Efficacy of a new jet nozzle for removal of carious dentin with an air abrasion system

Kosuke HONDA, Naoto KINOSHITA, Tetsuya ABE, Makoto HASEGAWA and Akihiko SHIMIZU

Department of Dentistry and Oral Surgery, Hyogo College of Medicine, 1-1, Mukogawa-cho, Nishinomiya, Hyogo 663-8501, Japan
Corresponding author, Kosuke HONDA; E-mail: ko-honda@hyo-med.ac.jp

A new version of an air abrasion device, which expelled abrasive sodium bicarbonate powder, was fabricated to remove carious tissue. This device had a motor-driven mechanism to control the amount of powder expelled. The purpose of this study was to estimate the abrading efficacy of this device, in particular the new jet nozzle, for removal of carious dentin. Powder was supplied to the handpiece by a rotary gear attached to the powder control motor. Two types of jet nozzles, a cylinder-type and a bugle-type, were fabricated and evaluated. The duct of bugle-type nozzle had an isthmus to increase the air pressure on the powder and to spread it out in a cone-shaped flow. Results obtained showed that the bugle-type jet nozzle exhibited a more prominent abrasive capability. Compared to the cylinder-type nozzle, it was thus more effective in removing the carious dentin which remained in the undercut region of the cavities.

Key words: air abrasion, jet nozzle, caries removal, sodium bicarbonate powder

INTRODUCTION

Mechanical instruments, such as a round bur or a hand excavator, have generally been used for caries removal. The air abrasion technique has recently been introduced as an alternative to these conventional mechanical techniques. This method hinges on the principle of abrading or preparing tooth structures with powder particles expelled at a high speed\(^1\)\(^{-2}\). Presently, several air abrasion devices are available for the purposes of tooth surface cleaning or caries removal — whereby their presence and emergence in restorative dentistry may signal an end to the use of mechanical instruments for caries removal. However, the air abrasion devices currently on the market are not without flaws; they do not afford good control to the amount of powder to be expelled.

Against this backdrop, we produced a new air abrasion device for carious dentin removal. The new device had a motor-driven mechanism to control the amount of powder to be expelled and a bugle-type nozzle to disperse the powder.

The purpose of this study, therefore, was to evaluate the efficacy of this new air abrasion device which comprised a motor mechanism and a newly invented jet nozzle.

MATERIALS AND METHODS

Structure of the device

The device we fabricated comprised a body unit, a handpiece, and a foot switch (Fig. 1). Table 1 shows the technical data of this device. There were two chambers: the abrasive powder chamber and the water chamber. The abrasive powder used in this device was sodium bicarbonate powder (diameter of powder particles: 50—70 \(\mu\)m), which was manufactured by EMS (Nyon, Switzerland) as an abrasive powder for Air-Flow\(^R\). Under compressed air pressure, the abrasive powder was expelled with water flow to abrade carious dentin.

Bicarbonate powder was supplied to the handpiece by a rotary gear attached to the powder control motor (Fig. 2). Compressed air was supplied from the air compressor in the unit, and air pressure could be increased to a maximum of 0.3 MPa. Two types of jet nozzles were fabricated: a cylinder-type versus a bugle-type (Fig. 3). The cylinder-type nozzle had a straight duct, and diameter of the nozzle orifice was 1.2 mm. The bugle-type nozzle was identical in appearance to the cylinder-type nozzle, but the configuration of the duct resembled that of a bugle. Moreover, the duct had an isthmus to increase the air pressure and to spread out the powder in a cone-shaped flow (Fig. 4). With the bugle-type nozzle, diameters of the orifices were 1.0 mm and 1.2 mm. For the 1.0-mm-diameter nozzle orifice, diameter of the duct isthmus was 0.6 mm (0.6-1.0 nozzle). For the 1.2-mm-diameter nozzle orifice, diameter of the duct isthmus was 0.8 mm (0.8-1.2 nozzle). As for the handpiece coupling, it was also manufactured by EMS.

Efficacy evaluation of the device

1. Adjustability of the amount of abrasive powder to
Table 1  Technical data of the trial version of air abrasion device in this study

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>Width: 260 mm, Height: 440 mm, Length: 320 mm</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>AC: 100V</td>
</tr>
<tr>
<td>Air Supply</td>
<td>Built-in air compressor: 18 L/min under 0.3 MPa</td>
</tr>
<tr>
<td>Water Supply</td>
<td>Built-in water tank (4 L) and a water pump</td>
</tr>
<tr>
<td>Powder Supply</td>
<td>Built-in powder chamber (40 g) and a rotary gear attached to the powder control motor</td>
</tr>
</tbody>
</table>

Fig. 1  Appearance of the trial version of the air abrasion device (a) and the jet nozzle (b). WC: water chamber, PC: powder chamber, JN: jet nozzle.

Fig. 2  A schematic illustration showing the mechanism of the air abrasion device. PC: powder chamber, G: rotary gear to supply the powder to the handpiece, M: powder control motor, WS: water supply, AC: air compressor.
be expelled
The amount of bicarbonate powder expelled per minute was measured to evaluate adjustability in five steps in the range of 1–5 g/min under compressed air pressure.
2. Abrasion test to compare abrasive capability between cylinder-type nozzle and bugle-type nozzle
a) Using artificial materials
An abrasion test was carried out using cubic blocks (1×1×1cm) of a tooling material (SANMODUR MS, Sanyo Chemical Industries Ltd., Kyoto, Japan). Knoop hardness number of these blocks was 8 KHN, surface roughness was 8 μm, and milling resistance was 73 N. In terms of physical properties, these blocks mimicked the caries-softened dentin of human teeth.

The nozzle was held perpendicular to the block surface at a distance of 1 mm, and the powder was expelled for 30 seconds continuously for each of the five steps (three cubic blocks per step) in the range of 1–5 g/min under 0.3 MPa air pressure. The depth and width of each abraded indentation were measured with a digital measuring microscope (STM, Olympus, Tokyo, Japan), and the mean depth and width of three blocks for each of the five steps in the range of 1–5 g/min were calculated. The abrasive capability of each jet nozzle was assessed based on the maximum depth (mean depth of three experimental blocks) of the indentation, and statistical analysis was performed using Student’s t-test at p<0.05 significance level.

b) Using extracted human teeth with deep carious lesions
To evaluate the abrasive capability in removing carious dentin, 12 extracted human teeth with deep carious lesions were used. This abrasion test was performed using the cylinder-type nozzle and two sizes of the bugle-type nozzle (0.6-1.0 nozzle and 0.8-1.2 nozzle) on four teeth each. The cavity was stained with a caries-detecting solution (Caries Check, Nishika Co., Shimonoseki, Yamaguchi, Japan) before abrasion. The abrasion procedures were performed by moving the tip of the nozzle along the outline form of each carious cavity. Serial 30-second abrasions (powder: 3 g/min, air pressure: 0.3 MPa) were repeated until the abraded dentin surface was no longer stained with the caries-detecting solution.

RESULTS
Adjustability of the amount of expelled abrasive powder
As shown in Fig. 5, the amount of bicarbonate powder expelled was adjustable in five steps in the range of 1–5 g/min under compressed air pressure. Furthermore, the amount of powder in the abrasive

Fig. 3 Sectional views of the two new types of jet nozzle: cylinder-type (a) and bugle-type (b). Diameter of the nozzle orifice of the cylinder-type is 1.2 mm (*). Diameters of the nozzle orifices of the bugle-type are 1.0 mm and 1.2 mm (**). The isthmus of the bugle-type nozzle with 1.0-mm-diameter orifice is 0.6 mm in diameter and that with 1.2-mm-diameter orifice is 0.8 mm (***)

Fig. 4 Comparison of abrasive powder dispersion between the cylinder-type nozzle (a) and bugle-type nozzle (b).
powder chamber did not influence the amount of bicarbonate powder expelled per minute.

**Abrasion test to compare abrasive capability between cylinder-type nozzle and bugle-type nozzle**

1. Using artificial materials as abraded materials
The maximum depth of indentation after abrasion with 0.6-1.0 bugle-type nozzle was 1.57±0.04 mm, which was significantly more (p<0.05) than that with the cylinder-type (1.14±0.07 mm). Therefore, the 0.6-1.0 bugle-type jet nozzle had a more prominent abrasive capability than the cylinder-type. As for the 0.8-1.2 bugle-type nozzle, the maximum depth of indentation after abrasion was 1.19±0.09 mm. This was significantly less than that with 0.6-1.0 bugle-type jet nozzle (p<0.05). Therefore, the 0.6-1.0 nozzle showed a higher abrasive capability than the 0.8-1.2 jet nozzle (Fig. 6).

2. Using extracted human teeth with deep carious lesions
With the cylinder-type nozzle, it was difficult to remove the carious dentin in the undercuts of the cavities (in all the four human teeth), although serial abrasions were repeated. However, the carious dentin could be easily removed using an excavator (Fig. 7A).

In contrast, the bugle-type nozzles were favorable for the removal of carious dentin remaining in the undercuts of the cavities. (Figs. 7B, C).
Fig. 7 Results of removal of carious dentin with the air abrasion device using extracted human teeth with deep carious cavities.

A: Abrasion with cylinder-type nozzle. Caries-softened dentin remained in the undercut region (arrows).
(a) Before abrasion; (b) After serial abrasion for 60 sec; (c) After serial abrasion for 120 sec.
B: Abrasion with 0.6-1.0 bugle-type nozzle. No caries-softened dentin remained in the undercut region.
(a) Before abrasion; (b) After serial abrasion for 30 sec; (c) After serial abrasion for 60 sec;
(d) After serial abrasion for 90 sec.
C: Abrasion with 0.8-1.2 bugle-type nozzle. No caries-softened dentin remained in the undercut region.
(a) Before abrasion; (b) After serial abrasion for 30 sec; (c) After serial abrasion for 60 sec;
(d) After serial abrasion for 90 sec.

DISCUSSION

The advantages of an air abrasion procedure in tooth caries treatment are that it can prepare minimal cavities and remove carious lesions with minimal removal of sound enamel and dentin\(^5\). In contrast, when rotary instruments are used, sound occlusal tooth structure is sometimes unavoidably removed in a bid to treat the proximal carious lesion. With an air abrasion procedure, this problem is circumvented because a direct approach to the proximal carious lesions can be achieved without significantly impairing sound enamel and dentin. Therefore, the air abrasion procedure is consistent with the principles of minimal intervention for carious lesions\(^2,3\).

In this study, sodium bicarbonate was selected as the abrasive powder because it offers less damage to sound tooth structure than alumina or other powder particles\(^8,9\). It should be mentioned that deleterious effects of air abrasion or air polishing procedures with sodium bicarbonate powder on sound dentin and cementum have been noted\(^1,10\). However, it was recently reported that a low-abrasive air polishing powder, which was an improved product of the standard sodium bicarbonate powder, minimized the deleterious effects on sound dentin and cementum, while effectively removing dental plaque\(^11\).

Indeed, the bicarbonate powder used in this study resulted in mild removal of carious lesions in the extracted human teeth, as compared with rotary instruments. On cavities prepared by air abrasion and those by a high-speed carbide bur, Borsatto et al.\(^12\) reported that there were no remarkable differences in the degree of marginal microleakage between these two methods. However, an air abrasion procedure may require that proper abrasion conditions designated for the respective carious cavities to be met — such as abrasion time, amount
of expelled powder, and air pressure—in order for carious dentin to be removed efficiently.

With a conventional air abrasion method, the volume of expelled powder tends to be affected by the air pressure supplied to the abrasive powder chamber and by the amount of powder remaining in the chamber. For this reason, we developed a new abrasive powder circulation system, in which the powder was precisely supplied from the powder chamber to the handpiece by a motor mechanism. Consequently, an accurate quantity of powder could be expelled irrespective of the volume of powder remaining in the chamber.

As for the abrasive capability, it depended on the kinetic energy which in turn depended on the abrasion conditions in our air abrasion system. The abrasion capability tended to increase with the volume of expelled powder, but there was little or no increase above 3.0 g/minute. This finding suggested that increasing the air pressure supplied from the powder chamber to the jet nozzle was more important than increasing the volume of the expelled powder in order to improve abrasive capability. Further on abrasive efficacy, a pilot test was carried out to investigate and compare the effects of nozzle position relative to the abraded subject. It was found that abrasive efficacy was influenced by the volume of expelled powder, when jet nozzle was positioned at an angle of 45° to the abraded subject as compared to a perpendicular position to the subject. In light of this finding, all abrasion procedures in this study were carried out with the jet nozzle held perpendicular to the experimental block.

Abrasion results of extracted human teeth demonstrated that air abrasion with the cylinder-type nozzle could not completely remove the carious dentin in the undercuts of cavities. This was probably because it was difficult to control the stream of abrasive powder toward the direction of the carious dentin remaining in the undercuts. In the same vein, it was reported that darkened areas of carious lesions were not always removed by sodium bicarbonate slurry in an air abrasion procedure. On the incomplete removal of carious dentin, it was suggested that the abrasive powder played a critical role. Bicarbonate powder particles break easily, such that the abrasive energy arising from the rebounding of powder particles on the cavity walls was lower than other types of abrasive powder, such as alumina powder.

To address the abovementioned shortcoming presented by abrasive powder, we designed a duct similar to a “bugle” by reducing its caliber in order to increase the air pressure on the powder particles. Santos-Pinto et al. reported that the cutting efficiency of an air abrasion system was influenced by the handpiece tip design. However, to the best of the authors’ knowledge, no attempts have been made to increase abrasive capability by improving the inner shape of the duct of a jet nozzle. As shown in this study, the bugle-type nozzle removed carious dentin more efficiently than the cylinder-type because the expelled powder particles were dispersed and spread out in a cone-shaped flow. However, at the isthmus of the duct, the inside metal wall of the duct may wear out and be damaged due to abrasion. Therefore, it may be necessary to line the inside of the duct with a solid material that does not wear out easily, or attach a disposable tip to the nozzle.

In this study, two sizes of the bugle-type jet nozzle, 0.6-1.0 nozzle and 0.8-1.2 nozzle, were fabricated. It is noteworthy that it was more difficult to fabricate the bugle-type jet nozzles than the cylinder-type nozzle. Moving forward to find the optimal abrasive energy for the removal of carious lesions, further study is required to investigate the ratio of the caliber of the duct to the isthmus as well as the diameter of the duct.

CONCLUSION

A new version of an air abrasion device, which expelled abrasive particles of sodium bicarbonate powder with water, was fabricated to selectively remove carious dentin. Of particular note was that the amount of expelled powder could be precisely controlled. It was found that the bugle-type nozzle was more effective than the cylinder-type nozzle in removing the caries-softened dentin existing in the undercut regions of cavities.

REFERENCES