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Estimation of enamel removal rate in micro-abrasion based drill-less dentistry

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ABSTRACT

Purpose: Drill less dentistry is painless, riskless, soundless and heatless and is very suitable for dental-related concerns where children are the most affected fraternity. Removing enamel from the teeth at the affected region by conventional drilling mechanism is challenging. The processed region is filled using amalgam or other sources for the occupation. The proceedings are a painful experience for the patients due to heat generation while drilling, which also induces vibrations and related noises. There are higher possibilities for tissue damage and disturbances in the unaffected regions. Air-abrasion-based drill-less dentistry handles such problems in a novel way and provides a comparatively pleasant treatment experience to patients.

Design/methodology/approach: The enamel removal rate influences the drill-less dentistry as it empowers to predict the quantum of material that can be abraded while executing the process. The mathematical expression of the enamel removal rate has been estimated based on the basic laws of physics and assumptions.

Findings: The current work exhibits mathematical modelling to predict the enamel removal. The expression also reveals that the velocity, density and mass flow rate of abrasive particles has a crucial role in deciding the rate of enamel removal from the tooth. The present mathematical expression provides beneficial inputs to the research fraternity in the dental field.

Research limitations/implications: The current mathematical expression has arrived through basic laws of physics and assumptions. The enamel removal rate is estimated using an analytical model, and the current mathematical expression can be improvised through fine-tuning fine. The present preliminary studies could be helpful in developing an accurate predictive model in future.

Practical implications: The present research supports drill-less dentistry and provides a mathematical solution in terms of derived formulations in predicting the enamel removal rate, as enamel removal rate plays an essential role in drill-less dentistry.

Originality/value: The mathematical expression facilitates the problem handling more practically and efficiently. The mathematical expression is helpful in studying and deciding the processing conditions such as stream velocity, particle density and mass flow rate on effective enamel removal rate from the tooth structure.

Keywords: Enamel removal rate, Dentistry, Air-abrasion, Modelling

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BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

1. Introduction

The term “air abrasion” was originated from Black [1]. The principal motive for such technology was to launch an innovative approach that could handle and improve the existing process effectively. Lima et al. [2] reviewed and expressed the air-abrasion technique uniquely for medical applications to process teeth without harming tissues. The real challenge was given by cavities which were to be processed within the constraints in terms of dimensions. The discovery of new materials and the launch of high-volume suction enabled excellent bonding of teeth’s structure. This smart evolution has provided a new elevation for air-abrasion technology to flourish, as specified by Walmsley [3]. Dr J. Tim Rainey was a dentist by profession from the USA who first researched the implementation of air abrasion in micro abrasion. The initial machine in association with air abrasion was launched by Dr Robert Black (Late) seven decades ago after facing several failures. However, his student cum friend Dr Rainey incorporated adhesive based material for restoration and modified the technique in line with future demands. This abrasion technology evolved commercially when “S.S White technology” started preparing cavities with this technique in 1951. Tooth preparation got a new direction due to the evolution and incorporation of adhesive dentistry and air-abrasion technology. This integration eliminated mechanical retention, as exposed by Arvind et al. [4]. The Air-abrasion technique relies on the principle called “pseudo-mechanism” to execute the non-rotary cuts on the hard tissues (Dentistry). The “pseudo-mechanism” provides the kinetic energy for executing the cutting process where abrasives in the particle form hit the surface of the tooth to be processed with pre-defined velocity. Kinetic energy and air abrasion with microparticles have equal weightage in the successful accomplishment of “cavity preparation”. Research explored and expressed the pre-eminence of bonding (Dents) in association with enamel that exhibits superior performance over other competing techniques such as acid-based etching, carbide burs, etc. [4-8].

2. Science behind the technique

Aluminium oxide in the form of particles is engaged for preparing the teeth’s structure, and the same impinges on the surface of teeth with high velocity. These particles, together with air, take a stream from under a compressed state and reach the surface of the teeth. Stream formation is possible either with normal air or nitrogen gas. Some cases involve carbon dioxide gas for processing the teeth. Two main factors decide the efficiency of enamel abrasion/removal rate. The first one is associated with the hardness of teeth. The combination of parameters involved in the preparation of teeth is the other factor influencing efficiency. The dimension (size) of the particle, nozzle’s diameter of the handheld device, the magnitude of the air supply (pressure), the remoteness of the object to be processed, the quantum of the output of particles through the nozzle, period of exposure and handheld device’s angulation are the various parameters which have their influencing part in the process specifically material (enamel) removal rate and depth of infiltration as expressed by Hegde et al. [9].

Furthermore, the entire focus of the air-abrasion is on the cutting operation, which is also the prime objective of this process, as stated by Black [10]. The concept is to achieve the deep formation of a cavity with a small area of operation. Here the material removal differs from the conventional techniques where the area and depth of operation are bigger and shallower, respectively, in conventional operations as disclosed by Naim [11]. This air abrasion facilitates ideal surface roughness and bonding, as investigated by Chan et al. [12]. This processing technique also prepares the surface in association with acid to fit the etching; the same can be applied for fissure sealants as specified by Myres [13]. Laurel [14] described that the degree of abrasion by alumina particles (27 micrometres by size) falls next to the diamond that is a positive factor for the process. These particles also possess hardness in the range of 16 to 18 Giga Pascal, as asserted by Krell [15].

A shroud environment can be established when water is added to an air-abrasion system that eliminates the entry of dust into the system. The inclusion of water considerably detaches alumina and prevents the tooth from attaching alumina, as examined by Paolinelis et al. [16]. The schematic arrangement of the Experimental set up is shown in Figure 1, and the processing conditions are given in Table 1. Abrasives such as Aluminium-oxide, silicon carbide and boron carbide are considered in the present work.

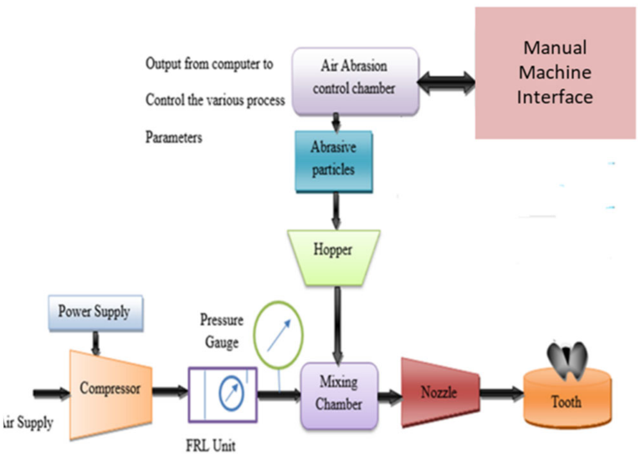

Fig. 1. Schematic arrangement of experimental set-up

Table 1.
Process conditions

Sl. No.	Parameters	Range	Unit
1.	Air pressure (P_a)	40 to 160	psi
2.	Diameter of the nozzle (D_N)	0.015 to 0.027	Inches
3.	Angle of nozzle (α_N)	40 to 120	Degree
4.	Stand-off distance (S_D)	0.5 to 2	mm
5.	Dwell time (W_T)	1 to 2	min.
6.	Particle size (P_S)	27 or 50	µm

3. Mathematical modelling of enamel removal rate for cubical-abrasive

The enamel removal rate (ERR) is acting an essential role in drill-less dentistry as it empowers to prediction of the quantum of material that can be abraded while executing the process [17-19]. The ERR has arrived based on the formula as expressed by Mishra [20]. The below-mentioned assumptions are followed while formulating the mathematical model/expression for ERR [21, 22].

- Dentin, tooth's caries and enamel are considered/assumed as brittle in nature in the current expression.
- The size of the abrasives is considered spherical to handle the expression with simplicity.
- For brittle materials, the volume of material removed equalsthe volume of the hemisphere.
- The material removal volume is assumed to be equal to the hemisphere's volume.

Since dentin, tooth's caries and enamel have the characteristics of brittleness and hardness, ERR expression is chiefly based on the brittle nature of the material [23,24]. The present work involved enamel and dentin with a hardness value of 278 KHN and 67 KHN, respectively. Here, the cubical assumption is made on the shape of the abrasive and material removal is assumed to be executed by the half portion of the abrasive.

The side of the cube is assigned as 'c' and 'z' as the diagonal length of the cube (Fig. 2). The volume of the abraded material is assumed to be equal to half the volume of the abrasive's cube or triangular prism.

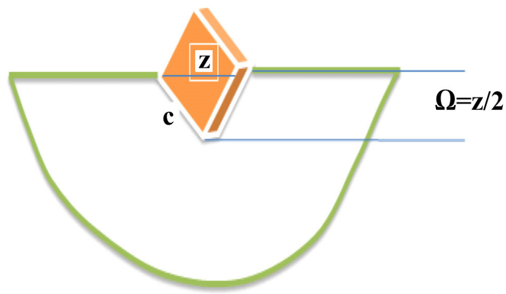

Fig. 2. Cubical assumption of abrasive

Based on Pythagoras' Theorem,

$$z^2 = c^2 + c^2 = \sqrt{(c^2 + c^2)}$$

$$z = \sqrt{2}.c \quad (1)$$

While considering the depth of indentation,

$$\Omega = z/2$$

By substituting z in equation 1, Ω becomes,

$$\Omega = (\sqrt{2} \cdot c/2)$$

$$\Omega = (c/\sqrt{2}) \quad (2)$$

However, the practical volume of the abrasive in terms of a cube,

$$R = c^3 \quad (3)$$

Therefore, the volume of abraded material,

$$R_{dental} = {}^{1}/_{2}.z.{}^{z}/_{2}.c = \frac{(\sqrt{2}.c).(\sqrt{2}.c).c}{4}$$

$$R_{dental} = {}^{c^3}/_{2} = \frac{(\sqrt{2}\Omega)^3}{2}$$

$$R_{dental} = \sqrt{2}\Omega^3 \quad (4)$$

The formulation for enamel removal rate (ERR) is given by, ERR = R X [Mass flow rate (abrasives)/ mass of individual abrasive particles]

$$ERR = R.\left({}^{Q}/_{q}\right) \quad (5)$$

Kinetic energy for abrasive particles as given below,

$$K_e = {}^{1}/_{2}.q.T^2$$

Therefore, mass (q) of individual abrasive particles,

$$q = R.\rho$$

$$q = c^3.\rho \quad (6)$$

Hence Kinetic energy,

$$K_e = {}^{1}/_{2}.c^3.\rho.T^2 \quad (7)$$

Therefore, work done by abrasives is given below, W_d = ½ X Area X Hardness X Indentation

$$W_d = {}^{1}/_{2}.\sqrt{2}.c.c.H_d.\Omega$$

$$W_d = \frac{c^2 H_d \Omega}{\sqrt{2}} \quad (8)$$

According to the energy balance principle, Work done by abrasive particles = Kinetic Energy of abrasive particles

$${}^{1}/_{2}.c^3.\rho.T^2 = \frac{c^2.H_d.\Omega}{\sqrt{2}}$$

Through solving the previous equation, we get Indentation (Ω) as

$$\Omega = \frac{c.\rho.T^2}{\sqrt{2}.H_d} \quad (9)$$

Through substituting the equations 4, 9 and 6 in 5 and, we can achieve ERR as,

$$ERR = \frac{\rho^2 T^6 Q}{2.H_d{}^3} mm^3/_{min} \quad (10)$$

Through a similar procedure, Caries Removal Rate (CRR) and Dental Removal Rate (DRR) can also be derived as given below,

$$CRR = \frac{\rho^2 T^6 Q}{2.H_d{}^3} mm^3/_{min} \quad (11)$$

$$DRR = \frac{\rho^2 T^6 Q}{2.H_d{}^3} mm^3/_{min} \quad (12)$$

Through the above formulations, it can be determined that the impact velocity, mass flow rate of abrasives and density of particles influence the ERR.

4. Results and discussion

By using the various abrasives such as alumina, silicon carbide and boron carbide and by varying the mass flow rate values from 2-4 gm/min in steps of 0.5 gm/min increments and velocity values from 100-300 m/s in steps of 50 m/s increments, the Enamel Removal Rate and Dentin Removal Rate could be obtained and the following graphs were generated by using the formula derived. It can be seen from Figure 3. that the rate of enamel removal rate increases with the increase in the velocity of the abrasives. Also, it increases with the increase of the mass flow rate of abrasives from Figure 4. From Figure 5, it is found that the rate of enamel removal rate is higher in the case of boron carbide when compared to both silicon carbide and alumina.

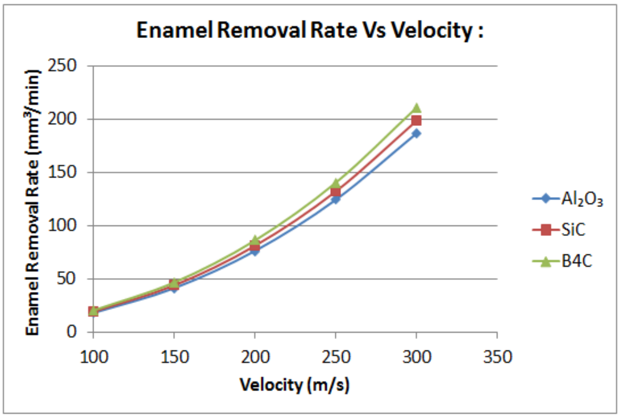

Fig. 3. Effect of velocity on enamel removal rate

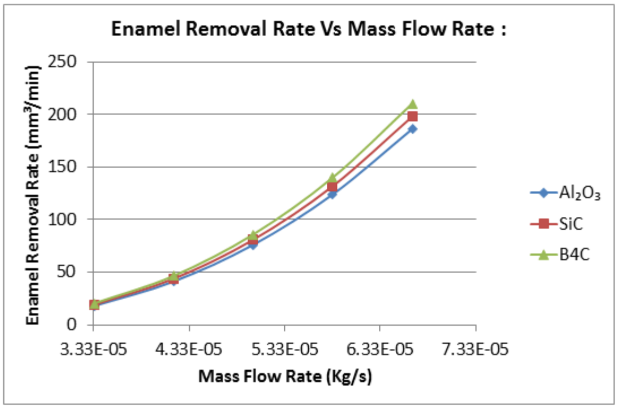

Fig. 4. Effect of mass flow rate on enamel removal rate

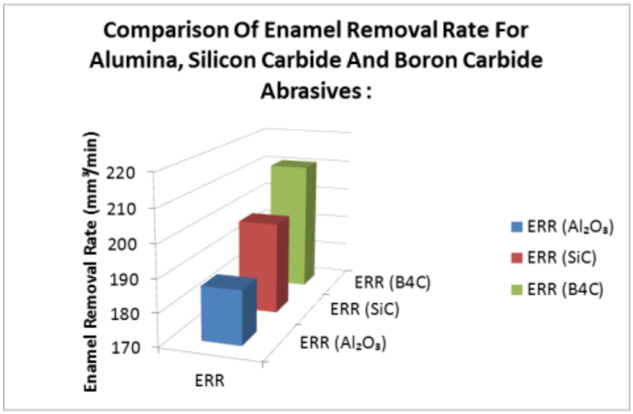

Fig. 5. Comparison of enamel removal rate using various abrasives

The abrasion efficiency is high for boron carbide, resulting in higher removal rate compared to silicon carbide and alumina. Bioactive glasses have been applied in various dental-related applications [25-27] where the current analytical model can be experimented with replacing the abrasives with bioactive glasses.

5. Summary

Air-abrasion technology carries positive factors in executing dill-less dentistry. The combination of high velocity and micron-level size of particles precisely abrades the teeth's enamel at the targeted region without disturbing the healthy neighbour tooth structure. The current work presents mathematical modelling to predict enamel removal. The expression also reveals that velocity, density and mass flow rate of abrasive particles have a crucial role in deciding the rate of enamel removal from the tooth. The present mathematical expression provides beneficial inputs to the research fraternity and dental field.

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Additional information

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