An *In Vitro* Comparison of the Effects of Various Air Polishing Powders on Enamel and Selected Esthetic Restorative Materials

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Abstract

- **Objective:** The purpose of this study was to investigate the effects of each of the commercially available air polishing powders on the surface characterization of human enamel, hybrid composite, and glass ionomer using a highly standardized protocol. The air polishing powders utilized in the study included aluminum trihydroxide, calcium carbonate, calcium sodium phosphosilicate, glycine, and sodium bicarbonate.
- **Methods:** The hybrid composite and glass ionomer cement were mixed and photo light-cured for 40 seconds according to manufacturer's directions, and formed in a specially prepared mold that was coated using a Teflon® aerosolized spray. The enamel samples were prepared by removing sections of human enamel from extracted unerupted third molars using a water-cooled, slow-speed diamond rotary saw. The enamel sections were approximately one centimeter in diameter and 3 mm thick. The enamel sections were flattened using a series of silicon carbide grit papers (600, 800, and 1200 grit) mounted on a rotating polishing wheel. A flat polished enamel surface, at least 5 mm in size, was produced and embedded in the hybrid composite material used for testing purposes, resulting in a sample approximately 10 mm in diameter and 2 mm thick. The restorative material samples were wet-polished to produce a uniform smooth surface and to remove the resin-rich surface layer, using the same series of silicon carbide grit papers used on the enamel (600, 800, and 1200 grit). The 1200 grit abrasive paper used is equivalent to a dental polishing disc commonly used to finish dental restorations. All samples were stored in distilled water at 37°C prior to testing. Each of the three types of samples was treated with each air polishing powder for one, two, and five seconds. A test group of five samples each of hybrid composite, glass ionomer cement, and enamel was fabricated for each of the six types of abrasive powder and three-time exposures for the air polishing treatment, resulting in a total of 270 samples. The treatment samples were exposed to the air polishing powders for the three periods of time using a custom mounting jig and shutter device that was fabricated to standardize the air polishing treatments. The air polishing handpiece was placed in a mounting jig that positioned the tip of the handpiece at an 80° angle from the sample surface. The exposure to the air polishing air, water, and polishing powder was regulated by an articulated metal plate positioned between the tip and the test sample. The holder for the test sample kept the sample in a constant circular motion to simulate clinical use of the air polishing handpiece. A custom computer program was developed to activate a stepper motor that rotated the metal plate away from the sample for the controlled exposure times of one, two, and five seconds before the plate moved back to intercept the polishing spray mixture.
- **Results:** The effect of the air polishing application on the surfaces of the tooth enamel and restorative materials was evaluated for changes in surface roughness and surface topography. The average surface roughness value was evaluated with a contact profilometer prior to and after the air polishing treatment. Changes in the surface characterization of each sample due to air polishing treatment were recorded using scanning electron microscopy. Epoxy resin replicas of representative test samples were made for evaluating under the scanning electron microscope. Samples were sputter-coated with gold palladium and the scanning electron photomicrographs were taken at a magnification of 25X and at a 45° angle. Based on evaluation with the contact profilometer, there were statistically significant interactions between the type of powder and material, type of power and time, and type of material and time. The SEM photomicrographs were used to evaluate the clinical significance of the effects of the air polishing on each type of material. The SEM photomicrographs provided a visual quantitative analysis of the effects of air polishing powders on the restorative materials and the enamel. Any disruption of the surface characterization was considered to be clinically significant and represented volumetric loss and violation of the integrity of the restorative materials and/or enamel.
- **Conclusions:** Based on the results of this study, the air polishing powders that are compatible with use on hybrid composite and glass ionomer cements are EMS glycine and EMS sodium bicarbonate. The air polishing powders that are compatible for use on enamel include EMS glycine, Dentsply sodium bicarbonate, and EMS sodium bicarbonate.

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Introduction

Over 35 years ago, air polishing (AP) was introduced to dentistry and dental hygiene by an inventive dentist named Dr. Robert Black.[1-7] This alternative method of polishing teeth that uses a spray of compressed air, water, and an abrasive agent (Figure 1) has become a mainstay in the equipment used by dental hygienists.[8] Since it was introduced, it has been widely investigated using both *in vivo* and *in vitro* studies.[9-39]

Figure 1. *Air polishing is accomplished with a spray of compressed air, water, and specially formulated polishing powder.*

Once it was determined that air polishing could be used on enamel without harm,[15] there were well-founded concerns regarding the effect that the AP powder particles could have on restorative materials. Since then, a profusion of studies have been conducted on various types, brands, and formulations of composites and glass ionomers, gold, amalgam, porcelain, titanium implant materials, and orthodontic bands and brackets.[11,16-39] As a result of the research efforts, air polishing has become the method of choice for removing dental plaque and biofilm from orthodontic bands and brackets,[11] implant surfaces,[12,13, 22-27] and heavily stained enamel,[10] and is the choice for preparing tooth surfaces prior to sealant placement.[28,29]

In addition to the supragingival powder applications, there is interest in subgingival AP which has been an object of research.[30-39] The use of subgingival AP began in Europe and has recently been introduced in the United States. The objectives for subgingival use include the removal of subgingival biofilm in periodontal pockets and the management of subgingival biofilm as a part of the treatment regimen for peri-implantitis.[30-38] To date, the powders that have been used for subgingival AP include glycine and a powder formulation that contains erythritol.[39] Glycine is widely available for supragingival and subgingival AP in the United States; however, erythritol powder is currently commercially available only in Europe.

Since air polishing was introduced in 1976, there have been a number of polishing units made by a variety of manufacturers, and there are multiple variations of this equipment. The variation of these units include table-top models which can be combined with piezoelectric or magnetostrictive ultrasonic scalers, and hand-held models that connect to the handpiece hose that supplies air and water. Some units operate off the air and water supply to the air and water syringe. No matter which type of equipment is selected, the units operate basically in the same manner. Compressed air and water must be mixed with the powder to result in a spray that is delivered with a handpiece, making it a two-body abrasive system. The result is that dental stains and dental plaque biofilm are removed as a result of the compressed air, water, and abrasive particles being propelled by kinetic energy.

The most critical item in the air polishing armamentarium is the polishing powder.[14] Initially, the equipment utilized specially processed sodium bicarbonate as the abrasive agent, as it was the only abrasive powder available. When investigating the abrasives that had potential for use as AP, Dr. Black was challenged with some limiting requirements as the abrasive agent had to remove stain safely, remove heavy stain while leaving the enamel surface intact, could not injure soft tissues or tooth structures, must be physiologically compatible with the digestive system, and could not become embedded as a foreign body in the soft tissues of the oral cavity.

Specially processed sodium bicarbonate is well-suited as an abrasive agent; however, due to the salt content, there are some contraindications for the use of the powder. The use of the specially processed sodium bicarbonate is contraindicated for patients on a sodium-restricted diet and patients with renal disease (there are additional contraindications for the use of AP and these are also related specifically to the salt content of the sodium bicarbonate powder). Furthermore, there are patients who simply cannot tolerate the taste of the sodium bicarbonate. Industry responded with the first alternative abrasive powder for AP, which was aluminum trihydroxide, introduced in 2003.[14] Since aluminum trihydroxide was made commercially available, there have been three additional powders that have been introduced. Currently, sodium bicarbonate, aluminum trihydroxide, glycine, calcium carbonate, and calcium sodium phosphosilicate (novamin)[8] are available commercially in the United States.

As with prophylaxis polishing pastes, there is no universal standard for the formulation of air polishing powders. There are numerous manufacturers and distributors that sell their own brands. It should be emphasized that each brand of powder has the potential to be quite different than other brands, even among of the same type of powder. When companies have AP powders formulated, in most instances they will specify the size of the main abrasive particle as well as additional ingredients that are included to keep the powder free-flowing.

It is important for dental hygienists and dentists to be familiar with the hardness of each of the types of powders when considering the use of air polishing. There has been a misconception among some dental hygienists and dentists that the shape of the powder determines its ability to remove stain. In fact, it is the particle hardness that is the primary determinant of the ability of the AP abrasive agent to remove dental stains and dental plaque biofilm.[10] Importantly, an oral examination should precede the use of any type of polishing agent to determine the types of restorations present. There are several types of powders that should be avoided in the presence of esthetic restorations.

Materials and Methods

To date, no study has been identified in the scientific literature that has compared the effects of each of the types of commercially available air polishing powders: sodium bicarbonate (from two different manufacturers), aluminum trihydroxide, glycine, calcium carbonate, and calcium sodium phosphosilicate (novamin) on hybrid composites, enamel, and glass ionomer. The purpose of this study was to investigate the effects of each of the identified powders on the surface characterization of human enamel, hybrid composite, and glass ionomer using a highly standardized protocol. The effects of the powders were evaluated with a profilometer and scanning electron microscopy.

Air Polishing Powders

Sodium Bicarbonate. Sodium bicarbonate proved to be an excellent but not perfect choice as a powder, given the limiting requirements an AP abrasive agent had to meet. The inventor of AP, Dr. Robert Black, collaborated with chemists, pharmacists, engineers, and various scientists and came up with the formula that has now become the "gold standard" for air polishing powders. The final formulation for the sodium bicarbonate powder is tribasic, free-flowing, food grade, and contains calcium carbonate and scant amounts of silica.[16] The Mohs Relative Scale hardness value for sodium bicarbonate is 2.5 and the particles average 74 µm in size.[16]

Aluminum Trihydroxide. There was a call from dental hygienists and dentists for a sodium bicarbonate-free air polishing powder due to the concern that sodium bicarbonate powder is contraindicated for use on some patients, as discussed above. Aluminum trihydroxide air polishing powder was introduced in 2003. Aluminum trihydroxide is much more abrasive than sodium bicarbonate, with a Mohs hardness value of 4.0 and a particle size ranging from 80–325 µm.

Calcium Carbonate. Calcium carbonate is a naturally occurring substance that is found in rocks, sea shells, pearls, and egg shells. Medically, calcium carbonate is used as a calcium supplement, as an antacid, and is an ingredient in many pharmaceutical compounds. Additionally, calcium carbonate is used as an abrasive and is a common ingredient in dentifrices. Calcium carbonate has a Mohs hardness value of 3 and the particle size is 55 µm.

Glycine. Glycine is the smallest nonessential amino acid found in proteins. For use in powders, glycine crystals are grown using a solvent of water and sodium-salt. Glycine particles for use in air polishing have a Mohs hardness value of 2 and the particles are 20–25 µm in size. Notably, glycine powder has the smallest particle size and the lowest Mohs hardness number of all of the air polishing powders currently available.

Calcium Sodium Phosphosilicate (novamin). The last AP powder to be made commercially available is calcium sodium phosphosilicate (novamin). Novamin is both a trade name and a generic name. Calcium sodium phosphosilicate is a bioactive glass and has a Mohs hardness value of 6, making it the hardest air polishing particle used. The particles vary from 25–120 µm in size. For purposes of comparison, the hardness number and particle size for each type of powder are shown in Table I.

Table I
A Comparison of the Mohs Hardness Index Number and Particle Size for Each Type of Air Polishing Powder Utilized in the Study

Type of Powder	Mohs Hardness Index	Particle Size
Glycine	2	20-25 µm
Sodium bicarbonate	2.5	74 µm
Calcium Carbonate	3	55 µm.
Aluminum Trihydroxide	4	80-325 µm
Calcium sodium phosphosilicate	6	25-120 µm

Esthetic Restorative Materials

With the advances in esthetic restorative materials, many esthetic restorations are all but impossible to detect, even with enhanced magnified vision. It becomes of critical importance, then, for the dental healthcare provider to have a scientific basis for determining the appropriate air polishing powder to use on or in the vicinity of these artfully created restorations. Because of slight inherent overspray from AP handpieces, the highly abrasive powders should not be used even in the vicinity of these esthetic restorations.[5,10,15]

The esthetic restorative materials selected for this investigation include a hybrid composite and a resin-filled glass ionomer.

Hybrid Composites. Hybrid composites contain a wider distribution of filler particle sizes than some other types of composites. The dispersed phase consists of a blend of microfill (~0.04 µm) and small (~0.06–1.0 µm) filler particles.[41] Filler particle content by volume percent varies from 57–70%. This combination of particles improves the polish-ability and surface smoothness of the restoration, as well as increases its mechanical properties. Hybrid composites can be used in the restoration of both anterior and posterior teeth (*i.e.*, class I, II, III, IV, and V restorations). Improvements in the esthetic properties and strength of the hybrid composite have made it the most widely manufactured direct placement restorative material.

Resin Modified Glass Ionomer Cements. Resin modified glass ionomer cements (RMGIC) incorporate a photo-polymerizing resin (2-hydroxyethyl-methacrylate, HEMA). The addition of the light-cured resin improves the handling characteristics and mechanical properties of the glass ionomer.[42] RMGIC can be used as cavity liners, bases, tooth core buildups, luting agents, and low stress area restorations. The photo-polymerized component provides a "quick set" and minimizes disruption of the restoration during the slower acid-base reaction.

Types and brands of restorative materials and air polishing powders utilized in this study are shown in Table II.

Table II
Types, Brands of Restorative Materials, Air Polishing Powders Utilized in This Study

Manufacturer	Restorative Materials	Composition
GC America	Fuji II LC	Resin modified glass ionomer cement
Kerr	Point 4	Light-cured hybrid composite
Manufacturer	**Air Abrasive Powders**	**Composition**
Dentsply	Prophy Jet	Sodium bicarbonate
Dentsply	Jet Fresh	Aluminum trihydroxide
EMS	Classic	Sodium bicarbonate
EMS	Soft	Glycine
KaVo	Prophy Pearls	Calcium carbonate
Osspray	SYLC	Calcium sodium phosphosilicate

Materials Preparation

Composite resin and glass ionomer cement samples were identically prepared and were formed in a custom-made mold lubricated with a Teflon® aerosol spray. The resin composite and triturated glass ionomer cement materials were packed into the mold form to produce a sample 10 mm in diameter and 2 mm in depth. A glass microscope slide was compressed onto the restorative material to create a smooth, flat surface. The composite resin and glass ionomer cement samples were polymerized for 40 seconds using a photo-curing light (COE Lunarta, GC America, Alsip, IL, USA). The restorative materials were wet-polished to produce a uniform smooth surface and to remove the resin-rich surface layer using a series of 600, 800, and 1200 grit silicon carbide abrasive paper attached to a rotary polishing machine (Leco, St. Joseph, MI, USA; Figure 2). An example of a glass ionomer sample can be seen in Figure 3. The 1200 grit abrasive paper is equivalent to a 3M/ESPE Super Fine dental polishing disc (3M ESPE, St. Paul, MN, USA), which is commonly used to finish dental restorations.

Enamel samples were prepared by removing sections of tooth enamel from extracted, unerupted, human third molars using a water-cooled, slow-speed diamond rotary saw. The enamel sections were approximately one centimeter in diameter and 3 mm thick (Figures 4 and 5). The enamel surfaces of the samples were

Figure 2. *Photograph illustrating the wet polishing of samples to create uniformly smooth surfaces.*

Figure 3. *Photograph of a glass ionomer sample. (Photograph courtesy of Peggy Cain, UNMC College of Dentistry Photographer.)*

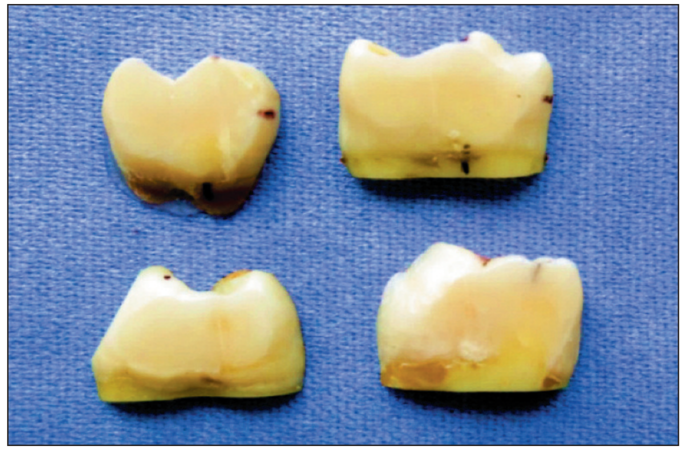


Figure 4. *Enamel samples were prepared by removing sections from extracted, unerupted third molars.*

Figure 5. *Enamel sample embedded in composite material prior to treatment with an air polishing powder.*

flattened using a series of silicon carbide grit papers (600, 800, and 1200 grit) mounted on a rotating polishing wheel. A flat polished enamel surface, at least 5 mm in size, was produced and embedded in the hybrid composite, which was prepared in the same manner as the hybrid composite samples used for testing purposes, resulting in a sample approximately 10 mm in diameter and 2 mm thick. Test samples were stored in distilled water at 37°C prior to testing.

The dental restorative materials and the tooth enamel samples were exposed to six simulated dental AP treatments. All procedures were performed with the EMS S-1 (Electro Medical Systems, Nyon, Switzerland) as received from the manufacturer, with the air polishing unit operating at a medium setting.

Each AP procedure was used for three different exposure times (one second, two seconds, and five seconds) on five samples of each material (enamel, hybrid composite, glass ionomer cement). These test times are based on the time-exposure theory of Atkisson-Cobb[43] and confirmed by Barnes: one tooth receives 0.5 seconds of exposure to air polishing powder during one maintenance air polishing procedure.[8,10-13,15,16,19-21] Therefore, these times represent one-year, two-year, and excessive five-year air polishing exposures.

A custom mounting jig and a shutter device were fabricated to standardize the AP treatment procedures (Figure 6). The AP handpiece was placed in a mounting jig that positioned the tip at an angle of 80° and 4 mm from the surface of the test sample.

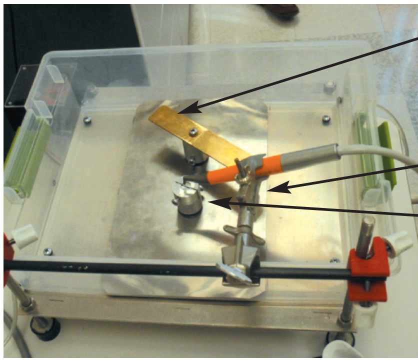


Figure 6. *Custom mounting jig and shutter device fabricated to standardize the air polishing treatment procedures.*

The duration of the compressed air, water, and polishing abrasive was regulated by an articulated metal plate positioned between the handpiece tip and the test samples. The plate deflected the air abrasive until a constant pressure stream was achieved. A custom computer program (LabVIEW, National Instruments Co., Austin, TX, USA) was used to activate a stepper motor that rotated the metal plate away from the sample. The sample was anchored in a holder that kept it in a constant circular motion to simulate the instructions for clinical use of the AP handpiece. The computer program allowed for the controlled exposure times of one, two, or five seconds before the plate movement returned to intercept the polishing spray mixture.

A test group size of five (n = 5) tooth enamel, hybrid composite, and glass ionomer cement samples were fabricated for each of the six types of abrasive powder and three time exposures for the AP treatment. A total of 270 experimental samples were fabricated.

Evaluation

The effect of the polishing powder application on the surfaces of tooth enamel and restorative materials was evaluated for changes in the surface roughness and surface topography (SEM). The surface roughness (Ra - average surface roughness value) of each sample was measured prior to and after air polishing treatment. The Ra was measured for each sample with a contact profilometer (Mitutoyo SJ-400, Mitutoyo Corp., Kanagawa, Japan) using ANSI/ASME B46.1 standards. Three measurements were made across the center of the samples using a 2 µm diameter diamond stylus tip with a .75 mN load. Five sampling lengths, each with a cutoff value of 0.25 mm, were used for a total trace length of 1.25 mm. The sample's surface roughness was defined by the arithmetic mean of the magnitude of the deviation of the profile from the mean line measured within the sampling length (R_a). Three measurements were recorded from each sample and the average of the R_a values was recorded as the sample's surface roughness

Scanning Electron Microscopy

Changes in the surface characterization of a sample due to air polishing treatment were recorded using scanning electron microscopy (Hitachi 3000N variable pressure SEM, Hitachi North America, New York, NY, USA). The scanning electron photomicrographs (SEM) were used to evaluate the clinical significance of the effects of air polishing on each type of material treated in the study. Any disruption of the surface characterization was to be interpreted as clinically significant. Epoxy resin replicas of representative test samples were made for evaluation under a scanning electron microscope. Impressions for the replicas were made using a light bodied vinyl polysiloxane impression material (Reprosil® Light Body, Caulk, Milford, DE, USA) and poured with an epoxy resin (WEST® System Epoxy Resin, Jamestown Distributors, Bristol, RI, USA). Samples were sputter-coated with gold palladium and scanning electron photomicrographs were taken at a magnification of 25X and at a 45° angle.

Analysis

Descriptive statistics that were used to analyze the results included the mean, standard deviation, median, minimum, and maximum. For each outcome, a three-way ANOVA model was used to determine if there were differences in the outcome based on type of powder, material, and duration. The model included interaction terms for powder type and material, and powder type and duration to see if differences in powder type varied based on material or duration.

Statistical Analysis of Roughness. Six AP powders (EMS Classic® sodium bicarbonate [EMS, Geneva, Switzerland], KaVo Prophy Pearls® [KaVo Dental GmbH, Biberach, Germany] calcium carbonate, EMS Soft® glycine, Dentsply Prophy Jet® sodium bicarbonate [Dentsply Co. York, PA, USA] Dentsply Jet Fresh® aluminum trihydroxide, Osspray SYLC® calcium sodium phosphosilicate [novamin, GSK, Weybridge, UK]) were used on three different materials (hybrid composite, glass ionomer, and human enamel) for three different time durations (one second, two seconds, or five seconds). Five samples were used for each combination of powder, material, and time duration. The outcome measure evaluated was the change in roughness (roughness prior to treatment vs. roughness following treatment). The purpose of the analysis was to determine if there were differences between types of air polishing abrasive, materials, and duration of polishing with respect to the mean change in roughness.

Results

Based on the ANOVA model, overall there were statistically significant interactions between the type of powder and material ($p < 0.0001$), type of powder and time ($p < 0.0001$), and time and type of material ($p < 0.0001$).

Roughness Evaluated With Profilometry

To better understand differences in the mean change in roughness, separate one-way ANOVA models were run for type of powder by material, type of powder by time, and material by time.

Type of Powder by Material

Regarding roughness, based on the ANOVA model the interactions between the treatment material and brand of air polishing powders were statistically significant (Table III). In other words, there were statistically significant differences between the brands/types of powders for each of the materials treated; hybrid composite, enamel, and glass ionomer.

Hybrid Composite. Regarding the specific effects of each of the brands of AP powders on the abrasion of the hybrid composite samples treated, there was no statistically significant difference between the change in surface characterization produced by the EMS glycine and the EMS sodium bicarbonate on the hybrid composite samples. Among all of the powders, the EMS glycine and EMS sodium bicarbonate powders produced the least amount of abrasion of the surface characterization of the hybrid composite samples treated.

The KaVo calcium carbonate, Dentsply aluminum trihydroxide, and Dentsply sodium bicarbonate powders did not produce statistically significantly different effects from each other on the surface characterization of the hybrid composite samples. However, each one of these powders produced statistically significantly greater changes in the abrasion of the surface characterization of the hybrid composite than did the EMS glycine or EMS sodium bicarbonate powders.

The effects of the Osspray calcium sodium phosphosilicate air polishing powder on the abrasion of the surface characterization of the hybrid composite were statistically significantly different from all of the other powders utilized in the study. The Osspray calcium sodium phosphosilicate produced the greatest amount of abrasion (loss of surface material) of all of the air polishing powders on the hybrid composite samples.

Enamel. The effects of the EMS glycine and the EMS sodium bicarbonate produced statistically significant abrasive effects on the surface characterization of the enamel samples that were similar to each other. The EMS glycine and the EMS sodium bicarbonate proved to be the least abrasive air polishing powders to enamel. Dentsply sodium bicarbonate, KaVo calcium carbonate, and the Dentsply aluminum trihydroxide powders produced statistically significant abrasive effects on the surface characterization of the enamel samples that were similar to each other. While these powders were not statistically significantly different from each other, they were more abrasive than the EMS glycine and EMS sodium bicarbonate powders (Table III).

The Osspray calcium sodium phosphosilicate air polishing powder produced abrasive effects on the surface characterization of the enamel that were statistically different from all other and proved to be the most abrasive of all of the air polishing powders to enamel (Table III).

Glass Ionomer. The interaction between material and type of powder assessment was the greatest with the glass ionomer, due to the inherent roughness of the glass ionomer and the fact that glass ionomer is the softest of all materials that were treated with the AP powders utilized in this study. The Dentsply sodium bicarbonate powder produced the greatest change in the surface characterization (smooth to rough) of the glass ionomer. However, statistically the effects were not entirely different than the changes brought about by Dentsply aluminum trihydroxide, KaVo calcium carbonate, Osspray calcium sodium phosphosilicate, or the EMS sodium bicarbonate.

Pairwise comparisons were calculated to determine if there was a statistically significant difference in the mean change in roughness of the treated materials between the powder types ($p < 0.0001$). For each material treated, (enamel, the hybrid composite, and the glass ionomer), there was a statistically significant difference in the mean change in roughness between the powder types ($p < 0.0001$). Pairwise comparisons are presented in Tables IV, V, and VI.

Table VII combines all materials and contains the analysis of the air polishing powders by the amount of treatment time. There were no statistically significant differences in the mean change in roughness by any of the air polishing powder types ($p = 0.20$) after the one-second and two-second treatment times

Table III
Outcome of Material and Type of Powder: Change in Roughness (Ra- μm)

Material	Powder	N	Mean	Std Dev	Median	Minimum	Maximum	Grouping*
Hybrid Composite	EMS glycine	15	0.10	0.03	0.10	0.00	0.14	A
	EMS sodium bicarbonate	15	0.34	0.06	0.31	0.24	0.43	A
	KaVo calcium carbonate	15	0.73	0.12	0.72	0.48	0.91	B
	Dentsply aluminum trihydroxide	15	0.77	0.10	0.77	0.54	0.92	B
	Dentsply sodium bicarbonate	15	0.84	0.22	0.83	0.58	1.42	B
	Osspray calcium sodium phosphosilicate	15	2.29	0.51	2.27	1.59	3.09	C
Enamel	EMS sodium bicarbonate	14	0.04	0.04	0.03	0.01	0.14	A
	EMS glycine	15	0.05	0.04	0.04	0.01	0.16	A
	Dentsply sodium bicarbonate	15	0.09	0.12	0.06	0.02	0.51	AB
	KaVo calcium carbonate	15	0.31	0.16	0.30	0.09	0.56	B
	Dentsply aluminum trihydroxide	15	0.38	0.24	0.29	0.12	0.93	B
	Osspray calcium sodium phosphosilicate	15	1.49	0.39	1.41	0.87	2.17	C
Glass Ionomer	EMS glycine	15	2.23	0.25	2.21	1.79	2.67	A
	Dentsply aluminum trihydroxide	15	2.47	0.47	2.34	1.89	3.23	AB
	Osspray SYLC calcium sodium phosphosilicate	15	2.49	0.70	2.26	1.81	4.40	AB
	EMS sodium bicarbonate	15	2.54	0.32	2.46	1.95	3.13	AB
	KaVo calcium carbonate	15	2.84	0.39	2.82	2.29	3.78	BC
	Dentsply sodium bicarbonate	14	3.02	0.36	2.99	2.52	3.68	C

* For each material listed abrasives with the same letter are not significantly different.

(p = 0.11). For each time listed, abrasives in the table with the same letter are not statistically significantly different.

However, there was a statistically significant difference in the mean change in roughness between the powder types (p = 0.0010) after treatment for five seconds. The EMS glycine and the EMS sodium bicarbonate powders produced the smoothest surfaces on all materials at one, two, and five seconds. Dentsply aluminum trihydroxide, Dentsply sodium bicarbonate, and KaVo calcium carbonate produced statistically significantly greater roughness in the enamel, hybrid composite, and glass ionomer than the EMS glycine or EMS sodium bicarbonate, but did not produce statistically significantly greater roughness than each other.

Osspray SYLC produced the greatest mean change in surface roughness on all materials after five seconds of treatment. Because there were no statistically significant differences in the change of roughness for the one-second and two-second treatment times, the only pairwise comparisons calculated were for the five-second treatment time, as shown in Table VIII.

There was a statistically significant difference in the mean change in roughness between the powder types (p = 0.0011). There were statistically significant differences between Osspray calcium sodium phosphosilicate and Dentsply sodium bicarbonate, EMS glycine, EMS sodium bicarbonate, and KaVo calcium carbonate.

Table IX presents the descriptive statistics for material and time. There was no statistically significant difference in the mean change in roughness on the composite samples between the time durations (p = 0.34). Likewise, there was no statistically significant difference in the mean change in roughness of enamel between the time durations (p = 0.18). Conversely, there was a statistically significant difference in the mean change in roughness in the glass ionomer samples between the time durations (p < 0.0001). The treatment of the glass ionomer for five seconds resulted in a surface that was statistically significantly rougher than the effects produced by the powders at one and two seconds. This is due to the fact that the glass ionomer is the softest of the three study material samples.

Roughness Visually Evaluated With Scanning Electron Microscopy

The SEM photomicrographs were used to evaluate the clinical significance of the effects of air polishing on each type of material treated in the study.

Evaluation of surface characterization provides a visual quantitative analysis of the effects of AP powders on restorative materials and enamel. No measurements were made of volumetric loss, as any disruption of the surface characterization was considered to be clinically significant and represented volumetric loss, and thus a violation of the integrity of the restorative mate-

Table IV

Hybrid Composite, Pairwise Comparisons of Type of Powder

	Dentsply aluminum trihydroxide	Dentsply sodium bicarbonate	EMS glycine	EMS sodium bicarbonate	KaVo calcium carbonate	Osspray calcium sodium phosphosilicate
Dentsply aluminum trihydroxide		0.952	< 0.0001	< 0.0001	0.9981	< 0.0001
Dentsply sodium bicarbonate	0.952		< 0.0001	< 0.0001	0.7835	< 0.0001
EMS glycine	< 0.0001	< 0.0001		0.0759	< 0.0001	< 0.0001
EMS sodium bicarbonate	< 0.0001	< 0.0001	0.0759		0.0003	< 0.0001
KaVo calcium carbonate	0.9981	0.7835	< 0.0001	0.0003		< 0.0001
Osspray calcium sodium phosphosilicate	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	

Table V

Enamel, Pairwise Comparisons of Type of Powder

	Dentsply aluminum trihydroxide	Dentsply sodium bicarbonate	EMS glycine	EMS sodium bicarbonate	KaVo calcium carbonate	Osspray calcium sodium phosphosilicate
Dentsply aluminum trihydroxide		0.0033	0.0005	0.0005	0.9299	< 0.0001
Dentsply sodium bicarbonate	0.0033		0.9939	0.9891	0.0562	< 0.0001
EMS glycine	0.0005	0.9939		1.0000	0.0120	< 0.0001
EMS sodium bicarbonate	0.0005	0.9891	1.0000		0.0112	< 0.0001
KaVo calcium carbonate	0.9299	0.0562	0.0120	0.0112		< 0.0001
Osspray calcium sodium phosphosilicate	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	

Table VI

Glass Ionomer: Pairwise Comparisons of Type of Powder

	Dentsply aluminum trihydroxide	Dentsply sodium bicarbonate	EMS glycine	EMS sodium bicarbonate	KaVo calcium carbonate	Osspray calcium sodium phosphosilicate
Dentsply aluminum trihydroxide		0.0090	0.6762	0.9982	0.1920	1.0000
Dentsply sodium bicarbonate	0.0090		< 0.0001	0.0312	0.8449	0.0170
EMS glycine	0.6762	< 0.0001		0.4066	0.0034	0.5979
EMS sodium bicarbonate	0.9982	0.0312	0.4066		0.4017	0.9998
KaVo calcium carbonate	0.1920	0.8449	0.0034	0.4017		0.2741
Osspray calcium sodium phosphosilicate	1.0000	0.0170	0.5979	0.9998	0.2741	

rials and/or enamel. Short of an actual clinical trial, adding SEM analysis provided important and more comprehensive evaluation of the effects of these AP powders on the samples of the restorative materials and enamel. An actual clinical trial would be unethical since harm to subject's restorations on enamel could occur.

Scanning electron photomicrographs were taken of all study samples of restorative materials and enamel after treatment with each of the air polishing powders for all treatment times; one second, two seconds, and five seconds. For the majority of the SEM photomicrographs, there was no significant visual difference between the effects of the air polishing powders on the restorative materials and enamel. Further, any visual effects of the AP powders on the study samples after treatment with the powders for five seconds mirrored the effects seen at one and two seconds of treatment. Therefore, it was determined to include the SEMs of the samples treated for five seconds in this report as this provided an exaggerated amount of treatment time. The five seconds of treatment time, as stated pre-

Table VII
Time and Type of Powder, Outcome: Change in Roughness (Ra-µm)

Time	Powder	N	Mean	Std Dev	Median	Minimum	Maximum	Grouping*
1	EMS glycine	15	0.76	1.05	0.08	0.00	2.61	A*
	EMS sodium bicarbonate	15	0.96	1.20	0.28	0.01	3.13	A
	Dentsply aluminum trihydroxide	15	1.09	0.88	0.77	0.15	2.51	A
	Dentsply sodium bicarbonate	15	1.17	1.23	0.67	0.02	3.02	A
	KaVo calcium carbonate	15	1.18	1.13	0.65	0.09	3.01	A
	Osspray calcium sodium phosphosilicate	14	1.75	0.47	1.86	0.87	2.29	A
2	EMS glycine	15	0.79	1.06	0.10	0.01	2.67	A
	EMS sodium bicarbonate	14	0.96	1.07	0.39	0.01	2.46	A
	Dentsply aluminum trihydroxide	15	1.03	0.85	0.73	0.12	2.47	A
	Dentsply sodium bicarbonate	15	1.25	1.09	0.67	0.17	3.01	A
	KaVo calcium carbonate	15	1.34	1.38	0.83	0.04	3.68	A
	Osspray calcium sodium phosphosilicate	15	1.81	0.43	1.81	1.09	2.39	A
5	EMS glycine	15	0.84	1.08	0.12	0.04	2.53	A
	EMS sodium bicarbonate	15	1.06	1.23	0.38	0.02	3.03	A
	Dentsply aluminum trihydroxide	15	1.44	1.31	0.91	0.03	3.56	AB
	Dentsply sodium bicarbonate	15	1.45	1.28	0.83	0.30	3.78	AB
	KaVo calcium carbonate	15	1.749	1.14	0.88	0.34	3.23	AB
	Osspray calcium sodium phosphosilicate	15	2.66	0.71	2.67	1.57	4.40	C

* For each time listed abrasives with the same letter are not significantly different

Table VIII
Five-Seconds, Pairwise Comparisons of Type of Powder

	Dentsply aluminum trihydroxide	Dentsply sodium bicarbonate	EMS glycine	EMS sodium bicarbonate	KaVo calcium carbonate	Osspray calcium sodium phosphosilicate
Dentsply aluminum trihydroxide		1.0000	0.6238	0.8985	1.0000	0.0692
Dentsply sodium bicarbonate	1.0000		0.7006	0.9373	1.0000	0.0508
EMS glycine	0.6238	0.7006		0.9956	0.6936	0.0005
EMS sodium bicarbonate	0.8985	0.9373	0.9956		0.9342	0.0031
KaVo calcium carbonate	1.0000	1.0000	0.6936	0.9342		0.0524
Osspray calcium sodium phosphosilicate	0.0692	0.0508	0.0005	0.0031	0.0524	

Table IX
Outcome of Material and Time: Change in Roughness (Ra-µm)

Material	Time	N	Mean	Std Dev	Median	Minimum	Maximum	Grouping*
Hybrid Composite	1	30	0.74	0.64	0.66	0.00	2.29	A
	2	30	0.79	0.61	0.68	0.09	2.39	A
	5	30	1.00	0.92	0.81	0.12	3.08	A
Enamel	1	30	0.30	0.47	0.09	0.01	1.84	A
	2	29	0.34	0.48	0.12	0.01	1.42	A
	5	30	0.55	0.66	0.32	0.02	2.17	A
Glass Ionomer	1	29	2.43	0.37	2.43	1.79	3.13	A
	2	30	2.44	0.45	2.40	1.81	3.68	A
	5	30	2.92	0.49	2.95	2.18	4.40	B

* For each time listed abrasives with the same letter are not significantly different

viously, is approximately the equivalent of an individual having their teeth air polished twice per year for five years.[8,10-13,15,16,19-21,42]

SEMS: Treatment Outcomes

All SEM treatment outcomes are based on the SEMs of the three materials, hybrid composite, enamel, and glass ionomer, which were treated with each of the six air polishing powders for five seconds. All SEM photomicrographs were taken at 25X and at a 45° angle.

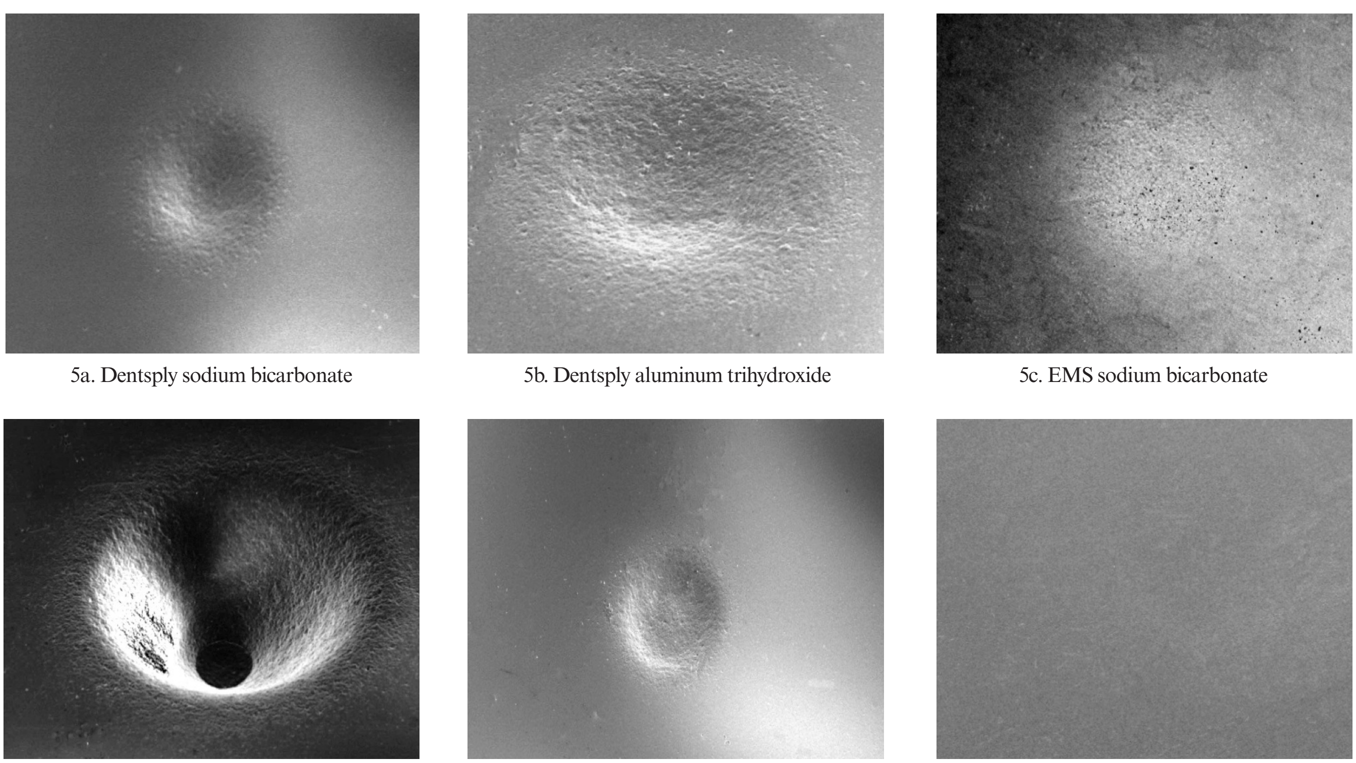
Hybrid Composite. The SEM photomicrographs of the hybrid composite treated with the six air polishing powders can be seen in Figures 5a-5f. Changes in the surface characterization of the hybrid composite after treatment with each of the powders revealed that the least amount of change in surface characterization was found on the hybrid composite treated with the EMS glycine, followed by EMS sodium bicarbonate. The greatest amount of change in the surface characterization of the hybrid composite was caused by Osspray calcium sodium phosphosilicate, followed by KaVo calcium carbonate powder. Analysis of the SEM photomicrographs revealed powders that caused the least to the greatest amount of disruption of the surface characterization in the hybrid composite samples to be EMS glycine, EMS sodium bicarbonate, Dentsply sodium bicarbonate, KaVo calcium carbonate, Dentsply aluminum trihydroxide, and Osspray calcium sodium phosphosilicate; Dentsply sodium bicarbonate and KaVo calcium carbonate were very close in values, with little discernable difference in the amount of volumetric loss.

Human Enamel. The SEM photomicrographs of the human enamel treated with the six air polishing powders can be seen in Figures 6a-6f. An analysis of the changes in the surface characterization of the enamel after treatment with each of the powders revealed that the least amount of change in surface characterization was found on the enamel that was treated with the EMS glycine, followed by Dentsply sodium bicarbonate. The greatest amount of change in the surface characterization of the enamel was created by the Osspray calcium sodium phosphosilicate, with less by KaVo calcium carbonate. Analysis of the SEM photomicrographs revealed that the powders that caused the least to the greatest amount of disruption in the surface characterization in the enamel samples were EMS glycine, Dentsply sodium bicarbonate, EMS sodium bicarbonate, Dentsply aluminum trihydroxide, KaVo calcium carbonate, and Osspray calcium sodium phosphosilicate. The Dentsply sodium bicarbonate and EMS sodium bicarbonate were very close in value of the disruption of the surface characterization of the enamel. There was little discernable difference in the amount of volumetric loss caused by each of these two powders.

Glass Ionomer. The SEM photomicrographs of the glass ionomer treated with the six air polishing powders can be seen in Figures 7a-7f. An analysis of the changes in the surface characterization of the glass ionomer after treatment with each of the powders revealed that the least amount of change in surface characterization was found on the glass ionomer that was treated with the EMS glycine, followed by the Dentsply sodium bicarbonate air polishing powder.

The greatest amount of change in the surface characterization of the glass ionomer was created by the Osspray calcium sodium phosphosilicate, with less change by KaVo calcium carbonate. Analysis of the SEM photomicrographs revealed that the powders that caused

Hybrid Composite



5a. Dentsply sodium bicarbonate
5b. Dentsply aluminum trihydroxide
5c. EMS sodium bicarbonate
5d. Osspray calcium sodium phosphosilicate
5e. KaVo calcium carbonate
5f. EMS glycine

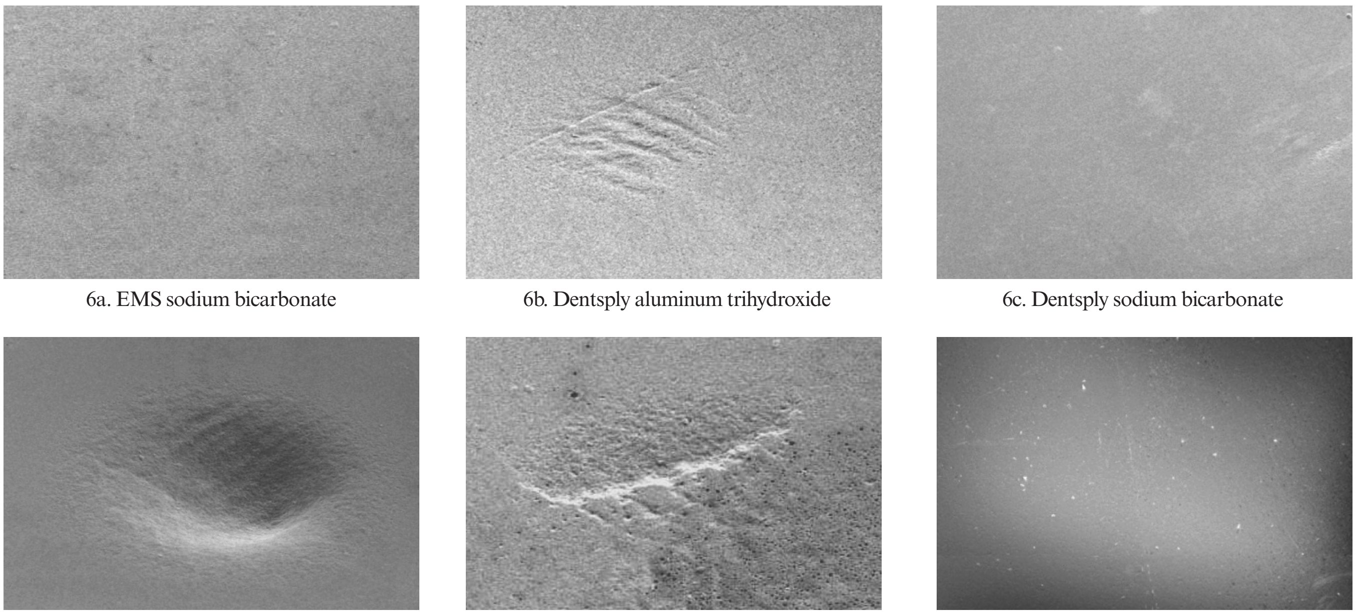
Figures 5a-5f. *Scanning electron photomicrographs of hybrid composite treated for 5 seconds with the indicated air polishing powder.*

the least to the greatest amount of disruption of the surface characterization in the glass ionomer samples were EMS glycine, EMS sodium bicarbonate, Dentsply sodium bicarbonate, KaVo calcium carbonate, Dentsply aluminum trihydroxide, and Osspray calcium sodium phosphosilicate. The Dentsply sodium bicarbonate, KaVo calcium carbonate, and Dentsply aluminum trihydroxide were very close in value for the disruption of the surface characterization of the glass ionomer. There is little discernable difference in the amount of volumetric loss caused by each of these three air polishing powders.

Clinical Trends

The scanning electron photomicrographs (SEMs) were used to determine the clinical significance of treating each of the study sample surfaces with the AP powders. By comparing each of the study sample surfaces and the amount of change brought about to the surface characterization by the powders, there was clearly a trend as to the amount of change that occurred associated with each, which can be seen in Table X. Clearly the EMS glycine and EMS sodium bicarbonate, respectively, brought about

Human Enamel



6a. EMS sodium bicarbonate

6b. Dentsply aluminum trihydroxide

6c. Dentsply sodium bicarbonate

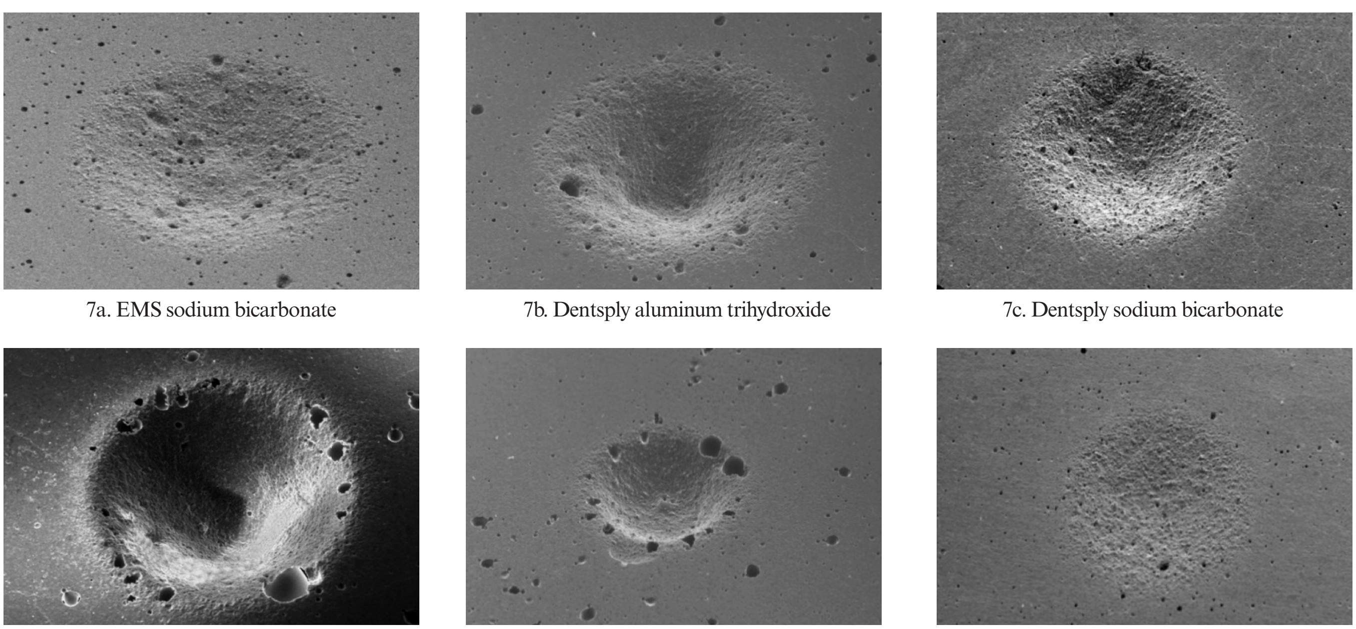
6d. Osspray calcium sodium phosphosilicate

6e. KaVo calcium carbonate

6f. EMS glycine

Figures 6a-6f. *Scanning electron photomicrographs of enamel treated for five seconds with the indicated air polishing powder.*

Glass Ionomer



7a. EMS sodium bicarbonate

7b. Dentsply aluminum trihydroxide

7c. Dentsply sodium bicarbonate

7d. Osspray calcium sodium phosphosilicate

7e. KaVo calcium carbonate

7f. EMS glycine

Figures 7a-f. *Scanning electron photomicrographs of glass ionomer treated for five seconds with the identified air polishing powder.*

Table X
Summary of Results of the Effects of the Air Polishing Powders on Hybrid Composite, Human Enamel and Glass Ionomer Samples

Air Polishing Powder	Hybrid Composite	Human Enamel	Glass Ionomer
Least Change in Surface Characterization	EMS glycine	EMS glycine	EMS glycine
	EMS sodium bicarbonate	EMS sodium bicarbonate	EMS sodium bicarbonate
↓	Dentsply sodium bicarbonate	Dentsply sodium bicarbonate	Dentsply sodium bicarbonate
	KaVo calcium carbonate*	Dentsply aluminum trihydroxide	KaVo calcium carbonate*
	Dentsply aluminum trihydroxide	KaVo calcium carbonate	Dentsply aluminum trihydroxide*
Greatest Change in Surface Characterization	Osspray calcium sodium phosphosilicate	Osspray calcium sodium phosphosilicate	Osspray calcium sodium phosphosilicate

the least amount of change in surface characterization. The greatest amount of change in the surface characterization was brought about by the Osspray calcium sodium phosphosilicate, which caused excessive removal of the hybrid composite, human enamel, and glass ionomer sample materials. In some instances the Osspray calcium sodium phosphosilicate (novamin) removed all of the restorative material leaving a hole in the sample, as can be seen in the respective SEM photomicrographs.

The remaining three powders, Dentsply sodium bicarbonate, KaVo calcium carbonate, and Dentsply aluminum trihydroxide, caused clinically significant, detrimental changes in the surface characterization. While the Dentsply sodium bicarbonate caused clinically significant and detrimental changes in the hybrid composite and glass ionomer materials, it was compatible with human enamel. However, the EMS sodium bicarbonate powder was slightly less abrasive to human enamel than the Dentsply sodium bicarbonate powder. The KaVo calcium carbonate and Dentsply aluminum trihydroxide caused clinically significant detrimental changes to the hybrid composite, glass ionomer, and human enamel. Any disruption in the surface characterization of the restorations violates the integrity of that restoration in that it represents volumetric loss of the restorative material.

Discussion

The purpose of this study was to investigate the effects of commercially available air polishing powders on the surface characterization of a hybrid composite, a glass ionomer, and human enamel using a highly standardized protocol. This is the only research found in the literature to date that has been conducted on air polishing powders that utilized a standardizing device so that the treatment times were exact. A custom mounting jig and shutter device were fabricated to standardize the treatment procedures. The shutter exposure time was controlled by a customized computer program so that the exposure times of the powder, air, and water stream were an exact one, two, and five seconds. The handpiece was secured according to universal treatment instructions so the nozzle would be 3–5 mm and in a constant circular motion.

The scanning electron photomicrographs offered excellent visual documentation on the effects of the various powders on the surface characteristics of the study samples. The visual SEM effects were supported by the results of profilometry.

Conclusion

There are no universal standards for the formulations of air polishing powders. Even though more than one manufacturer makes and distributes AP powders that are identified by their primary ingredient, the powders differ among manufacturers. In this study, it was found that the Dentsply sodium bicarbonate powder differs greatly in abrasion potential from the EMS sodium bicarbonate powder, which was statistically and clinically significantly less abrasive. Therefore, dentists and dental hygienists need to be aware that air polishing powders differ in their formulations from manufacturer to manufacturer, and should expect different results from powders made by different manufacturers.

The results of this research indicate that there are air polishing powders that are significantly less abrasive than others, even with similar ingredients, specifically sodium bicarbonate. It also appears that for esthetic restorations, EMS glycine and EMS sodium bicarbonate were satisfactory. Based on the results of this study, esthetic restorations should not be air polished with Dentsply sodium bicarbonate, Dentsply aluminum trihydroxide, KaVo calcium carbonate, or Osspray calcium sodium phosphosilicate air polishing powders. Moreover, based on these results, it is the recommendation of these investigators that Dentsply aluminum trihydroxide, KaVo calcium carbonate, and Osspray calcium sodium phosphosilicate not be used as air polishing powders due to their highly abrasive nature, which resulted in clinically significant damage to the surface characterization of enamel, hybrid composite, and glass ionomer. Dentsply sodium bicarbonate is compatible with enamel and other restorative materials (amalgam, gold, porcelain); however, not with esthetic restorative materials. The SEM photomicrographs were used to determine the clinical significance of treating each of the study sample surfaces with the air polishing powders. By comparing each of the study sample surfaces and the amount of change brought about to the surface characterization by the air polishing powders, there is clearly a trend as to the amount of change that occurred associated with each of the air polishing powders, which can be seen in Table X.

Clearly, the EMS glycine and EMS sodium bicarbonate brought about the least amount of change in surface characterization. The greatest amount of change in the surface characterization was brought about by the Osspray calcium sodium phosphosilicate, which caused a complete disruption in the surface characterization of the hybrid composite, human enamel, and glass ionomer. In some instances, the Osspray calcium sodium phosphosilicate (novamin) removed all of the restorative material leaving a hole in the sample, as can be seen in the respective SEM photomicrographs. The KaVo calcium carbonate and Dentsply aluminum trihydroxide caused clinically significant detrimental changes to the hybrid composite, glass ionomer, and human enamel. The Dentsply sodium bicarbonate caused clinically significant and detrimental changes in the hybrid composite and glass ionomer materials; however, it is compatible with human enamel.

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