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The effect of air-abrasion on the susceptibility of sound enamel to acid challenge

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ABSTRACT

Objective: To evaluate the effect of air-abrasion using three abrasive powders, on the susceptibility of sound enamel to an acid challenge.
Methods: 40 human enamel samples were flattened, polished and assigned to 4 experimental groups ($n = 10$); a: alumina air-abrasion, b: sodium bicarbonate air-abrasion, c: bioactive glass (BAG) air-abrasion and d: no surface treatment (control). White light confocal profilometry was used to measure the step height enamel loss of the abraded area within each sample at three stages; after sample preparation (baseline), after air-abrasion and finally after exposing the samples to pH-cycling for 10 days. Data was analysed statistically using one-way ANOVA with Tukey's HSD post-hoc tests ($p < 0.05$). Unique prismatic structures generated by abrasion and subsequent pH cycling were imaged using multiphoton excitation microscopy, exploiting strong autofluorescence properties of the enamel without labelling. *Z*-stacks of treated and equivalent control surfaces were used to generate non-destructively 3-dimensional surface profiles similar to those produced by scanning electron microscopy.
Results: There was no significant difference in the step height enamel loss after initial surface air-abrasion compared to the negative control group. However, a significant increase in the step height enamel loss was observed in the alumina air-abraded samples after pH-cycling compared to the negative control ($p < 0.05$). Sodium bicarbonate as well as BAG air-abrasion exhibited similar enamel surface loss to that detected in the negative control group ($p > 0.05$). Surface profile examination revealed a deposition effect across sodium bicarbonate and BAG-abraded groups.
Conclusion: This study demonstrates the importance of powder selection when using air abrasion technology in clinical dentistry. Pre-treating the enamel surface with alumina air-abrasion significantly increased its susceptibility to acid challenge. Therefore, when using alumina air-abrasion clinically, clinicians must be aware that abrading sound enamel excessively renders that surface more susceptible to the effects of acid erosion. BAG and sodium bicarbonate powders were less invasive when compared to the alumina powder, supporting their use for controlled surface stain removal from enamel where indicated clinically.

1. Introduction

Minimally invasive dentistry (MID) advocates the maximum preservation of intact and repairable dental hard tissues through minimising the unnecessary alteration of healthy tooth structure [1]. Ideally, dental polishing techniques aim at removing surface stains efficiently and selectively without altering the underlying sound tooth surface. In air-abrasion, abrasive particles are emitted from a nozzle in an air stream and aimed at the tooth surface. These particles impact the hard tooth surface at high velocity, resulting in the transfer of kinetic energy and the resulting physical removal of adherent extrinsic surface stains/debris [2]. Air-abrasion eliminates bone vibration and minimises a rise in tissue temperature and consequently, reduces the unpleasant characteristics associated with the use of conventional mechanical instruments [3,4]. However, air-abrasion can result in alterations in an intact enamel surface due to its lack of clinical tactile feedback during use leading to operator over-use on the tooth surface concerned [5]. Hence, air-abrasion operating parameters should be subjected to precise

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control, and the polishing powder should be minimally invasive, not damaging sound tissue whilst still efficient at surface stain removal at the same time [6,7].

Historically, different air-abrasion powders have been used in clinical practice including alumina, calcium carbonate, glycine and sodium bicarbonate. Bioactive glass 45S5 (BAG) powder has been introduced due to its unique properties such as antibacterial effects, remineralisation potential and selective removal of softer diseased/damaged tooth structure [8,9]. A summary of the properties of a selection of clinical powders currently available can be found in Table 1. To the authors' knowledge, there are no previous published studies assessing the susceptibility of dental enamel to acid challenge following the air-abrasion procedures using BAG powder. Therefore, the aim of this study was to compare the effect of three different powders (sodium bicarbonate, alumina and BAG) on the susceptibility of sound dental enamel to subsequent acid challenge. The assessment was conducted in vitro using white light confocal profilometry, a "gold standard" method for assessing enamel surface loss [10], and multiphoton excitation fluorescence to examine surface topography. Two null hypotheses investigated in this study were (i) the use of air-abrasion has no effect on increasing the susceptibility of dental enamel to acid challenge when compared to a negative control group, and (ii) there is no difference in the level of mineral loss using different powders.

2. Materials and methods

Extracted, caries-free human molars were collected using ethics approval reviewed by the East Central London Research Ethics Committee (Reference 10/H0721/55), stored in refrigerated de-ionised water and used within a month from extraction. One buccal enamel slab from each tooth was sectioned using a diamond-wafering blade (XL 12205, Benetec Ltd., London, UK). Forty enamel slabs were included in this study after inspecting the integrity of the surface using a confocal tandem-scanning microscope (TSM) (Noran Instruments, Middleton, WI, USA), with an ×20 air objective in reflection scanning mode. The samples were included face down in acrylic resin using a hard-anodized aluminium and brass sample former (Syndicad Ingenieurbüro, München, Germany). The outer enamel layer was removed using a water-cooled rotating polishing machine (Meta-Serv 3000 Grinder-Polisher, Buehler, Lake Bluff, Illinois, USA) using a sequential polishing protocol; 180-grit silica carbide disk (Versocit, Struers A/S, Copenhagen, Denmark) for 5 s, 600-grit for 10 s, 1200-grit for 20 s, 2400-grit for 30 and 4000-grit for 45 s, followed by 3 min of ultrasonication to remove the smear layer at the enamel surface. This standardised polishing protocol permitted the removal of approximately 400 μm from the outer enamel layer.

Each samples' surface topography was scanned prior to surface air-abrasion, after surface air-abrasion and after subsequent pH-cycling, using non-contact white light confocal profilometry (Xyris™ 4000 WL, TaiCaan™ Technologies Ltd., Southampton, UK) with a 10 μm step-over distance and 10 nm vertical resolution. The quantification flatness of the profilometry system used in this study was calibrated using the National Physical Laboratory optical flat. The maximum of the flatness error in the present system is 0.5 μm. Therefore, the baseline required flatness of the samples included in the present study was the step height value of less than 0.5 μm.

A standard scan area (3 mm × 2 mm) was selected on the enamel sample surface, including the targeted area in the centre surrounded by sound enamel acting as an internal sample reference level (control). The resulting topographic images were analysed using surface metrology software (Boddies v1.81, TaiCaan™ Technologies Ltd., Southampton, UK) by levelling the reference peripheral sound enamel areas to a "zero" plane. The step height of the lesion surface in relation to the sound enamel level was obtained by averaging five measurements taken within each sample. The differences in the enamel step height for each sample were calculated between pre-abrasion and post-abrasion, and between and post-abrasion and post-pH-cycling (Fig. 1).

An Aquacut™ clinical air-abrasion unit (Velopex, Harlesden, UK) was used to treat the enamel surface for 5 sec using the following operating parameters: air pressure, 60 psi; powder flow rate dial, 3 g/min; nozzle angle, 90°; nozzle-surface distance, 3 mm and the internal nozzle diameter, 600 μm [6]. The samples were allocated into four experimental groups ($n = 10$) according to the

Table 1
The advantages and disadvantages of a selection of commercially available clinical air polishing/abrasion powders.

Powder	Advantages	Disadvantages
Alpha alumina (Al_2O_3)	- Efficient removal of extrinsic stains [5]	- Non-selective, highly abrasive on tooth structure [11] - It is an inert powder and therefore, does not have a beneficial effect on tooth structure [12]
Aluminium trihydroxide ($Al(OH)_3$)	- Useful in patients on sodium restricted diets [13]	- Avoid using on glass ionomers, resin composites, luting cements and cast restorations [14]
Bioactive glass (BAG)	- With the correct parameters, can effectively remove extrinsic stains [5] - Bioactive and biocompatible. - Reduces dentine hypersensitivity [15] - Greater whitening effect and increased patient comfort when compared to sodium bicarbonate [23]	- Potentially longer clinical time required for its use
Calcium carbonate ($CaCO_3$)	- Efficient and effective stain removal demonstrated however more clinical studies required to determine abrasive potential [13]	- Greater defects produced on radicular dentine when compare to sodium bicarbonate [16]
Glycine	- Produces less surface damage on restorative materials when compared to sodium bicarbonate powders. [16] - Removes plaque more efficiently than hand instruments [17]	
Sodium bicarbonate ($NaHCO_3$)	- Efficient removal of extrinsic stains [18]	- Prolonged use on cementum, dentine and composite is contraindicated as can result in excess tissue removal [12,19] - Does not remove stains as effectively as BAG, increased dentine hypersensitivity [23]