materials needs to be investigated.

5.6 Conclusions

- The results of this study showed that the four burs used in polishing the remaining adhesive resin off of the enamel surface of teeth at debonding all caused some damage to the enamel surface. This was demonstrated by an increase in roughness values post polishing and also supported by the SEM images.
- The greatest amount of increase in roughness values was found with the use of a white stone and the least was found with the use of a thirty fluted carbide bur.
- There was no statistically significant difference between the roughness values obtained with the twenty fluted carbide and those of the thirty fluted carbide bur. Statistically significant differences in post polishing roughness values were found between all other burs.

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APPENDICES

APPENDIX A

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
1737 West Polk Street
Chicago, Illinois 60612-7227

Notice of Determination of Human Subject Research

January 19, 2010

*2010004-
51977-1*

20100054-51977-1

Niloufar Nouri Mahdavie, DDS
Orthodontics
1111 S. Wabash Ave Apt #2507
Chicago, IL 60605
Phone: (312) 996-7138

RE: **Protocol # 2010-0054**
The Effect of Various Debonding Burs on the Enamel Surfaces of Teeth After Debonding Metal Brackets

Dear Dr. Mahdavie:

☒The UIC Office for the Protection of Research Subjects received your "Determination of Whether an Activity Represents Human Subjects Research" application, and has determined that this activity **DOES NOT meet the definition of human subject research** as defined by 45 CFR 46.102(f). Specifically, extracted and deidentified teeth that previously have been gathered from oral surgery offices will be utilized to test the study hypothesis.

You may conduct your activity without further submission to the IRB.

If this activity is used in conjunction with any other research involving human subjects or if it is modified in any way, it must be re-reviewed by OPRS staff.

APPENDIX A (continued)

☐ The UIC Office for the Protection of Research Subjects received your "Determination of Whether an Activity Represents Human Subjects Research" application, and has determined that this activity **DOES meet the definition of human subject research** as defined by 45 CFR 46.102(f).

You must submit either a Claim of Exemption or an Initial Review Application for IRB review. Your research cannot be conducted until written notice of an exemption determination or IRB approval has been granted.

For guidance on submitting your application, please refer to the guidance at: http://tigger.uic.edu/depts/ovcr/research/protocolreview/irb/index.shtml

APPENDIX B

UNIVERSITY OF ILLINOIS
AT CHICAGO

Office for the Protection of Research Subjects (OPRS)
Office of the Vice Chancellor for Research (MC 672)
203 Administrative Office Building
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Notice of Determination of Human Subject Research

April 11, 2011

20110307-60152-1

20110307-60152-1

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RE: **Protocol # 2011-0307**
The Effect of Various Debonding Burs on the Enamel Surfaces of Teeth After Debonding Metal Brackets (previously UIC Research Protocol #2010-0054)

Dear Dr. Mahdavie:

☒The UIC Office for the Protection of Research Subjects received your "Determination of Whether an Activity Represents Human Subjects Research" application, and has determined that this activity **DOES NOT meet the definition of human subject research** as defined by 45 CFR 46.102(f).

You may conduct your activity without further submission to the IRB.

If this activity is used in conjunction with any other research involving human subjects or if it is modified in any way, it must be re-reviewed by OPRS staff.

APPENDIX B (continued)

☐ The UIC Office for the Protection of Research Subjects received your “Determination of Whether an Activity Represents Human Subjects Research” application, and has determined that this activity **DOES meet the definition of human subject research** as defined by 45 CFR 46.102(f).

You must submit either a Claim of Exemption or an Initial Review Application for IRB review. Your research cannot be conducted until written notice of an exemption determination or IRB approval has been granted.

For guidance on submitting your application, please refer to the guidance at: http://tigger.uic.edu/depts/ovcr/research/protocolreview/irb/index.shtml

APPENDIX C

TABLE V

RAW DATA – Ra VALUE AND ARI INDEX FOR GROUP 1

Bur Used	**Ra Value Before (µm)**	**Ra Value After (µm)**	**ARI Index**
Twelve Fluted	1.02	1.67	2
Twelve Fluted	1.19	1.83	3
Twelve Fluted	1.16	1.76	3
Twelve Fluted	1.11	1.78	2
Twelve Fluted	1.05	1.62	2
Twelve Fluted	1.06	1.7	2
Twelve Fluted	1.12	1.69	1
Twelve Fluted	1.11	1.71	2
Twelve Fluted	1.18	1.73	3
Twelve Fluted	1.11	1.68	2
Twelve Fluted	1.05	1.67	2
Twelve Fluted	1.15	1.77	2
Twelve Fluted	1.09	1.66	3
Twelve Fluted	1.05	1.67	2
Twelve Fluted	1.03	1.67	2

APPENDIX C (continued)

TABLE VI

RAW DATA – Ra VALUE AND ARI INDEX FOR GROUP 2

Bur Used	Ra Value Before (µm)	Ra Value After (µm)	ARI Index
Twenty Fluted	1.16	1.35	2
Twenty Fluted	1.02	1.22	3
Twenty Fluted	1.05	1.23	3
Twenty Fluted	1.05	1.22	2
Twenty Fluted	1.19	1.41	1
Twenty Fluted	1.11	1.35	1
Twenty Fluted	1.15	1.37	3
Twenty Fluted	1.04	1.26	2
Twenty Fluted	1.12	1.31	2
Twenty Fluted	1.08	1.26	2
Twenty Fluted	1.17	1.30	3
Twenty Fluted	1.11	1.28	2
Twenty Fluted	1.10	1.25	2
Twenty Fluted	1.01	1.19	3
Twenty Fluted	1.14	1.35	2

APPENDIX C (continued)

TABLE VII

RAW DATA – Ra VALUE AND ARI INDEX FOR GROUP 3

Bur Used	**Ra Value Before (μm)**	**Ra Value After (μm)**	**ARI Index**
Thirty Fluted	1.10	1.24	2
Thirty Fluted	1.18	1.31	2
Thirty Fluted	1.03	1.19	2
Thirty Fluted	1.08	1.24	2
Thirty Fluted	1.06	1.24	3
Thirty Fluted	1.09	1.25	1
Thirty Fluted	1.07	1.19	2
Thirty Fluted	1.07	1.22	2
Thirty Fluted	1.05	1.17	3
Thirty Fluted	1.16	1.30	2
Thirty Fluted	1.15	1.26	2
Thirty Fluted	1.10	1.23	2
Thirty Fluted	1.10	1.20	1
Thirty Fluted	1.09	1.22	2
Thirty Fluted	1.14	1.24	3

APPENDIX C (continued)

TABLE VIII

RAW DATA – Ra VALUE AND ARI INDEX FOR GROUP 4

Bur Used	**Ra Value Before (µm)**	**Ra Value After (µm)**	**ARI Index**
White Stone	1.12	2.12	2
White Stone	1.15	2.10	2
White Stone	1.05	2.03	1
White Stone	1.05	2.05	2
White Stone	1.09	2.22	2
White Stone	1.06	2.20	1
White Stone	1.09	2.10	3
White Stone	1.12	2.22	2
White Stone	1.08	2.11	2
White Stone	1.12	2.12	3
White Stone	1.09	2.20	2
White Stone	1.16	2.15	1
White Stone	1.10	2.14	3
White Stone	1.05	2.09	2
White Stone	1.11	2.07	3

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