Tooth Surface Comparison after Air Polishing and Rubber Cup: A Scanning Electron Microscopy Study

Sara Camboni
Ecole Polytechnique Fédérale de Lausanne (EPFL), Tribology and Interfacial Chemistry Group (TIC)
Lausanne, Switzerland

Marcel Donnet, PhD
EMS Electro Medical Systems SA, Dental Research Group
Nyon, Switzerland

Abstract

- **Objective:** To demonstrate, using microscopic observations, the difference between two well-known oral prophylaxis techniques: polishing paste and air polishing. The observations were performed on human enamel.
- **Methods:** Enamel samples were obtained from plaque-rich human teeth extracted for orthodontic or clinical purposes. In order to allow a reliable comparison between different applications, each enamel sample was divided into two parts: one underwent air-polishing, whereas polishing paste was applied to the other. AIR-FLOW® Master was selected together with AIR-FLOW® PLUS for the prophylaxis powder application. For the polishing-paste application, several different pastes were used, including Cleanic®, CCS®, Proxyt®, and SuperPolish. A comparative test control was also used by cleaning the enamel with sodium hypochlorite (6%).
- **Results:** The enamel treated with AIR-FLOW PLUS showed a similar surface when compared to the control enamel; however, there was complete cleaning down to the tooth microstructure. On the other hand, use of the polishing paste resulted in an enamel surface that appeared abraded and flattened. Moreover, some of the natural irregular enamel surfaces demonstrated some filling in with debris.
- **Conclusion:** AIR-FLOW PLUS powder was able to more deeply clean without creating any damage to the enamel, making it suitable for regular cleaning treatments. The polishing pastes were found to abrade the enamel surface, to flatten it, and deposit debris into the microcavities. Both methods having different mechanical effects can therefore be considered as complementary, in that some patients experience a sense of “roughness” following a cleaning. A clinical recommendation for this experience would be to use the air polish first to clean the enamel surface, and follow with a little polishing paste to smooth the surface, if required.

(J Clin Dent 2016;27:13–18)

Introduction

Oral prophylaxis is the removal of plaque, calculus (calcified plaque), and stain from exposed and unexposed surfaces of the teeth by scaling, cleaning, and polishing. Tooth brushing is the most widely used mechanical means of personal plaque control in the world. However, it is not able to completely and efficiently remove all the dental plaque. Given that the bacterial ability of colonizing a tooth surface exponentially increases with the prior presence of plaque residuals, it is not difficult to accept the idea that a large majority of patients do not have plaque-free mouths.

There are two main approaches that dentists and dental hygienists use to remove plaque and stains from patients’ teeth; rubber cup and air polishing. The former is a procedure in which a dental polishing paste is applied to tooth surfaces with a rotary rubber cup or rotary bristle brushes to remove plaque and stains from teeth. New techniques also involve using pasteless technology, which takes advantage of only the abrasive factor of the rubber cup method; paste is not used. The air polishing technology uses air and water pressure to deliver a controlled stream of specifically designed sodium bicarbonate or erythritol powders through a handpiece nozzle. Fine particles of powder are propelled by compressed air surrounded by a warm spray and directed onto the surfaces of the teeth. This pressurized jet of air, water, and powder removes surface stains, plaque, and other soft deposits, such as food particles trapped in between the teeth. The use of air polishing devices is recommend-
between the two because crystal orientation is different in each.

As the maturation stage progresses, mineralizing enamel becomes progressively less porous, creating an apismatic layer (10–30 microns thick). The latter, also known as final enamel, is always present on deciduous and permanent teeth, anterior and posterior, upper and lower, as well as in all of their regions. It is made up predominantly of hydroxyapatite crystals, arranged parallel to each other and perpendicular to the enamel surface. The presence of this prismless layer is believed to be caused by the cessation of secretory activity of ameloblasts and the retraction of Tomes’ process. Less permeable than underlying enamel and less soluble as well, it softens at slower rates. Because of this, the thickness of the prismless layer in erupted teeth always undergoes modifications. Indeed, during the lifespan of a tooth, abrasion can occur because of several factors, such as mastication, diet, dental treatments, dental shocks, etc. It is thus common to find enamel surfaces characterized by an alternation of prismatic and apismatic zones, the latter of which can have different morphologies, such as micro-scratches, pits, small defects, and irregularities.

The enamel surface can also present the so-called Retzius grooves and perikymata. The latter are incremental lines that appear brown in a stained section of mature enamel. These lines are composed of bands or cross- striations on the enamel rods that seem to traverse the enamel rods. The former are shallow grooves noted clinically on the non-masticatory surfaces of some teeth. Together, Retzius grooves and perikymata confer to teeth what one might call “natural roughness.” They are usually lost through tooth wear, except on the protected cervical regions of some teeth, especially the permanent maxillary central incisors, canines, and first premolars. Overall, if seen from the perspective of bacteria, the enamel surface may offer many places to hide.

Many studies have reported the effects of air polishing and rubber cup on enamel as noted above (with sodium bicarbonate). Results are contradictory in that while some studies found the air polishing method abrasive to enamel, other studies did not find this effect. Nevertheless, most of the experiments were conducted on prepared enamel or on bovine teeth, thus not acting on real human enamel surfaces. In fact, simulating natural human enamel can be very difficult for research since the teeth are generally covered with proteins and biofilm layers that make effective tooth surface observation difficult. Secondly, the tooth structure is highly variable among the samples, which also makes comparison between enamel samples very difficult. Moreover, previous experiments were generally conducted macroscopically with profilometric observations or general microscopic observation. There remains, therefore, the need for deeper observations on what is happening when using both prophylaxis methods, rubber cup and air polishing, on natural enamel surfaces.

Materials and Methods

Fifteen erupted human permanent molars that were extracted for orthodontic or clinical purposes were used in this study. Only buccal and labial parts of the tooth where used.

The experimental teeth were stored in a 1% Chloramine-T solution directly after extraction and used within two months after extraction. Before use, teeth were stripped of residual blood and gum, and further disinfected with a glutaraldehyde 0.1 M – cacodylate 3% solution for seven days. After that, teeth were stored in a refrigerator in a physiological solution (Ringer’s solution, Merck KGaA, Darmstadt, Germany), where they were conserved until use (a few weeks). Enamel slices of the lingual and buccal sides of the teeth were then obtained using a low speed diamond blade machine (SYJ-150, MTI KJ GROUP, Richmond, CA, USA). As teeth are characterized by non-morphological homogeneity, the best compromise for allowing a reliable comparison between different treatment applications on enamel consisted of breaking each enamel sample into two parts with mechanical pincers. In this way, the adjacent areas of the broken enamel sample could be easily compared.

For the control teeth, the visually cleanest surfaces were chosen. In order to avoid misalignment of the two adjacent parts, treatment was directly carried out on the same enamel slice by covering half of the enamel surface with a 2 mm thick silicon plate and firmly pressing it onto the enamel to fully cover one part of the surface. The edge of the silicon plate was then marked on the enamel using a cutter. The air polishing treatment was then applied with an AIR-FLOW® Master device (EMS, Nyon, Switzerland) with a six LED power setting (2.2 bars dynamic pressure inside powder chamber) and an LED (35 mL/min) water setting for 30 seconds (powder consumption was 1.1 g). In order to clean the rest of the enamel, the entire enamel slice was then treated twice for 10 minutes in an ultrasonic bath with 6% sodium hypochlorite solution. This procedure was designed to avoid subjecting some enamel surface to artificial changes as the procedure remains in the safe treatment level proposed by Lippert, et al. (three days in 13% sodium hypochlorite solution).

For the test teeth, the air polishing treatment was performed similarly to the control teeth with one difference: that is, the usage of a broken enamel fraction which was fixed onto a support with double-sided tape for a treatment time lasting only 10 continuous seconds.

The air polishing treatment used AIR-FLOW® PLUS powder (EMS, Nyon, Switzerland), which is prophylaxis powder containing erythritol with a median diameter of approximately 11–14 µm. This powder has low abrasiveness and is therefore recommended for subgingival biofilm removal where dentin is exposed. It is also used for supragingival biofilm removal and tooth polishing. Due to its gentle behavior, it does not harm the gingiva and can be applied in all areas without causing pain.

The polishing treatment was carried out with a contra-angle handpiece (Endo 02088, Sirona Dental Systems, Inc, Long Island City, NY, USA) and a Pro-Cup Soft (ref 990/30, KerrHawe SA, Bioggio, Switzerland). Different polishing pastes with different RDA values were used for comparison purposes: Prophy Paste CCS® (RDA 250, Directa AB, Upplands Väby, Sweden); Proxyl® (RDA 83, Ivoclar Vivadent AG, Schaan, Liechtenstein); Cleanic® (RDA 27, KerrHawe SA, Bioggio, Switzerland) and SuperPolish (RDA 9.8, KerrHawe SA, Bioggio, Switzerland).

For the polishing paste treatment, the hand piece was set at 3000 rpm and a very small amount of water was allowed to irrigate the area. The enamel fraction was fixed onto a support with double-sided tape. The treatment time was approximately 30 continuous seconds for the enamel fraction.

For all test teeth, every time an enamel sample was treated with the polishing paste, the adjacent broken one was air polished with
AIR-FLOW PLUS powder. In this way, a direct comparison between the two dental cleaning methods could be made on the same enamel structure.

It should be noted that the observation of the same surface, just by covering one part, is only possible for the control teeth. For the treatment area and especially for the polishing paste, the breaking of the enamel provides more relevant independent tooth surfaces without experimental artifacts.

After treatment, samples where rinsed with 50 mL distilled water and put with 50 mL water into an ultrasonic bath (CP104, NGL Cleaning Technology SA, Nyon, Switzerland) for one minute. After sonication, samples were again rinsed with 50 mL distillated water and dehydrated using a graded ethanol series and finally air dried in a desiccator. After complete drying, both enamel fractions of the same teeth where assembled together on the microscope holder and coated with 15 nm gold (Q150T ES, Quorum Technologies, Laughton, Lewes, UK). Samples were observed with a scanning electron microscope (XL-30 FEG, Philips, The Netherlands) and images where taken at different magnifications (200x, 500x, 2000x, 5000x) at five kV. For the most relevant controlled comparison, the images where taken with both sides close to the enamel fracture on the same perikymata line.

In order to ensure more objective image assessment, 15 microscopic images were presented to ten judges who were blinded to the treatment method image recorded. All images were at the same magnification (2000x) and considered being the most representative of the different treatments. There were seven images taken from the polishing paste treatment, six taken from the AIR-FLOW PLUS treatment, and two from the sodium hypochlorite reference treatment. To prepare the judges, images found in the literature were first shown to them. The study images were then laid out in random order at the same time, and the judges were asked to fill in a questionnaire with choices on each image according to the following guidelines:

1. Presence of scratches (yes or no)
2. Surface smoothness (0 = plane to 5 = with craters)
3. Residue on the surface (0 = no residue to 5 = many residues)

The number of responses was then $N = 70$ for the polishing paste, $N = 60$ for the AIR-FLOW PLUS treatment, and $N = 20$ for the sodium hypochlorite reference treatment. The responses were then compared statistically using pairwise Welch’s unequal variances t-test with a level of significance of $p < 0.05$.

**Results**

The control tooth showed the normal prismatic and aprismatic zone characteristics (Figure 1). The cutter marks the limit between the zone treated with sodium hypochlorite (Figure 1, left) and the zone treated with AIR-FLOW PLUS powder (Figure 1, right). Higher magnification (2000x) of the “bulk” structure (approximately 300 microns away from the separation limit) is shown in Figure 2.

Figure 3 shows an example of broken enamel, which really allows a comparison to be made of the treatment methods on comparable enamel structures on both sides within a range of a few millimeters. According to this test procedure, the two adjacent natural enamel samples can be observed more deeply to show different surface structures according to the prophylaxis method used (Figure 4). One sample was treated with AIR-FLOW PLUS (Figure 4A and C), whereas the other underwent treatment with Cleanic polishing paste (Figure 4B and D). Two magnifications were used: 500x (Figure 4A and B) and 2000x (Figure 4C and D). Complementary observations have been made according to the different polishing pastes (Figure 5). Here, only the 2000x magnification is presented.

Concerning the judgements, the first decision (presence of scratches [yes or no]) resulted in only the polishing paste treatment generating scratches on the enamel surface. For the second judgement
Discussion

The surface enamel presents different structures with different access to the enamel prisms depending on the history of the tooth. The structure with alternation of prismatic and aprismatic zones is more often seen on molars. Figure 1 shows a representative enamel structure found in our tests. As this structure was only obtained through mild chemical cleaning, it is representative for the effective surface of human natural healthy enamel without mechanical cleaning action, as demonstrated in some published articles.3,7,8 As the sodium hypochlorite solution cleaning mechanism comes from organic media dissolution,18 some plaque residue can be observed in the form of small granular accumulations due to the mild treatment (Figure 2A). This presence is also pinpointed in the prismatic zone, especially in the cavities or indentations represented by enamel rods. The presence of these unclear residues was more difficult to assess by the judges of the images, and this probably explains the high error bars found for the sodium hypochlorite result (Figure 6) and the evaluation of a “less clean surface.”

When observing the same enamel surface, it is apparent that the AIR-FLOW PLUS powder treatment (Figure 1) caused no damage. The alternation of prismatic and aprismatic zones is neat and the enamel rods are empty and clean (Figure 2B). Figure 1, with the direct comparison on the same enamel surface, clearly shows that at a microscopic level, the AIR-FLOW PLUS treatment does not damage the natural enamel surface, but leaves it completely clean.

The observation of native enamel structure (Figure 1) leads to two considerations. First, when rugosimetric measurements are carried out,11 it appears that the roughness values found for the natural tooth present large variations. Furthermore, there remains the risk that the small cavities of the prismatic zone are covered with small organic debris, leading to a profilometric smooth surface.
When using a cleaning method such as air polishing, these debris are removed and the enamel could present an increased profilometric roughness, but this does not mean that the surface is altered. Secondly, this enamel structure is natural and standard for human teeth. When passing our tongue over tooth surfaces, we do not feel any particular roughness differences. Therefore, it can be stated that this prismatic region of enamel can be visually observed as rough, but this is generally not perceptible when the patient passes their tongue over the surface. It has been found that there must be larger defects of approximately 20 microns present to be detected by the tongue, or the presence of two close surfaces with different mean roughness values.

The comparison of the AIR-FLOW PLUS powder treatment with the polishing paste treatment (Figure 4) shows that the polishing paste has an abrasive action that effectively flattens the surface. Figure 4B shows an enamel sample characterized by the common alternation of prismatic and apirismatic zones, but this time it looks flattened and some evident scratches are easily identifiable. They cross the entire visible surface with a random pattern. The blowup (Figure 4D) further highlights the presence of these scratches, and also allows us to verify that the cavities represented by enamel rods are filled with particles; these could be polishing paste residue, abraded tooth debris, organic debris, or plaque remnants.

The observation of the natural enamel surface is a key point of this study; natural enamel is often characterized by this alternation of smooth and rough (prismatic) areas by nature. Thus, these small prismatic holes can serve as a hiding place for debris or bacteria, which could then serve as a source for further bacterial growth. In order to avoid this issue, polishing paste, when used alone, should be applied very intensively in order to flatten the surface down to the bottom of these holes, which means a greater loss in enamel material. According to the SEM, approximately five microns of the enamel needs to be removed in order to avoid these hiding places.

According to Figure 5, all polishing pastes scratch the surface in the same manner in order to achieve the flattening effect that is also recognized unanimously by the reviewers. Here we do not analyze the size of every scratch; only their existence is highlighted. For all the different pastes, the results remain the same. That is, the presence of scratches indicates material removal, and this removed material can be hidden in the holes found in the prismatic enamel structure irrespective of the RDA value. Therefore, this study revealed that the polishing paste is actually not able to ensure complete removal of residue (Figure 6). In order to complete the cleaning, an air polishing treatment before or after would be suggested.

When considering previous studies based on prepared enamel, investigators faced the following issue: the preparation consisted of high polishing of the enamel surfaces, thus removing the final enamel layer and avoiding its natural roughness. In this way, surfaces were compromised and did not represent the real clinical condition of standard human enamel. Therefore, observation of polishing paste effects on natural enamel alteration cannot be extrapolated from such studies, and thus the results obtained by this kind of research cannot be considered fully clinically relevant for human prophylaxis applications.

The residue observed in the enamel prismatic region after the application of polishing paste is very likely plaque residue. It might have been swept away by the rubber cup, but part of it may have found a safe place to embed in the cavities represented by enamel rods. This fact needs further biological studies. Indeed, as stated earlier, the ability of bacteria to colonize a tooth surface increases exponentially with the prior presence of plaque residue. A further biological study is therefore needed to examine these aspects in depth, and to clarify whether this potential residue of the rubber cup technology is negligible over the other rubber cup advantages. Nevertheless, when considering the accessibility and the treatment time, the AIR-FLOW treatment makes the tooth surface clean in less time than the polishing paste (1/3 of the time) and is able to handle complex surfaces.

The statistical analysis relies on the fact that every sample was subjected to the same cleaning protocol. Considering that this protocol is very intensive, the presence of residue on the surface is relevant with regard to clinical usage. On the statistical assessment (Figure 6), the air polishing treatment is found to leave a cleaner but rougher surface. Nevertheless, this rough surface is the natural enamel surface, whereas the polishing paste modifies the enamel surface. The important point of these observations is the ability of air polishing to deeply clean the surface.

**Conclusions**

The first clinical outcome of this study is that the use of AIR-FLOW PLUS powder does not create microscopically observable defects on the enamel surface. Furthermore, this treatment deeply cleans the enamel structure down to the native enamel surface. Its morphological pits ended up clean and empty, and the surface did not present any scratches. Therefore, this cleaning procedure can be used repeatedly without clinical concerns.

With the polishing paste procedure, the enamel looked smoother and flatter than the air polished enamel, but less natural at the same time. It is clear that polishing paste abrades the enamel and, together with its flattening effect, it levels the surface by amassing the debris into the enamel concavities. Due to its slight abrading effect, the polishing paste treatment would be recommended only for longer intervals between cleanings (e.g., a yearly treatment) or maybe only once at the beginning of a recall program.

In order to improve the clinical outcome, these observations suggest that it would be advisable to also carry out air polishing with AIR-FLOW PLUS powder when polishing paste is used. In this way, the former would completely clean teeth surfaces of any kind of bacterial residue, and the latter would gently flatten the enamel, thus considerably reducing the number of cavities where future bacteria could hide. Nevertheless, there remains the question if it is really necessary to flatten the enamel or if it would be enough to get the natural enamel surface completely free of biofilm to ensure the best treatment outcome.

In conclusion, as far as the comparison between the two dental prophylaxis methods is concerned, air polishing performed with AIR-FLOW PLUS powder was found to be a clinically superior cleaning method when compared with polishing paste, which showed some abrasion of the enamel. Therefore both methods show different mechanical outcomes which can be more complementary than competitive. Clinically, if tooth preservation is the primary concern, air polishing with AIR-FLOW PLUS powder is an ideal cleaning method that will not damage to tooth enamel.
Acknowledgement: This study was supported by EMS Electro Medical Systems SA.

Conflict of Interest: Ms. Camboni is employed by Ecole Polytechnique Fédérale de Lausanne and declares no conflict of interest. Dr. Donnet is employed by EMS Electro Medical Systems SA, which supported this study.

For correspondence with the authors of this paper, contact Marcel Donnet – mdonnet@ems-ch.com.

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