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ORIGINAL ARTICLE

Optimal parameters of dental ultrasonic instrument diamond coating for enamel removal

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Abstract *Background/purpose:* Ultrasonic instruments are commonly used in dentistry because of their safety, acceptance by patients, ease of viewing the surgical area, and highly precise cutting. However, they do not efficiently remove enamel. The aim of this study is to optimize the surface coating parameters of an ultrasonic diamond grinding tip for enamel removal.
Materials and methods: The experiments were conducted using a triple-axle precision moving platform. The ultrasonic handpiece was mounted on the platform column, and powered by an ultrasonic device with a voice coil motor providing a uniform down force of 2 N to grind adult molar specimens. The commercially available diamond tips UL3A (Cur scaler, Bonart, Taiwan) and EX1 (Newtron, Acteon, France) were used in this study. The Taguchi method and analysis of variance were used to determine the optimal surface parameters (mesh size, crystal shape, protrusion, and crystal density) of dental diamond tips. By using the optimal surface characteristics, new tips N1 and N2, having the same geometrical shape and dimension of UL3A and EX1, respectively, were fabricated and their grinding performance was tested.
Results: The optimal enamel removal parameters of the grinding tip are diamonds of 100/120 mesh size, shape of well-formed crystal facet, 75 μm protrusion, and density of 45 crystals per square millimeter surface area. The material removal rate (MRR) of enamel for N1 (UL3A with new characteristics) is 0.064 mm^3/s, 3.4 times that of the original UL3A tips. For N2 (EX1 with new characteristics) it is 0.126 mm^3/s, which is 3.2 times that of the original EX1 tips.
Conclusion: Protrusion, shape, and density of diamonds of an ultrasonic dental tip are significantly related to the MRR of enamel, and the optimal combination of these parameters is

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obtained. Knowledge of the importance of these variables will help in more effective use of the ultrasonic technology in dentistry.

Introduction

Ultrasonic technology has been used in dentistry for more than 50 years[1,2] in applications including endodontics, periodontics, and oral and maxillofacial surgery. An ultrasonic dental instrument uses a piezoelectric transducer to convert electricity into mechanical energy to create a high-frequency vibration. This vibration in turn allows the diamond grinding tip to clean, polish, and cut teeth.

In general, an ultrasonic dental instrument has the following advantages over a high-speed air-turbine instrument: (1) ability to identify hard and soft tissues, (2) less pain during the procedure,[3,4] (3) wider field of view for the dentist, and (4) more accurate cuts.[5] However, an ultrasonic dental instrument has a lower material removal rate (MRR) than a conventional high-speed air-turbine instrument, and cannot cut through enamel efficiently.[6] Furthermore, the ultrasonic tip has the disadvantages of higher wear and cost. Improvements in tip design will help to increase the enamel removal rate, making ultrasonic dental instruments more attractive in the clinical setting.

The aim of this study is to investigate the diamond coating parameters of an ultrasonic dental grinding tip using the Taguchi method so that the optimal surface parameters of the diamond tip can be obtained and the MRR of enamel can be increased.

Materials and methods

A piezoelectric ultrasonic surgery unit (Piezosurgery, Bonart, Taiwan) with a handpiece mounted on the column of a three-axis precision platform was used in this study. The piezoelectric transducer of the surgery unit converts electricity into mechanical energy, which in turn creates ultrasonic vibrations of the diamond tip locked at the front end of the handpiece to grind enamel. To simulate the movement of a dentist's hand, a 2 N downward force was applied to the handpiece while it was moving back and forth along the x-axis.

During the experiment, a scanning electron microscope (SEM) was used to observe the structure of two tips: UL3A and EX1, as shown in Fig. 1. The dental ultrasonic grinding tip used in the study had a spherical head covered with diamonds. The diamonds on both tips were composed of synthetic diamonds approximately 90 μm in diameter. The density and protrusion of the diamonds were also measured. Each square millimeter contained approximately 45 diamonds on UL3A and approximately 60 diamonds on EX1. The amounts of protrusion were approximately 38.5 μm and 47.8 μm for UL3A and EX1, respectively.

The enamel removal experiments were conducted under the conditions given in Table 1. A three-dimensional laser scanning microscope (VK9700, Keyence, Japan) was then used to observe the depth and size of enamel removal.

The Taguchi method[7] was applied to design the experiments and obtain the optimal values of the related variables. After the diamonds were removed from UL3A via electrolysis, new MBG diamonds (Diamond Innovation, Worthington, USA) were attached by electroplating. Four variables (mesh size, shape, density, and protrusion of diamonds) were chosen as the control variables, and they were denoted by A, B, C, and D, respectively. The mesh size was set at two levels whereas the other variables were analyzed at three levels. The L18 orthogonal array ($2^1 \times 3^7$) was selected for experiments and data analysis.

The levels of each variable are given in Table 2. Specifically, 140/170 and 100/120 were taken as two levels of the mesh size because the former is the mesh size of UL3A and EX1, and the latter is often used with a high-speed bur. In terms of crystal shape, MBG610, MBG620, and MBG640, ranging from diamonds of high friability to medium toughness and friability, and to the less medium toughness and friability were selected. In selection levels of the density and protrusion of diamonds, the values of UL3A and EX1 were taken as a reference. The three levels of diamond density chosen were 35, 45, and 55 crystals/mm^2, and they were 55, 45, and 35 μm for the diamond protrusion.

In the experiment, each trial (combination of surface parameters) on the L18 orthogonal array was repeated four times. The data were recorded and the signal-to-noise (S/N) ratio[7] was calculated to obtain the effect of each variable, with a larger S/N ratio indicating a greater effect. The analysis of variance[8] (ANOVA) was also applied to determine if the variable is statistically significant by checking its F-value. After obtaining the optimal surface characteristics of a diamond tip, new tips N1 and N2 having the same geometrical shape and dimension of UL3A and EX1, respectively, were fabricated and their grinding performances were tested.

Results

The S/N ratios from the 18 sets of data for the four variables are shown in Fig. 2. Regarding variable A, Level 2 has a higher S/N ratio, indicating better efficiency for 100/120 mesh size. Level 1 of variable B (diamond shape) has the highest S/N ratio because the sharp edges of more angular crystals can cut deeper into the material. For variable C or diamond density, the highest S/N ratio is Level 2, which has a higher density as compared to Level 1. Hence, there are more functional crystals, leading to a higher removal efficiency. However, the higher density of Level 3 results in less cutting depth under the same amount of down force. In addition, the smaller chip removal pocket of densely packed crystals hinders debris removal, which in turn reduces MRR as a result. As for variable D, Level 1 has the best MRR because the higher protrusion of diamonds allows for a