Ultrasonic Margin Preparation for Fixed Prosthodontics: A Pilot Study

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ABSTRACT

Purpose: Atraumatic, oscillating ultrasonic instruments have recently been developed for prosthodontic margin finishing. This in vitro observational pilot study aimed to compare the condition of crown preparation margins finished using new ultrasonic instruments with margins finished with conventional rotary instruments.

Methods: Two extracted human canine teeth were prepared for crowns. A split-tooth model was used to refine the margins: half of the margin was finished with conventional rotary instruments, the other with ultrasonic instruments. The profiles of the margins were observed using scanning electron microscopy, and a quantitative comparison of surface roughness was obtained using surface roughness analysis software.

Results: The margins finished with the ultrasonic instruments exhibited a better-defined axial wall/margin angle and a smoother marginal surface. Rotary instruments produced a sharper and more continuous external line angle. Two-dimensional surface roughness analysis showed that the margins produced with the ultrasonic instruments were approximately half as rough as the margins prepared with the conventional rotary instruments.

Conclusion: The ultrasonic instruments produce margins in better condition than the current standard and appear to have some practical advantages.

CLINICAL SIGNIFICANCE

Preparations for fixed prosthodontics finished with these ultrasonic instruments created better-defined margins, which could result in more successful prostheses.

(J Esthet Restor Dent 24:201–210, 2012)

Caries has been identified as one of the most common complications of fixed partial dentures.[1] Marginal discrepancies can result in leakage. This leads to secondary caries and esthetic problems, ultimately resulting in failure of the prosthesis.[2] Smooth and precise preparation margins facilitate impression taking and fabrication of a precisely fitting restoration, which contribute to a durable, esthetic, and functional result.

Ultrasonic instruments have an oscillating action, compared with the rotation of conventional instruments, which has led to their recent adaptation for finish line preparation in fixed prosthodontics by Sous and colleagues.[3]

Ultrasonic instruments are largely atraumatic to the gingival attachment, pulp, and adjacent teeth.[4,5] Esthetic restorations in the anterior dentition often demand a preparation with a subgingival finish line.[4] The oscillating action of ultrasonic instruments reduces trauma to the soft tissues during subgingival margin preparation, facilitating accurate impression taking.[6]

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 DOI 10.1111/j.1708-8240.2011.00477.x

The action also allows for a greater degree of control when preparing areas with difficult access.[6] This limits dentin exposure during minimally invasive procedures, which is preferred for bonded restorations.[4] Furthermore, damage to the adjacent teeth can be avoided.[4,7] Vanderlei and colleagues[5] reported that temperature increases during cutting with an ultrasonic instrument are not sufficient to cause pulpal damage.

This in vitro observational pilot study aimed to compare the condition of crown preparation margins finished using new ultrasonic instruments with margins finished with conventional rotary instruments. The null hypothesis was that there would be no difference in the condition of the margins prepared with the two types of instrument.

METHODS AND MATERIALS

Ethical approval was obtained for the use of extracted human teeth. Two canine teeth were selected for this observational pilot study. Examination under a light microscope (×10) revealed no cracks, caries, or discoloration. The teeth were cleaned with pumice and stored in distilled water. Light-body addition silicone impression material (Exahiflex, GC Corp., Tokyo, Japan) was used to create a simulated periodontal ligament on the root surfaces. This provided tooth mobility to absorb some of the ultrasonic energy and mimic the clinical use of ultrasonic instruments. The canines were mounted in acrylic (Orthocryl, Dentaurum, Ispringen, Germany) with adjacent natural teeth forming proximal contacts. The canines were then prepared for all-ceramic crowns using conventional diamond crown preparation burs in a new high-speed handpiece (646c Powertorque, Kavo, Biberach, Germany). All tooth preparation was completed by a single operator, aiming for a six-degree taper, and the margins were prepared to a rounded shoulder configuration above the cemento-enamel junction, as described by Shillingburg.[8]

The margins were finished using the split-tooth technique. One-half of the margin on each preparation was finished using an end-cutting bur (Tissue Guard End-Cutting [TGE] bur, fine grit [60 μm], Premier Two Striper, PA, USA) in the handpiece with water spray for 30 seconds, followed by a TGE very fine grit (45 μm) bur for 60 seconds. The other half of the margin on each tooth was finished using a Satelec Perfect Margin Shoulder (PMS) Kit in a factory calibrated ultrasonic generator (P5XS Newtron, Satelec, Merignac, France) with water spray. The PMS1 tip (76-μm grit) was used for 30 seconds, followed by the PMS2 tip (46-μm grit) for 60 seconds, and the PMS3 tip (no grit) for 120 seconds, each at the power settings recommended by the manufacturer. The sequence of tooth preparation is depicted in **Figure 1**, and the preparations were observed under the light microscope (×10).

The samples were rinsed with distilled water, dried, and sputter coated with gold. The margins were then viewed using a scanning electron microscope (SEM) (Cambridge Instruments S360, Cambridge, UK) at an accelerating voltage of 10 kV. Images were captured with a frame grabber (Dindima Image Slave, Dindima Group Pty Ltd., Ringwood, Victoria, Australia). The profiles of the margins were qualitatively compared at different magnifications. Three regions were viewed: area 1: the axial wall/margin angle, area 2: the surface of the margin, area 3: the external line angle (**Figure 2**). Images were also taken of the profiles of each of the instruments before use. The tooth preparation and the analysis of the SEM images were carried out by the same investigator.

Surface roughness analysis software (Scandium, Olympus, Adelaide, Australia) was used to obtain a quantitative comparison of the margins finished with each instrument, from SEM images, using stereo pairs. The areas of the margins where the surface roughness was calculated were randomly selected by a third party. The term roughness refers to a variety of measured parameters, and two were selected: R_a, the roughness mean parameter and R_{max}, the maximum roughness. The roughness of each sample was measured both in one dimension (along a line parallel to the margin, and a line perpendicular to the margin) and in two dimensions (along a surface).

 DOI 10.1111/j.1708-8240.2011.00477.x

1. Bulk tooth preparation

Burs	*Function*	*Diamond grit size*
Hager Meisinger burs  847 833 842	847: Depth cuts 833: Palatal reduction 842: Interproximal and facial reduction	64-126 µm

2. Rotary Finishing

Bur	*Duration of use*	*Function*	*Diamond grit size*
Tissue Guard End-cutting 1.4mm diameter Fine grit	30s	Finish line preparation	60µm
Tissue Guard End-cutting 1.4mm diameter Very fine grit	60s	Finish line refinement	45µm

3. Ultrasonic Finishing

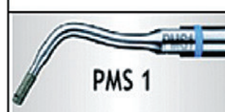
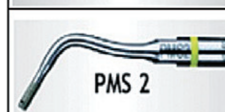
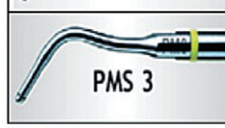
Insert	*Duration of use*	*Power Setting*	*Function*	*Diamond grit size*
 PMS 1	30s	15	Finish line preparation	76µm
 PMS 2	60s	15	Finishing	46µm
		6	Polishing	
 PMS 3	120s	10	Polishing	Smooth

FIGURE 1. Tooth preparation sequence. PMS = Perfect Margin Shoulder.

FIGURE 2. SEM image of split-tooth model, marked for orientation of margin prepared with rotary instruments on the left and ultrasonic instruments on the right (×25). Area 1: axial wall/marginal angle; area 2: margin surface; area 3: finishing line.

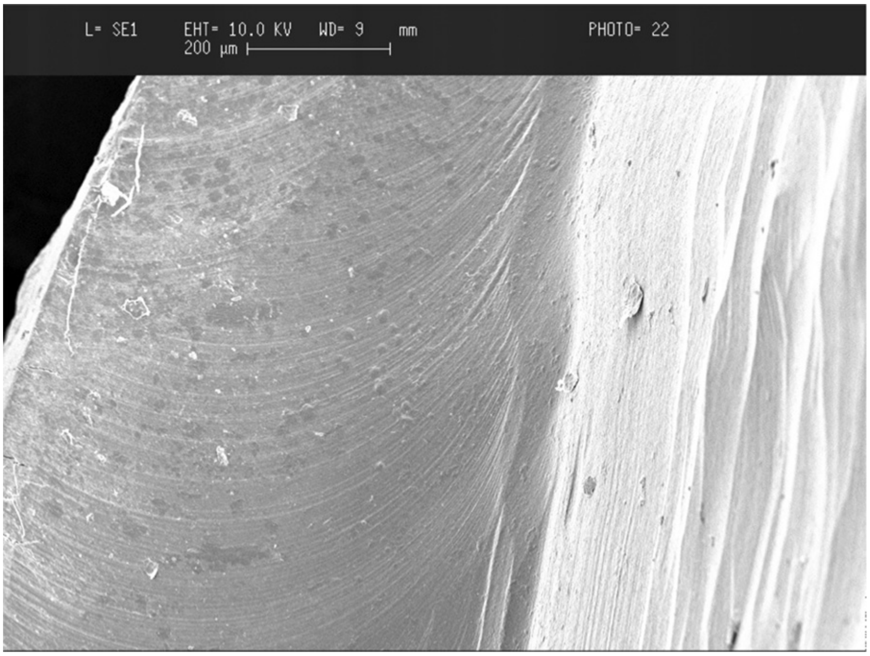


FIGURE 3. SEM image of sample prepared with rotary instruments (×100). Area 2, the margin surface, showing concentric patterns due to the rotation of the instrument.

RESULTS

When examined under the light microscope, the sections of the margin prepared with the ultrasonic tips appeared to be smoother than those finished with the rotary instruments. There was some artifactual cracking visible on the root surfaces of the samples, with SEM.

Under SEM (100×) the margin finished with the rotary TGE instruments appeared rougher overall. In area 1, there was some damage to the axial surface of the preparation (Figure 2). This was nonuniform, trough-like, and in the axial direction. The axial surface/marginal angle was therefore rough and irregular. There was an obvious concentric pattern on the surface of the margin (area 2, Figure 3). Despite this, the external line angle (area 3) created with the rotary instruments was sharp, continuous, and better defined than that produced with the ultrasonic instruments (Figure 4).

The axial wall/margin angle (area 1) produced with the ultrasonic instruments was well defined, and very smooth (Figure 2). The margin surface (area 2) appeared smoother overall, with little evidence of any stroke pattern (Figure 5). The margin was also wider than the margin prepared with the rotary instrument. The external line angle (area 3) was discontinuous (Figure 6). This line was very sharp and distinct in some regions, but rough and chipped in other regions.

SEM images (2,000×) were used to visualize the dentinal tubules and the presence or absence of smear layer on the margins. The margins finished with the rotary instruments were covered with copious debris, within which concentric indentations were visible. The dentinal tubules were barely visible, and those that could be identified were often occluded. The margins finished with the ultrasonic instruments appeared to have less smear layer. The margin profile was slightly irregular and appeared to have small craters within the surface. However, the dentinal tubules were conspicuous. They were arranged in a regular pattern, but appeared smaller than expected, with some cracking of their apertures.

Surface roughness analysis was carried out to obtain quantitative results. The profile of the margin finished with the rotary instruments showed greater roughness

 DOI 10.1111/j.1708-8240.2011.00477.x

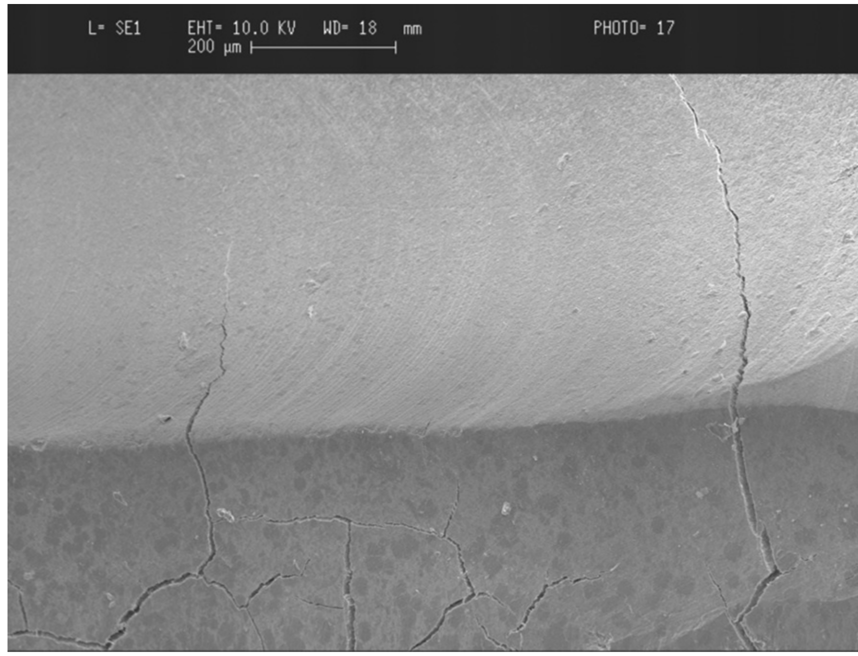


FIGURE 4. SEM image of sample prepared with rotary instruments (×100). Note the sharp definition and continuity of area 3, the finishing line.

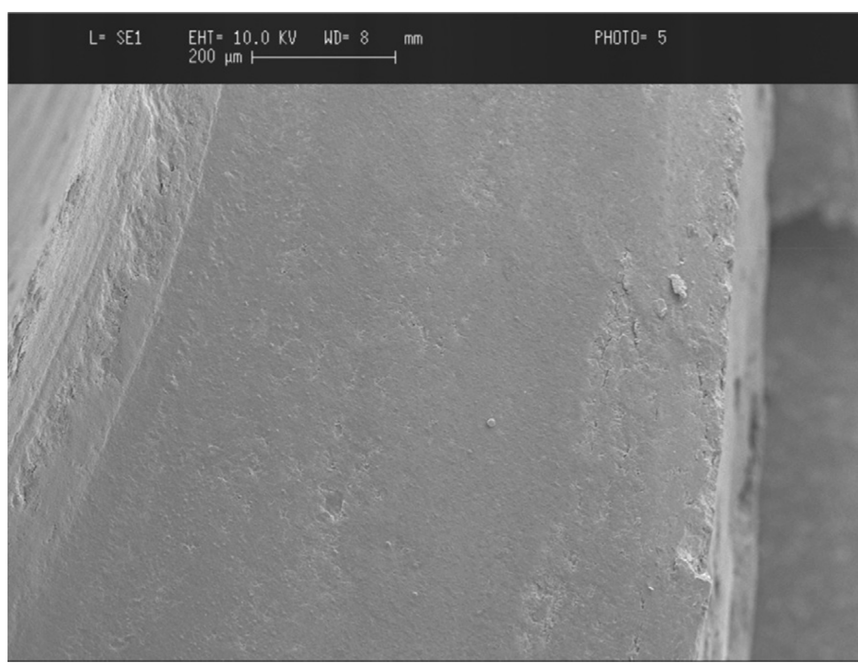


FIGURE 5. SEM image of sample prepared with ultrasonic instruments (×100). Area 2, the margin surface of the sample, and absence of any stroke patterns.

closer to the axial wall (area 1) and external line angle (area 3) with a smoother surface between the two areas (area 2). The roughness mean parameter (R_a) of the surface finished with the rotary instruments was 2.18 μm, and the maximum roughness (R_{max}) was 119 μm. The line profiles of the margins finished with the ultrasonic instruments were more uniform, but there was an area of increased roughness toward the finishing line (area 3). The roughness mean parameter (R_a) of the surface finished with ultrasonic instruments was 0.58 μm, and the maximum roughness (R_{max}) was 45 μm (Table 1).

FIGURE 6. SEM image of sample prepared with ultrasonic instruments (×100). Note the rough and discontinuous finishing line in area 3.

TABLE 1. Mean surface roughness (µm)

	Ultrasonic instruments		Rotary instruments	
1D	R_a	0.58	R_a	2.18
	R_{max}	45.00	R_{max}	119.00
2D	R_a	0.75	R_a	1.63
	R_{max}	15.76	R_{max}	41.14

1D = one dimension; 2D = two dimensions; R_a = the arithmetic mean of the absolute departure of the roughness profile from the mean line; R_{max} = the maximum peak-to-valley height in one sampling length.

The surface finished with the rotary instruments was over three times rougher than the surface finished with the ultrasonic instruments in one dimension. Two-dimensional analysis produced similar results, although the surface produced with the rotary instruments was over twice as rough as the surface produced with the ultrasonic instruments.

The margins produced with the ultrasonic instrument were superior to those produced with the rotary instruments in two of the three areas studied. The ultrasonic instruments produced preparation margins that were smooth, with a well-defined and rounded axial wall/margin angle (Figures 2, 5, and 6). Furthermore, the dentin surfaces prepared with the ultrasonic instruments exhibited less debris and were cleaner with exposed dentinal tubules, a condition that is more suitable for bonding procedures.[9] However, the rotary instruments produced sharper and more continuous external line angles (Figure 4).

The information from the surface of the margins could be correlated to the surface of the instrument, its shape, and its functional mode.

With rotary instruments, significant damage to the axial wall of the sample was noted (Figure 2). This damage is

DISCUSSION

The margins produced with the ultrasonic instrument were in a better condition than those produced with the rotary instrument. Thus, the null hypothesis was rejected.

A strength of this pilot study was the use of the split-tooth model. This provided a robust control and reduced factors that may have influenced interpretation of the results. Similarly, all tooth preparation was completed by a single operator, which further reduced possible variations. The use of SEM and surface roughness analysis gave both quantitative and qualitative results.

 DOI 10.1111/j.1708-8240.2011.00477.x

related to the shape of the instrument and is thought to have been caused by the end-cutting tip of the bur scratching the axial surface of the preparation while cutting the interproximal margin. This caused the axial wall/margin angle (area 1) to be rough and irregular, which complicates fabrication of an esthetic and well-fitting prosthesis.[8] The surface of the margin (area 2) appeared slightly rougher than the margin produced with the ultrasonic instruments (Figure 3). A possible explanation is that although the finest grit size used for the rotary and ultrasonic finishing was comparable (45 μm and 46 μm), the preparation sequence with the ultrasonic instruments ended with the use of the PMS3 tip, which has no coating of grit. There was a circular pattern noticeable on the surface of the margin prepared with the rotary instruments, which was not present on the ultrasonic preparations. This is related to the shape of the bur and its rotating action, and it is probable that the small working surface of the bur created shallow indentations in the margin surface as it rotated. The external line angles on the margins prepared with the rotary instruments however were ideal (Figure 4).

The margin surfaces prepared with the ultrasonic instruments were smoother and wider than those prepared with the rotary instruments (Figure 5). A smooth surface is important for a well-fitting restoration, and assists in strengthening the ceramic butt margin of a restoration, by ensuring that the material remains under compression. The increased width of this margin compared with the margin produced by the rotary instrument can be explained by the presence of diamond particles on the shank of two of the ultrasonic instruments, whereas the rotary instruments had diamond particles on the tip only, preventing axial cutting. The axial wall/margin angle (area 1) on the samples prepared with ultrasonic instruments was smooth and close to 90°, forming a well-rounded shoulder (Figure 2). It is important that this angle is smooth to enhance marginal fit, castability, and esthetics.[10] A well-defined, sharp external line angle without a lip of unsupported enamel is critical to the fit of a restoration. The chipped finishing lines observed by SEM on the margins prepared with the ultrasonic instruments may have been due to the oscillating action of the instrument, which caused pieces of enamel to fracture. The PMS3 tip is thought to remove shards of unsupported enamel. It is possible that the areas with chipping were not thoroughly instrumented. This requires further investigation, as a chipped and irregular finish line could compromise the adaptation of the definitive restoration. Another method of analysis of margin accuracy could have been to evaluate the fit of definitive crowns on abutments finished with the two different instruments.

Bonding to dentin is complicated by a high proportion of organic material, high intrinsic water content, and the smear layer.[11] In order to achieve bonding to dentin, the smear layer is often removed with an acid to expose the collagen network and increase permeability of the tubules.[9] However, this increase in dentinal tubule permeability can also cause tooth sensitivity after bonding.[11] The results suggest that cutting dentin with an ultrasonic instrument produces less debris than cutting with rotary instruments, providing a bonding surface that has less smear layer and a greater density of exposed dentinal tubules. Etchant application to this surface could be of shorter duration.[12]

The two-dimensional results of surface roughness analysis are considered to be more clinically significant than the one-dimensional results, as they are taken from a surface, rather than from a line profile. As the diameter of the ultrasonic working tip is almost the same as the width of the margin, the surface is instrumented uniformly with one stroke, thus eliminating irregularities produced by translation of the instrument tip across the margin surface. The diameter of the rotary instrument used was smaller, and the corresponding roughness of the margin is thought to be related to the different levels of instrumentation of the surface. The concentric markings produced by the rotary mode of action are also thought to contribute to the roughness value of this margin, as compared with the oscillatory action of the ultrasonic instruments.

The line profiles for both samples were relatively consistent across the margin, but became more irregular as they approached the external line angle.

 DOI 10.1111/j.1708-8240.2011.00477.x

This may be due to the shearing of enamel as observed on the SEM images of the margin finished with the ultrasonic instruments (Figure 6). However, this was also observed on the margin finished with the rotary instruments and may be due to the instruments behaving differently when cutting enamel, as opposed to dentin. Further research is required in this area.

There was some cracking visible on the root surfaces of both samples. This is thought to be largely artifactual and the result of specimen preparation for scanning microscopy.[13] Future studies might consider using epoxy replicas made from silicone impressions as a means to reduce this effect. It was difficult to determine whether there was a higher degree of cracking associated with either finishing instrument, and further research is required into subsurface damage caused by ultrasonic diamond instruments. Xu and colleagues[14] reported that preparation of enamel with diamond instruments caused subsurface damage in the form of median-type cracks and micro-cracks. Furthermore, these authors stated that larger diamond grit sizes produced longer subsurface cracks in enamel. Fine diamond finishing burs were recommended by these authors for crack removal. It is unknown whether ultrasonic diamond instruments cause subsurface damage, but they may replace fine diamond finishing burs in the future.

The quality of the margins produced with the ultrasonic instruments is promising. With further research and development, they have the potential to overtake rotary and hand instrumentation for finishing in fixed prosthodontics. A key advantage is their lack of rotation, permitting improved control during delicate preparations.[4] The frequency of oscillation can be adjusted to change the abrasive activity of the instrument, to complete a smooth subgingival finish line.[6]

The oscillating action also prevents soft tissue damage. This has two distinct advantages in situations where esthetics is of particular importance. Damage to the gingiva, especially in individuals with a thin biotype, can result in unsightly recession of the gingival margin.[15] The absence of gingival lesions produced during finishing line repositioning facilitates the impression taking procedure and may eliminate the need for gingival retraction cord.[3]

A conventional high-speed handpiece used under normal loading with a water flow of 40 mL/minute prevents increases in temperature of the pulp.[16] Von Fraunhofer and colleagues[17] reported higher cutting efficiency with higher coolant flow rates. Unfortunately, a higher coolant flow rate also decreases visibility. The increased length of the ultrasonic tip means that the water flow originates from further up the shaft of the instrument than with traditional burs, which improves visibility while cutting.

CONCLUSION

Within the limitations of this observational pilot study, the advantages of ultrasonic instruments for finishing preparations in fixed prosthodontics are illustrated. The ultrasonic instruments produce margins in better condition.

This very practical advantage in margin preparation suggests an important role in the future.

Further research will investigate the consequence of this on clinically relevant procedures such as resin bonding.

DISCLOSURE AND ACKNOWLEDGEMENTS

The authors do not have any financial interest in the companies whose materials are included in this article.

The authors are grateful to Satelec, a division of Acteon (France), for providing the ultrasonic generator, PMS tips, and research funding; The New Zealand Government for further funding; Premier Dental, for providing the Two Striper Tissue Guard End-Cutting burs; Ms. Liz Girvan, University of Otago Centre for Scanning Electron Microscopy for assistance with the SEM and surface roughness analysis; and Olympus Soft Imaging Solutions for providing the Scandium software for surface roughness analysis.

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This article is accompanied by commentary, Ultrasonic Margin Preparation for Fixed Prosthodontics: A Pilot Study, Mamaly Reshad, BDS, DDS, MSC
DOI 10.1111/j.1708-8240.2011.00478.x