Chapter 6

The parameters that improve the cleaning efficiency of sub-gingival air polishing on titanium implant surfaces: An in-vitro study

Ceylin S. Tasteppe, Xingnan Lin, Marcel Donnet, Daniel Wismeijer, Yuelian Liu

ABSTRACT

Background: The aim was to unravel how the air-polishing behaves on a titanium surface by evaluating the size and the shape of the cleaned area, influence of the different device settings, and pocket depths and cleaning movements.

Methods: 48 titanium SLA surface film-coated discs were treated with an air abrasive system using a subgingival plastic nozzle. Two subgingival models were employed: open-ended (step 1) and defined-size (step 2). In step 1, the most effective parameters were investigated by 5 sec static applications under different settings. In step 2, the best settings were used for dynamic application to test the influence of different movements (up-down, slowly up, rotation). For both steps, the powder and water consumption and total cleaned area were calculated.

Results: Air pressure was the main factor which had the strongest effect on the cleaning. Increasing the air pressure extended the cleaning area. Other factors, like the nozzle depth and excessive powder flow amount had a weak influence. The cleaning effect reached deeper than the nozzle physically reached. The step 2 showed that there was no significant difference between different nozzle movements however the cleaning efficiency decreased significantly without movement.

Conclusions: To get the most effective clinical use of air polishing, it should be applied with high pressure, with deep insertion of the nozzle and enough water flow. On top of these, the nozzle has to be moved to get the best cleaning effect.

KEY WORDS: Air abrasion, peri-implantitis, dental implants, titanium, dental instruments, subgingival, instrumentation
INTRODUCTION

Air polishing is a mechanical cleaning method using an abrasive powder applied by a jet (stream) of compressed water. The aim of the air polishing is to clean and polish a surface by removing the organic deposits attached to it\(^1\). This method was first developed for supra-gingival surfaces of natural teeth and subgingival use of it was avoided because of the possibility of damage to the sub-gingival tissues\(^2,3\). However, in 2003, with the development of low abrasive glycine and erythritol powders together with subgingival nozzle, its application has widened to cover sub-gingival root surface cleaning and even implant surface cleaning\(^4-6\). To prove the success of the air polishing as an implant surface cleaning method, several aspects such as cleaning efficiency, surface modification, cell response and clinical results were tested\(^7,8\). The in-vitro studies showed that the cleaning efficiency on the titanium discs was significantly higher than other mechanical cleaning methods but it caused a slight modification on the titanium surface depending on the powder type used\(^10,11\). The in-vivo studies showed that considerable re-osseointegration was reported when applied in combination with surgical treatment\(^12,13\). The clinical studies tested the method either as a maintenance care or treatment for peri-implant infections\(^14,15,16\). In both cases, a significant improvement of the clinical symptoms was observed. When used as a maintenance care, the air polishing was more effective than the other methods (such as plastic curettes)\(^17\). However, if it was used as an adjunctive treatment, it had a limited beneficial effect compared to the mechanical treatment alone\(^18\). In case of being the main surface treatment for peri-implantitis and when applied non-surgically, certain clinical parameters (BOP, PPD, GI) improved better than the other treatment groups\(^19\). The studies which applied the method surgically as the main surface treatment also reported significant improvements in all clinical parameters\(^20-22\).

In the light of these studies, we know that air-polishing works successfully on above mentioned situations however we are lacking the detailed information on how it works. Up to now, there has been no study investigating how deep the cleaning reaches, which factors affect the efficiency. The best air and water settings for cleaning and whether the pocket and nozzle insertion depth has an influence on cleaning have not been illustrated, making it difficult to maximize the clinical usage of air polishing device.
The aim of this study was to unravel how the air-polishing behaves on a titanium surface by evaluating the size and the shape of the cleaned area, influence of the different device settings, and pocket depths and cleaning movements. In the current study, we optimized the intensities of water and air-powder and the movements of nozzle when it is applied for surface cleaning, which will cast a light on how to get the most out of air polishing treatment in clinical work.

MATERIALS AND METHODS

Study design

Titanium discs and 2 different subgingival models were used to mimic the implant surface cleaning in-vitro. The discs were first covered with a film to enhance the visibility of the cleaning effect and then placed in the subgingival model and treated with the plastic nozzle under different settings. The study was performed in 2 parts. In the first part, the treatment was applied by static nozzle and the shape and the size of cleaned area was measured. The second part of the study was the dynamic application of the nozzle mimicking the clinical use. The best parameters which were discovered in the first part were applied in this step. 3 different motions were tested and the total cleaned surface area was calculated and compared between test groups.

Titanium Discs, Surface Preparation and CaP coating

Forty-eight Titanium discs (Cibe Company, Jiang Shu, CHINA) of 10 mm in diameter were used for the experiments. To produce the SLA surface, the discs were sandblasted by 120 µm Al₂O₃ particles at 3.9 Bar and acid etched by using a mixture of 9.5% HCl and 24.5% H₂SO₄ at 60°C for 30 min and then ultrasonically cleaned in distilled H₂O for 15 min.

The SLA surface properties of the discs were visualized by SEM photos to assure the procedure.

Film formation on the titanium discs
The discs were coated with biomimetic CaP coating to mimic the mineral accumulated implant surface while enhancing the visibility of the cleaning effect.24

Subgingival Models: Open-ended and Defined size

Two subgingival models were used for the experiments.

Open-ended model: This was a silicon model which included a middle slot with 4mm (shallow pocket) or 10mm (deep pocket) in depth. The main feature of this model was that the pocket side borders were not defined in size. Thus the right and left hand of the nozzle was open, allowing maximum powder extension in a confined area environment. In other words, the pocket was big enough to let the cleaning reach the furthest area it could reach. The titanium disc was inserted into this slot to mimic a dental implant with peri-implant pocket and surrounding gingiva. The flexible nature of the silicon allowed us to imitate the gingiva.

Defined Size Pocket: This was a hard plastic model with a room for the titanium disc and the plastic nozzle. This room was defined in size. Therefore, the cleaning took place in an area which was restricted from sides and depth. The model consisted of 3 layers which were fixed together with the help of screws. The screws were loosened in order to make space prior to the placement of the disc and tightened afterwards. Thanks to the nozzle room, the friction between the nozzle and the disc was prevented. Therefore, we eliminated the false cleaning effect created by friction (Figure 1).

Figure 1. Subgingival modesl and diagrams. A) Open-ended silicon model for static step. Titanium disc and nozzle inserted. B) Defined-size pocket model: hard plastic model for dynamic step. Titanium disc and nozzle inserted. C) Representative diagram showing the layers of the defined-size pocket mode.
**Air Powder Abrasive Device**

An air-powder abrasive device (AIR-FLOW® master, Nyon, Switzerland) was used with a plastic subgingival nozzle (PERIO-FLOW® nozzle, Nyon, Switzerland). All applications were done on PERIO MODE and using an Erythritol powder with 14 um mean size (EMS AIR-FLOW® PLUS Powder, Nyon, Switzerland). In the treatment step 1, two different powder chambers were used. First chamber was the PERIO+PLUS chamber (EMS AIR FLOW®, Nyon, Switzerland) and the second one was a modified powder chamber which was not available in the market. This chamber allows higher powder flow without increasing the output power.

**Powder and Water consumption measurement**

To determine the mean amount of powder usage per group, the powder and water consumption was measured with a balance (Mettler Toledo PR 8002) after each application. The pressure inside the chamber was measured by a manometer (DPI 802 P GE Druck) during the treatment (dynamic pressure).

**Treatment Settings - Static Step**

The experimental design was created according to a statistical plan with four parameters at two levels. The air and water pressure settings were reported as the number of the LED lights shown on the display of the device. The corresponding air pressure was mentioned the table 1.

This statistical plan resulted in 16 test groups. Air polishing treatment was applied for 5 seconds on each disc. The plastic nozzle was inserted vertically 3 mm in 4 mm-depth pockets, and 7 mm in 10 mm-depth pockets.
Table 1. Statistical design according to different parameters for different settings. The test groups were created with combinations of these factors.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Definition</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Air pressure (Perio mode)</td>
<td>4 LED (1.7 Bar)</td>
<td>17 LED (2.9 Bar)</td>
</tr>
<tr>
<td>B</td>
<td>Water</td>
<td>5 LED (0.109 gr / sec)</td>
<td>11 LED (0.512 gr /sec)</td>
</tr>
<tr>
<td>C</td>
<td>Nozzle depth</td>
<td>3 mm</td>
<td>7 mm</td>
</tr>
<tr>
<td>D</td>
<td>Powder amount</td>
<td>Low</td>
<td>high</td>
</tr>
</tbody>
</table>

Cleaning Path Calculations (Static Step)

The light microscope photos of the cleaned discs were analyzed to determine how far the cleaning effect reached, what the shape of the cleaning path was and how widespread the cleaning was. The parameters calculated were: 1- Total cleaned surface area; 2- The width of the cleaning; 3- Depth of penetration. The cleaned area was calculated by point counting measurement \(^{25}\). The influence of setting parameters on total cleaned surface area was analyzed statistically to determine which parameter had the biggest effect (Figure 2).

Statistics (Static Step)

The analysis was carried out by using a multi-factorial \(2^4\) statistical design (ANOVA). As the factorial analysis of variance assumes that the dependent variable approximates a multivariate normal distribution, the assumption was checked graphically with a Q-Q-Plot. As the factorial ANOVA assumes homoscedasticity of error variances, which means that the error variances of all data points of the dependent variable are equal or homogenous throughout the sample, this was tested with the Levene’s Test with a significance level of 0.05. Only the factors with a p<0.05 value were considered as significant for the statistical model.
Treatment Settings – Dynamic Step

The most effective air, water settings and powder chamber were used under the light of step 1 results. However, this time, the application was done with moving nozzle similar to the clinical application. The aim was to determine which movement was more efficient on cleaning the titanium disc.

The treatment conditions were 17 LED power output and 11 LED water flow. The nozzle depth was 10 mm. The application time was 5 seconds. 6 discs per test group and 2 discs per control group were used. The treatment groups were: Test Gr1: Up and Down Movement with powder, Test Gr2: Slowly Up Movement with powder, Test Gr3: Rotation Movement with powder, Control Gr1: Up and Down without Powder, Control Group 2: Slowly Up without powder, Control Group 3: Rotation movement without powder.

Total Cleaned Surface Area Calculation (Dynamic Step)

Total cleaned surface area on the discs was calculated by point counting method on the printed light microscope photos after air polishing treatment.

Statistics (Dynamic Step)

To compare the cleaned surface area per group, a pairwise Student T-Test was used in order to assess whether the means of two groups were statistically different from each other. The significance level was fixed at p<0.05.

RESULTS

Powder and Water Consumption (Static Step)

The air pressure inside the Perio Plus Chamber was 2.9 Bar for 17 LED pressure settings and 1.7 Bar for 4 LED pressure settings. The water flow was 0.512 gr/sec for 11 LED water settings and 0.109 gr/sec for 5 LED water settings. The average powder consumption for the Perio Plus chamber was 0.09 gr/sec. The powder consumption increased with higher pressure.
settings. The average powder consumption for the modified chamber (high powder flow) was 0.20 gr/sec.

Influence of Treatment Settings on Cleaning Efficiency (Static Step)

Among the 4 tested factors, 2 of them had an individual influence on the treatment results: air pressure and excessive powder amount. These factors’ effect, either positive (air pressure) or negative (excessive powder amount), was independent of the other conditions. The rest of the factors, nozzle depth and water amount, did not have a direct effect on the results however had a conditional influence in combination with other factors. Such as, the combination of the air pressure and the nozzle depth, the combination of the water amount and powder amount (Table 2).

Factors were considered relevant with a p < 5%. The coefficient of determination of this model statistical model was: $R^2 = 85.63\%$ which means that 85% of the results could be explained by these factors.

Table 2. P values of the parameters which influence the efficiency.

<table>
<thead>
<tr>
<th>Source</th>
<th>P value</th>
<th>Regression</th>
<th>Coefficient CR(X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Pressure (A)</td>
<td>4.4 x 10^{-7}</td>
<td>1.689</td>
<td></td>
</tr>
<tr>
<td>Air Pressure + Nozzle Depth (AC)</td>
<td>0.001</td>
<td>0.637</td>
<td></td>
</tr>
<tr>
<td>Powder Amount (D)</td>
<td>0.009</td>
<td>-0.470</td>
<td></td>
</tr>
<tr>
<td>Air Pressure + Powder Amount (AD)</td>
<td>0.004</td>
<td>-0.533</td>
<td></td>
</tr>
<tr>
<td>Water + Powder Amount (BD)</td>
<td>0.02</td>
<td>0.389</td>
<td></td>
</tr>
</tbody>
</table>

According to these analyses, the air pressure (A) had the major positive effect meaning that the high pressure groups had bigger cleaned surface area in all cases. In other words, if the air pressure was high, regardless of the other settings, the total surface area was always bigger (Figure 3).

The following factors had lower influence on the results:

The excessive powder flow (D & AD) did seem to have a small detrimental effect. This effect was observed when the modified chamber was used. This chamber had a higher powder flow.
However, this did not lead to a better cleaning. There was too much powder coming out and this excessive powder accumulated on the surface instead of cleaning it. Increasing the water amount (BD) could only reduce this negative effect slightly but the water was not enough to dissolve the excess of powder completely.

The nozzle depth (C) had a positive influence under the condition of high pressure (AC). In the treatment groups where the nozzle was inserted deep and the application was done at high pressure, the total cleaned surface area was bigger than expected. In other words, the deep pockets exaggerated positive influence of the high pressure on cleaning. However, the negative influence of the low pressure on the cleaning was also exaggerated in deep pockets. Meaning that, if the air pressure was lower in deep pockets, the cleaned surface area contracted more than expected.

**The structure of the cleaning Path (Static Step)**

The shape of the cleaned area had three or more separate parts which we named “islands” in this paper (Figure 2). The size and the position of the islands changed depending on the settings. But there was a central dot in every disc which corresponded to the powder exit of the nozzle. This dot was called as the central point. The powder came out of the exit and hit directly to this point without mixing with the water. The cleaning path was spread around the nozzle. The cleaned area was wider and deeper than the nozzle’s actual size. At the powder exit point, the width of the nozzle was approximately 1.4 mm but the mean size of the cleaned area was 5.5 mm. A fare bigger region was cleaned. There was an uncleaned area between the central point and islands.

**Total Cleaned Surface Area**

The average of the total cleaned surface area of the groups with high pressure was 8 mm$^2$ and the low pressure was 3.5 mm$^2$. 
The width of the cleaning (Static Step)

The width of the cleaning was the distance from the most right to the most left of the cleaned area. This distance was proportional to the total surface area size. Therefore, this parameter was mostly influenced by the air pressure. The mean distance of all groups which had high pressure settings were: 6.53 mm. The mean distance of all groups which had low pressure settings were: 4.35 mm.

Depth of cleaning penetration (Static Step)

The depth of cleaning penetration was the distance between the powder exit and the lowest border of the cleaned area. This point was the deepest point where the cleaning reached. This distance was 2.8 mm in the average for cleaning groups which was longer than the distance between the powder exit and the tip of the nozzle (1.8 mm) (Figure 2). This showed that the cleaning with powder reached further than the nozzle end. Therefore, when the method was applied in the pocket, the cleaning effect reached deeper than the nozzle physically reached. However, this was not the case when there was no powder coming out of the nozzle.

Figure 2. (A) Post-treatment light microscope photograph of treated titanium disk. A = Central point; x = width of cleaning: distance from the furthest right to the furthest left extent of the cleaned area; y = depth of penetration; * = cleaned surface areas: ("islands"). (B) Post-treatment light microscope photograph of treated titanium disk with nozzle. Comparison
of x and y was done. x = distance between central point (A) and tip of nozzle; y = depth of cleaning: distance between central point and tip of cleaning effect.

**Influence of Different movements on the cleaning efficiency (Dynamic Step)**

**Total Cleaned Area**

We tested the influence of different movements on total cleaned area. There was no significant difference between different nozzle movements however the cleaning efficiency decreased significantly without movement (Figure 4). Therefore, the static application of the nozzle resulted significantly less cleaning than any one of the applied movements. On the other hand, if the application was done with the

![Figure 3](image)

**Figure 3.** Post treatment photos of titanium discs after static and dynamic treatment. The borders of the subgingival pocket are shown by the pink layer superposed on titanium disc for
Dynamic step samples. The treatment took place inside these borders. The total cleaned surface area borders are mentioned in black. (A) Static treatment with high Pressure settings in 10mm pockets; (B) Static treatment with low settings in 4 mm pocket; (C) Dynamic treatment with rotation (Control); (D) Dynamic Treatment with rotation (Test); (E) Dynamic treatment with Slowly Up (Control); (F) Dynamic treatment with Slowly Up (Test); (G) Dynamic treatment with Up and Down Control. (H) Dynamic treatment with Up and Down Test.

**Figure 4.** Cleaned surface area per group for step 2. The groups signed with * are statistically significantly different (* : P ≤ 0.005)

same movements but without powder, the cleaning efficiency again decreased significantly (Figure 4). In conclusion, the presence of the powder and one of the described movements had a big influence on the cleaning efficiency (Figure 3).

**DISCUSSION**

Although subgingival air polishing on titanium implants has been shown to be effective on removing biofilm, we do not know how it behaves while removing the biofilm from this surface. Therefore, in this study we aimed to find out the nature of the air polishing technique
and the parameters that play a role on cleaning the titanium surface. The study consisted of 2 steps, static and dynamic application.

This first step, which was the static application, showed that the main factor influencing the cleaning efficiency was air pressure. The higher the pressure was applied, the better was the cleaning. The size of the cleaned area enlarged and cleaning got deeper with high pressure. Therefore, in order to get the best efficiency, we recommend to use the device in highest ‘subgingival mode’ settings. The ‘subgingival mode’ of the device has a 20% less pressure output than the normal mode. This is the previously defined safe limit and has already been clinically applied without problems. Therefore, the air pressure should not exceed this limit to prevent the risk of emphysema. There are a couple of more cautions in addition to this such as the plastic nozzle design. It is specially designed to prevent the direct pressure on the tissues. The other caution is how the cleaning is applied. It is advised to apply it with 5 seconds periods. Subgingival application of longer than 5 seconds on the same location may increase the emphysema risk. Several clinical studies where the method was applied with the above mentioned principles, did not report any emphysema complications. The recommendations mentioned in this study should be implemented within these limits and be temperate by the real clinical situation evaluation.

On the other hand, some other factors influenced the cleaning efficiency, too. Interestingly, a modification which allowed a higher powder flow without increasing the pressure, did not improve the cleaning effect, even deteriorated. The excess powder needed to be diluted with more water. Therefore, we do not need a higher powder flow than the standard chamber allows for better cleaning.

Another interesting finding was that the pocket depth strengthened the high pressure’s positive effect. This can be explained by the working principle of the nozzle. The plastic nozzle has 3 air-powder outlets and one water outlet. The water and powder mix after they leave the nozzle and the walls around reflect air, water and powder mixture and increase the efficiency. Therefore, the nozzle works better in closed pockets as long as there is sufficient pressure. Having a more closed and restricted space, the deep pockets create this effect intensely.
However, if the pressure was not high enough, the cleaning effect was hindered. Because in this case, the walls, instead of reflecting, stopped the mixture.

The shape of the cleaning path highlights the nozzle working path. The cleaning path on vertical and horizontal axis was bigger than the own size of the nozzle (Figure 2). This means that, the clinician, under the restriction of the clinical parameters, has the possibility to clean a bigger surface than he covers with the nozzle. Also he can reach the bottom of a pocket even if the nozzle does not physically reach there. This can be the explanation of the success seen in the previous clinical studies\textsuperscript{5, 6, 14, 19, 30}. However, we need to keep in mind that, the nature of the soft tissue, the pocket shape, the reachability of the zone restricts the direct translation of the \textit{in vitro} results into the clinics. The cleaning path highlighted also a nozzle weakness: there was an uncleared area between the central point and cleaned islands. The cleaning mixture did not reach here with static nozzle application. Therefore, nozzle movements are strongly recommended in order to reach these areas.

Under the light of the step 1 results, we applied the best test group settings and repeated the experiment with a moving nozzle, but then in a restricted pocket model in order to stay closer to the real application. To imitate the possible clinical applications, the nozzle movements of up and down, rotation and slightly up was used. This movement was compared with the static application. The main outcome of this test was the fact that the nozzle cleaned much better with movement independent of what kind of movement it was. So the clinicians must definitely be advised to move the nozzle. The type of the movement had a less effect. We could not show a statistically significant difference between the cleaning efficiency of different movements. The cleaning was not complete but, we observed a superficial cleaning effect also on the uncleansed area. The powder may have had a cleaning there slightly.

There is a number of limitations of this study which should be taken into account while extrapolating the results to the clinical situation. One limitation of this study was the specimen type. Although the material type and the micro surface properties of the discs used in this study was the same with the dental implants, the threaded shape of the implants is totally different than the flat shape of the discs. We selected a titanium flat surface to have a clear visibility of the cleaning path given that all the observations and measurements had to be done
depending on the visual input. Evaluation on a threaded surface might cause many visualization problems which could eventually make the measurement process less reliable. Therefore, the flat surface specimens were selected to better understand the basic working principles and extend of the nozzle cleaning capacities. We speculate that, if the method was applied on a threaded shape implant, the implant threads would act as physical limitation on the depth of cleaning penetration. Although the effect might be limited than, we still expect the air pressure and nozzle depth to be very effective parameters on the threaded surface looking at the statistical significance. However, the role of the other parameters could be weakened due to the limiting implant shape. Following this study with another one on implant specimens will give more insight to the clinical situation however the above mentioned challenges should be solved.

Another limitation of the study was about the mineral layer used on the titanium discs instead of a real peri-implantitis biofilm. We mimicked the Ca deposit on implants which represent the calcified biofilm seen on the implants and we tried the remove it. The reason why we did not choose an in vitro biofilm was that the in vitro biofilms were less sticky comparing to the real peri-implantitis biofilm and could be sonicated easily. In that case, it was not possible to measure neither the cleaning path nor the difference of the cleaning efficiency of different movements. The attachment of the biomimetic CaP coating on the surface was shown to be very firm by scratch and hardness tests therefore we chose it as our model.

Although we mimicked the soft tissue around the pocket in our silicon model, the properties of the gingiva and susceptibility to probing changes depending on the inflammation. It should be stated this could have an influence on the application of the method.

To the best of our knowledge, there has been no other study investigating the cleaning path of subgingival air polishing so far. However there has been in vivo and in vitro studies showing the cleaning efficiency on teeth and implants and comparing it with other methods. Flemmig et al. showed the efficacy of glycine powder air polishing was greater in removing bacteria biofilms in deep periodontal pockets than scaling and root planning. He claims that the main function of the water jet appears to be flushing of biofilm dislodged by the glycine-air jet and residual glycine powder out of the pocket which is in line with our findings. Another
study\textsuperscript{7} which investigated the \textit{in vitro} cleaning potential of glycine air flow application on implants showed that, the efficiency changed depending on the angulation of the pocket where the implant is inserted. Similar to our approach, the authors used an indelible ink for the assessment of accessibility instead of biofilm. This kind of biofilm-alternatives provides us with better visibility of the method’s working principle. Our results are in line with the clinical success of the method. Furthermore, knowing how the method works better, the clinician can improve his nozzle handling to increase the clinical outcome.

CONCLUSIONS

Within the limitation of this \textit{in vitro} study, it is shown that to get the most effective clinical use of air polishing, it should be applied with high pressure, with deep insertion of the nozzle and enough water flow. The powder flow is not an important factor. On top of these, the nozzle has to be moved to get the best cleaning effect. Nevertheless, these guidelines need to be adapted to the real clinical situation with the help of a following \textit{in vivo} study.

ACKNOWLEDGEMENTS

This study was funded by EMS (Electro Medical Systems), Nyon, Switzerland.
REFERENCES


11. Tastepe, C.S., Liu, Y., Visscher, C.M., and Wismeijer, D. Cleaning and modification of intraorally contaminated titanium discs with calcium phosphate powder abrasive


