Air-Abrasion in Dentistry: A Short Review of the Materials and Performance Parameters

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ABSTRACT

The selection of abrasive material and parameters of the Air-Abrasion device for a particular application is a crucial detail. However, there are no standard recommendations or manuals for choosing these details; the operator must depend on his experience and knowledge of the procedure to select the best possible material and set of parameters. This short review attempts to identify some of the effects that the selection of material and parameters could have on the performance of the Air-Abrasion procedure for a particular application. The material and parameter data are collected from various studies and categorized according to the most popular materials in use right now. These studies are then analyzed to arrive at some inferences on the performance of Air-Abrasion materials and parameters. This review arrives at a few conclusions on the effectiveness of a material and parameter set, and that there is potential for developments in the area of standardizing parameter selection; also, there is scope for further studies on Bio-Active Glass as an alternative to the materials currently used in Air-Abrasion.

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Keyword

Air Abrasion; Particle Effects; Alumina; Sodium Bicarbonate; Glycine; Erythritol

Introduction

The air-abrasive process, also known as “abrasive” and abbreviated by its pioneer R. B. Black in 1945, is a dental technique that involves using finely divided particles. These particles are sprayed in a focused and pinpoint stream through compressed air to effectively remove dental tissues [1]. Black felt the need to introduce, such a device to ease the patient’s dread of the dental drill. The author suggests that this technique eliminates the psychological and physical discomfort experienced by the patient when a drill with a rotary bur is used as the treatment. The discomfort experienced during dental procedures with rotary burs is primarily attributed to factors such as pressure, vibrations, heat, and pain resulting from direct mechanical stimulation [1,2].

Air abrasion is used in a variety of procedures in dentistry, and studies have been performed on various aspects of the applications, such as caries removal, periodontal surgery, orthodontic treatment, pre-treatment of enamel, pre-treatment of resin composites, dental restorations, and cavity preparation. We will analyze the materials used and parameters associated with the air-abrasion tool in these studies.

This review paper aims to provide a comprehensive overview of the abrasive materials, devices, and settings utilized in various tasks. Specifically, it focuses on the examination of the abrasive material and parameters involved, including propellant pressure, the angle of the nozzle to the target, the distance between the nozzle tip and the target, and the duration of abrasion [3]. The objective is to investigate the impact of these parameters on the performance of the air-abrasion technique, particularly about specific measurable effects [3].

The following (Table 1) lists some of the notable review articles related to air abrasion, and it is clear that no other review explicitly addresses the effects of parameters and material used in air abrasion.

Effects of Parameters

The parameters discussed in the following sub-sections are critical in influencing air abrasion's effectiveness for a particular application. Therefore, the operator must possess knowledge and familiarity with the optimal operating parameters/settings to achieve the best possible result [3].

Particle Size and Pressure

Air abrasion works on converting the mechanical energy of compressed air to kinetic energy [1]. The size of the abrasive particles used in air abrasion is a critical factor. Smaller particles have less mass and are generally easier to accelerate and control with compressed air. These particles can remove very fine layers of material with high precision. Nevertheless, smaller particles may have limitations in terms of effectively removing thicker or tougher materials. Due to their smaller size, they may require a longer duration to abrade surfaces compared to larger particles. The pressure of the compressed air used to propel abrasive particles is a significant control parameter. Higher pressure results in increased kinetic energy for the particles. Higher pressure accelerates the abrasive particles to higher velocities, which can be advantageous for removing materials quickly and efficiently. The pressure level needs adjusting according to the material being treated. The select of particle size and pressure should be carefully balanced, taking into account the specific application and desired outcome. Smaller particles and lower

Table 1: List of existing review papers

Author	Year	Title	Area of review
Banerjee et al. [4]	2002	Air-Abrasion: Its Uses and Abuses	A broad look at the tools and applications of air abrasion in dentistry.
Hegde et al. [5]	2010	A new dimension to conservative dentistry: air abrasion	A review of development, clinical uses, and essential accessories required for air abrasion.
Aurelio et al. [6]	2016	Does air particle abrasion affect the flexural strength and phase transformation of Y-TZP ceramics? A systematic review and meta-analysis	A review of the effect of air abrasion on mechanical strength and phase transformation of Y-TZP.
Huang et al. [7]	2019	Intraoral Air Abrasion: A review of devices, materials, evidence, and clinical applications in restorative dentistry	A review of devices and evidence, and a study particularly aimed at alumina air abrasion.
Moharrami et al. [8]	2019	Effects of air abrasive decontamination on titanium surfaces: A systematic review of in vitro studies	A study focused on air abrasion effects specifically on titanium surfaces used in prosthetic dentistry and other applications.

pressure may be preferable for important precision and minimal material removal. Conversely, larger particles and higher pressure may be needed for faster material removal in industrial applications.

Distance and Angle to Target

The distance between the nozzle emitting the abrasive particles and the target surface is known as the "distance of impact" or the "Standoff distance. The material diverges and spreads out as it moves away from the tip of the nozzle [2]. When the nozzle is closer to the surface, the abrasive particles have a shorter distance to travel, resulting in a more concentrated and intense impact. This can be advantageous for tasks requiring rapid material removal. On the other hand, when the nozzle is farther from the surface, the abrasive particles have a longer distance to travel, and their impact is less intense.

The angle of impact, which refers to the angle at which abrasive particles strike the surface, plays a crucial role in the material removal process. It can significantly influence the efficiency and direction of material removal. When the abrasive particles hit the surface at a perpendicular angle (80-90 degrees), they are generally more effective at removing material directly beneath the nozzle. On the other hand, an oblique angle of impact may result in material removal along a specific path. In situations, in which complex shapes or precise material removal patterns are required, operators carefully adjust, and control the angle of impact to achieve the desired results.

Treatment Time and Cutting Speed

The duration of treatment depends on the quantity of material for removal, and whether the abrasion is performed statically or dynamically. In the case of dynamic cutting, the treatment time is influenced by the cutting speed, which refers to the rate, at which material is removed from the target. Maintaining an appropriate cutting speed is essential to ensure the desired level of economy and efficiency during the process [2].

Treatment time for air abrasion refers to the duration required to complete a specific dental or material removal procedure using air abrasion equipment. It is typically measured in seconds or minutes. The treatment time can be influenced by factors, such as the type and hardness of the dental material removed. Harder materials generally require longer treatment times compared to softer ones.

The depth of material removal needed for the dental procedure affects treatment time. Shallow procedures will generally take less time than deeper ones. The experience and skill of the dental professional using the equipment play a role in treatment time. In dental applications, minimizing treatment time is desirable to reduce patient discomfort and optimize chairside efficiency. However, it should be balanced with the need for precision and controlled material removal.

Cutting speed in air abrasion refers to the velocity, at which the abrasive particles are propelled from the nozzle and impact the target surface. It is measured in units like meters per second (m/s). The pressure of the compressed air used to propel the abrasive particles affects cutting speed. Higher pressure results in higher particle velocities.

The design and shape of the nozzle play a significant role in determining the direction and concentration of the abrasive stream, which, in turn, affects the cutting speed. Additionally, smaller abrasive particles are typically easier to accelerate, leading to higher cutting speeds. The distance between the nozzle and the target surface also influences the cutting speed, with closer proximity often resulting in more intense and faster material removal.

Material and Methods

In this compilation, various studies have been collected that focus on the selection of abrasive materials, and we examine the parameters utilized in these studies. After going through several studies, it was seen that the most commonly used materials are Alumina (Al_2O_3), and Sodium Bicarbonate to some extent; but recent studies focus on the advantages of Bio-Active Glass (BAG). In this review, we will examine studies that specifically investigate the use of Alumina and Sodium Bicarbonate as abrasive materials. Additionally, we will explore comparative studies that compare the effectiveness of Alumina and Bioactive Glass (BAG). Furthermore, we will analyze comparative studies that involve Sodium Bicarbonate, Glycine, and Erythritol being compared against Alumina and BAG. It is important to note that studies comparing air abrasion with other methods have been excluded from this review.

Alumina

Alumina or Aluminium oxide was recognized quite early on, in fact by Robert Black in 1945, as being a near-ideal material for the air-abrasion process. The authors identified several advantages of this material that render it suitable for the air-abrasion process. These include its non-toxic nature, chemical stability, lack of specific affinity for water, free-flowing properties, colorlessness, affordability, and ready availability [1,9]. Additionally, experimental data from [10,11] indicates that the dust particles generated during the Alumina air-abrasion process pose no health hazards to either the operator or the patient.

The various studies, which use Alumina as the abrasive material are collected in Table 2 along with the data on parameters, and a focus on how a particular parameter value or a group of parameters might influence the results.

Sodium Bicarbonate, Glycine and Erythritol

Sodium Bicarbonate (SB), Glycine, and Erythritol are particles that are considered suitable for air-abrasion polishing applications. The conventionally used SB particles of larger size are regarded to be more abrasive on soft as well as hard tissues and restorative materials [23-26]. The use of Sodium Bicarbonate (SB) as an abrasive material has been observed to cause increased wear of composite resins. This wear can have implications both in terms of oral health and aesthetic appearance [27-30]. Moreover, it is important to note that the use of abrasive particles can lead to increased surface roughness. This enhanced roughness creates an environment that promotes biofilm formation and bacterial adhesion. Consequently, there is an increased risk of developing secondary caries and potential gingival inflammation [31-34].

The various studies, which use SB, Glycine, and Erythritol as the abrasive material are collected in Table 3 along with the data on parameters, and a focus on how a particular parameter value or a group of parameters might influence the results.

Comparative studies

In the previous sections, we reviewed studies focusing on conventionally used particles. In this section, we will shift our attention to one of the emerging novel materials known as Bio-Active Glass (BAG). Table 4 presents a direct comparison of BAG with various conventionally used materials.

Discussion

The inferences made from the collection of various materials and parameters used in air abrasion applications are important in a clinical setting, where the professional performing the procedure must be well-versed in the outcome of their choice of material and set of parameters. This knowledge proves useful in increasing the procedure's efficiency and lowering the time required [3]. Tables 2-4 encapsulate the performance of the major and popular materials, such as Alumina, Sodium Bicarbonate, Glycine, and Erythritol, as well, as the newer Bio-Active Glass material. Some of the main performance variables are discussed below by drawing inferences from Tables 2-4.

Table 2: Parameters used in Alumina abrasion applications

Author (year)	Measured effect	Parameters					Results & Conclusion
		Average Particle size (s) (μm)	Pressure (kPa)	Angle (°)	Distance (mm)	Treatment Time (static)/Relative speed (dynamic)	Summary
Paolinelis et al. (2006) [12]	Knoop Hardness Number (KHN)	71	413.7	90°	3	0.15 mm/s	The alumina abrasion particles were more effective in removing healthy dentine with higher KHN than carious dentine with lower KHN.
Motisuki et al. (2006) [13]	N/A	1) 27 2) 50 3) 125	482.6	90°	1	15 s	The 125 μm particles penetrated the soft carious tissue rather than cutting them and ended up cutting healthy dentine more efficiently. 27 μm and 50 μm particle sizes perform the task better under the selected parameters.
Addison et al. (2007) [14]	Bi-axial flexure strength and surface roughness	1) 25 2) 50 3) 110	1) 241.3 2) 482.6	1) 45° 2) 90	20	30 s	The 25 μm particle had the least impact on strength, resulting in an unpredictable defect distribution on the surface. The 50 μm particle at 482.6 kPa and 45° produced a more even and homogeneous distribution of surface defects.
Halpern et al. (2010) [15]	Shear bond strength of brackets	1) 25 2) 50 3) 100	482.6	90° to buccal surface	NM	<1 s	100 μm particle size gives the largest bond strength of 10.24 MPa.
Özcan et al. (2013) [16]	Bi-axial flexural strength	1) 30 2) 50 3) 110	280	90	10	20 s	The 50 μm alumina particles decreased the bi-axial flexural strength as well as the Weibull modulus. The silica-coated alumina of 30 μm and 110 μm is seen to be the opposite.
Coskun et al. (2018) [17]	Shear bond strength	1)50 2)110 3)250	1)172.37 2)344.74 3)517.12	90	1)10 2)20 3)30	1)10 s 2)20 s 3)30 s	110 μm with 517.12 kPa and 20 mm distance results in the roughest surface. The same particle size and pressure result in maximum shear bond strength.
Lümkemann et al. (2018) [18]	Tensile bond strength, acidity parameters, and surface properties	50	1)50 2)200 3)400	45	10	10 s	Air abrasion pressure affects surface roughness parameters but has no bearing on the tensile bond strength.
Martins et al. (2019) [19]	Bond strength	1) 30 2) 50 3) 110 4) 120	1: 50 2: 280	90	10	1: 15 s 2: 20 s	The surface roughness varies from highest to lowest corresponding to the descending order of particle size used when the zirconia is untreated.
Salerno et al. (2019) [20]	Surface profile and characteristics	27	500	1: 45 2: 90	1: 1 mm 2: 2 mm 3: 5 mm	1: 10 s 2: 20 s 3: 30 s	45° incidence angle helps to reduce the damage to the target material.

Author (year)	Measured effect	Parameters					Results & Conclusion
		Average Particle size (s) (μm)	Pressure (kPa)	Angle (°)	Distance (mm)	Treatment Time (static)/Relative speed (dynamic)	Summary
Kim et al. (2020) [21]	Flexural strength	1) 50 2) 110	1) 100 2) 200 3) 300	90	10	10 s	It is seen that the flexural strength decreases for both 50 μm and 110 μm particle size at higher pressures (200-300 kPa).
Zhang et al. (2020) [22]	Flexural strength	50	1) 100 2) 200 3) 300 4) 400 5) 500	NM	10	15 s/cm^2	It is observed that the higher range of the chosen pressures (300 kPa, 400 kPa, & 500 kPa) causes a decrease in flexural strength.

N/A: Not Applicable, NM: Not Mentioned

Cutting Efficiency

The cutting characteristics of the air abrasion device are primarily attributed to the kinetic energy of the particles involved [2]. Based on the given information, it can be inferred that the cutting efficiency of an air abrasion device depends on the mass of the particles, related to their size, as well as the velocity, at which they exit the nozzle. If the velocity remains constant, achieved through settings on the propelling device, then the cutting efficiency would primarily rely on the mass or density of the particles. In the case of Alumina, the data presented in Table 2 indicates that larger-sized Alumina particles demonstrate equal cutting efficiency when removing both carious and healthy dentine [12,13]. This is an undesirable property, which persists even when the particle size of Alumina is smaller, although to a lesser extent.

However, Table 4 shows that BAG with a particle size similar to that of the Alumina has better cutting efficiency and can selectively cut through undesirable material and conserve the desirable material even at higher pressures.

Surface topology

In various applications, such as orthodontics, implants, and polishing, the surface topology is desired to possess specific properties to fulfill the requirements of each application. For instance, in orthodontics, shear bond strength is crucial for the adhesion of orthodontic brackets. In the case of implants, the surface should promote osseointegration and provide stability. In polishing applications, the surface should be designed to minimize biofilm retention. Therefore, the surface topology is tailored to meet the specific needs and desired properties of each application [37,40,41,52,53].

The surface characteristics of dental materials are affected the most due to SB applied perpendicular to the material, and Glycine and Erythritol cause lower roughness, possibly due to them being softer and having smaller particle sizes (Table 3). The increased surface roughness due to SB may be desirable in orthodontics applications, in which the brackets are bonded more securely. In the case of polishing and cleaning the surface to remove biofilm, glycine, and Erythritol, applied at angles between 30º - 60º seem to be more effective.

Remineralization

Many studies have looked at the prevention of caries in dentine and fluoride has been identified as an effective mitigating agent. The remineralization process repopulates dentine's mineral content by using fluoride as a catalyst.

This is an important factor in this review because the fluoride-containing BAG is the only material to re-mineralize dentine and help prevent caries.

Conclusion

This short review looked at the common materials available for the air-abrasion procedure, and the parameters that affect their performance. Bio-Active Glass, or a combination of BAG and Alumina provides the best cutting efficiency for smaller particle size and moderate pressure. Sodium bicarbonate is more effective for orthodontic applications because it provides more surface roughness and hence, better bond strength, but it may not be

Table 3: Parameters used in Sodium Bicarbonate (SB), Glycine, and Erythritol applications

Author (year)	Material/ Materials compared	Measured effect	Parameters					Results & Conclusion
			Average Particle size (s) (μm)	Pressure (kPa)	Angle (°)	Distance (mm)	Treatment Time (static)/ Relative speed (dynamic)	Summary
Shibli et al. (2003) [35]	SB	Number and morphology of fibroblasts	NM	NM	45	NM	30 s	Proliferation of the cell was reduced due to the air abrasion but no effect was seen on the morphology of the cell.
Engel et al. (2009) [28]	1: SB 2: Glycine	Surface measurement of sealant removal	NM	NM	NM	5	10 s	Air abrasion after the application of a sealant is not advisable since even a small amount of damage due to glycine makes the sealant redundant.
Vieira et al. (2012) [36]	SB	Bacteria removal efficacy	NM	482.63	NM	10	60 s	Bacteria removal under the given parameters was successful.
Parmagnani et al. (2012) [37]	SB	Surface micro-morphology	4	230	90	5	10 s	Air abrasion causes increased surface friction resistance and surface changes on metal brackets.
Tanaka et al. (2012) [38]	SB	Resistance to sliding	NM	230	90	2	10 s	Resistance to sliding increased due to air abrasion using sodium bicarbonate.
Drago et al. (2014) [39]	1: Glycine 2: Erythritol	Biofilm removal	1:25 2:14	NM	30-60	20	5 s	Erythritol was found to be a competent alternative to glycine for biofilm removal.
Menini et al. (2015) [40]	1: Glycine 2: SB	Surface morphology	1:<65 2:<150	NM	60	5	NM	Both powders do not produce damage to the surface morphology.
Sinjari et al. (2019) [41]	1: Glycine 2: Erythritol 3: SB	Surface roughness	1: 65 2: 14 3: 65	310	90	1 cm	10 s	The samples treated with erythritol have the lowest surface roughness due to the smaller particle size.

N/A: Not Applicable, NM: Not Mentioned, SB: Sodium Bicarbonate

Table 4: Parameters used in studies involving the comparison of different particles

Author (year)	Materials compared	Measured effect	Parameters					Results & Conclusion
			Avg. Particle size (s) (μm)	Pressure (kPa)	Angle (°)	Distance (mm)	Treatment Time (static) / Relative speed (dynamic)	Summary
Paolinelis et al. (2008) [42]	1: Alumina powder 2: Bioactive glass (BAG)	Atomic ratios of air-abrasive tracers	1: 27 2: 29	1) 138 2) 413 3) 689	90	5	1 mm/s	Retention of particles on dentine is lower corresponding to increasing pressure. BAG cut sound and carious dentine at a similar rate.
Banerjee et al. (2011) [43]	1: Alumina powder 2: Bioactive Glass (45S5)	Visual analysis of lesion boundary	1: 27 2: 25	413.7	Cusp Incline	15	NM	Alumina powder causes over-preparation of cavities in both sound and carious dentine. The 45S5 seems to selectively remove caries from teeth with lesions but does not remove sound surfaces in bulk.
Külünk et al. (2011) [44]	1: Alumina 2: Synthetic Diamond 3: Cubic boron nitride	Shear bond strength of ceramic to metal alloy	1: 50 & 110 2: 35 3: 70	315	NM	10	15 s	The 110 μm Alumina provides superior shear bond strength when compared to the other candidates.
Khalefa et al. (2013) [45]	1: Sodium bicarbonate 2: Glycine 3: Calcium carbonate	Surface roughness	NM	NM	90	14.5-15.5	60 s	The Sodium bicarbonate and Glycine cause little change to the surface roughness and the enamel. Whereas, Calcium carbonate is found to be more aggressive than necessary.
Milly et al. (2014) [46]	1: Alumina 2: BAG	Cutting efficiency	NM	413.685	90	2	NM	BAG is noted to have more controllable and conservative cutting efficiency.
Tan et al. (2015) [47]	1: Alumina 2: Fluoride-containing BAG (Lab prepared)	Cutting efficiency	1: 29 2: 59	552	90	1	10 s	The fluoride-containing BAG is significantly better at cutting than the alumina, and it also took lesser particle output to achieve this.
Farooq et al. (2016) [48]	1: Alumina 2: BAG	Cutting efficiency	1:29 2:(25-45)	600-700	NM	1	15 s	A combination of Alumina and BAG has the potential for better cutting of enamel and also provides remineralization.
Hassan et al. (2017) [49]	1: Alumina 2: BAG	Cutting efficiency	20-25	600-700	NM	1	1: 2.96 s 2: 23.01 s	Both particles have comparable cutting efficiency.
Wei et al. (2017) [50]	1: SB 2: Glycine 3: Calcium carbonate	Cleaning efficiency and surface damage	1:76 2:25 3:55	1) 172.37 2) 241.32 3) 310.26 4) 379.21	30-90	1-2	2 min	At the lowest pressure, Calcium carbonate has the highest cleaning capacity. As pressure increases, the efficiency of glycine improves but Calcium carbonate is still superior, followed by SB.
Sultan et al. (2019) [51]	1: BAG 2: SB 3: Glycine	Dentine loss	NM	551.5	90	4	5-10 s	Dentine loss is minimum in the case of the BAG.

N/A: Not Applicable, NM: Not Mentioned, SB: Sodium Bicarbonate suitable for surface cleaning applications for the same reason. Glycine and Erythritol are more suitable for surface cleaning and biofilm applications when smaller-sized particles are used at a smaller incidence angle. BAG has the capability for remineralization, which none of the other materials can do.

The selection of the right parameter for a particular task is not standardized and depends on the experience of the person operating the Air-Abrasion equipment. The development of methods to select the optimum set of parameters and materials depending on a variety of scenarios would make air-abrasion procedures easier, faster, more efficient, and hence cost-effective. Therefore, while Alumina is widely used in many applications, Bio-Active Glass (BAG) has emerged as a promising alternative material with the potential to be equally effective. BAG offers additional properties that Alumina may not possess, making it a compelling option for specific air-abrasion procedures. Further research and exploration of BAG as an alternative material in air-abrasion procedures holds great potential for advancements in the field.

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Authors' Contribution

The review idea was conceived by LG. Keni and A. Eram. M. Zuber authored the paper's introduction, while R. Vinay KR and Ch. K N compiled the relevant literature. LG. Keni and S. Kumar contributed to the literature survey. A. Eram and DD. Shetty handled the reviewing and editing process. P. S and A. Eram authored the conclusion and discussion sections. The work was supervised and proofread by M. Zuber and Ch. K N. The final version of the manuscript was reviewed, modified, and approved by all the authors.

Conflict of Interest

None

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