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The Efficiency of Dentifrice Abrasive Particles under Different Tooth-brushing Parameter

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Abstract
This study highlights the effectiveness of the three commercial abrasive particles that are widely used in toothpaste which are perlite, baking soda, and activated charcoal powder. In this study, each abrasive particle was tested under different tooth brushing parameters using an in-vitro approach to simulate the tooth brushing process. The results suggested that perlite was found to be the most effective abrasive particle to be used compared to that of the other two particles tested since it produced the highest scratch factor, deeper scratch, and wider scratch area. The results also highlight that the use of activated charcoal particles would lead to the erosion of the enamel under excessive load and prolonged use of baking soda will not be harmful. The results obtained would be useful as a benchmark for future studies in investigating the efficiency of other types of abrasive particles.

1. Introduction

Abrasive particles in dentifrice / tooth paste are one of the crucial ingredients that help to remove stain from the enamel either by abrading, grinding and polishing. Calcium carbonate, alumina, silica, perlite, and calcium carbonate are the type of minerals that are widely used as abrasive particles in the toothpaste[1]. There is no doubt that these abrasive particles are effective in teeth cleaning and their Relative Density (RDA) value is still within safe range which are suitable to be used for teeth cleaning purpose[2]. However, there are still limited information on their performance under different tooth brushing parameter.

Recently, activated charcoal particles have become a major trend for teeth cleaning purpose due to its ability for tooth whitening. However, a recent case that involves frequent use of oral cleaning product consists of charcoal powder as abrasive particles have resulted to toothache and enamel erosion on the user [3]. Steven [4] highlighted that the RDA value of activated charcoal is only around 70 to 90, but its abrasiveness level is too high, which could lead to tooth erosion. A recent survey was conducted by the

Authority Dental to investigate user awareness level on the effect of charcoal particles for tooth cleaning purpose [5].Survey results found that, 81% of user did not consult the dentist prior to the use of the activated charcoal powder. Among 19% of those who consulted the dentist, only 30.3% of the users are aware on its abrasiveness level. On the other hand, some user claimed that the use of baking soda (sodium bicarbonate) during tooth cleaning process would also lead to whiter teeth. However, its side effect under prolong use remains unclear[6].

The utilization of toothbrush simulator or in-vitro test have been widely used in previous research [7]–[10]to investigate tooth wear phenomenon. The use of acrylic specimen as the scratch surfaces [11] instead of a real teeth set provides a simple manner to understand the interaction between toothbrush and toothpaste particle during teeth cleaning process. However, previous researches[11]–[13] are only focussed on the interaction of certain type of abrasive particles such as perlite and silica where the interaction of other abrasive particles such as baking soda and activated charcoal powder remains unclear. This provides a room for further investigation to understand the interaction of other abrasive particles that mainly related to its cleaning efficiency and tooth wear phenomenon.

Generally, abrasive particles with a higher RDA value resulted to an efficient teeth cleaning due to a higher stain removal rate, which could also lead to problematic issues such as tooth erosion; especially under frequent use. Thus, the efficiency of each abrasive particles were investigated in this study through a series of scratching test under different tooth brushing parameter in order to correlate the relationship between particles efficiency with brushing cycle and loading condition. The primary goal of this study was to obtain the scratch characteristics of each particle in terms of its scratch factor, depth of scratch, and the scratch pattern.

2. Methodology

In this study, the efficiency of three common abrasive particles namely perlite, baking soda, and activated charcoal powder were investigated through a series of scratch test using a custom test rig / Reciprocating Toothbrush Simulator (Figure 1). Scratch tests were conducted on the acrylic / Perspex plate since it would be easier to understand the interaction of the abrasive particles on a flat surface rather than on uneven surface (real teeth). A commercial soft bristle type toothbrush with an equispaced filaments having equal length was used to investigate each particles entrainment during tooth brushing process. To resemble the toothpaste, each abrasive particle was mixed with glycerol (equal mass ratio) to ensure the particle would not disperse during scratching test.

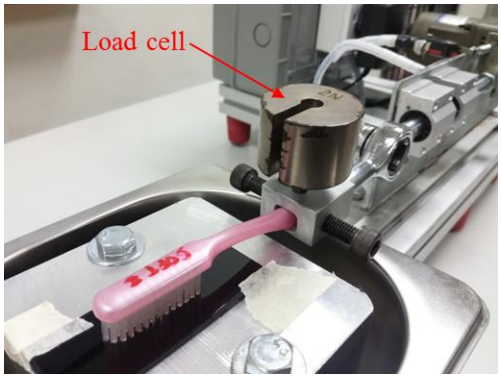

Figure 1. Reciprocating toothbrush simulator apparatus.

Table 1. Details of the experimental design.

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Load (N)	Cycles	Particles
0	0.5 / 1 / 25	Perlite / Baking Soda / Charcoal
1.5	0.5 / 1 / 25	Perlite / Baking Soda / Charcoal
2.5	0.5 / 1 / 25	Perlite / Baking Soda / Charcoal

The experimental design was tabulated in Table 1. For analysis purpose, the depth of scratch was measured using Mitutoyo Surface Profilometer while the scratch factor was determined through Equation 1:

$$\text{Scratch Factor} = \frac{\text{Number of scratches}}{\text{Number of filaments}} \quad (1)$$

3. Results and Discussion

3.1. Scratch Factor

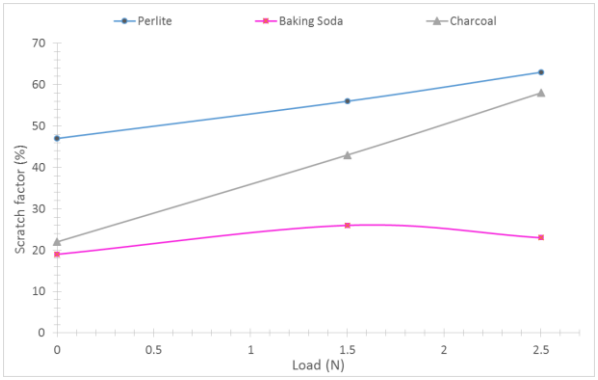

Figure 2. Scratch factor of each particle under different loading condition.

The efficiency of the abrasive particles can be determined through the scratch factor which indicates how well each abrasive particle entrained within each filaments tip to cause scratch during the movement of the brush head. Generally, the trend in Figure 2 indicates that as the external load increased, the number of scratches increased, hence resulting to an increase on the scratch factor. However, under excessive load (2.5 N), the number of scratch produced by the baking soda particles decreased gradually. It was also observed that the baking soda particles have the lowest scratch factor compared to perlite and charcoal particles under different loading condition.

The difference on the scratch factor produced by each particle can be explained well by the unique physical characteristic of each abrasive particle (Figure 3). For perlite and charcoal particles (Figure 3A and 3C), both particles share similar characteristic where they have flat surface with sharp edges. Flat surface are beneficial since it will help the particles to be well entrained under the filament tip while the sharp edges will help to cut through the scratch surfaces to produce a continuous scratch. Baking soda (Figure 3B) on the other hand is more granular with uneven surface making it difficult to be hold properly by the filament tip especially under excessive load during the movement of the brush head. This suggests that physical characteristic (shape) of an abrasive particles plays a major role towards an effective tooth cleaning process. Thus, it is essential to choose an appropriate particle with beneficial characteristic in order to ensure effective cleaning can be achieved during tooth brushing process.

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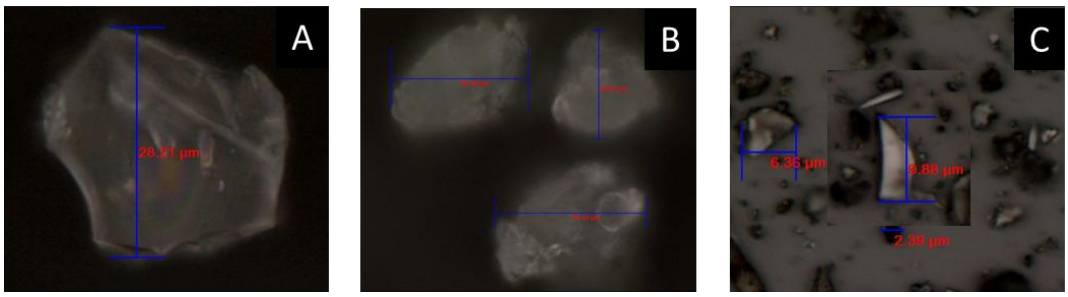

Figure 3. Particles characteristic under optical microscope. A (perlite), B (baking soda), C (charcoal)

3.2. Depth of Scratch

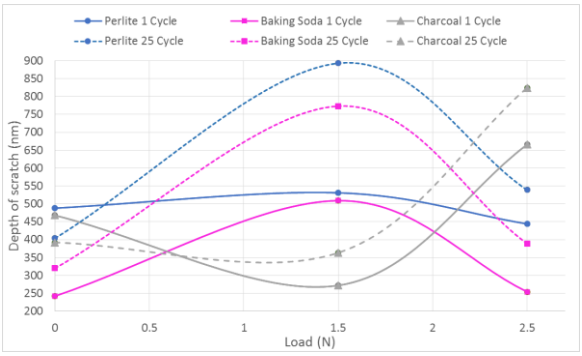

Figure 4. Depth of scratch produced by each particle under different loading condition and crushing cycle

Inset figure (Figure 4) depicts the depth of scratch produced by each particle under different load and brushing cycle. The trend suggests that higher brushing cycle (dotted line) will results to a higher depth of scratch. Similarly, increasing the load will also results to a deeper scratch; but the depth of scratch decreased once it exceeded the optimal load (1.5 N) for both perlite and baking soda particles. It was observed that both perlite and baking soda particles achieved its maximum depth of scratch under the optimal load (1.5 N) while the maximum depth of scratch for charcoal particles was achieved under excessive load (2.5 N).

It is interesting to note that, as an excessive 2.5 N load was applied, the filament deflected which results to less abrasive particles accumulated at the tip of the filament (particles spreading out from the brush zone), hence contributing to reduction on the depth of scratch for both perlite and baking soda particles. In contrast, charcoal produce highest depth of scratch even though the filaments bent under excessive load of 2.5 N due to its porous structure (Figure5) which enable it to accumulate around the bent filament under excessive load. This indicates that, charcoal could lead to erosion of the enamel if the user exerted excessive load (where the filaments deflected). Therefore, it is advised that care must be taken (in terms of applied load) when handling activated charcoal powder for teeth cleaning purpose to avoid the enamel erosion issues.

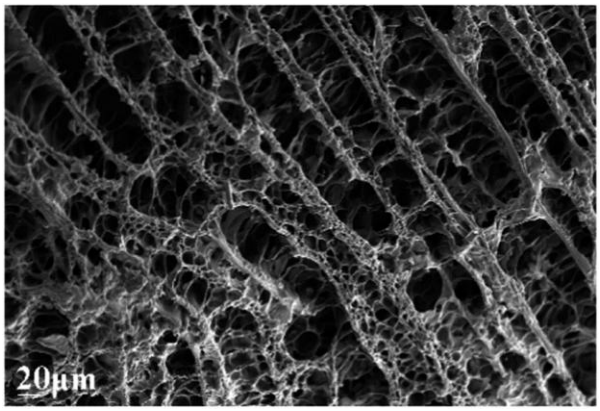

Figure 5. The porous structure of activated charcoal powder [14]

3.3. Scratch Pattern

Figure 6 shows the scratch pattern produced by different abrasive particles under different brushing cycle. It was observed that the number of scratches increased under higher cycle for all of the particles tested. This is

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due to the fact that for a lower brushing cycle (1 cycle), there is a tendency for the slurry mixture (glycerol + abrasive particle) are not well entrained within the bristle tip, thus producing less number of scratch. However, as the brush move back and forth (higher cycle), the motion of the bristle create a space for the slurry mixture to entrained and trapped within the bristle tip producing a higher number of scratches. This provide a good fundamental understanding why it is a good practice to brush our teeth for a certain number of cycle to ensure that wider scratch area would be produced that could remove stains and plaque that forms on the enamel.

In terms of particles efficiency, perlite particles surpass the other two particles under lower and higher brushing cycle. The scratch produced by the perlite particles is generally more bold and intense. Similarly, the scratch produced by the charcoal particle is almost identical to the perlite scratch. However, it is less obvious, slightly thinner, and less intense. This similarity can be explained due to the fact that the charcoal particles had a similar physical characteristic as mention in the previous section. The intensity level of the scratch produced by each particle under higher cycle denotes that the scratches produced were deeper and correlates well with the findings from Figure 4.

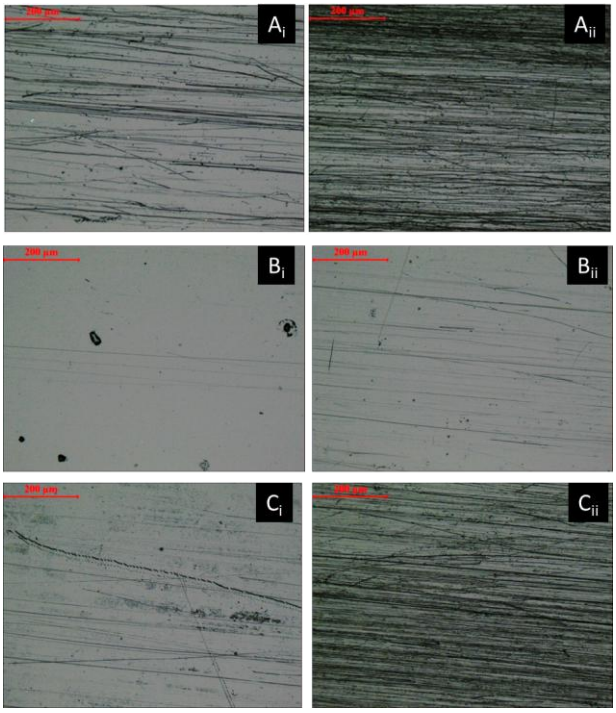

Figure 6. Scratch pattern produced by different abrasive particles under different brushing cycle. A (Perlite), B (Baking Soda), and C (Charcoal). Subscript roman number denotes number of brushing cycle. i (1 cycle) and ii (25 cycles)

Conclusion

A simple abrasive scratch test was conducted using three selected abrasive particles (perlite, baking soda, and activated charcoal) to determine each particle efficiency under different tooth brushing parameters. Overall, the perlite particles surpass all the other two particles in terms of the scratch factor, depth of scratch, and the scratch area. It is interesting to note that the perlite particles produced deepest scratch compared to the activated charcoal particles even though it has a lower RDA value than the charcoal particles. This suggests that the abrasivity level of on abrasive particle does not solely depend on the RDA value. Even though baking soda has the lowest RDA value

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among all the abrasive particles tested, the depth of scratch produced by the baking soda particles lies in the moderate level proving that it is safe for prolong use and would not results in tooth wear phenomena.

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