Received: 13 June 2023 | Revised: 2 May 2024 | Accepted: 4 May 2024

DOI: 10.1111/idh.12838

ORIGINAL ARTICLE

International Journal of Dental Hygiene · IFDH · WILEY

In vitro evaluation of surface roughness of titanium abutments after air polishing with different abrasive powders

Pedro Francisco Almeida Roberto[1] | **Henrique Soares Luís**[1,2,3] | **Sofia Arantes Oliveira**[2]

[1]Faculdade de Medicina Dentária, Rede de Higienistas Orais para o Desenvolvimento da Ciência (RHODes), Universidade de Lisboa, Lisbon, Portugal

[2]Faculdade de Medicina Dentária, Unidade de Investigação em Ciências Orais e Biomédicas (UICOB), Universidade de Lisboa, Lisbon, Portugal

[3]Centro de Inovação em Tecnologias e Cuidados da Saúde (ciTechCare), Politécnico de Leiria, Leiria, Portugal

Correspondence
Pedro Francisco Almeida Roberto, Rua Professora Teresa Ambrósio, Cidade Universitária, 1600-277 Lisboa, Portugal.
Email: pedrofroberto93@gmail.com

Abstract

Objectives: The purpose of this study was to evaluate the effects of air polishing with sodium bicarbonate and erythritol powders on surface roughness and morphological changes in titanium abutments.

Methods: A total of 45 grade V titanium discs were divided in three groups: Group A (Control) air polished with air/water; Group B, air polished with sodium bicarbonate powder; and Group C, air polished with erythritol powder. After air polishing, the samples' roughness (S_a) in micrometres were analysed with an optical profilometer. The samples' surface morphology study was conducted via scanning electronic microscope (SEM). Data were described using mean and standard deviation of roughness values (S_a). Inferential analysis was performed using the ANOVA multiple comparison test followed by Tukey's post hoc test. Both tests used a 5% level of significance.

Results: After air polishing, average roughness of group A, B and C were 0.036, 0.046 and 0.037 μm, respectively, with statistically significant differences between groups A and B ($p < 0.05$). No statistically significant differences were found between group A and group C, as well as between group B and C ($p > 0.05$). As for the morphology analysis, damages to the titanium surface were only observed in group B.

Conclusions: The study indicates that air polishing with erythritol powder maintains titanium abutment integrity better than sodium bicarbonate, which increased surface roughness and caused damage. Erythritol is preferable for minimizing surface alterations and maintaining morphological stability.

KEYWORDS
dental hygiene process of care, hand, instrumentation, sonic, ultra sonic

1 | INTRODUCTION

Implant-supported prosthodontic rehabilitations, whether by single implant crowns, partial bridges or full-arch prostheses, is well-documented in the literature and is a treatment option in the rehabilitations of edentulous spaces.[1–4]

The mucosa surrounding the implant is called peri-implant mucosa and is formed during the healing process following implant or abutment placement.[5] On the other hand, osseointegration occurs when hard tissues form a contact with the implant surface to ensure its stability.[6] Peri-implant connective tissue has clinical and histological characteristics that are in part similar to those of a natural tooth supracrestal connective tissue of the periodontium. However, the major difference is observed in the cellular composition and fibre orientation. The connective tissue surrounding the implant is in direct contact with the titanium surface and consist of collagen fibres that originate from the periosteum of the alveolar bone crest. They have a parallel orientation to the implant surface, in contrast to the attachment to the connective tissue of the teeth, which is in a perpendicular direction to the root cementum.[7]

Peri-implant diseases present themselves in two forms, peri-implant mucositis and peri-implantitis. In 2011, it was defined that bleeding on probing (when a force of <0.25N in applied) is the key parameter in the diagnosis of peri-implant mucositis, whereas peri-implantitis is characterized by changes in bone level observed radiographically in addition to the increase in probing depth, concomitant with the presence of bleeding. Suppuration may also be present.[8]

The inflammatory response when biofilm is present appears to be similar in peri-implant mucositis and gingivitis; however, if persistent, the inflammatory response may be more pronounced in peri-implant tissues, as the extent and infiltration is more widespread, and may reach bone tissues due to the structural differences between each of the complexes.[9] This, adding to the reduced vascularization and cellular response in the peri-implant connective tissue, represents more susceptibility to disease initiation and progress.[10] Currently, the prevalence of peri-implant disease is still a controversial topic and is quite variable between studies.[11] A meta-analysis in 2015 reported a prevalence of mucositis of 43% (19%–65%) and of peri-implantitis of 22% (1%–47%).[12]

The maintenance of peri-implant tissues is crucial for implant and prosthodontic longevity; however, to date, there is no consensus about the interval between these appointments.[13,14] During those appointments for implant maintenance, several instruments can be used to remove biofilm from the areas around implants, abutments and prosthetic crowns such as ultrasonic scalers, gracey curettes, plastic and carbon curettes, rubber cup and polishing with air powder. The choice should be related to their effectiveness and the balance between the advantages and disadvantages of their use.[15–20]

The devices with a combination of water, compressed air and fine powder particles are an alternative for periodontal maintenance.[19,20] This technology started with the use of powders based on sodium bicarbonate, initially with particles of 250 µm, and was considered a highly abrasive material, leading to risks in its use on soft tissues, hard tissues and even restorative materials, as it resulted in a perceptible surface wear.[21–27] Erythritol was introduced more recently and is used worldwide as a food additive and artificial sweetener, non-toxic, having the ability to be water soluble. Due to this and the fact that it also has antiseptic characteristics, it is recommended for supra and subgingival plaque removal.[28,29]

Some polishing powders are safe and effective in removing oral biofilm, others promote the formation of roughness and irregularities on the surface of titanium after air polishing, leading to an greater accumulation of bacterial biofilms.[18]

In order to contribute to the knowledge on implant maintenance, an in vitro study was designed by the researchers aiming to evaluate the effects of air polishing with sodium bicarbonate and erythritol powders on surface roughness and morphological changes in titanium abutments, after being used for 10s at a distance of 3mm and at an angle of 45°.

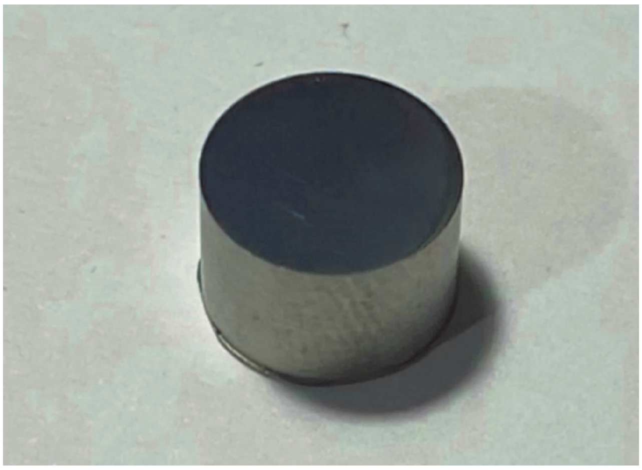

FIGURE 1 Titanium discs.

2 | STUDY POPULATION AND METHODOLOGY

The sample size for the study of surface roughness (S_a) was calculated using the Snedecor Cochran formula: $n = 1 + 2C(s/d)^2$.[30] A size treatment effect of 0.93 was assumed based on a similar study,[31] an alpha of 5% and a beta value of 20%. The result was a sample size of 15 titanium discs per group, 45 titanium discs in total.

Fourty-five titanium discs grade V with 8mm in diameter and 5mm of thickness were used as specimens (Figure 1).

All the titanium discs had the same treatment of cutting and polishing with the objective of achieving a surface similar to the ones of the prosthetic titanium abutments. The protocol for polishing the samples was followed exactly the same for all specimens. During this procedure, the specimens were examined under the microscope to check that there were no scratches or flaws in the polish. Therefore, and because there was a control group (polished with air and water), which is considered not to cause damage to the titanium surface, the S_a was not measured prior to the different surface treatments.

The specimens were divided randomly into three groups, of 15 specimens each, that received different surface treatments, Group A: water and air; Group B: water, air and sodium bicarbonate; and Group C: water, air and erythritol. All the air powders used in the study as well as the device used for blasting were from the brand EMS (Electro Medical Systems, Switzerland).

The device used for the surface treatment was the AirFlow Prophylaxis Master, with the same distance of work (3mm), angle (45°) and time (10s). The time was controlled using a stopwatch, and the distance and angle were kept by a support that hold both the titanium disc and the device (Figure 2). The application of surface treatment was done at the clinic of the Faculdade de Medicina Dentária at the Universidade de Lisboa.

Before and after the treatment, the samples were submerged in an 70% alcohol ultrasonic bath for 180s. Previously to the analysis in the optic profilometer and scanning electronic microscope, the discs were cleaned using a swab with 100% alcohol and then

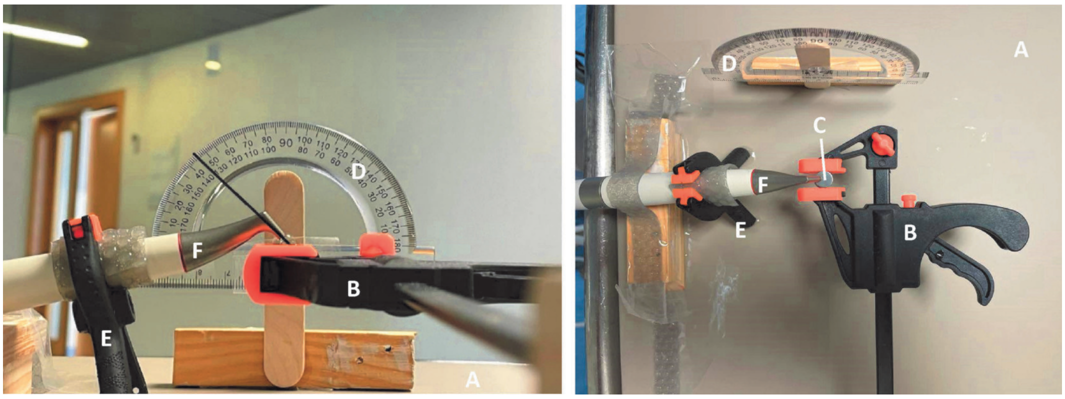

FIGURE 2 Support that allows fixing the parameters, distance (3 mm) and angle (45°), of blasting of the specimens. (A) Wooden Base; (B) Clamp; (C) Titanium Disc; (D) Protractor; (E) Spring Clamp; (F) Device Handle.

TABLE 1 Descriptive statistics, mean roughness (S_a) and standard deviation, of the three groups under study (air/water, sodium bicarbonate and erythritol).

	n	Mean (S_a, μm)	Standard deviation (SD, μm)
Air/water	15	0.0361	0.0074
Erythritol	15	0.0376	0.0099
Sodium bicarbonate	15	0.0462	0.0132

submerged again in a 70% alcohol ultrasonic bath to remove any debris. This analysis was performed at Instituto Superior Técnico at the Universidade de Lisboa.

The surface roughness (S_a) was evaluated in all the titanium discs using an Optic Perfilometer (Filmetric, Profilm 3dR, EUA). Two evaluations were performed in each specimen with 20× ampliation and a field of view of 1×0.85 mm and the mean S_a of each sample was obtained.

Surface morphology was analysed using a scanning electron microscope (phenon proX G6 desktop). Three discs of each group were randomly chosen, and two images of the surface were taken, with 1000× and 2000× ampliation.

Roughness data were analysed with the software SPSS (IBM SPSS statistics, version 27.0). The descriptive analysis of the results includes the mean and standard deviation of the roughness values (S_a). The inferential analysis was performed using the ANOVA multiple comparison test followed by a Tukey's post hoc test, or an equivalent nonparametric test depending on data normality analysis. The significance level was 5%.

3 | RESULTS

3.1 | Surface roughness (S_a)—Optic perfilometer

After air polishing the titanium discs with the different powders under study, the roughness values were obtained using optical profilometry.

After analysing the roughness of the 15 specimens from each of the three groups, it was found that (Table 1) the average for the group air polished with air/water was 0.03609 μm with a standard deviation of 0.00738 μm; the group air polished with Erythritol had a mean of 0.03757 μm with a standard deviation of 0.00992 μm; and the group air polished with sodium bicarbonate had a mean of 0.04615 μm with a standard deviation of 0.01324 μm.

From the ANOVA analysis, there is a significant difference among the groups ($p = 0.025$). The Tukey's post hoc test was performed to check which group or groups had a statistically significant difference found by ANOVA and was able to detect a statistically significant difference between specimens from the air/water and sodium bicarbonate air polishing groups with $p = 0.031$ and 95% confidence interval (−0.193314, −0.0007772).

3.2 | Surface morphology—SEM

The analysis of the surface morphology after air polishing of the titanium discs with the different polishing powders under study was performed by viewing the images obtained by scanning electron microscopy technique.

Figures 3–5 show the images obtained by scanning electron microscopy at 1000× and 2000× of the groups air polished with air/water, sodium bicarbonate and erythritol, respectively. These show the changes in the surface morphology of the titanium discs of the three groups analysed.

In Figure 3, where we can see the surface of the air/water air-polished titanium discs (grey surface), the visible spots in the image correspond to the presence of some dirt residues, resulting from the handling of the specimens. There seem to be no scratches or damage that had been caused by the air/water air polishing.

Figure 4 represents the surface of the titanium discs air polished with sodium bicarbonate (grey surface). There are some scratches and some damage.

These correspond to the irregularities observed on the surface of the specimens, being well visible mainly in the image with

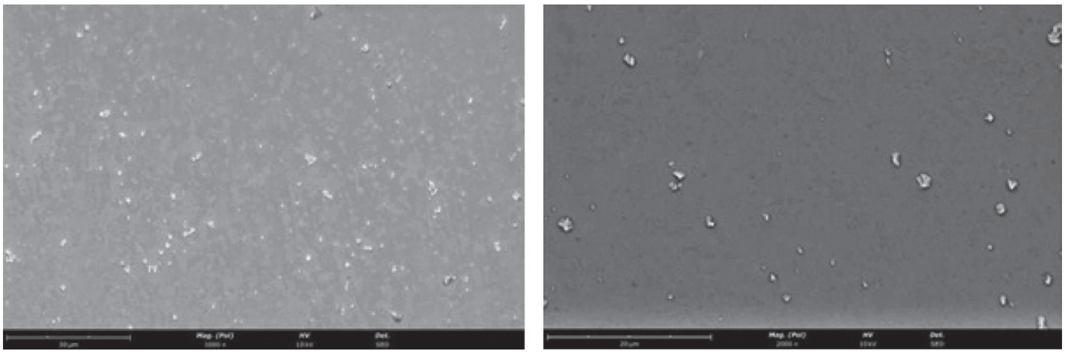

FIGURE 3 SEM images 1000× e 2000× (specimen of the air/water air polished group).

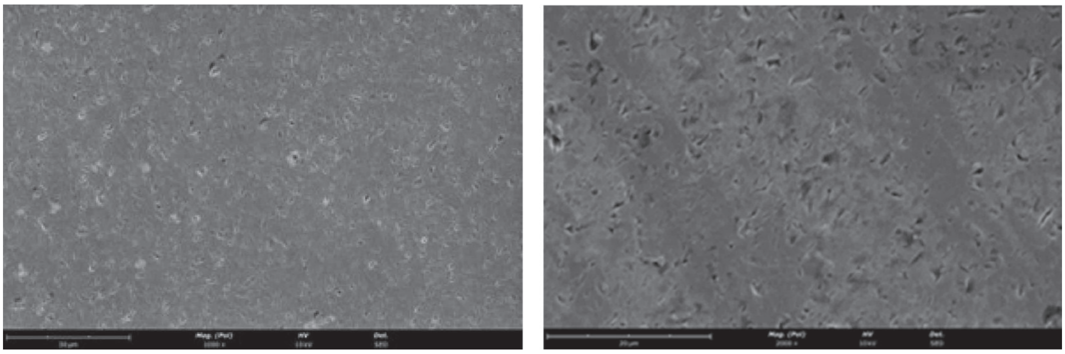

FIGURE 4 SEM images 1000× e 2000× (specimen of the sodium bicarbonate air polished group).

magnification of 2000×, which meets the increased roughness also found in this group.

In Figure 5, it is possible to find the presence of some dirt residues on the titanium surface (grey surface). Additionally, the surface of the specimens seems not to have been damaged by the air polishing with erythritol powder, the images being similar to those presented in the air/water air polished group, presented in Figure 3.

4 | DISCUSSION

Although there is no robust clinical evidence on which modality is best to effectively treat peri-implant mucositis and peri-implantitis,[32] several in vitro tests demonstrate that air powders have equal or superior decontamination power when compared with other types of treatment.[33,34] The use of low particle size powders creates less damage to titanium surfaces than other methods, and it is an effective technique in decontamination, both supragingival, for pockets up to 5 mm and also in cases where a surgical approach through flap opening is required.[35] Nevertheless, there is still no consensus regarding the best powder to be used.[36]

As far as roughness is concerned, most studies on this subject have used R_a to characterize it. However, with the evolution of techniques and the possibility of measuring S_a, it proved to be a more reliable and precise measure in the 3D study of surfaces,[31] since it is a three-dimensional measure.[37]

The results of the present study match those obtained in a 2019 study[36]; however, comparisons need to be made with some caution as the roughness in S_a was analysed on the titanium surface of implants in two areas, at the implant neck and at the thread, different from that performed in the present study, which was aimed at assessing the roughness of abutments, so the control values of the two studies are initially different. In the study by Matsubara, the groups air polished with glycine and erythritol showed very slight increases in the roughness of titanium. In that same study, the sodium bicarbonate group was the only product that caused statistically significant changes in the surface, as observed in this study, increasing the roughness value.[36]

As previously stated, most studies similar to the present one does not use S_a but R_a. However, the findings are similar, that is, sodium bicarbonate causes a greater increase in roughness than erythritol/glycine, although sometimes this change is not statistically significant.[31,38–40]

A 2019 study aimed to compare air polishing with glycine and sodium bicarbonate compared with a control group air polished with air/water, found that only sodium bicarbonate caused statistically significant changes, with $p < 0.05$, at the level of roughness, as observed in the present study, although the measure used was R_a.[31]

With the roughness values obtained in the present study, sodium bicarbonate made the surface of titanium rougher, and this change was statistically significant when compared with the air/water air polished group. Despite this, the erythritol group had a mean value

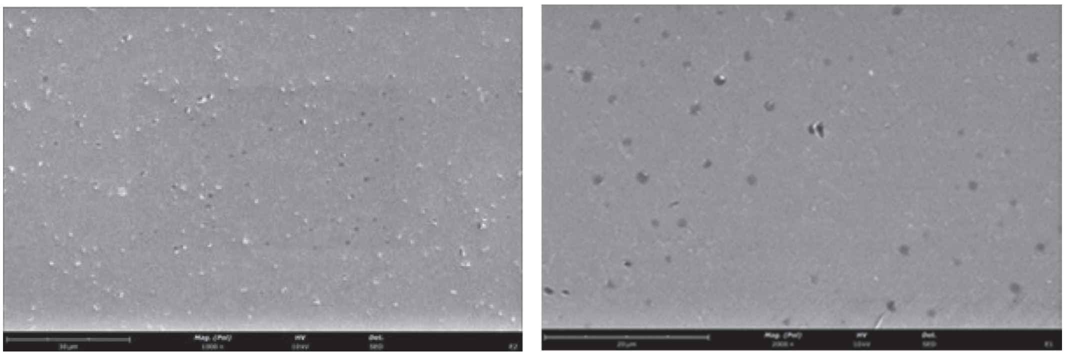

FIGURE 5 SEM images 1000× e 2000× (specimen of the erythritol air polished group).

very close to the air/water group, and no statistically significant differences were found, which goes against the perception that powders of lower abrasiveness cause less damage to the titanium surface.

The results of the roughness analysis using the optical profilometer agree with the results obtained for the analysis of the surface morphology with the scanning electron microscope. The surface of the titanium was clearly more damaged in the group in which sodium bicarbonate was used. The surfaces of the erythritol air polished group resembled the air/water air-polished control group much more. Thus, the higher S_a values observed in the group in which the specimens were air polished with bicarbonate powder are correlated with the images acquired by scanning electron microscopy, since they show the presence of larger craters and surface damage when compared with the control and the erythritol-treated group. In the case of specimens, air polished with erythritol powder, the roughness mean did not present statistically significant differences in relation to the control group, agree with the images obtained by scanning electron microscopy, showing practically no damage on the titanium surface. With the roughness values obtained in this study, we were able to see that sodium bicarbonate made the titanium surface rougher, and this change was statistically significant when compared to the air/water group. Despite this, we found that the erythritol group had an average very close to the air/water group, with no statistically significant differences found, which is in line with the perception that fewer abrasive powders seem to cause less damage to the titanium surface. Looking at the microscopy images, we can see that the group air-polished with sodium bicarbonate have more pronounced scratches and damage on their surface when compared to the other two groups, which are very similar to each other.

When comparing the results of the present study with the existing literature, it is possible to see that studies which analysed SEM images are not consensual on this subject. Some studies show that there are differences in images between the air power used[36,38,39] and others show no differences.[41–43]

The increased roughness of the titanium surface used in implants and abutments may facilitate the accumulation of biofilm, which may contribute to the onset of peri-implant diseases.[44] It is not possible, however, to conclude which roughness limit may contribute concretely to biofilm accumulation, that is, it has not yet been defined which is the roughness value from which there is actually a greater facility in plaque accumulation to values that may be harmful. Further studies in this area are necessary to conclude the impact of these powders of different abrasivities and also their effectiveness in biofilm removal.

We found three more recent systematic review on the area of study. The first, from 2019, shows us that air polishing can remove contamination without damaging the surfaces, but sodium bicarbonate tended to damage more the surface compared with lower size particles, as found in this present study.[33]

Abdulbaqi and colleagues found that erithrytol powder can be used to substitute hand and ultrasonic instrumentations, with good outcomes in clinical attachment levels. The erithrytol was also better tolerated by patients compared with conventional treatments.[45]

Other, not completely related with this study, found that air polishing with lower size particles was associated with less discomfort during the non-surgical debridement, what is also an advantage for the use of this type of powders.[46]

The findings of this study highlight the critical need for careful selection of air-polishing powders in the maintenance of titanium dental implants and abutments. The significant differences observed in the surface roughness of titanium specimens treated with sodium bicarbonate compared to those treated with air/water and erythritol underscore the potential for air-polishing powders to impact implant longevity and health. Specifically, the detrimental effects of sodium bicarbonate on titanium surfaces, as evidenced by SEM imaging, suggest that powders with lower granulometry, such as glycine and erythritol, should be preferred to minimize damage and the risk of dental plaque formation.

However, the clinical relevance of these findings must be tempered by the recognition of the study's limitations. The in vitro nature of the research, the use of a single type of air-polishing machine, a specific configuration, and one brand of powder may limit the generalizability of the results. To comprehensively understand the implications of air-polishing on titanium implant surfaces, further studies should explore a broader array of conditions, including the use of different air-polishing machines, brands of powder, application angles and blasting durations. Such research is essential to develop evidence-based guidelines for the maintenance of dental implants, ultimately improving patient outcomes.

5 | CONCLUSION

Based on this study's findings, air polishing with sodium bicarbonate significantly increases the surface roughness of titanium abutments and causes morphological damage. Conversely, erythritol powders are more suitable for air polishing titanium abutments because they maintain the original surface properties, thus preserving their integrity and preventing damage.

6 | CLINICAL RELEVANCE

6.1 | Scientific rationale for the study

Oral health professionals must select the best prophylaxis air powder for titanium implants and abutments. Studies suggest that finer powders cause less damage.

6.2 | Principle findings

There are statistically significant differences in surface roughness between titanium treated with air/water and sodium bicarbonate, unlike the erythritol-treated group. Electron microscopy shows more damage with sodium bicarbonate compared with control and erythritol groups.

6.3 | Practical implications

Finer-grained powders such as glycine and erythritol are preferable for air polishing titanium to prevent surface roughness and subsequent plaque formation, enhancing implant maintenance.

AUTHOR CONTRIBUTIONS

P.R., H.L. and S.O. conceived the ideas; P.R. collected the data; H.L. and P.R. analysed the data; and P.R., H.L. and S.O. led the writing and article revision.

ACKNOWLEDGEMENTS

We would like to thank all the members of the Instituto Superior Técnico (IST Lisboa) who helped in the laboratorial part of this work.

FUNDING INFORMATION

The authors declare no funds or financial support. EMS provided the materials but did not finance the study.

CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Pedro Francisco Almeida Roberto https://orcid.org/0009-0002-6995-5457

REFERENCES

1. Abrahamsson I, Berglundh T, Lindhe J. The mucosal barrier following abutment dis/reconnection. An experimental study in dogs. *J Clin Periodontol*. 1997;24(8):568-572. doi:10.1111/j.1600-051x.1997.tb00230.x
2. Pjetursson BE, Bragger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). *Clin Oral Implants Res*. 2007;18(Suppl 3):97-113. doi:10.1111/j.1600-0501.2007.01439.x
3. Jung RE, Pjetursson BE, Glauser R, Zembic A, Zwahlen M, Lang NP. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. *Clin Oral Implants Res*. 2008;19(2):119-130. doi:10.1111/j.1600-0501.2007.01453.x
4. Sailer I, Muhlemann S, Zwahlen M, Hammerle CH, Schneider D. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. *Clin Oral Implants Res*. 2012;23(Suppl 6):163-201. doi:10.1111/j.1600-0501.2012.02538.x
5. Berglundh T, Abrahamsson I, Welander M, Lang NP, Lindhe J. Morphogenesis of the peri-implant mucosa: an experimental study in dogs. *Clin Oral Implants Res*. 2007;18(1):1-8. doi:10.1111/j.1600-0501.2006.01380.x
6. Albrektsson T, Sennerby L. State of the art in oral implants. *J Clin Periodontol*. 1991;18(6):474-481. doi:10.1111/j.1600-051x.1991.tb02319.x
7. Berglundh T, Lindhe J, Ericsson I, Marinello CP, Liljenberg B, Thomsen P. The soft tissue barrier at implants and teeth. *Clin Oral Implants Res*. 1991;2(2):81-90. doi:10.1034/j.1600-0501.1991.020206.x
8. Lang NP, Berglundh T, Working Group 4 of Seventh European Workshop on P. Periimplant diseases: where are we now?–Consensus of the Seventh European Workshop on Periodontology. *J Clin Periodontol*. 2011;38(Suppl 11):178-181. doi:10.1111/j.1600-051X.2010.01674.x
9. Heitz-Mayfield LJ, Lang NP. Comparative biology of chronic and aggressive periodontitis vs. peri-implantitis. *Periodontology 2000*. 2010;53:167-181. doi:10.1111/j.1600-0757.2010.00348.x
10. Ivanovski S, Lee R. Comparison of peri-implant and periodontal marginal soft tissues in health and disease. *Periodontology 2000*. 2018;76(1):116-130. doi:10.1111/prd.12150
11. Tarnow DP. Increasing prevalence of peri-implantitis: how will we manage? *J Dent Res*. 2016;95(1):7-8. doi:10.1177/0022034515616557
12. Derks J, Tomasi C. Peri-implant health and disease. A systematic review of current epidemiology. *J Clin Periodontol*. 2015;42(Suppl 16):S158-S171. doi:10.1111/jcpe.12334
13. Tomasi C, Tessarolo F, Caola I, Wennstrom J, Nollo G, Berglundh T. Morphogenesis of peri-implant mucosa revisited: an experimental study in humans. *Clin Oral Implants Res*. 2014;25(9):997-1003. doi:10.1111/clr.12223
14. Monje A, Aranda L, Diaz KT, et al. Impact of maintenance therapy for the prevention of Peri-implant diseases: a systematic review and meta-analysis. *J Dent Res*. 2016;95(4):372-379. doi:10.1177/0022034515622432
15. Mengel R, Buns CE, Mengel C, Flores-de-Jacoby L. An in vitro study of the treatment of implant surfaces with different instruments. *Int J Oral Maxillofac Implants*. 1998;13(1):91-96.
16. Mann M, Parmar D, Walmsley AD, Lea SC. Effect of plastic-covered ultrasonic scalers on titanium implant surfaces. *Clin Oral Implants Res*. 2012;23(1):76-82. doi:10.1111/j.1600-0501.2011.02186.x

17. Hakki SS, Tatar G, Dundar N, Demiralp B. The effect of different cleaning methods on the surface and temperature of failed titanium implants: an in vitro study. *Lasers Med Sci*. 2017;32(3):563-571. doi:10.1007/s10103-017-2149-2
18. Gulati M, Govila V, Anand V, Anand B. Implant maintenance: a clinical update. *Int Sch Res Notices*. 2014;2014:908534. doi:10.1155/2014/908534
19. Sculean A, Bastendorf KD, Becker C, et al. A paradigm shift in mechanical biofilm management? Subgingival air polishing: a new way to improve mechanical biofilm management in the dental practice. *Quintessence Int*. 2013;44(7):475-477. doi:10.3290/j.qi.a29615
20. Petersilka GJ. Subgingival air-polishing in the treatment of periodontal biofilm infections. *Periodontology 2000*. 2011;55(1):124-142. doi:10.1111/j.1600-0757.2010.00342.x
21. Hashino E, Kuboniwa M, Alghamdi SA, et al. Erythritol alters microstructure and metabolomic profiles of biofilm composed of *Streptococcus gordonii* and Porphyromonas gingivalis. *Mol Oral Microbiol*. 2013;28(6):435-451. doi:10.1111/omi.12037
22. Graumann SJ, Sensat ML, Stoltenberg JL. Air polishing: a review of current literature. *J Dent Hyg*. 2013;87(4):173-180.
23. Petersilka G, Faggion CM Jr, Stratmann U, et al. Effect of glycine powder air-polishing on the gingiva. *J Clin Periodontol*. 2008;35(4):324-332. doi:10.1111/j.1600-051X.2007.01195.x
24. Pelka M, Trautmann S, Petschelt A, Lohbauer U. Influence of air-polishing devices and abrasives on root dentin-an in vitro confocal laser scanning microscope study. *Quintessence Int*. 2010;41(7):e141-e148.
25. Giacomelli L, Salerno M, Derchi G, Genovesi A, Paganin PP, Covani U. Effect of air polishing with glycine and bicarbonate powders on a nanocomposite used in dental restorations: an in vitro study. *Int J Periodontics Restorative Dent*. 2011;31(5):e51-e56.
26. Arabaci T, Cicek Y, Ozgoz M, Canakci V, Canakci CF, Eltas A. The comparison of the effects of three types of piezoelectric ultrasonic tips and air polishing system on the filling materials: an in vitro study. *Int J Dent Hyg*. 2007;5(4):205-210. doi:10.1111/j.1601-5037.2007.00265.x
27. Pelka MA, Altmaier K, Petschelt A, Lohbauer U. The effect of air-polishing abrasives on wear of direct restoration materials and sealants. *J Am Dent Assoc*. 2010;141(1):63-70. doi:10.14219/jada.archive.2010.0022
28. Kroger JC, Haribyan M, Nergiz I, Schmage P. Air polishing with erythritol powder – in vitro effects on dentin loss. *J Indian Soc Periodontol*. 2020;24(5):433-440. doi:10.4103/jisp.jisp_414_19
29. Park EJ, Kwon EY, Kim HJ, Lee JY, Choi J, Joo JY. Clinical and microbiological effects of the supplementary use of an erythritol powder air-polishing device in non-surgical periodontal therapy: a randomized clinical trial. *J Periodontal Implant Sci*. 2018;48(5):295-304. doi:10.5051/jpis.2018.48.5.295
30. Clark V. Sample size determination. *Plast Reconstr Surg*. 1991;87(3):569-573. doi:10.1097/00006534-199103000-00030
31. Biazussi BR, Perrotti V, D'Arcangelo C, et al. Evaluation of the effect of air polishing with different abrasive powders on the roughness of implant abutment surface: an in vitro study. *J Oral Implantol*. 2019;45(3):202-206. doi:10.1563/aaid-joi-D-18-00156
32. Esposito M, Grusovin MG, Worthington HV. Interventions for replacing missing teeth: treatment of peri-implantitis. *Cochrane Database Syst Rev*. 2012;1(1):CD004970. doi:10.1002/14651858.CD004970.pub5
33. Moharrami M, Perrotti V, Iaculli F, Love RM, Quaranta A. Effects of air abrasive decontamination on titanium surfaces: a systematic review of in vitro studies. *Clin Implant Dent Relat Res*. 2019;21(2):398-421. doi:10.1111/cid.12747
34. Sahrmann P, Ronay V, Hofer D, Attin T, Jung RE, Schmidlin PR. In vitro cleaning potential of three different implant debridement methods. *Clin Oral Implants Res*. 2015;26(3):314-319. doi:10.1111/clr.12322
35. Tastepe CS, van Waas R, Liu Y, Wismeijer D. Air powder abrasive treatment as an implant surface cleaning method: a literature review. *Int J Oral Maxillofac Implants*. 2012;27(6):1461-1473.
36. Matsubara VH, Leong BW, Leong MJL, Lawrence Z, Becker T, Quaranta A. Cleaning potential of different air abrasive powders and their impact on implant surface roughness. *Clin Implant Dent Relat Res*. 2020;22(1):96-104. doi:10.1111/cid.12875
37. Wennerberg A, Albrektsson T. Suggested guidelines for the topographic evaluation of implant surfaces. *Int J Oral Maxillofac Implants*. 2000;15(3):331-344.
38. Cochis A, Fini M, Carrassi A, Migliario M, Visai L, Rimondini L. Effect of air polishing with glycine powder on titanium abutment surfaces. *Clin Oral Implants Res*. 2013;24(8):904-909. doi:10.1111/j.1600-0501.2012.02490.x
39. Bennani V, Hwang L, Tawse-Smith A, Dias GJ, Cannon RD. Effect of air-polishing on titanium surfaces, biofilm removal, and biocompatibility: a pilot study. *Biomed Res Int*. 2015;2015:491047. doi:10.1155/2015/491047
40. Janiszewska-Olszowska J, Drozdzik A, Tandecka K, Grocholewicz K. Effect of air-polishing on surface roughness of composite dental restorative material - comparison of three different air-polishing powders. *BMC Oral Health*. 2020;20(1):30. doi:10.1186/s12903-020-1007-y
41. Schmidt KE, Auschill TM, Heumann C, et al. Influence of different instrumentation modalities on the surface characteristics and biofilm formation on dental implant neck, in vitro. *Clin Oral Implants Res*. 2017;28(4):483-490. doi:10.1111/clr.12823
42. Mensi M, Cochis A, Sordillo A, Uberti F, Rimondini L. Biofilm removal and bacterial re-colonization inhibition of a novel erythritol/chlorhexidine air-polishing powder on titanium disks. *Materials*. 2018;11(9):1510. doi:10.3390/ma11091510
43. Menini M, Piccardo P, Baldi D, Dellepiane E, Pera P. Morphological and chemical characteristics of different titanium surfaces treated by bicarbonate and glycine powder air abrasive systems. *Implant Dent*. 2015;24(1):47-56. doi:10.1097/ID.0000000000000176
44. Subramani K, Jung RE, Molenberg A, Hammerle CH. Biofilm on dental implants: a review of the literature. *Int J Oral Maxillofac Implants*. 2009;24(4):616-626.
45. Abdulbaqi HR, Shaikh MS, Abdulkareem AA, Zafar MS, Gul SS, Sha AM. Efficacy of erythritol powder air-polishing in active and supportive periodontal therapy: a systematic review and meta-analysis. *Int J Dent Hyg*. 2022;20(1):62-74. doi:10.1111/idh.12539
46. Bühler J, Amato M, Weiger R, Walter C. A systematic review on the patient perception of periodontal treatment using air polishing devices. *Int J Dent Hyg*. 2016;14(1):4-14. doi:10.1111/idh.12119

How to cite this article: Roberto PFA, Luís HS, Oliveira SA. In vitro evaluation of surface roughness of titanium abutments after air polishing with different abrasive powders. *Int J Dent Hygiene*. 2024;00:1-7. doi:10.1111/idh.12838