RESEARCH ARTICLE

The Effect of Ultrasonic Instruments on the Quality of Preparation Margins and Bonding to Dentin

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ABSTRACT

Statement of the Problem: Ultrasonic instruments have recently been developed for finishing crown preparations. They are successful in accessing difficult areas on the preparation margin, but their effects on the dentin surface and on bond strength are contradictory.

Purpose: The aim was to evaluate the condition of crown preparation margins finished using new ultrasonic instruments and to assess their effects on dentin bond strength.

Methods: Characteristics of tooth surfaces prepared using two different ultrasonic protocols were compared; Perfect Margin Shoulder (PMS®) (PMS 3, Satelec, Merignac, France) 1, 2, and 3 (complete finishing) versus PMS 1 and 2 (partial finishing). They were assessed using scanning electron microscopy (SEM) and surface roughness analysis. Bonding of composite resin to dentin surfaces prepared with the complete PMS kit was compared with dentin surfaces prepared with finishing diamond burs, using micro-tensile testing.

Results: SEM images revealed a clear difference between the two preparation sequences (PMS 1, 2 versus PMS 1, 2, and 3). Surfaces finished using the PMS tips 1, 2, and 3 appeared continuous, even, and smooth compared with PMS tips 1 and 2 only. The additional use of the PMS 3 uncoated tip enhanced smear layer removal. There was no significant difference when comparing the surface roughness obtained with the PMS 1, 2, and 3 protocol with the PMS 1 and 2 only ($p > 0.05$). Micro-tensile bond strength was not significantly different between the surfaces prepared with the ultrasonic instruments and the surfaces prepared with the diamond burs ($p > 0.05$).

Conclusion: The use of the complete PMS finishing kit (PMS 1, 2, and 3) produced better quality finishing lines than PMS 1 and 2. The use of ultrasonic instruments to prepare dentin resulted in comparable bond strengths to the use of diamond burs.

CLINICAL SIGNIFICANCE

The extremely precise preparation margin possible with ultrasonic instruments improves the quality and accuracy of crown preparations, which may lead to better impressions and closer adaptation of restorations. The complete set of three Perfect Margin Shoulder instruments is recommended, which can produce comparable bond strengths to preparations with rotary instruments.

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INTRODUCTION

Ultrasonic instruments have an oscillating motion compared with the rotation of conventional dental cutting instruments. Advantages have led to their recent adaptation for finishing line preparation in fixed prosthodontics.[1] Ultrasonic devices for this aspect of dentistry have not been previously well researched but

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appear to have considerable potential. Ultrasonic instruments are "handy to bevel enamel and dentin margins at difficult [to access] areas."[2] Ultrasonic instruments allow the production of extremely precise finishing lines.[3] Restorations can therefore be closely adapted to preparations, resulting in less marginal micro-leakage and secondary caries while still preserving the enamel.[4,5] Additionally, smooth, precise preparation margins can improve the quality and accuracy of impressions. Ultimately, these characteristics all contribute to the provision of a long-term successful prosthesis. Additionally, ultrasonic instruments are largely atraumatic to the gingival attachment, pulp, and adjacent teeth.[4] However, contradictory evidence exists concerning the effect of sono-abraded enamel/dentin surfaces on bond strength.[2]

The current study had two aims. The first aim was to identify the effect of a smooth, uncoated ultrasonic tip, Perfect Margin Shoulder (PMS®) (PMS 3, Satelec, Merignac, France), for the production of smooth finishing lines. The null hypothesis was that there would be no difference in surface characteristics of finishing lines prepared using the PMS 1 and 2 tips compared with PMS 1, 2, and 3.

The second aim was to compare the micro-tensile bond strength (μTBS) of composite resin bonded to dentin surfaces prepared with ultrasonic instruments and those prepared with diamond burs. The null hypothesis was that there would be no difference in bond strengths.

METHODS AND MATERIALS

Analysis of Surface Characteristics

Specimen Preparation

Ethical approval was obtained for the use of extracted human teeth. Four permanent canine teeth that had been stored in phosphate buffered saline solution (PBS) since extraction were selected using inclusion criteria that rejected those with caries, cracks, or other defects. The teeth were cleaned, and their root surfaces were coated with a thin layer of light-bodied addition silicone impression material (Exahilflex, GC Corp., Tokyo, Japan) to simulate a periodontal ligament. This allowed the tooth to absorb some of the ultrasonic energy produced by the instruments, mimicking the clinical situation. The roots were embedded in acrylic resin (Castapress, Vertex-Dental B.V., Zeist, The Netherlands).

Each tooth was prepared to receive a porcelain fused to a metal crown using a newly serviced high-speed handpiece (646c Powertorque, Kavo, Biberach, Germany) and diamond crown preparation burs (Hager & Meisinger, Neuss, Germany). A cylindrical bur was used to place depth grooves in the labial and palatal surfaces, the proximal surfaces were reduced with a tapered diamond bur, and the palatal surface was reduced with a football-shaped bur. A single operator carried out the tooth preparations.

A split tooth model was employed. The midlines of the buccal and palatal aspects were indicated by scribing the adjacent acrylic. The crown margin on one-half of each tooth was finished using PMS tips 1 and 2 in the ultrasonic instrument (P5XS Newtron, Satelec). The other half was finished using PMS tips 1, 2, and 3 to identify the specific role played by the smooth, uncoated ultrasonic instrument, PMS 3. The prepared specimens were stored in PBS for at least 24 hours before scanning electron microscopy (SEM) analysis.

SEM

Samples were mounted on 25-mm aluminum stubs using double-sided carbon tape and coated with 25 nm of gold palladium using a high-resolution sputter coater (Emitech K575X Peltier-cooled, EM Technologies Ltd, Kent, England).

Samples were examined using both an SEM (S360 Cambridge Instruments, Cambridge, UK) and a field emission SEM (JSM-6700F, JEOL Ltd, Tokyo, Japan). All images were captured with a frame grabber (Image Slave, Dindima Group Pty Ltd, Ringwood, VIC, Australia).

The Cambridge microscope obtained images at a variety of magnifications and locations on the teeth. The series included both sides of the split tooth model

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and the junction of the two different preparations. Three separate areas were observed on each side of the model: area 1: axial wall/margin angle, area 2: margin surface, area 3: external line angle. All regions were observed at ×100 magnification. Area 2 was also observed at ×1,000, ×3,000, and ×5,000 using the JEOL microscope.

Surface Roughness Analysis

The aim was to analyze the surface roughness of the finishing lines of each side of each sample to obtain a quantitative comparison of the two finishing protocols. Four samples were analyzed.

A diamond Berkovich tip was used as a scanning probe on a Triboindenter (Ti-950, Hysitron, Eden Prairie, MN, USA) to raster scan a 10 × 10 micron area with a contact force maintained at 1 μN.

Image analysis from the topography scan was used to calculate surface roughness. All the measurements were done by the same operator at the Nanomechanical Research Laboratory, University of Auckland. For each side of each sample, 10 identical surfaces were randomly selected by a third party.

Two roughness parameters were selected: the mean roughness (R_a) and the maximum roughness (R_{max}).

Care was taken to ensure that the scanning probe remained in contact with the complete area with the finishing lines to be analyzed. For this purpose, the coronal portion of each abutment was cut off. Because this part of the study was destructive, it was carried out at the end of the investigation with the samples still coated for SEM. As the coating thickness was minimal (25 nm), this was not considered in the final data.

Statistical Analysis

R_a and the R_{max} values were obtained using image topography analysis software (TriboView, Hysitron). Data were analyzed using Stata Intercoded 10–1 for Windows (Stata Corp., College Station, TX, USA). For each comparison, the mean was modeled using linear regression and robust standard errors to account for the clustering by sample.

μTBS Testing

Specimen Preparation

Twenty permanent third molar teeth, stored in phosphate buffered formalin since extraction, were selected using the inclusion criteria described earlier. Teeth were cleaned with pumice to remove soft tissue and were stored in PBS. Teeth were then embedded in acrylic resin. Consistent flat dentin surfaces were produced on the buccal aspects by wet grinding at 300 rpm with 120-μm grit SiC paper (Grinding/Polishing machine, Struers TegraPol-21 & TegraForce5, Struers, QLD, Australia).

Specimens were randomly allocated into two groups of 10. Dentin surfaces of one group were finished using ultrasonic instruments with a factory-calibrated ultrasonic generator (P5XS Newtron) with water spray.

1 PMS 1 (76-μm grit): power setting 15 for 30 seconds
2 PMS 2 (46-μm grit): power setting 15 for 60 seconds;
  power setting 6 for 60 seconds
3 PMS 3 (no grit): power setting 10 for 120 seconds

The other group was finished using end-cutting burs (Tissue Guard End-Cutting, TGE, Premier Two Striper®, Plymouth, PA, USA).

1 Red (60 μm) for 30 seconds
2 Yellow (45 μm) for 60 seconds

Two 2.0-mm diameter conical glass fiber root canal posts (Rebilda Post 20, Voco, Cuxhaven, Germany) were bonded on the dentin of each tooth as follows.

The bonding surfaces were cleaned with water spray and dried with a gentle airstream. A silane coupling agent (3M ESPE, St. Paul, MN, USA) was applied to the coronal ends of the posts, a gentle stream of air was applied to disperse the silane, and the material was left for 60 seconds. Adhesive (RelyX™ ARC Adhesive Resin

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Cement, 3M ESPE) was mixed and applied to the posts, which were placed perpendicular to the tooth surfaces, and light-cured from three different angles in 20-second intervals.

Specimens were then stored in PBS for at least 24 hours before testing. All preparations were carried out by the same investigator.

μTBS Evaluation

Tensile testing was carried out using a tensile tester (Model T5002, J. J. Lloyd Instruments Ltd, Southampton, UK) fitted with a 50-N load cell. Specimens were prepared for testing by attaching lengths of brass tubing (internal diameter of 2.0 mm) to the posts bonded to the tooth samples. One end of the tubing was compressed flat and perforated with a bur. The tubing was attached to the post with cyanoacylate adhesive (Permabond, Permabond Engineering Adhesives Ltd, Winchester, UK). The flattened end was connected to the crosshead of the testing machine using a custom-made jig. The acrylic block holding the tooth was secured in the lower clamp of the testing machine.

Specimens were tested to failure at an extension rate of 0.5 mm/second. Force-extension data for each specimen were recorded using a plotter (JJ "X Y" Plotter, type PL100, J. J. Lloyd Instruments Ltd). The sensitivity scale of the tensile tester was calibrated at $x = 1$ giving a deflection of 1 mm on the plotter per 0.2 N of force. Force at failure was measured manually from the plotted data and converted to MPa using the surface area of the bond.

Statistical Analysis

The tensile strength results were analyzed by calculating the means of the two groups. Data were not normally distributed, and variances were inhomogeneous, therefore, differences among means were tested for statistical significance ($p < 0.05$) using the Mann–Whitney *U*-test using SPSS for Windows 2007 (IBM, Armonk, NY, USA).

RESULTS

Surface Characteristics

Effects on Surface Characteristics of Tooth Preparation

SEM images revealed clear differences between the two preparation sequences (PMS 1, 2 versus PMS 1, 2, and 3). At the junction of the two preparation protocols, this difference was most clearly seen (Figure 1). The surface prepared with PMS 1 and 2 appeared discontinuous and uneven compared with the continuous and even surface of the area finished with tips 1, 2, and 3.

Area 1 had a more definite angle between the axial wall and the margin surface where the PMS tip 3 was used (Figure 2).

Area 2 was the region with the clearest distinction between the two preparations. The margin surface had clear peaks and valleys where tips 1 and 2 were used. However, where tip 3 was applied, the surface was noticeably flattened and continuous (Figure 3).

FIGURE 1. Split tooth model demonstrating the junction between the two types of finishing preparations (magnification ×25).

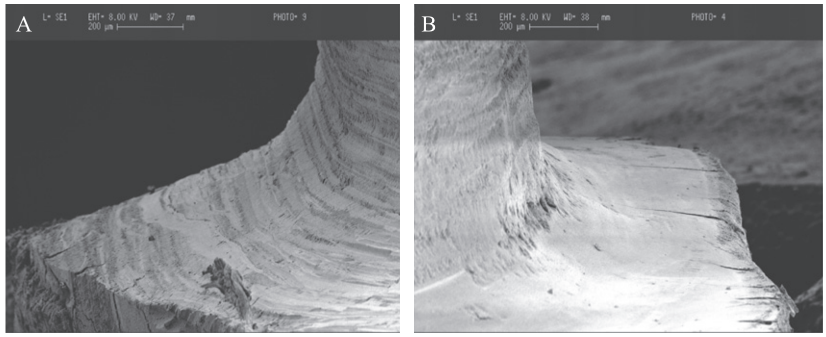

FIGURE 2. Area 1 at magnification ×100. A, Surface finished with Perfect Margin Shoulder (PMS) tips 1 and 2 only. B, Surface finished with PMS tips 1, 2, and 3.

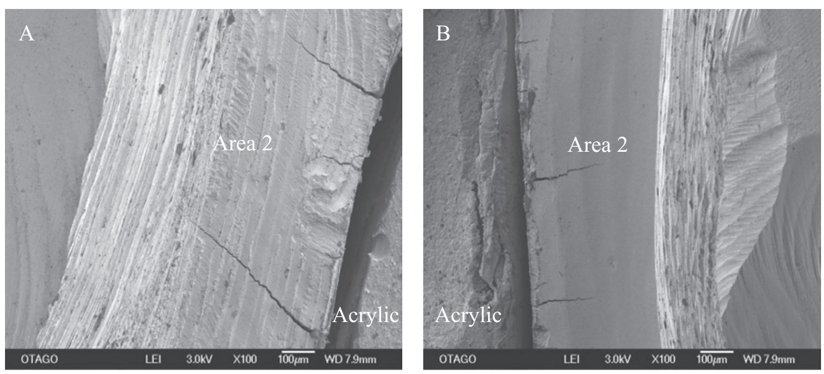

FIGURE 3. Area 2 at magnification ×100. A, Surface finished with Perfect Margin Shoulder (PMS) tips 1 and 2 only. B, Surface finished with PMS tips 1, 2, and 3.

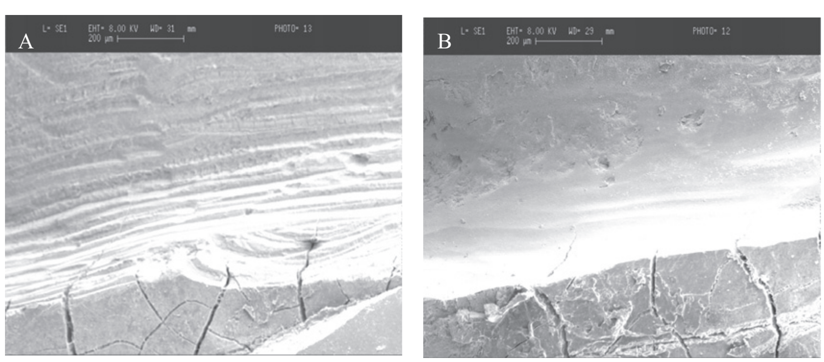

FIGURE 4. Area 3 at magnification ×100. Note artifactual cracks on root surface. A, Surface finished with Perfect Margin Shoulder (PMS) tips 1 and 2 only. B, Surface finished with PMS tips 1, 2, and 3.

In area 3 (the external line angle), where the PMS tip 3 was used, the angle was clearer and sharper (Figure 4). There was some cracking visible on the root surfaces of the samples, which may be an artifact from the SEM processing.

The dentinal walls of the preparations made by the PMS 1 and PMS 2 tip combination were smeared with a layer of debris (Figure 5); the additional use of the PMS 3 uncoated tip enhanced smear layer removal, revealing the dentinal tubules (Figure 6).

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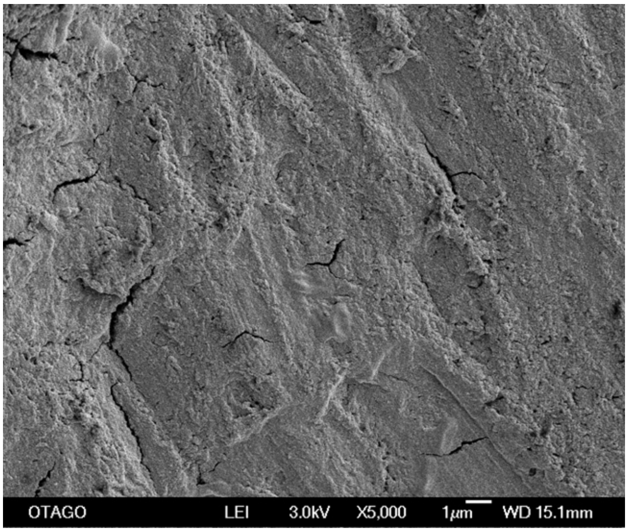

FIGURE 5. Example of dentin surface prepared with the Perfect Margin Shoulder 1 and 2 combination. Area 2 at magnification ×5,000.

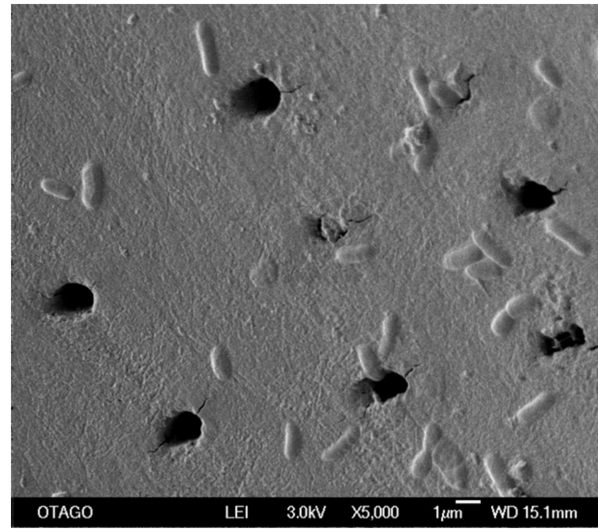

FIGURE 6. Example of dentin surface prepared with the Perfect Margin Shoulder 1, 2, and 3 showing open dentinal tubules. Area 2 at magnification ×5,000.

Surface Roughness Analysis

The unadjusted means for group 1 (PMS 1, 2, 3) and group 2 (PMS 1, 2) are presented in Table 1. There was no significant difference when comparing the surface roughness obtained with the PMS 1, 2, and 3 and with the PMS 1 and 2 ($p > 0.05$).

TABLE 1. Mean surface roughness for each finishing protocol (nm)

Protocol	R_a (SD)	R_{max} (SD)
PMS 1, 2	103.3 (98.3)*	868.5 (632.9)†
PMS 1, 2, 3	96.6 (43.6)*	797.9 (254.4)†

PMS = Perfect Margin Shoulder; R_a = arithmetic mean of the absolute departure of the roughness profile from the mean line; R_{max} = maximum peak-to-valley height in one sampling length; SD = standard deviation.

*The mean was modeled using linear regression and robust standard errors to account for the clustering by sample, and the *p*-value was 0.657.

†The mean was modeled using linear regression and robust standard errors to account for the clustering by sample, and the *p*-value was 0.460.

μTBS

The mean μTBS values for the two finishing protocols are shown in Table 2. There was no statistical difference between the two preparation methods ($p > 0.05$).

DISCUSSION

The finishing lines produced with the PMS 1, 2, and 3 tips were in a better condition than those produced with PMS 1 and 2. Thus, the first null hypothesis was rejected.

Bond strengths to composite resins achieved with the use of the PMS ultrasonic tips were similar to those with traditional diamond burs. Thus, the second null hypothesis was approved.

Observations of surface characteristics confirmed that the ultrasonic instrument produces an extremely precise finish and illustrate the role played by the uncoated ultrasonic tip (PMS 3). This tip removes shards of unsupported enamel and produces an external line angle which is sharp and well defined.

A split tooth model was employed, with the same tooth for the two finishing protocols. This model eliminated the variability that may be encountered by using different teeth.

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TABLE 2. Mean micro-tensile bond strengths for each finishing protocol (MPa)

Method	*N*	Mean bond strength (SD)
Two Striper	18	4.6 (2.1)*
PMS	22	4.4 (3.2)*

SD = standard deviation.
*$p = 0.334$.

The same investigator carried out tooth preparation and SEM analysis.

It is unclear if the cracking in the samples is artifactual and resulted from specimen preparation for SEM[6] or if the ultrasonic instruments caused the subsurface damage. Future studies might consider using epoxy replicas made from silicone impressions to eliminate artifactual cracks.[7]

Roughness data didn't reveal a distinct difference between the two finishing protocols; the preparation involving the use of the additional PMS tip 3 did not result in a statistically significantly smoother surface ($p = 0.460$).

The additional tip produces a very precise and distinct finishing line, which could improve the quality and accuracy of impressions, ultimately resulting in restorations that are more closely adapted to teeth. This could improve the long-term prognosis by reducing the risks of secondary caries, which is responsible for most failures in fixed prosthodontics.[8] In addition, the uncoated PMS tip 3 enhanced smear layer removal.

The second part of the study focused on the bond strength to dentin. The surface was prepared with two finishing protocols. To better identify the role played by the finishing protocol (ultrasonic tips versus burs) on bonding strength, no etching was performed after preparation. Surfaces were only cleaned with water spray and dried with a soft stream of air, avoiding desiccation. This may explain the relatively low μTBS values registered.

To increase the sample size, two glass fiber root canal posts were bonded per tooth (40 in total). This prevented both posts from being directly aligned with the tensile tester. Although a purpose-built anchoring device was used to minimize lateral forces on the bond surface during testing, it is possible that testing was not purely tensile. This may account for the variability observed in the data.

The smear layer is an unstable substrate for bonding.[9] Current concepts of dentin adhesion involve removal of the smear layer to allow exposure of the dentinal tubules. According to Van Meerbeek and colleagues (2006), sono-abrasion produces thinner smear layers than conventional techniques.[10] This may suggest that more tubules are exposed, leading to an enhanced mechanical bond. A thicker layer (conventional techniques using diamond abrasion) could plug the dentinal tubules, preventing the formation of resin tags. However, there was no statistical difference in bonding strengths in the present study.

CONCLUSION

The use of the complete finishing PMS kit (PMS 1, 2, and 3) produced a more precise and distinct finishing line and enhanced smear layer removal compared with the use of only PMS 1 and 2 tips.

The use of ultrasonic instruments to prepare dentin surfaces led to comparable bond strengths to those prepared with diamond burs.

CLINICAL IMPLICATIONS

The production of extremely precise crown preparation margins can improve the quality and accuracy of impressions and allows for close adaptation of restorations. This approach results in less marginal micro-leakage and secondary caries while still preserving enamel.[3,4]

Additionally, PMS instruments and rotary diamond burs produce dentine surfaces with equal capacities to bond to adhesive resins.

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These characteristics all contribute to the production of long-term esthetic and functional prostheses.

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