Doctoral (PhD) Dissertation

# Studies on the effect of prophylactic air abrasion devices on dental composites

**Kinga Dorottya Németh D.M.D**

Doctoral School of Clinical Medical Sciences

Head of the Doctoral School: Lajos Bogár M.D., Ph.D., D.Sc.

Program leader: Ákos Károly Nagy D.M.D., Ph.D., Habil.

**Supervisor: Edina Lempel D.M.D., Ph.D., Habil.**

University of Pécs

DCHCMPhS

Pécs, 2025

# Table of content

# I.Introduction

Resin-based composites are the most widely used filling materials in modern dental practice. Numerous ongoing studies focus on these materials, aiming to test and improve the practical application and longevity of composites. The surface structure of resin-based composites differs significantly from that of enamel, exposed dentin, or cementum. The properties of the filling material under intraoral conditions depend, among other factors, on the material's composition, the degree of monomer-to-polymer conversion, the polishing process, and the application of prophylactic air-abrasion treatments.[1] Air-abrasive cleaning is a commonly used tool in professional oral hygiene. During this process, powders of varying quality and particle sizes are projected onto the tooth surface under high pressure to remove plaque, tartar, and discoloration that adhere strongly to the teeth. This modern technique enables efficient and rapid treatment while facilitating the cleaning of hard-to-reach tooth surfaces. Numerous air polishing (AP) systems are available in dental practice for the removal of deposits from supra- and subgingival tooth surfaces. Among prophylactic air polishing powders, sodium bicarbonate was the first to be marketed, with a particle size of 250 µm. This traditional type is highly abrasive, damaging and roughening restoration surfaces and causing permanent damage to the enamel as well.[2] To eliminate these negative effects, glycine, calcium carbonate, fine-particle sodium bicarbonate, and erythritol-based prophylactic powders were introduced in the early 2000s.[3,4] With the use of these powders, satisfactory results can be achieved with reduced abrasive impact.

During the cleaning process, however, the powder particles also reach the surface of composite fillings, whose hardness does not match that of natural enamel, thus potentially leaving marks and small indentations. The resulting roughened surface facilitates further biofilm formation, thereby compromising the maintenance of oral hygiene.[5] The dental biofilm present on teeth and around fillings is a major etiological factor of secondary caries and periodontal disease. Therefore, it is essential to ensure adequately smooth, non-plaque-retentive surfaces around restorations.[6] Although several studies have demonstrated the negative effects of air-abrasion, we have found no recommendations for the optimal post-polishing method of enamel or composite fillings to ensure proper surface restoration, enhance esthetic appearance, and support cariological and periodontal health. Adequate polishing is one of the cornerstones for the long-term survival of composites, with many approaches known, ranging from single-step to multi-step polishing protocols. In our study, we compared the polishing efficiency of a one-step silicone brush and a two-step rubber polishing system on various types of composites following air polishing.

The roughening effect mentioned above may even be beneficial in the context of repairing failed composite fillings. Since the bond strength of a fresh repair composite to the surface of an aged restoration is weak, mechanical roughening of the latter is necessary. Despite the high survival rate of resin-based composite fillings (88–98%), these materials are highly technique-sensitive and may undergo varying degrees of degradation due to mechanical, chemical, and physical stresses in the oral environment. These factors can lead to minor or major failures within the material or at the composite–enamel interface, often manifesting as secondary caries.[7] In the case of small fractures or chipping within the material, the primary goal is repair to avoid unnecessary loss of healthy tooth structure.[8] In this repair process, surface roughening by air polishing prior to layering the new composite can be a recommended method. As the restoration has already been present in the oral cavity for a prolonged period, structural, chemical, and physical changes occur within the material, a process known as aging. The ideal bond between two composite layers is chemical, based on the bonding of resin monomers to the matrix or exposed filler particles. However, in practice, the bond between the old and new composite layers is mostly micromechanical, achieved by penetration and polymerization of new monomers into surface irregularities of the aged composite. These irregularities can be created using air-abrasion devices.[9] There is a broader literature background on the use of aluminum oxide or silica-coated powder particles in air-abrasion and their impact on the microtensile bond strength between the old and the repair composite. However, in clinical practice, prophylactic sodium bicarbonate-based air polishing systems are most commonly used.[10] Nevertheless, we found no literature addressing the effect of sodium bicarbonate air polishing on the microtensile bond strength between old and new composites. Air polishing treatments can significantly alter surface structures, and powder particles may remain embedded in the surface, influencing the formation of chemical and physical bonds with the repair composite. Thus, a surface cleaning procedure—such as rinsing with phosphoric acid or EDTA—may be necessary after air-abrasion. In addition to surface characteristics, the use of an adhesive bonding agent between composite layers is an important influencing factor. Its presence, absence, or type can significantly affect microtensile bond strength.[11]

# II. Objectives

## II.1. Effect of air polishing and different post-polishing methods on surface roughness of nanofill and microhybrid resin composites

The first phase of our research project entailed the investigation of the impact of AP methodologies on the surface roughening of various categories of dental RBCs, utilizing atomic force microscopy.

The objective of the study was to

(1) assess the impact of a calcium carbonate-based prophylactic air abrasion method on nanofill and microhybrid dental RBC and enamel;

(2) compare the changes of the surface roughness of the treated samples using atomic force microscopy;

(3) examine the effectiveness of one-step and two-step post-polishing methods to restore surface smoothness.

The null hypotheses of our study were as follows: (1) there is no difference in surface roughness between RBCs and native enamel before and after air polishing with calcium carbonate; (2) there is no difference in surface roughness between RBCs containing different sizes of filler particles after air polishing with calcium carbonate; (3) there is no difference in surface roughness between RBCs and on the enamel surface after different post-polishing procedures.

## II.2. Comparative evaluation of the repair bond strength of dental resin composite after sodium bicarbonate or aluminum oxide air abrasion

In the subsequent phase of our research, the repair of a damaged RBC restoration was simulated using a repairing RBC layer. The bond strength of fresh repairing RBC to old RBC samples' surfaces treated with different types and sizes of abrasive or prophylactic powders and subjected to thermal cycling ageing was tested by using a microtensile biaxial tensile strength testing machine.

The aim of this study was to

(1) compare the effect on microtensile bond strength of sodium bicarbonate air polishing with the generally recommended aluminum oxide air abrasive surface treatment;

(2) investigate the cleaning effect of phosphoric acid as a strong acid or ethylene-diamine-tetraacetic acid (EDTA) as a chelator, and the significance of the presence and type of adhesive agent on microtensile bond strength after surface treatment.

The null hypotheses of our investigation were as follows: (1) there is no difference in μTBS using sodium bicarbonate or aluminum oxide air abrasive particles before RBC repair; (2) there is no effect of using phosphoric acid or EDTA as a cleaning method on the repair μTBS; (3) there is no additional effect of the application of adhesive system on the repair μTBS.

# III. Materials and methods

## III.1. Effect of air polishing and different post-polishing methods on surface roughness of nanofill and microhybrid resin composites

In this study, 8 x 5 mm enamel slices, 2 mm in thickness, were prepared from the buccal surface of unerupted third molars extracted for orthodontic reasons. The third molars were immersed to 5.25% sodium hypochlorite solution for 5 min immediately after the extraction for disinfection, then were stored in 0.9% sterile physiologic saline solution at 37 °C (Cultura Incubator, Ivoclar Vivadent, Schaan, Liechtenstein) for one week right before the slice preparation to avoid desiccation. Light-cured RBC samples were fabricated using a cylindrical polytetrafluoroethylene (PTFE) mold (with an inner diameter of 6 mm and height of 2 mm) from nanofill (Filtek Ultimate) and microhybrid (Enamel Plus HRi) RBCs. Materials were handled as specified by the manufacturer. The prepared samples were randomly divided into five groups (n=5x5). Surface characteristics of materials cured against a Mylar strip were used as a control group (Group 1). The samples of Group 2 were air polished (Prophy-Mate Neo, NSK-Nakanishi Co., Kanuma, Tochigi, Japan) with a 54 µm particle size calcium carbonate prophylactic powder (Mohs Hardness Index: 3) (Prophy-Mate Profilactic Powder, NSK-Nakanishi Co., Kanuma, Tochigi, Japan) for 5 seconds at a 20-degree angle from a distance of 5 mm. Samples of Group 3 were air polished for 10 seconds with the same parameters. Samples of Group 4 and Group 5 were post-polished after the AP. In Group 4, a two-step rubber diamond polisher (fine-10s, 8-32 µm grit size, KendaNobilis, Kenda AG, Vaduz, Liechtenstein; then extra fine-10s, 4-8 µm grit size, KendaUnicus, Kenda AG, Vaduz, Liechtenstein) was used. In Group 5, a one-step polisher, an abrasive-impregnated polishing brush with in-build silicone carbide abrasive particles (Occlubrush cup, KerrHawe SA, Bioggio, Switzerland) was used for 10 s to polish the surface.

Samples were analyzed by scanning electron microscope (SEM) (JSM-6300, JEOL, Tokyo, Japan) at 1000x and 2000x magnification as a preliminary test. The SEM examination was used to evaluate the clinical significance of the effects of AP on each type of material treated in the study. All destructive surface changes compared to native enamel and RBC surfaces were considered clinically significant.

The samples were analyzed with atomic force microscope (AFM) to provide information about the exact surface topography as well as changes in the mean height values of irregularities. Surface roughness was determined using an AFM unit (Asylium Research, Santa Barbara, CA, USA) synchronized with an Olympus epifluorescence microscope (Olympus, Tokyo, Japan). Images were taken in non-contact mode, with a line scan frequency of 0.3 Hz. For each sample, 30 μm x 30 μm images were scanned in three randomly selected areas at a resolution of 512 x 512 pixels. The average surface roughness (Ra) and 3-dimensional images were obtained and analyzed with the designated AFM software (IgorPro 6, WaveMetrics Inc., Lake Oswego, Oregon, USA).

Data were analysed using ANOVA, Tukey's post-hoc test, multivariate analysis and effect size statistics ($p<0.05$) in SPSS v. 26.0 (SPSS, Chicago, IL, USA).

## III.2. Comparative evaluation of the repair bond strength of dental resin composite after sodium bicarbonate or aluminum oxide air abrasion

As a first step of the sample preparation, RBC blocks were prepared (n = 16) to simulate the old restoration to be repaired. A custom-made laser cut transparent thermoplastic poly(methyl-methacrylate) (Perspex, Chelmsford, UK) template with an inner dimension of 8 mm height, 8 mm width and 20 mm length was used for sample preparation. Thereafter, the blocks were subjected to the aging procedure, followed by surface conditioning prior to repair with the "new" RBC.

Group 1. Specimens without polishing, aging and surface conditioning served as positive control.

Group 2. Polished and aged specimens without surface conditioning served as negative control.

Group 3. Polished and aged specimens were air abraded (Aquacare Twin, Velopex International, London, UK) with 53 µm aluminum oxide particles ($Al_2O_3$, AquaAbrasion, Velopex International, London, UK). The tip of the handpiece was positioned vertically to the surface at a distance of 10 mm over the course of 10 s with a pressure of 4 bar and 90° inclination. The remnant particles were removed using an air-water syringe and then the specimen surface was dried with oil-free air.

Group 4. The conditioned surface of samples treated as described for Group 3 was cleaned using 35% phosphoric acid ($H_3PO_4$) for 15 s and the etchant was thoroughly rinsed with an air-water syringe for 30 s. The specimen surface was dried with oil-free air.

Group 5. After the procedure as described in Group 4, a thin layer of two-step etch-and-rinse adhesive (Adper Single Bond 2) was applied with circular brushing motion with a disposable applicator for 20 s. The surface was dried with oil-free air-water syringe for 10 s and light-cured for 10 s.

Group 6. After the procedure as described in Group 4, a thin layer of universal adhesive (Scotchbond Universal Plus Adhesive) was applied with circular brushing motion onto the air abraded surface with a disposable applicator for 20 s and left for 20 s. The surface was then dried with oil-free air-water syringe for 10 s and light-cured for 10 s.

Group 7. The conditioned surface of samples treated as described for Group 3 was cleaned using 15% ethylene diamine tetra-acetic acid solution (EDTA). The solution was applied via drain tube onto the specimen surface and left for 1 min, then was thoroughly rinsed with an air-water syringe for 30 s. The specimen surface was dried with oil-free air.

Group 8. A thin layer of Adper Single Bond 2 was applied with the above detailed method to the conditioned surface of samples treated as described for Group 7.

Group 9. A thin layer of Scotchbond Universal Plus Adhesive was applied with the above detailed method to the conditioned surface of samples treated as described for Group 7.

Group 10. Polished and aged specimens were air polished (Aquacare Twin, Velopex International, London, UK) with 65 µm sodium bicarbonate particles ($NaHCO_3$ AquaPolishing, Velopex International, London, UK). The tip of the handpiece was positioned vertically to the surface from a distance of 4 mm over the course of 10 s with a pressure of 4 bar and 45 degrees of inclination, according to the manufacturer's recommendation. The remnant particles were removed using an air-water syringe, and then the specimen surface was dried with oil-free air.

Group 11. The conditioned surface of samples treated as described for Group 10 was cleaned using 35% phosphoric acid with the above detailed method.

Group 12. A thin layer of Adper Single Bond 2 was applied with the above detailed method to the conditioned surface of samples treated as described for Group 11.

Group 13. A thin layer of Scotchbond Universal Plus Adhesive was applied with the above detailed method to the conditioned surface of samples treated as described for Group 11.

Group 14. The conditioned surface of samples treated as described for Group 12 was cleaned using 17% EDTA with the above detailed method.

Group 15. A thin layer of Adper Single Bond 2 was applied with the above detailed method to the conditioned surface of samples treated as described for Group 14.

Group 16. A thin layer of Scotchbond Universal Plus Adhesive was applied with the above detailed method to the conditioned surface of samples treated as described for Group 14.

After the surface treatment all substrate RBC specimens were individually placed into the plexiglass mold and repaired with the same type of RBC.

The microtensile bond strength of the surface treated and repaired composite blocks was measured. For the test procedure, the blocks were sliced longitudinally into 1mm x 1mm x 20 mm sticks (SIEG SX3, Shanghai SIEG Machinery Co., Shanghai, China). Each composite stick was individually bonded (Super Bond, Henkel Loctite, Düsseldorf, Germany) to a custom-made microtensile tensile test jig. The jigs were 3D printed (Markforged X7, Montreal, QC, Canada) from Markforged Onyx (MarfkorgedX7, Montreal, Quebec, Canada). The specimen was subjected to a 5 kN load on a biaxial tensile strength testing machine (Zwick/RoellZ5. 0,ZwickRoell, Ulm, Germany). The applied load force (N) divided by the bonding surface area ($mm^2$) gave the microtensile tensile strength (MPa).

After µTBS tests, five specimens were randomly selected and subjected to failure mode analysis under a scanning electron microscope (JEOL JSM-IT500HR, JEOL, Tokyo, Japan). Failure modes were recorded as adhesive (between substrate and repair

RBC), cohesive (within the substrate or the repair RBC), or mixed (both adhesive and cohesive).

For further analysis of the surface structure by scanning electron microscopy (JEOL JSM-IT500HR, JEOL, Tokyo, Japan), additional composite samples were prepared according to the methods described in groups 2, 3, 4, 7, 10, 11, 14 above. During the surface conditioning procedure, half of the sample surface was covered with a metal strip to avoid air abrasion/AP. This method provided specimens where the treated and untreated surfaces were directly comparable and the surface effect of the abrasives could be judged. Additionally, an energy-dispersive X-ray spectroscope (FEG-SEM-EDS; JEOL JSM-IT500HR, JEOL, Tokyo, Japan) was used to collect detailed elemental information along with electron microscopy images to enable the chemical characterization of the surface-treated specimens.

# IV. Conclusion of new results

## IV.1. Effect of air polishing and different post-polishing methods on surface roughness of nanofill and microhybrid resin composites

Within the limitations of our first *in vitro* study the following conclusions can be stated:

- Air polishing with calcium carbonate powder can cause abrasion on the enamel surface and can increase the surface roughness of both nanofill and microhybrid RBCs.
- The destructive effect of the extended air polishing time (10 s) is more significant on the enamel compared to the 5 s air polishing, however, did not influence the surface roughness of the RBCs.
- The effect size of factor *Material* (type of RBCs) and *Treatment* (air polishing and post-polishing) on the surface roughness is large.
- Post-polishing with rubber polisher series can decrease the surface roughness of RBCs after air polishing in a

significant manner, thus, the post-polishing of RBCs with rubber polisher series is recommended after air polishing.

- Post-polishing with rubber polisher series has no beneficial effect on enamel after air polishing, however, in-build silicon carbide particles polishing brushes significantly increased the surface roughness.

**Clinical significance:** It has been demonstrated that air polishing has the potential to compromise the surface smoothness of enamel and resin-based restorations. However, the utilisation of two-step rubber polishers following the air polishing process has been shown to restore surface smoothness, thereby mitigating the risk of increased biofilm accumulation and discolouration.

## IV.2. Comparative evaluation of the repair bond strength of dental resin composite after sodium bicarbonate or aluminum oxide air abrasion

Within the limitations of our second *in vitro* study, analyzing the different variables influencing the repair process of aged RBC has led to the following conclusions:

- A diverse combination of the applied surface preparation, cleaning method and intermediate adhesive layer significantly contributes to the repair bond strength achieved.
- The widely available and routinely applied prophylactic cleaning method, namely sodium bicarbonate air polishing followed by EDTA-cleaning and universal adhesive application, can provide a similar RBC repair bond strength to that of the commonly recommended aluminum oxide air abrasion with or without phosphoric acid cleaning and/or adhesive application.

**Clinical significance:** Sodium bicarbonate air polishing followed by EDTA cleaning and universal adhesive application could constitute a viable alternative in the RBC repair protocol.

# V. Bibliography of the candidate's publications


- Németh K. D., Haluszka D., Seress L., Lovász B. V., Szalma J., Lempel E. Effect of Air-Polishing and

Different Post-Polishing Methods on Surface Roughness of Nanofill and Microhybrid Resin Composites. *Polymers (Basel)*. **2022**;14(9):1643. doi: 10.3390/polym14091643.
SJR indicator: Q1, IF: 5.0, *Citations: 10 (independent citations: 9)*

- Németh K. D., Told R., Szabó P., Maróti P., Szénai R., Pintér Z. B., Lovász B. V., Szalma J., Lempel E. Comparative Evaluation of the Repair Bond Strength of Dental Resin Composite after Sodium Bicarbonate or Aluminum Oxide Air-Abrasion. *Int J Mol Sci.* **2023**; 24(14):11568. doi: 10.3390/ijms241411568.
SJR indicator: D1, IF: 4.9*, Citations: 1 (independent citations: 1)*

- Lempel E.; Németh K. D.; Lovász B. V.; Szalma J. Adhesive management of anterior tooth wear in combination with the Dahl concept: a 27-months observational case-series. *Oper Dent.* **2021** 46:594-608. doi: 10.2341/20-190.
SJR indicator: Q1, IF: 2.937, *Citations: 5 (independent citations: 5)*

- Lempel E.; Gyulai S.; Németh K. D. Lokalizált frontfogkopás adhezív rehabilitációja Dahl-koncepcióval kombinálva. Esetsorozat-tanulmány. *Fogorv Szle.* **2022**; 115:80-93. doi: 10.33891/FSZ.114.2.80-93.
  SJR indicator: Q4

**Cumulative impact factor: 12,837**

# VI. References


1. Nyvad, B. & Kilian, M. Microbiology of the early colonization of human enamel and root surfaces in vivo. *European J Oral Sciences* 95, 369–380 (**1987**).
2. Graumann, S. J., Sensat, M. L. & Stoltenberg, J. L. Air polishing: a review of current literature. *J Dent Hyg* 87, 173–180 (**2013**).
3. Müller, N., Moëne, R., Cancela, J. A. & Mombelli, A. Subgingival air-polishing with erythritol during periodontal maintenance: Randomized clinical trial of twelve months. *J Clinic Periodontology* 41, 883–889 (**2014**).
4. Flemmig, T. F. *et al.* Subgingival Debridement Efficacy of Glycine Powder Air Polishing. *Journal of Periodontology* 78, 1002–1010 (**2007**).

5. Bühler, J., Amato, M., Weiger, R. & Walter, C. A systematic review on the effects of air polishing devices on oral tissues. *Int J Dental Hygiene* 14, 15–28 (**2016**).
6. Giti, R., Dabiri, S., Motamedifar, M. & Derafshi, R. Surface roughness, plaque accumulation, and cytotoxicity of provisional restorative materials fabricated by different methods. *PLoS ONE* 16, e0249551 (**2021**).
7. Lempel, E. *et al.* Long-term clinical evaluation of direct resin composite restorations in vital vs. endodontically treated posterior teeth — Retrospective study up to 13 years. *Dental Materials* 35, 1308–1318 (**2019**).
8. Blum, I. R., Jagger, D. C. & Wilson, N. H. F. Defective dental restorations: to repair or not to repair? part 1: direct composite restorations. *Dent Update* 38, 78–84 (**2011**).
9. Rathke, A., Tymina, Y. & Haller, B. Effect of different surface treatments on the composite-composite repair bond strength. *Clin Oral Investig* 13, 317–323 (**2009**).
10. Baena, E., Vignolo, V., Fuentes, M. V. & Ceballos, L. Influence of repair procedure on composite-to-composite microtensile bond strength. *Am J Dent* 28, 255–260 (**2015**).
11. Loomans, B. & Özcan, M. Intraoral Repair of Direct and Indirect Restorations: Procedures and Guidelines. *Operative Dentistry* 41, S68–S78 (**2016**).

# VII. Acknowledgments

I would like to express my grateful thanks to my supervisor, **Edina Lempel**, Associate Professor, who has helped me during my research with her extensive professional knowledge and unwavering support, sparing no time or effort. Her deep commitment to academic excellence and meticulous attention to detail have significantly shaped this dissertation. Without her encouragement and assistance I would not be where I am today.

My appreciation also goes to **László Seress,** Emeritus Professor from Central Electron Microscopy Laboratory of University of Pécs, Medical School and to **Péter Szabó,** PhD, from Szentágotai János Research Center University of Pécs and **Dóra Haluszka,** Assistant Professor from Institute of Biophysics and Radiobiology, Semmelweis University - Faculty of Medicine for their help with the scanning electron microscopy and atomic force microscopy studies required for my research.

I am thankful to to the members of 3D Printing and Visualization Center, University of Pécs especially **Roland Told** and **Péter Maróti**, Associate Professor.

I also owe thanks for **Réka Szénai,** DMD and **Zsolt Pintér,** DMD, PhD who helped in the preparation of the research and **Bálint Lovász** for his final language editing on my publications.

Last but not least, I would like to thank my **family**, my **daughter**, my **husband** and my **parents** for supporting me on this journey.