تأثير متغيرات الضغط الهوائي ومعدل تدفق الجزيئات الساحلة td فعالية القطع الساكن في نظام السحل الهوائي – دراسة مخبرية

حسام مللي*

الملخص

خلفية البحث وهدفه: هدف هذا البحث إلى تقييم أثر الضغط الهوائي و معدل تدفق جزيئات المادة الساحلة في معدل القطع الساكن في أجهزة السحل الهوائي باستخدام جزيئات الألومينا و الزجاج المنشط حيوياً.

مواد البحث وطرائقه: شملت المتغيرات المدروسة الضغط الهوائي بقيم: 20 – 40 –60 –80 psi ، ومعدل تدفق الجزيئات الساحلة بقيم: 1–3– 5 ونوع المادة الساحلة المستخدمة: الألومينيا – الزجاج الفعال حيوياً. شملت الدراسة 12 مجموعة اختبارية تحتوي كل مجموعة على 20 عينة. قيّم معدل القطع من خلال قياس الزمن الذي يتطلبه تيار السحل الهوائي لاختراق سماكة محددة من المادة الشبيهة بالميناء Macor™. حلّلت النتائج احصائياً باستخدام تحليل التباين (ANOVA)، وتحليل Tukey post-hoc عند مستوى الدلالة ($p<0.05$).

النتائج: كان لمعدل تدفق الجزيئات الساحلة أثر دال احصائياً في معدل القطع ($p<0.05$). انّ زيادة قيمة الضغط الهوائي المستخدم قد أدى إلى زيادة معدل القطع بشكل دال إحصائياً ($p<0.05$). لم تسبّب زيادة قيمة الضغط الهوائي من القيمة 60 psi إلى القيمة 80 psi في مجموعة الزجاج المنشط حيوياً أي زيادة في معدل القطع ($p>0.05$). كان معدل القطع في مجموعات الألومنيا أعلى احصائياً مّما هو عليه في مجموعات الزجاج المنشط حيوياً ($p<0.05$).

الاستنتاج: انّ قيمة الضغط الهوائي المستخدم ومعدل تدفق الجزيئات الساحلة له تأثير مهم في معدل القطع الساكن في أجهزة السحل الهوائي. كان الزجاج المنشط حيوياً أكثر محافظة على الأنسجة المقطوعة من الألومينيا مما يدعم استخدامه كمادة ساحلة في طب الأسنان الترميمي الأصغري.

كلمات مفتاحية: السحل الهوائي– معدل القطع – الزجاج المنشط حيوياً – الألومينا – معدل تدفق الجزيئات الساحلة– الضغط الهوائي.

* مدرس – قسم مداواة الأسنان – كلية طب الأسنان – جامعة دمشق.

In Vitro Effect of Air Pressure and Powder Flow Rate Operating Parameters on the Air-Abrasion Cutting Rate in A Static Cutting Mode

Hussam Milly*

Abstract

Objective: To evaluate the effect of air pressure and powder flow rate (PFR) operating parameters on the air-abrasion cutting rate in a static cutting mode using alumina and bioactive glass (BAG) abrasive powders.

Methods: The operating parameters investigated were: air pressure (20, 40, 60 and 80 psi), PFR (1, 3 and 5 dial settings) and the abrasive powder itself (BAG-45S5 vs. alumina), presenting 12 experimental groups (n=20). The CR was determined as the time in seconds it took the abrasive stream to penetrate a standardised thickness of an enamel analogue block. Data was statistically analysed using two-way analysis of variance (ANOVA) and Tukey post-hoc testing ($p<0.05$).

Results: PFR affected significantly the CR of air-abrasion for both abrasive powders. The increase in air pressure increased CR significantly in all groups except the jump from 60 to 80 psi in BAG powder group. The CR in Al_2O_3 powder groups was significantly greater than that in BAG groups.

Conclusion: Air pressure and PFR have an important role in determining the CR of air abrasion. BAG powder is more conservative than Al_2O_3 powder encouraging their role in minimally invasive dentistry.

Key words: Air-abrasion, Cutting rate, Bio-active glass (BAG), Alumina, Powder flow rate (PFR), Air pressure

* Assistant Professor in Restorative Dentistry Faculty of Dentistry – Damascus University.

Introduction:

Air-abrasion is a non-mechanical method of cutting tooth tissue which employs the use of kinetics to micro-chip away the surface of hard tissues. This technology was developed by Black in 1945 to find an alternative method to the conventional slow-speed handpiece [1]. This technology has recently gained renewed interest and reassessment due to (a) The potential of newly developed powders to selectively remove diseased dental hard tissues and thus enhance the preservation of healthy tooth tissues during tooth preparation, (b) The widespread use of aesthetic restorations which rely on adhesive techniques for their retention and (c) The advance in technologies designed to reduce the overspill and spread of aerosolised powder in the dental surgery [2]. Air-abrasion is a sensitive technique depends on methods completely different from those of conventional cutting tools [3]. Air-abrasion units utilise compressed air, which can be adapted easily in a dental surgery, as a propellant to carry the abrasive particles. In a pneumatic conveying system, the pressure of two-phase flow P_t is diverted to pressure of gas P_g and pressure of solid Ps. When the particle diameter of the air-abrasives is small, such as in dental air-abrasion systems, the suspension velocity of the particle is very low and can be neglected. Thereby, the velocity of the particles is equal to the velocity of the propellant [4]. Powder flow rate in the air-abrasion system is correlated to the velocity of the propellant which is affected by the increase in the particle load[5]. In most air-abrasion units both powder flow rate (PFR) and air pressure can be controlled using pre-set dials. These unit's parameters have an important effect on air-abrasion cutting characteristics [5,6,7].

Ideally, the abrasive powder should be harder than carious dental tissues and at the same time softer than intact healthy tissues, to enable selective diseased tissue removal [8]. Using alumina (Al_2O_3) powder, the most commonly abrasive used, causes an undesirable over-preparation in the healthy tooth tissues since the cutting rate of sound enamel and dentine is much faster than the cutting rate of carious enamel or dentine [8,9]. In order to improve air-abrasion cutting efficiency with respects to caries removal, alternative powders were introduced such as dolomite, chalk, glass beads, crushed glass powder, crushed polycarbonate resin and recently, bioactive glass (BAG) [1, 8, 10, 11,12].

Bio-active glass powder (BAG) exhibits unique properties such as antibacterial effects, remineralisation effect and its potential to remove selectively diseased or damaged tooth structure [2, 9, 11, 13, 14]. As there are no previous published works assessing the cutting rate (CR) of air-abrasion when BAG powder is used in a static cutting mode, the purpose of this study is to investigate the effect of two specific parameters, air pressure and powder flow rate (PFR), on the cutting rate of two abrasive powders, alumina (Al_2O_3) and bio-active glass (BAG) powders. The two null hypotheses investigated in this study are both air pressure and PFR have no effect on the CR of air-abrasion used in a static cutting mode and that alumina and BAG powders produce the same cutting rate when used in the same commercial air-abrasion system.

Material and methods:

An Aquacut™ 4 Quattro air-abrasion unit (Velopex, Harlesden, UK) with a circular cross- section nozzle (internal diameter 600 µm) was used throughout the experiments. The abrasives tested were alumina powder (Al_2O_3; 27µm average particle size) and BAG (30-60-90 µm particle range). The powder flow rate and air pressure on the air-abrasion unit were controlled and calibrated as described in our previous study [3]. Air-abrasion CR was determined as the time in seconds it took the abrasive stream to penetrate a 2-mm thickness of an enamel analogue (Macor™, Corning, USA). Macor™ hardness (250 KHN), thermal prosperities and elastic modulus are similar to that of enamel (272 to 440 KHN) [15, 16, 17].

$$CR_{(mm/sec)} = Thickness_{(mm)} / Time_{(sec)}$$

A specifically designed apparatus was used to hold the static air-abrasion nozzle perpendicularly at a distance of 2 mm to the Macor surface (Figure 1).

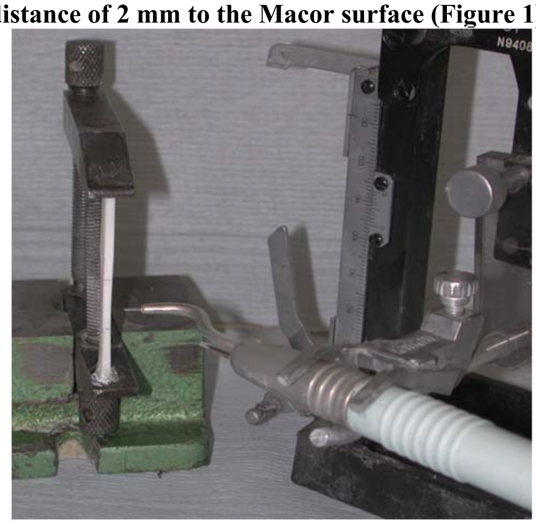

Figure 1: Air-abrasion handpiece hold perpendicularly to Macor bar.

Fibre illuminator (OSL1-EC, ThorLABS, USA) was oriented into the Macor surface, and the powder reservoir on the air-abrasion unit was refilled to a specific marked line after every abrasion. For investigation the effect of PFR on CR, the air pressure was fixed at 60 psi, while the powder flow rate switch was adjusted using three per-set values 1, 3 and 5. The powder flow rate switch was fixed at value 3 to assess the effect of four different air pressures (20, 40, 60 and 80 psi) values on CR. The conditions and the number of measurements for each group are described in Table 1.

Table 1 :presents the conditions of each experimental group

Group	PFR	Air Pressure(psi)	Powder	N
1	1	60	Al_2O_3	20
2	1	60	BAG	20
3	3	20	Al_2O_3	20
4	3	20	BAG	20
5	3	40	Al_2O_3	20
6	3	40	BAG	20
7	3	60	Al_2O_3	20
8	3	60	BAG	20
9	3	80	Al_2O_3	20
10	3	80	BAG	20
11	5	60	Al_2O_3	20
12	5	60	BAG	20

Statistical analysis:

The statistical analysis was performed with SPSS statistical package (version 19.0, SPSS Inc/IBM, Chicago, IL). Data were tested for normality using the Shapiro–Wilk W test, histograms and Q-Q plots. Data concerning the effect of unit's parameters on CR was statistically analysed using two-way analysis of variance (ANOVA) and Tukey post-hoc testing.

Results:

The mean±sd values of CR for each group are presented in Figure 2 and Figure 3. Air-abrasion CR in BAG groups increased significantly only when the powder flow rate switch was adjusted from the lowest to the middle value ($p<0.05$). However, alumina groups showed a significant difference in CR when the powder flow rate switch was adjusted from the lowest to the highest value according to the powder flow rate switch values ($p<0.05$). Statistical analysis revealed that the increase in air pressure increased CR significantly in all groups ($p<0.05$), except the jump from 60 to 80 psi in BAG powder group($p>0.05$).

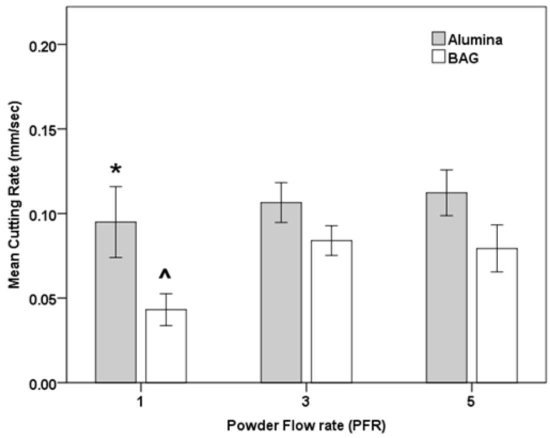

Figure 2: CR mean and standard deviations (mm/sec) for Al_2O_3 and BAG powders groups according to powder flow rate switch. (*) statistically significant difference in Al_2O_3 powder groups between 1 and 5 powder flow rate switch value (*$P<0.05$*). (^): statistically significant difference in BAG powder groups (*$P<0.05$*).

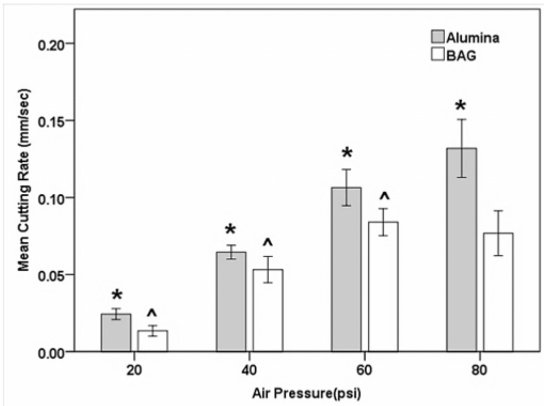

Figure 3: CR mean and standard deviations (mm/sec) for Al_2O_3 and BAG powders group according to the air pressure. (*): statistically significant difference in Al_2O_3 powder groups ($P<0.05$). (^): statistically significant difference in BAG powder groups ($P<0.05$).

The CR in Al_2O_3 powder groups was significantly greater than that in BAG groups ($p<0.05$), indicating that Al_2O_3 powder is more aggressive than BAG powder in the all conditions of this experiment. The percentages of CR increase in Al_2O_3 powder groups compared to that in BAG powder groups are presented in Table 2.

Table 2: reveals the percentages of CR increase in Al_2O_3 powder groups compared to those in BAG powder groups. CR was significantly different between two powders in all groups:

Group	CR (%) increase in Al_2O_3 groups
PFR:1 - Air pressure:60	50.9
PFR:3 - Air pressure:60	20
PFR:5 - Air pressure:60	27.8
PFR:3 - *Air pressure: 20*	42.2
PFR:3 - *Air pressure: 40*	17
PFR:3 - *Air pressure: 80*	40.9

Discussion:

Macor™ is a glass-ceramic material used in this study as an enamel analogue to evaluate the operating parameters of BAG air-abrasion. Its microstructure consists of an interlocked array of plate-like mica crystals (55 vol.% fluorophlogopite) dispersed within a glassy matrix (45 vol.% borosilicate glass). In the dental literature, Macor™ was used to assess the CR of different operative technologies, and was considered a reliable substitute for enamel, in this regard, since it behaves similarly to human dental enamel during the cutting process [7, 16, 17]. The use of Macor™ provides consistent hardness throughout air-abrasion CR assessment, a critical factor in studying the cutting rate of operative techniques.

Air-abrasion parameters such as internal nozzle diameter, nozzle angle, nozzle-substrate distance, the advancement rate of nozzle, the hardness and the thickness of targeted substrate have an important effect on air-abrasion cutting characteristic including BAG air-abrasion [3, 7, 18, 19, 20, 21]. Consequently, to evaluate the effect of air pressure and PFR for both powders, all other air-abrasion parameters were fixed in order. This study was conducted in a statistic cutting mode which is relevant clinically for specific applications such as the removal of any remaining enamel pit or fissure, infected dentin, or old restorative material from a specific limited spot, particularly in the final tooth preparation stage.

There was an increase in the CR when powder flow rate switch moved from minimal to middle value in BAG groups. However, increasing the powder flow rate switch value to the high value did not increase the cutting rate further and in some of the experimental groups an inversely proportional relationship between the high PFR and cutting rate was noticed. This finding is similar to that described by Paolinelis et al (2009). This paradoxical reduction may be caused by the surface chocking of particles when excessive quantities of abrasive is applied in a constrained volume leading to disruption of the cutting stream. Looking at the values of PFR for both powder, the increase in PFR in BAG between middle and high settings caused a decrease in the CR due to the excessive particles interruption as all other variables through the procedure were fixed.

The findings of this study suggest that there is an increase in the air-abrasion CR for both powders when air pressure increases. Since the increase in air pressure did not increase the PFR, proven in a previous study [3], the relationship between air pressure and CR can be explained dependent upon the kinetic energy theory (EK=1/2 MV2; M: the mass, V: the speed of particles) as the particle velocity increases due to the propellant pressure increase, and that in turn, increases the kinetic energy of particles making them more effective in cutting. This finding is consistent with previous studies [6, 7, 8]. It is important to be aware that in BAG powder groups only when the air pressure increased from 60 psi to 80 psi, there was no significant difference in CR. Indeed, a slight reduction (but not statistically significant) in CR was recorded when air pressure increased from 60 to 80 psi value in BAG powder groups. This result may be caused by the BAG particles scattering and fracturing as they hit the surface in a high speed due to their brittle nature and mechanical properties which include a lower fracture toughness of 0.6 MPa $m^{1/2}$ ([22]).

Minimally invasive dentistry (MID) is part of this minimum intervention care philosophy which focuses on the tooth-preserving operative techniques to restore teeth which aims to retain the maximum quantity of intact, repairable dental tissues [23]. Currently, there is no available operative technique with purely “self-limiting” nature to excavate selectively the irreparable carious tissues and resin-based restorative materials [2]. As with other clinical operative techniques, air-abrasion exhibits the lack of a pure “self-limiting” nature, when managing dentine caries [2, 24, 25, 26, 27]. The results of the present study demonstrated that the ultraconservative CR of BAG air-abrasion can be promoted by altering its operating parameters, thus enhancing its role as an operative technique in MID. Al_2O_3 powder was more aggressive than BAG powder in all settings examined in this study. In fact, abrasive particles in both powders have different hardness (aluminium oxide: 2300 VHN, BAG:458 VHN) [24]. The abrasive particles hardness contributes considerably in the cutting efficiency in air-abrasion system [8]. It is important to point out that when the settings of air-abrasion unit, included air pressure and PFR, are adjusted to low values, the difference in CR between two powders increased approximately twice implying that in low settings cutting efficiency of air-abrasion depends mainly on the nature of powder rather than on propellant pressure or on PFR.

Conclusions:

The two null hypotheses were rejected as air pressure and PFR have an important role in determining the CR of air abrasion and there was a significant influence of the powder in the CR. BAG powder is more conservative than Al_2O_3 powder. Adjusting air pressure and PFR into low values promoted the conservative CR of BAG air-abrasion.

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