©Operative Dentistry, 2010, **35-5**, 538-546

Removal of Enamel Caries with an Air Abrasion Powder

KW Neuhaus • P Ciucchi
M Donnet • A Lussi

Clinical Relevance

The results of the current study indicate that air abrasion with a powder for selective preparation of carious enamel saves healthy tooth substance. It also has a diagnostic potential for operative intervention in patients with high caries risk, because only carious enamel with underlying dentin caries is abraded. Furthermore, this powder could be used in cavitated lesions for selective enamel removal.

SUMMARY

This study compared the efficiency of air abrasion on enamel caries with selective enamel powder (SEP) or with alumina powder and a negative and positive control group. Ninety-three extracted molars with non-cavitated incipient enamel lesions were selected. After embedding the roots in resin, each lesion was sectioned perpendicular to the surface and photographed. Each lesion was classified microscopically as having or not having dentin involvement. The lesions were distributed into four groups with an equal number of enamel caries with or without dentin involvement. Each group was treated differently: Group 1 had SEP abrasion, Group 2 had alumina abrasion, Group 3 had sodium bicarbonate abrasion (negative control) and Group 4 had bur treatment (positive control). The surface was rephotographed after treatment. Superimposition of the photographs identified areas of "correct-excavation," "under-excavation" and "over-excavation." There were no statistical differences between lesions treated with or without dentin involvement for Groups 2 through 4. However, in the SEP group, all measured areas were significantly influenced by dentin involvement. In pairwise comparisons, no statistical differences were found between the alumina and bur groups. The SEP group, however, showed statistically significant differences for each area compared to the alumina group in enamel caries without dentin involvement. SEP performed as well as alumina and bur in lesions with dentin involvement. SEP

*Klaus W Neuhaus, Dr med dent MMA, University of Bern, Department of Preventive, Restorative and Pediatric Dentistry, Bern, Switzerland

Philip Ciucchi, med dent, Department of Preventive, Restorative and Pediatric Dentistry, Bern, Switzerland

Marcel Donnet, Dr Ing, EMS, Nyon, Switzerland

Adrian Lussi, Dr med dent, Dipl-Chem, prof, University of Bern, Department of Preventive, Restorative and Pediatric Dentistry, Bern, Switzerland

*Reprint request: Freiburgstrasse 7, Bern, 3010, Switzerland; e-mail: klaus.neuhaus@zmk.unibe.ch

DOI: 10.2341/10-009-L

is different in its ablative properties toward caries with dentin involvement or no dentin involvement. In terms of dental treatment, SEP seems to have a diagnostic potential for enamel lesions before operative intervention in patients with high caries risk.

INTRODUCTION

Due to improvements in dental materials and techniques in the last few years, some dental paradigms, such as the necessity for clean, bacteria-free cavities prior to restoration, have been questioned.[1-2] For reasons of mechanical stability and pulp vitality, it seems reasonable not to excavate all infected dentin, as long as a tightly sealed restoration is feasible.[2] The invention of composite restorations and adhesive techniques has enabled practitioners to be more conservative and lesion-oriented in their tooth preparations. This has made more selective operative techniques possible, with the goal of preserving the maximum amount of natural tooth structure. In this upcoming era of minimally invasive dentistry, new techniques, such as laser excavation, have been invented, and older ones, like chemo-mechanical excavation[3-4] and air abrasion,[5-6] are generating interest again.

Air abrasion was used by Black in the 1950s,[7] but was put aside due to the arrival of high-speed bur preparation. However, this technique has recently re-emerged in certain cases as an alternative to bur excavation. It has been shown that air abrasion devices are well accepted by patients, especially younger patients, due to reduced noise and less pain and vibration. Air abrasion has also demonstrated relative effectiveness in removing primary carious lesions and occlusal staining.[8] Moreover, the detection and diagnosis of occlusal caries was reported to be enhanced after air abrasion.[9] In a recent *in vitro* study, significantly better diagnostic validity was achieved in primary molars following air abrasion with alumina.[10]

The principle of air abrasion technology consists of striking the tooth surface with abrasive particles at high air pressure. The most common abrasive for cutting tooth structure is alumina (Al_2O_3), which has an average particle size of 27.5 µm. Blasting the tooth causes a removal of small amounts of tooth structure, producing a cavity with irregular contours, which is compatible with adhesive restorations.[11] The main drawback of this technique is the potentially hazardous powder cloud, especially from alumina, generated during patient treatment. Nevertheless, it has been demonstrated that there is not enough dust produced to create a health hazard for the patient or the practitioner.[12] By using water-cooling and adequate suction, the dust-water-cloud can be greatly controlled. However, the lack of tactile sense on the part of the operator and the general low specificity to the carious lesion seem to be obstacles to the wider use of air abrasion.[13]

Currently, air abrasion is primarily used for cleaning the fissure system of permanent molars in order to enhance the diagnosis of caries, thus avoiding dental probing. Probing surfaces with initial lesions may convert an initial carious lesion into a cavity, which may promote further lesion progression.[14] The air polishing technique uses sodium bicarbonate ($NaHCO_3$) instead of alumina powder to remove plaque and occlusal stains, thus permitting more accurate visual inspection.[10] However, its cautious use for examining stained fissures has been recommended, as over-excavation of sound fissures or arrested initial lesions may result.[15] Continuing studies on the carious process also bring up the question of how much carious tissue needs to be removed.[2] With the production of minimal temperature changes, air abrasion has several properties that make it suitable for small cavities. It has also been noted that air abrasion, unlike round burs, is end cutting.[16]

Horiguchi and others[17] have demonstrated the "low" selectivity of alumina air abrasion powder for carious dentin and enamel. This impaired selectivity associated with an end cutting property and lack of tactile feedback often results in over-excavation, that is, removing sound tissue. However, new types of abrasive powders, which are more selective to enamel or dentin caries, have been developed, allowing for a more conservative approach compared to the standard alumina powder. Bioactive glass has been reported to selectively clean and polish tooth surfaces after debonding orthodontic brackets, performing better than carbide burs.[18] Another study on teeth using bioactive glass with artificial enamel caries showed a higher selectivity than alumina air abrasion.[19] However, bioactive glass might still cause hazardous dust, as it is non-resorbable.

The current study compared the efficiency of air abrasion with an experimental, resorbable selective enamel powder (SEP) to alumina powder on natural caries. A quantitative comparison of air abrasion with SEP to air abrasion with sodium bicarbonate and with bur excavation was also done. The first hypothesis was that SEP is as capable as alumina air abrasion in removing enamel caries, regardless of dentin involvement. The second hypothesis was that SEP is as specific as alumina air abrasion in removing enamel caries.

METHODS AND MATERIALS

Ninety-three molars were selected from a pool of extracted molars (no water fluoridation) that had been stored in 1% chloramine solution. The teeth showed non-cavitated incipient enamel lesions with or without slight dentin involvement on either the mesial, distal, palatal or lingual surface. Each selected tooth was cleaned with a scaler (LM Dental, Parainen, Finland) in order to remove all soft tissue. Plaque was gently removed using a toothbrush and tap water. The cleaned teeth were stored in a pH-neutral solution[20] and remained there throughout the duration of the study. Each tooth was embedded in a resin block (Paladur, Heraeus Kulzer, Hanau, Germany) with the crown remaining exposed. Each surface of the resin block, except for the occlusal tooth surface, was ground (LaboPol, Struers, Germany). The carious lesion on each tooth was digitally photographed at 6.25X magnification (Leica M420, Leica, Heerbrugg, Switzerland). Each lesion was sectioned through the center, perpendicular to the surface, using a diamond disc (Isomet 11-1180 low speed saw, Buehler, Lake Bluff, IL, USA, 101.67 mm diameter, 0.3 mm thick). Every cut surface was then photographed at 16X magnification (Leica M420). Each lesion was classified microscopically, without staining, as having or not having dentin involvement.

The teeth were distributed into four groups with an equal number of enamel caries with or without dentin involvement:

Group 1: SEP abrasion (Air Flow Resorbable Selective Enamel Powder, DCP, EMS, Nyon, Switzerland) at 5 bar, powder flow rate 3.5 g/minute, water flow rate 60 mL/minute, average grain size 57 µm, 2-3 mm distance, angle 45°-70°.

Group 2: Alumina abrasion (Air Flow Prep K1 Max, EMS) at 5 bar, powder flow rate 3 g/minute, water flow rate 100 mL/minute, average grain size 36 µm, 2-3 mm distance, angle 45°-70°.

Group 3: Sodium bicarbonate abrasion (Air Flow Classic Lemon, EMS) at 5 bar, powder flow rate 3.5 g/minute, water flow rate 60 mL/minute, average grain size 66 µm, 2-3 mm distance, angle 45°-70°.

Group 4: Bur #1200 012, spherically-shaped, grain size 80 µm (Intensiv SA, Grancia, Switzerland).

The two test groups: 1, using SEP, and 2, using alumina, each consisted of 47 specimens. One half of each of the 47 teeth was placed in Group 1, the other half in Group 2. Each half tooth was glued with Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein) onto a microscope slide by placing it on the cut flat portion of the root. The specimens were placed in such a way that the carious lesion was on the edge of the slide in order to obtain as little interference as possible during treatment. After treatment, the specimens were removed from the microscope slide and photographs were taken under the same conditions as before the treatment. The outlines of the prepared cavity and the carious lesion were drawn before the photographs and were digitally superimposed using specific software (IM 500, Leica). Based on the superimpositions of the photographs, areas of "correct-excavation," "under-excavation" and "over-excavation" were created. These areas were calculated with the same software and expressed in square micrometers. For each lesion, these areas were subsequently divided by the area of the initial enamel lesion and thus expressed in percentages.

The negative control, Group 3 (sodium bicarbonate), and the positive control, Group 4 (bur), had 23 teeth each. After sectioning the lesions as described above, the teeth were reassembled by gluing each pair of half-teeth together at the root with Heliobond (Ivoclar Vivadent). In Group 3, each tooth was then air-abraded with sodium bicarbonate. In Group 4, each tooth was treated with a diamond bur, and the time needed for treatment was recorded. On the superimposed photographs, differences in carious lesion/excavated cavity areas were calculated in the same way as for the test groups.

Treatment time was recorded. For Groups 2 (alumina) and 4 (bur), time was taken until the prepared lesion looked clean when observed without a magnification device. In order to mimic a clinical situation, treatment time for Groups 1 (SEP) and 3 (sodium bicarbonate) was restricted to a maximum of 60 seconds.

In order to obtain a parameter for the accuracy of caries removal, for every lesion, the output parameters "correct-excavation," "under-excavation" and "over-excavation" (expressed in percentages) were combined in a ratio:

Accuracy = "correct-excavation"/["correct-excavation" + (M × "under-excavation") + (N × "over-excavation")] with M=0.5 and N=2.

The factors M and N were chosen in accordance with the goal of conservative caries excavation, with four times more weight on maintaining healthy tooth substance than on leaving caries behind.

SEM images (Cambridge S-360, LEO Electronics, Thornwood, NY, USA) were obtained from representative specimens in order to qualitatively compare the impact of the different treatment modalities on surface characteristics.

Descriptive statistics were obtained with R vs 2.9.1 software (R Development Core Team, www.r-project.org, access 7/31/2009). Box-and-whisker plots were obtained with the same software. For the outcome parameters "under-excavation," "over-excavation" and "correct-excavation," the Kruskal-Wallis test was performed in order to compare Groups 1 through 4 or lesions with and without dentin involvement, respectively (α=0.05). In the case of significant differences, the Wilcoxon Mann-Whitney test was applied to each group to test the influence of dentin versus no dentin involvement for the outcome parameters "under-excavation," "over-excavation" and correct-excavation" (α=0.05). The Wilcoxon Mann-Whitney test was also applied for pairwise comparison (α=0.01).

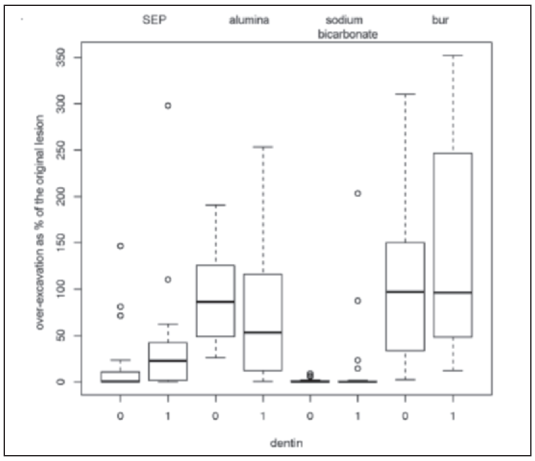

Figure 1a. *Box-plots of the over-excavated area expressed in proportion to the size of the initial lesion. (Zero indicates enamel caries only without dentin involvement, whereas 1 indicates dentin involvement.)*

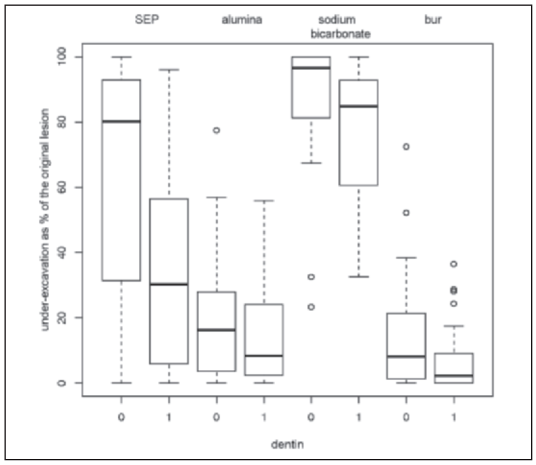

Figure 1b. *Box-plots of the under-excavated area expressed in proportion to the size of the initial lesion. (Zero indicates enamel caries only without dentin involvement, whereas 1 indicates dentin involvement.)*

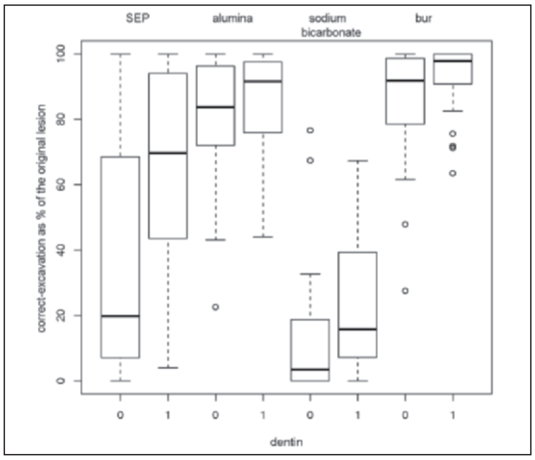

Figure 1c. *Box-plots of the area of correct excavation expressed in proportion to the size of the initial lesion. (Zero indicates enamel caries only without dentin involvement, whereas 1 indicates dentin involvement.)*

RESULTS

As a general finding, each lesion displayed areas of correct excavation, over-excavation and under-excavation.

The results were expressed as proportional to the initial enamel lesion according to the four different test groups: 1 (SEP), 2 (alumina), 3 (sodium bicarbonate) and 4 (bur). Each group was coded into lesions having dentin involvement (1) or only enamel demineralization (0). The outcome parameters of over-excavation (Figure 1a), under-excavation (Figure 1b) and correct-excavation (Figure 1c) are presented as box-and-whisker plots. It should be noted that the measured areas account for only enamel. Dentin excavation was regularly observed in the alumina and bur groups but was not taken into account.

As shown in Table 1, there were no statistical differences between lesions treated with or without dentin involvement for Groups 2 through 4 with respect to all outcome parameters. However, in the SEP group, all parameters were significantly influenced by dentin involvement (Table 1). These differences were seen in the amount of correct-excavation, under-excavation, over-excavation and accuracy.

In pairwise comparisons, no statistical differences were found between the alumina and bur groups with or without dentin involvement (Table 2). The sodium bicarbonate group was significantly different from the alumina and bur groups. The sodium bicarbonate group showed no statistical difference regarding under-excavation compared to the SEP group with or without dentin involvement. The SEP group, however, showed statistically significant differences for each tested parameter compared to alumina abrasion in caries without dentin involvement. However, in lesions with dentin involvement, SEP performed as well as alumina and bur.

The SEP group had a statistically significant difference between over-excavation with or without dentin involvement (Figure 1a). Alumina and bur over-excavated by nearly 100%. When only enamel caries was present, SEP did not cause any over-excavation.

Regarding under-excavation, only SEP showed a statistically different influence of dentin involvement (Figure 1b). The alumina and bur groups showed similar degrees of under-excavation. There was no statistically significant difference between the SEP and sodium bicarbonate groups.

The correct-excavation of the alumina and bur groups did not differ significantly with or without dentin involvement and had similar values of correct

Table 1: *Statistical Comparison Between Enamel Caries With or Without Dentin Involvement for Each Treatment Type*

	Group	Correct Excavation	Under-excavation	Over-excavation	Accuracy (ratio)
dentin involvement vs no dentin involvement	SEP[a]	0.007	0.003	0.007	0.046
	Alumina[a]	0.470	0.154	0.470	0.059
	Sodium bicarbinate[a]	0.109	0.756	0.109	0.159
	Bur[a]	0.045	0.566	0.060	0.566
dentin involvement	all groups[b]	<0.001	<0.001	<0.001	0.642
no dentin involvement	all groups[b]	<0.001	<0.001	<0.001	0.239

a=Wilcoxon Mann-Whitney
b=Kruskal Wallis
α=0.05

Table 2: *Statistical Comparison Between Each Treatment Type for Enamel Caries With or Without Dentin Involvement*

	Comparison	Correct Excavation	Under-excavation	Over-excavation	Accuracy (ratio)
dentin involvement	SEP vs alumina	0.048	0.063	0.048	0.9893
	SEP vs sodium bicarbonate	<0.001	0.029	<0.001	0.032
	SEP vs bur	0.023	<0.001	0.025	0.079
	alumina vs sodium bicarbonate	<0.001	0.004	<0.001	0.04
	alumina vs bur	0.263	0.020	0.341	0.095
	sodium bicarbonate vs bur	<0.001	0.001	<0.001	0.002
no dentin involvement	SEP vs alumina	<0.001	<0.001	<0.001	0.592
	SEP vs sodium bicarbonate	0.006	0.852	0.006	0.116
	SEP vs bur	0.001	<0.001	0.001	<0.001
	alumina vs sodium bicarbonate	<0.001	<0.001	<0.001	0.003
	alumina vs bur	0.573	0.188	0.573	<0.001
	sodium bicarbonate vs bur	<0.001	<0.001	<0.001	<0.001

a= pairwise comparison with the Wilcoxon Mann-Whitney test.
α=0.01

Table 3: *Time Taken for Each Treatment Type Measured in Seconds. Time Was Taken Until a Visually Clean Cavity was Achieved.*

Group	SEP	Alumina	Sodium Bicarbonate	Bur
Time in seconds	58.7	37.8	60.0	4.9
SD	5.6	12.0	0	1.2

excavation of about 90% (Figure 1c). On the other hand, there was a statistically significant difference in the SEP group, with 20% correct excavation when only enamel was involved and 70% correct excavation when decay had reached the dentin. SEP with dentin involvement had the same overall abilities of correct-excavation as alumina and bur. The negative control group also removed carious enamel when dentin was involved, although sodium bicarbonate was supposed to only have cleansing properties.

In regard to the ratio (accuracy), there was a statistically significant difference in the SEP group with or without dentin involvement (Table 1, Figure 2). The bur group had the lowest ratio when caries extended into dentin, which was significantly different from all other groups (Figure 2). There were no differences in accuracy between the alumina and SEP groups with or without dentin involvement. The accuracy of sodium bicarbonate was not statistically different from the SEP treatment.

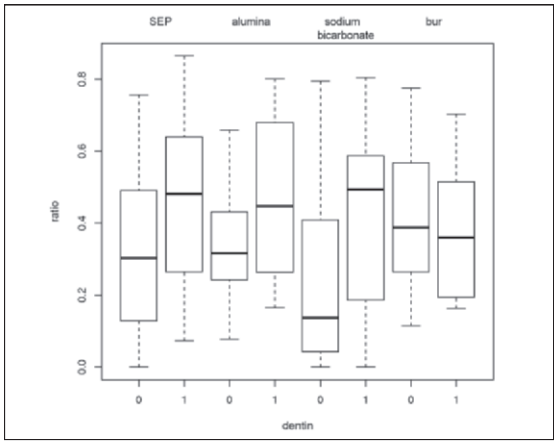

Figure 2. *Accuracy of the treatment modalities as calculated by the combined impact of correct excavation and over-excavation by differing extension of the caries into dentin. (Zero indicates enamel caries only without dentin involvement, whereas 1 indicates dentin involvement.)*

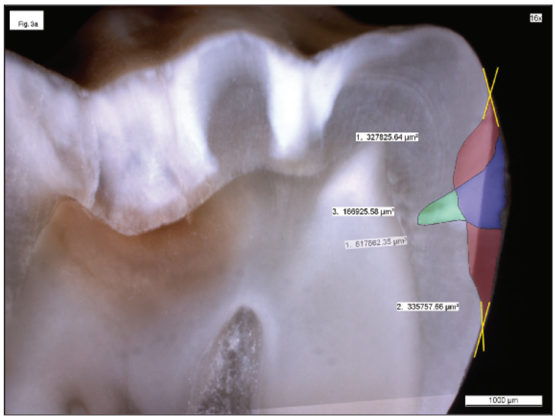

Figure 3a. *Alumina excavation. Wide angles and shallow cuts can be seen, in addition to the "over-excavation" compared to the original lesion.*

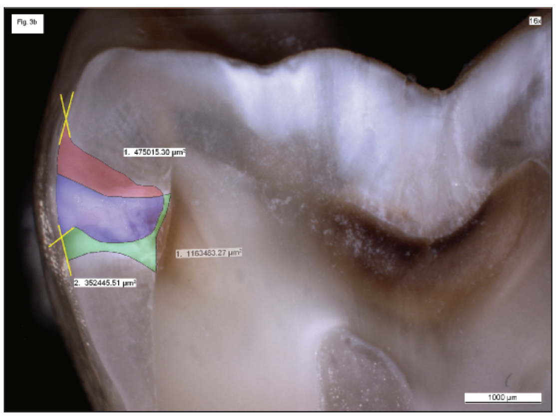

Figure 3b. *Superimposition of photographs taken before and after tooth surface excavation by SEP. The red shaded areas are over-excavated, the blue shaded are areas of correct excavation and the green shaded areas are under-excavated. Notice the narrow angles (yellow lines) and deep cut in addition to the under-excavation compared to the original lesion.*

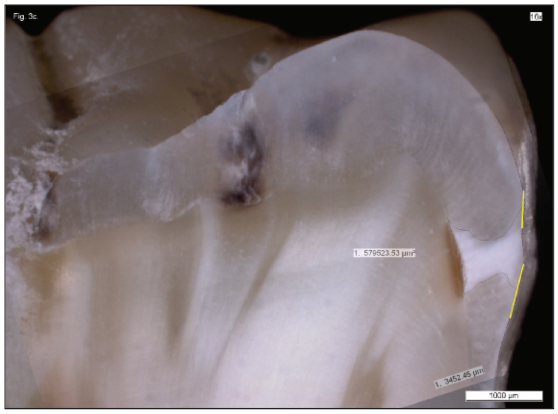

Figure 3c. *Sodium bicarbonate "excavation." Little or no carious tissue has been removed.*

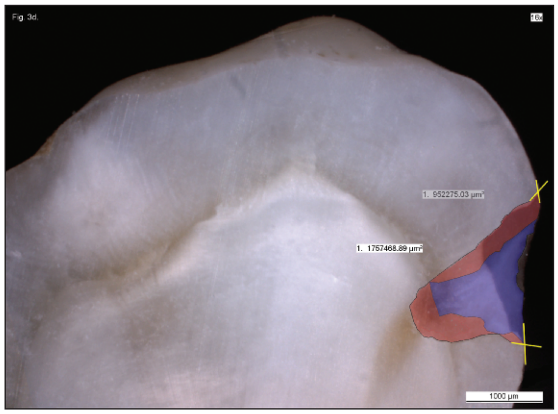

Figure 3d. *Bur excavation. There is no distinction between carious and healthy tissue, leading to over-excavation. The angles of the cut are also narrow when the bur was used.*

The treatment time for each group is given in Table 3. The bur was by far the fastest treatment option, with an average time of five seconds. Alumina required the shortest treatment time of the air abrasion techniques, with an average of 38 seconds.

Figures 3a-d present superimposed photographs of a tooth taken before and after the different treatments. The red shaded regions are areas of "over-excavation," the blue shaded regions are areas of "correct-excavation" and the green shaded regions are areas of "under-excavation." The yellow lines indicate the angles of the preparation border. Alumina air abrasion (Figure 3a) rendered a characteristic shallow and wide cut. It can also be noted that the angles of the preparation were wide, leading to smooth edges. This differed from the image produced by SEP treatment (Figure 3b). In this case, the cut was deeper and the bevel obtained was smaller, with a narrower angle. In all groups, remnants of carious enamel at the cavity walls (= under-excavation) were a common finding after treatment. However, this finding was more pronounced for the SEP and sodium bicarbonate groups. It should be noted that the SEP powder did not abrade carious dentin.

In specimens treated with sodium bicarbonate (Figure 3c), little or no carious tissue removal could be seen. In the case of specimens prepared with a bur (Figure 3d), over-excavation in three dimensions was common.

The SEM pictures support the findings illustrated in Figure 3. The region adjacent to the prepared enamel lesion was the primary focus. Alumina treatment also caused an irregular surface on healthy enamel, while neither SEP nor sodium bicarbonate affected non-carious enamel tissue. The bur treatment resulted in irregular preparation borders.

DISCUSSION

To date, most dentists have been trained to drill cavities with dental burs. This technique has obvious advantages, including multiple use, fast preparation, lower cost and the possibility of fully removing demineralization (enamel) and infected hard substance (dentin). On the other hand, this technique has some disadvantages, such as noise, vibration, pain (in dentin excavation) and the bur's inability to visually see to the kind of dental hard substance it cuts. Heat with potential pulp damage is reportedly still a problem in some countries, where the use of cooling water spray during preparation is uncommon.[21]

Air abrasion technology in dentistry has evolved since its introduction in the 1940s. Powders have been designed for cleaning purposes (sodium bicarbonate) or preparation measures (alumina). It has been postulated that air abrasion technology is more effective in hard enamel caries than in leathery dentin caries[6,13,17] and might be used in Class I or Class V restorations as well as in some strict indications for margin repairs.[8] However, to date, air abrasion technology has been blind to the kind of hard substance it abrades. V-shaped openings of fissures and significant loss of healthy enamel are known to be typical for air abrasion.[16,22-23] Although the use of selective tips and the correct inner diameter tip may result in precise cutting jets,[24] a reasonable compromise has to be found between air-abraded cavities with wide-shaped margins sacrificing sound enamel tissue and less invasive cavitations with a less favorable C-factor.[11]

Taking into account the ideal goal of minimally invasive dentistry (primarily irrespective of the filling material and its requirements), the authors of the current study investigated a new experimental powder for selective enamel excavation. They aimed to leave as much healthy enamel intact as possible, while cutting as much demineralized enamel as possible.

The results of the current study indicate that selective enamel powder (SEP) has the same cutting capabilities as bur or alumina when enamel caries extends into dentin. What needs to be taken into account is these results were obtained with a treatment time of one minute maximum for SEP. It could be extrapolated that even more carious enamel would be abraded without significantly abrading more healthy enamel with a treatment time of two-to-three minutes. In the case of caries solely confined to enamel, its excavation potential was not different from the negative control group with sodium bicarbonate. This could be due to the increased hardness of initial enamel lesions compared to undermined enamel caries with a larger pore volume. Furthermore, when the caries lesion was confined to enamel, there was a highly significant difference in excavation ability between SEP and alumina/bur. Therefore, when dentin was involved, the first hypothesis can be accepted, since SEP was as capable as alumina air abrasion and bur in removing enamel caries when caries extension involved dentin. Furthermore, a significantly different action of SEP could be observed when dentin was involved. The use of SEP can actually be differentiated by its ablative properties between dentin involvement and no dentin involvement. Thus, in terms of dental treatment, SEP seems to have diagnostic properties.

In clinical practice, it is sometimes difficult to predict whether or not a white spot already extends into dentin, although new methods of visual examination have proven to be more sensitive.[25] In some cases, the use of a dental probe might be iatrogenic, as it has been demonstrated that probed surfaces with initial lesions may convert an initial carious lesion into a cavity, which may promote further lesion development.[26] The use of radiographs is equally inadequate, as they often fail to detect caries in the earlier stages and are useless in buccal aspects.[14] Since the authors of the current study used natural caries lesions for this study, the range of lesion extension was from enamel lesions (D_1,D_2) to beginning dentin lesions (D_3). Another study examining air abrasion with bioactive glass on five teeth with artificial enamel caries showed a higher selectivity than alumina air abrasion.[19] However, apart from using a potentially hazardous powder, that study only examined artificial caries with a low number of treated teeth, rendering the results somewhat difficult to interpret.

The diagnostic property of alumina air abrasion has been proposed in an earlier study on occlusal surfaces;[9,27] however, the current authors find it has not yet been described for Class V defects. As SEP was able to abrade carious enamel as effectively as alumina in dentin-involving lesions but still remained four times more specific, it would be useful in the elimination of carious enamel in cavitated lesions. Furthermore, it could be used to diagnose the need for operative intervention as indicated by the presence of caries in patients with a high caries risk. It has been shown that it is difficult to reduce to an acceptable level the caries risk of high risk individuals.[28] Early operative intervention of progressing initial lesions, which, in this case would involve the clinical excavation of initial dentin caries, may prevent high risk patients from having to endure more invasive treatment in the future. This is in line with a recent systematic review that found possible insufficient evidence to support non-invasive treatment of early caries (D_1, D_2) (reported and commented by Ewoldsen & Koka[29]). In white spot lesions, surface discontinuities are the decision cut-off for operative intervention.[30] However, it was shown that microcavitations are present in most white spot lesions, including early enamel caries, and that their detection is dependent on the level of magnification.[31]

It is noteworthy that the negative control group (sodium bicarbonate) showed 18% abrasion capability when dentin caries was present, although sodium bicarbonate is supposed to have only cleansing properties. This could be explained by the fact that heavily undermined enamel is so brittle that it flakes off when subjected to any sort of mechanical pressure. Both the alumina and bur groups failed to show any difference in excavation selectivity with or without dentin involvement. The bur group had a shorter treatment time than the alumina group. However, the treatment time for the bur group would have been much longer had a finishing bur also been included.

The amount of healthy enamel removed was calculated in proportion to the size of the original lesion. As expected, the bur and alumina removed nearly 100% of healthy enamel, meaning that the preparation resulted in a cavity almost double the size of the original lesion. In contrast, SEP took only a quarter of the healthy enamel, making it four times more specific than alumina or bur treatment. In this case, the second hypothesis can be rejected, as SEP is more specific than alumina air abrasion in removing enamel caries. The control group with bicarbonate showed no signs of enamel over-excavation. However, bur treatment caused the greatest amount of over-excavation. This is mainly due to the lack of sensitivity of the bur to the decayed dental hard tissue, thus primarily relying on the operator's clinical skill.

As to the distance of the air abrasion nozzle to the surface, it has been recommended that the nozzle nearly touched the surface to be air abraded when using alumina.[32] This recommendation is due to the risk of over-excavation in lesion margin areas when the distance is increased. In the current study, the authors adjusted the distance for all groups to 2-3 mm. However, the cutting capability is dependent on many parameters, including grain size, grain shape, grain weight, but also kinetic energy and distance to the surface. Previous studies conducted by the current authors showed maximum energy at a distance of about 2 mm to 5 mm from the surface. This is due to air expansion at the nozzle outlet, leading to particle acceleration a few millimeters behind the nozzle end, resulting in a maximum kinetic energy at a distance of 2 mm to 5 mm. A greater distance will then reduce cutting efficiency due to powder dispersion and spraying a larger surface.

In order to combine and compare the single outcome parameters among the four treatment groups, an accuracy ratio was calculated. This accuracy ratio is new and has not been previously validated in the literature. It is impossible to compare the accuracy of treatment groups with only one outcome parameter. For example, although the bur group had high correct excavation (90%), it also had high over-excavation (100%). Sodium bicarbonate, on the other hand, had low over-excavation (0%) but also low correct preparation (10%). The accuracy of the different powders did not show significant differences between SEP and alumina. Variations in the factors M and N led to non-significant changes in accuracy, unless differences between M and N were 10-fold (for example, M=0.2, N=2) or greater. Since the differences were statistically significant for the single outcome parameters, the ratio itself might downsize the effect of its parameters.

CONCLUSIONS

The results of the current study showed that SEP was four times more specific than conventional alumina powder. Thus, SEP could be recommended as a method to diagnose and abrade enamel lesions that are questionable for operative intervention in patients with a high caries risk. If deemed necessary, further enamel excavation could be performed with the same powder. Furthermore, in cavitated lesions, SEP could be suitable to excavate carious enamel.

Acknowledgements

This study was partly funded by EMS, Nyon, Switzerland. The statistics were performed by Ms S Hayoz, Dept of Mathematics and Statistics, University of Bern, Bern, Switzerland.

(Received 1 February 2010; Accepted 9 April 2010)

References

1. Murdoch-Kinch CA & McLean ME (2003) Minimally invasive dentistry *Journal of the American Dental Association* **134(1)** 87-95.
2. Kidd EA (2004) How "clean" must a cavity be before restoration? *Caries Research* **38(3)** 305-313.
3. Beeley JA, Yip HK & Stevenson AG (2000) Chemochemical caries removal: A review of the techniques and latest developments *British Dental Journal* **188(8)** 427-430.

4. Banerjee A, Kidd EA & Watson TF (2000) *In vitro* evaluation of five alternative methods of carious dentine excavation *Caries Research* **34(2)** 144-150.

5. Rafique S, Fiske J & Banerjee A (2003) Clinical trial of an air-abrasion/chemomechanical operative procedure for the restorative treatment of dental patients *Caries Research* **37(5)** 360-364.

6. Banerjee A, Watson TF & Kidd EA (2000) Dentine caries excavation: A review of current clinical techniques *British Dental Journal* **188(9)** 476-482.

7. Black GV (1950) Airbrasive: Some fundamentals *Journal of the American Dental Association* **41(6)** 701-710.

8. Christensen GJ (1998) Air abrasion tooth cutting: State of the art *Journal of the American Dental Association* **129(4)** 484-485.

9. Goldstein RE & Parkins FM (1995) Using air-abrasive technology to diagnose and restore pit and fissure caries *Journal of the American Dental Association* **126(6)** 761-766.

10. Rodrigues Jde A, de Vita TM & Cordeiro Rde C (2008) *In vitro* evaluation of the influence of air abrasion on detection of occlusal caries lesions in primary teeth *Pediatric Dentistry* **30(1)** 15-18.

11. Antunes LA, Pedro RL, Vieira AS & Maia LC (2008) Effectiveness of high speed instrument and air abrasion on different dental substrates *Brazilian Oral Research* **22(3)** 235-241.

12. Wright GZ, Hatibovic-Kofman S, Millenaar DW & Braverman I (1999) The safety and efficacy of treatment with air abrasion technology *International Journal of Paediatric Dentistry* **9(2)** 133-140.

13. Paolinelis G, Watson TF & Banerjee A (2006) Microhardness as a predictor of sound and carious dentine removal using alumina air abrasion *Caries Research* **40(4)** 292-295.

14. Neuhaus KW, Ellwood R, Lussi A & Pitts NB (2009) Traditional lesion detection aids *Monographs in Oral Science* **21** 42-51.

15. Ricketts DN & Pitts NB (2009) Novel operative treatment options *Monographs in Oral Science* **21** 174-187.

16. Santos-Pinto L, Peruchi C, Marker VA & Cordeiro R (2001) Effect of handpiece tip design on the cutting efficiency of an air abrasion system *American Journal of Dentistry* **14(6)** 397-401.

17. Horiguchi S, Yamada T, Inokoshi S & Tagami J (1998) Selective caries removal with air abrasion *Operative Dentistry* **23(5)** 236-243.

18. Banerjee A, Paolinelis G, Socker M, McDonald F & Watson TF (2008) An *in vitro* investigation of the effectiveness of bioactive glass air-abrasion in the "selective" removal of orthodontic resin adhesive *European Journal of Oral Science* **116(5)** 488-492.

19. Pabari H, Banerjee A, Paolinelis G & Watson TF (2008) Selective removal of demineralised enamel *in-vitro*, using bioactive glass air-abrasion PEF IADR London abstract #0889.

20. Zero DT, Rahbek I, Fu J, Proskin HM & Featherstone JD (1990) Comparison of the iodide permeability test, the surface microhardness test, and mineral dissolution of bovine enamel following acid challenge *Caries Research* **24(3)** 181-188.

21. Christensen GJ (1996) Cavity preparation: Cutting or abrasion? *Journal of the American Dental Association* **127(11)** 1651-1654.

22. Santos-Pinto L, Peruchi C, Marker VA & Cordeiro R (2001) Evaluation of cutting patterns produced with air-abrasion systems using different tip designs *Operative Dentistry* **26(3)** 308-312.

23. Antunes LA, Vieira AS, Alves Dos Santos MP & Maia LC (2008) Influence of kinetic cavity preparation devices on dental topography: An *in vitro* study *The Journal of Contemporary Dental Practice* **9(2)** 146-154.

24. Peruchi C, Santos-Pinto L, Santos-Pinto A & Barbosa e Silva E (2002) Evaluation of cutting patterns produced in primary teeth by an air-abrasion system *Quintessence International* **33(4)** 279-283.

25. Topping GV & Pitts NB (2009) Clinical visual caries detection *Monographs in Oral Science* **21** 15-41.

26. Kühnisch J, Dietz W, Stösser L, Hickel R & Heinrich-Weltzien R (2007) Effects of dental probing on occlusal surfaces—a scanning electron microscopy evaluation *Caries Research* **41(1)** 43-48.

27. Goldstein RE & Parkins FM (1994) Air-abrasive technology: Its new role in restorative dentistry *Journal of the American Dental Association* **125(5)** 551-557.

28. Hausen H (2008) Caries prediction In: Fejerskov O & Kidd E (eds) *Dental Caries: The Disease and its Clinical Management* 2nd edition Blackwell Munksgaard, Oxford 527-542.

29. Ewoldsen N & Koka S (2010) There are no clearly superior methods for diagnosing, predicting, and non-invasively treating dental caries *The Journal of Evidence-Based Dental Practice* **10(1)** 16-17.

30. Baelum V (2010) What is an appropriate caries diagnosis? *Acta Odontologica Scandinavica* **68(2)** 65-79.

31. Kielbassa AM, Paris S, Lussi A & Meyer-Lueckel H (2006) Evaluation of cavitations in proximal caries at various magnification levels *in vitro Journal of Dentistry* **34(10)** 817-822.

32. Laurell KA & Hess JA (1995) Scanning electron micrographic effects of air-abrasion cavity preparation on human enamel and dentin *Quintessence International* **26(2)** 139-144.