Efficient cleaning of a macro-structured micro-rough dental implant shoulder with a new coronal vertical groove design: A technical note

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KEYWORDS
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SUMMARY

This evaluation assessed the influence of a new implant shoulder design on cleanability using a now established in-vitro study model. Eight test (Botticelli, Di Meliora AG, Basel, Switzerland) and eight control implants (T3 Osseotite, ZimVie, Winterthur, Switzerland) were embedded in standardized defects in simulated bone. The implant surfaces were painted to be visually distinguishable and debrided with ultrasonic instruments (US) and an air powder waterjet device (AIR). Uncleaned implants served as positive controls. After the standardized cleaning, the implants were photographed and divided into three zones (upper marginal shoulder zone [A], lower marginal shoulder zone [B], and fully threaded sub-shoulder zone [C]) and analyzed with an image-processing software.

On test implants, AIR was almost 100% efficacious in both upper zones (A/B), while US was only 80–90% efficacious. In control implants, results of both AIR and US were almost 100% in zone A, but only 55–75% in zone B. In both implants, AIR showed statistically significant higher efficacy than US ($p < 0.05$).

Within the limitations of the present in-vitro model, a new macro-structured micro-rough dental implant shoulder with a new coronal vertical groove design shows similar cleanability in comparison to an implant shoulder with a smooth and machined surface.

Introduction

A significant challenge in everyday clinical practice is the complete and thorough cleaning and decontamination of implant surfaces exposed to biofilm, which might lead to inflammatory peri-implant diseases, particularly in its early stages (Lindhe & Meyle 2008). Conventional implant designs pose a macroscopic challenge, especially with undercuts, making it difficult to achieve complete cleaning (Figuero et al. 2014). Bacteria and debris tend to accumulate in these areas between threads and are challenging to remove (Figuero et al. 2014). Additionally, micro-rough surface structures promote bacterial adhesion, further complicating the cleaning process and promoting colonization (Schmage et al. 2012). While these macro- and micro-morphological implant characteristics pose difficulties under pathological conditions, they play an indispensable role during implant placeFehment and tissue integration processes (Wróbel et al. 2010; Klinge et al. 2018).

Based on these considerations and conflicting biological aspects, the objective was to develop a new implant shoulder design. Horizontal threads, known to reduce cleanability (Sahrmann et al. 2013), were avoided in the marginal shoulder zone. Instead, a novel vertical groove design was proposed to overcome potential disadvantages in peri-implant disease initiation and progression by providing adequate cleaning accessibility while facilitating optimal tissue integration during the osseointegration process.

The purpose of this study was to demonstrate the feasibility of comprehensive cleaning and decontamination of this novel implant shoulder design. We hypothesized that even with micro-rough surface with these geometric changes, cleaning efficiency can be achieved similar to that of a parallel-walled machined surface in the shoulder area. The null hypothesis was that there would be no differences in the selected parameter of cleanability.

Materials and methods

In this study, a dental implant with a novel micro-rough shoulder macro-design (Botticelli, Di Meliora AG, Basel, Switzerland) was compared to a conventional implant with a smooth machined shoulder (T3 Osseotite, ZimVie, Winterthur, Switzerland) regarding its suitability to be cleaned/decontaminated if necessary.

3D-printed mounting blocks made of photopolymer (Vero-Dent PureWhite DEN847, Stratasys, Rheinmünster, Germany) were used, which harbored predefined fitting screw holes for the implants. The upper 5 mm coronal region of the blocks had saucer-shaped bone defects designed to simulate a 30-degree angulation (Fig. 1A). Before implant placement, the surfaces within the defect were stained with diluted acrylic paint (Marabu Acryl Color, Marabu, Bietigheim-Bissingen, Germany), air-dried for 24 hours, and then the implants were screwed into the blocks.

Eight implants from each group were cleaned with either an ultrasonic instrument (Piezon PS, EMS, Nyon, Switzerland) or an air powder waterjet device (Airflow® Perioflow with Airflow Plus Powder, EMS) for two minutes (power level of both US and AIR: 10, water flow rate: 10), according to the manufacturer's instructions, under direct vision and control. After treatment, the implants were removed from the blocks, and the cleaning efficiency (cleaned area as a percentage of the total area) was planimetrically measured at three different areas: the upper marginal shoulder zone (zone A; 1.25 mm),

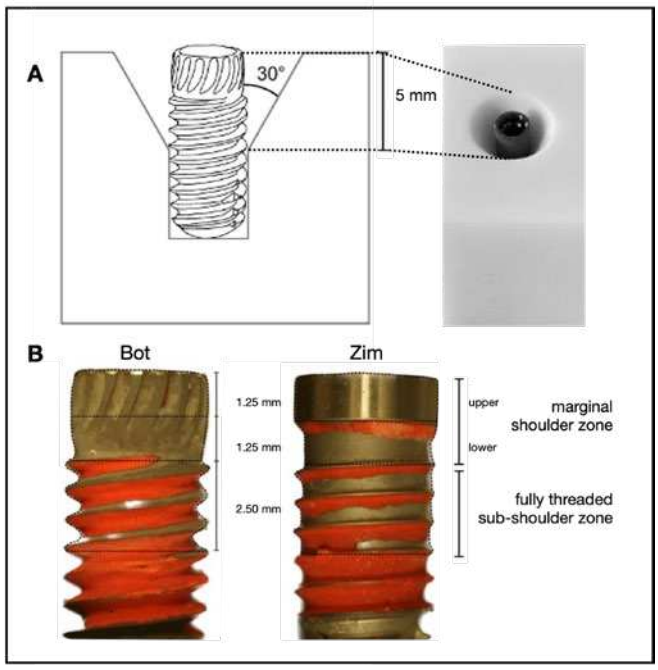

Fig. 1 Experimental set-up showing the defect configuration and implant position (A). Implants were removed after treatment and the cleaned areas determined in predetermined areas (B).

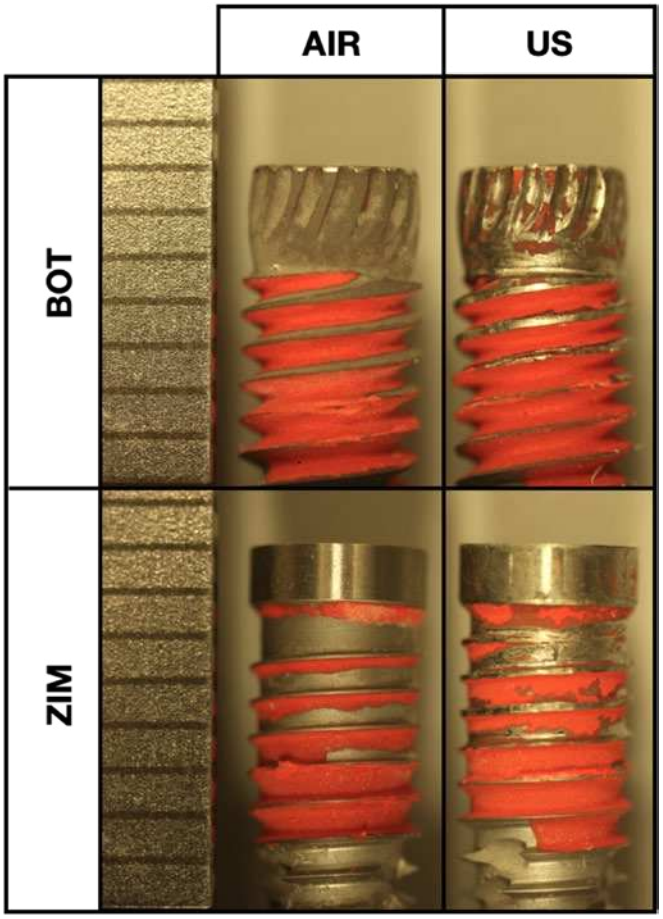

Fig. 2 Depiction of representative images taken after instrumentation of the two implants under investigation of the two manufacturers (BOT: Botticelli, ZIM: ZimVie). The red areas represent zones that were not accessed by the different instruments (AIR: airflow, US: ultrasound).

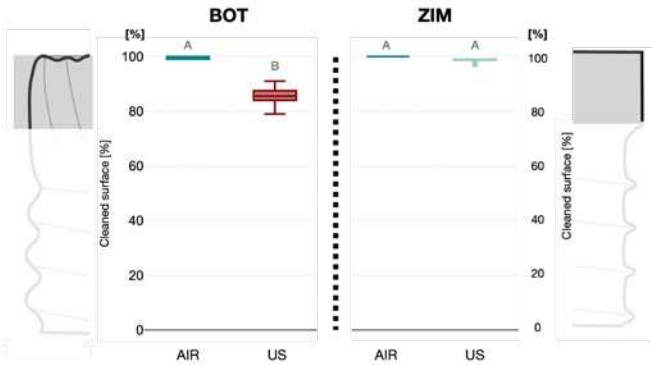

Fig. 3 Results (box plots) of the upper marginal shoulder zone (first 1.25 mm) after instrumentation. Identical capitals represent values that were not statistically significantly different (Kruskal–Wallis and Mann–Whitney; $p < 0.05$).

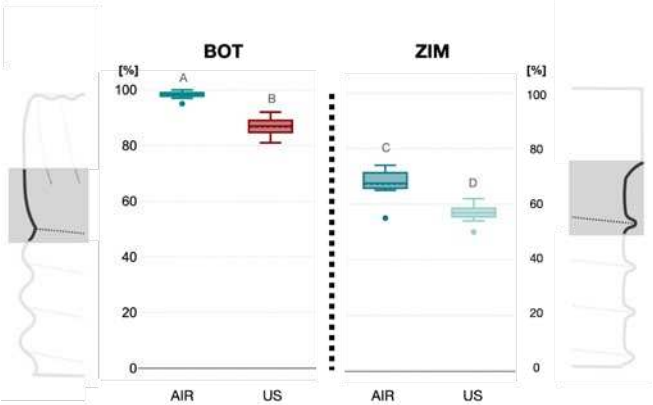

Fig. 4 Results (box plots) of the lower marginal shoulder zone (second 1.25 mm) after instrumentation. Identical capitals represent values that were not statistically significantly different (Kruskal–Wallis and Mann–Whitney; $p < 0.05$).

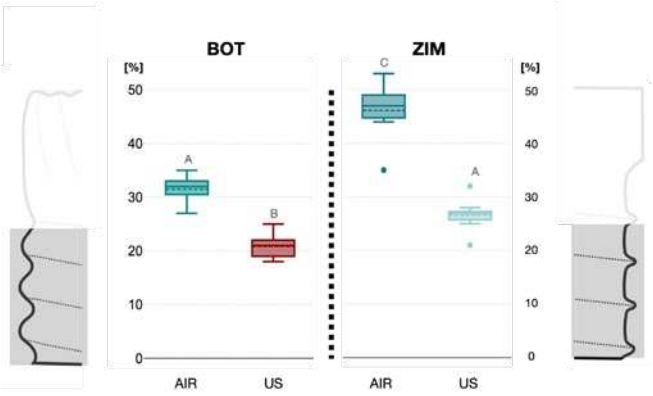

Fig. 5 Results (box plots) of the fully threaded sub-shoulder zone (2.5–5 mm) after instrumentation. Identical capitals represent values that were not statistically significantly different (Kruskal–Wallis and Mann–Whitney; $p < 0.05$).

the lower marginal shoulder zone (zone B; 1.25 mm), and the fully threaded sub-shoulder zone (zone C; 2.5 mm) (Fig. 1B). The cleaned implants were photographed using a tripod holder from two opposite sides with a digital single-lens reflex camera (Canon EOS 2000D, Wallisellen, Switzerland) under standardized settings. These images were analyzed by a blinded investigator (JB) using image-processing software (ImageJ version 1.53k, Wayne National Institutes of Health, Bethesda, MD, USA), and both the cleaned surface and the entire respective zone were measured to express the cleaning efficiency as a percentage.

Excel (version 16.70, Microsoft, Redmond, Washington, USA) was used for coding and documenting the data, and DATAtab Team (2022) (DATAtab: Online Statistics Calculator. DATAtab e.U. Graz, Austria, https://datatab.net) was used for statistical analysis. Descriptive statistics were used to describe mean, median and standard deviation, and IQR. The normality of the data distribution was tested with the Kolmogorov–Smirnov and Shapiro–Wilk tests. Non-parametric tests, including the Kruskal–Wallis and Mann–Whitney tests, were used to determine significant differences between the studied groups. A significance level of $p < 0.05$ was defined as statistically significant for all tests.

Results

Differences between the two implant types, zones and instruments could be observed as shown in Figure 1. Quantitative evaluations are depicted in Figures 3–5 as follows (at all other measured sites, the accessibility and efficiency were less than 10%): While AIR was almost 100% effective in the first 1.25 mm of both implants, US ranged between 80% and 90% ($p < 0.05$) in the Botticelli implant (BOT). In the lower marginal shoulder zone, i.e. the second 1.25 mm (Fig. 4), AIR was significantly better than US in BOT ($p < 0.05$), i.e. almost 100% versus 80–90%, respectively, but still with good cleaning potential. In the ZimVie implant (ZIM), the values dropped to below 80% with no statistically significant difference between AIR and US ($p > 0.05$). In the fully threaded sub-shoulder zone (2.5–5 mm, zone C, Fig. 5), no instrument accessed more than 50% of the surface. Notably, the ZIM threads were cleaned better as the BOT ones with both AIR and US ($p < 0.05$). In both implants, AIR was more efficient than US ($p < 0.05$).

Visually (Fig. 1), in the marginal shoulder zone, AIR and US were effective in both implant types, however, US resulted in visible surface changes, which could be attributed to a removal of the rough surface and smoothening (glossy appearance). But also scratches and signs of damage were visible after US application. While the upper marginal shoulder zone (zone A) was adequately accessed and cleaned with AIR and US in both implant types, the lower zone (zone B) was more thoroughly accessed in BOT, i.e. the vertical groove design seemed more cleanable than the coronal conventional initial threads.

Discussion

The present study investigated the cleanability of the recently developed Botticelli implant shoulder characterized by vertical grooves, which differs from known classic implant designs. Our results showed that these vertical grooves could indeed be as effectively cleaned as the parallel machined smooth shoulder design and even be more thoroughly cleaned in the lower part than threads in the control. Notably, it could be demonstrated that even the micro-rough surface of the Botticelli implant could be cleaned as efficiently as the smooth, non-structured neck area of the control implant. Thus, in the case of peri-implantitis, the micro-rough exposed shoulder area can be cleaned as comprehensively as a machined shoulder area.

In the lower section of the implant, however, the threads of the test implant could not be cleaned as effectively as in the control implant. Therefore, this suggests that the respective cleaning method is less effective in the deeper areas.

From a methodological point of view, an established in-vitro model was used, which utilizes acrylic paint to stain the im-

plant surface (Sahrmann et al. 2013; Sahrmann et al. 2015; Ronay et al. 2017). This method is simple, reproducible, visually well recognizable, scalable, and cost-effective option for a technical screening study with a focus to compare the mechanical cleanability of different implants. The main question remains, however, as to what extent acrylic paint is comparable with biofilm or reflects biofilm contamination of implant surfaces. Pre-study tests showed that the paint does not flake off piecemeal during cleaning but can be easily dissolved with an ultrasonic instrument and air powder waterjet device within two minutes. Another potential shortcoming of this study is the limitation of only one defect simulation. Clinical studies have shown how heterogeneous bone defects can be (Chrcanovic et al. 2017; Monje et al. 2019). Depending on the geometry and depth of the bone defect, cleaning results could of course vary (Tuchscheerer et al. 2021; Sanz-Martin et al. 2021). The current bone defect angle of 30 degrees is relatively narrow and challenging to achieve at the most apical part. Studies that have included various bone defects have shown that more horizontal defects can be cleaned with higher efficacy (Ronay et al. 2017), whereas narrower defects are anticipated to be cleaned less effectively (Sahrmann et al. 2013; Tuchscheerer et al. 2021).

Conclusion

Within the limitations of our screening, the study demonstrated and confirmed potential advantages of a vertical groove structure. The grooves allowed for equally effective cleaning of the implant shoulder compared to the conventional design and even a better cleaning in the lower implant shoulder zone. Furthermore, also micro-rough surface could be adequately accessed as a comparable smooth and machined surface. Future studies should now investigate the clinical impact of the Botticelli design in peri-implantitis situations.

Acknowledgments

The Botticelli implants were kindly provided for free by the company Di Meliora AG, Basel, Switzerland.

Conflict of interest statement

Stefan Stübinger declares a conflict of interest in that he is inventor of the Botticelli system and also a shareholder of the Di Meliora company. However, he is neither on the Di Meliora payroll, nor did he receive any financial compensation for this study. The other authors deny any conflict of interest related to this study.

Zusammenfassung

Einleitung

Die Studie untersuchte den Einfluss eines neuen Implantatschulterdesigns auf die Reinigungsfähigkeit mithilfe eines etablierten In-vitro-Studienmodells.

Material und Methoden

Insgesamt wurden je acht Testimplantate (Botticelli, Di Meliora AG, Basel, Schweiz) und Kontrollimplantate (T3 Osseotite, ZimVie, Winterthur, Schweiz) jeweils in standardisierte Knochendefekte eingebettet. Die Implantatoberflächen wurden mit Acrylfarbe gestrichen, um sie visuell unterscheiden zu können, und mit Ultraschallinstrumenten (US) oder einem Luft-Pulver-Wasserstrahl-Gerät (AIR) gereinigt. Nicht gereinigte Implantate dienten als positive Referenz. Nach der standardisierten Reinigung wurden die Implantate fotografiert und in drei Zonen unterteilt (obere marginale Schulterzone [A], untere marginale Schulterzone [B] und Sub-Schulter-Zone mit Windungen [C]) und mit einer Bildverarbeitungssoftware analysiert.

Resultate

Bei den Testimplantaten zeigte AIR in den beiden oberen Zonen (A/B) eine fast 100%ige Reinigung, US dagegen nur eine Reinigung von 80–90%. Bei den Kontrollimplantaten waren die Ergebnisse von AIR und US in Zone A fast 100%, aber nur 55–75% in Zone B. Bei beiden Implantaten zeigte AIR eine statistisch signifikant höhere Wirksamkeit als US ($p < 0{,}05$).

Innerhalb der Grenzen des vorliegenden In-vitro-Modells zeigt die makrostrukturierte mikroraue Dentalimplantatschulter mit einem neuen koronalen vertikalen Rillendesign eine ähnliche Reinigungsfähigkeit wie eine Implantatschulter mit glatter und bearbeiteter Oberfläche.

Diskussion

Insgesamt ist die Reinigungsfähigkeit von Dentalimplantaten von verschiedenen Faktoren abhängig, wie der Implantatoberfläche und der Reinigungsmethode. Die Ergebnisse dieser Studie deuten jedoch darauf hin, dass sich das neue Schulterdesign ähnlich gut reinigen lässt wie eine glatte und bearbeitete Oberfläche. Es ist jedoch zu beachten, dass es sich hierbei um eine In-vitro-Studie handelt, die nicht unbedingt die Bedingungen im menschlichen Körper widerspiegelt. Weitere Studien sind daher notwendig, um die klinische Relevanz dieser Ergebnisse zu bestätigen.

Résumé

Introduction

L'étude a examiné l'impact d'une nouvelle conception d'implant d'épaule sur la capacité de nettoyage à l'aide d'un modèle d'étude in vitro établi.

Matériel et méthodes

Au total, huit implants de test (Botticelli, Di Meliora AG, Bâle, Suisse) et des implants de contrôle (T3 Osseotite, ZimVie, Winterthour, Suisse) ont été incorporés dans des défauts osseux standardisés. Les surfaces des implants ont été marquées optiquement et nettoyées à l'aide d'instruments à ultrasons (US) et d'un appareil à jet d'air, d'eau et de poudre (AIR). Les implants non nettoyés ont été utilisés comme témoins positifs. Après le nettoyage standardisé, les implants ont été photographiés et divisés en trois zones (zone marginale supérieure de l'épaule [A], zone marginale inférieure de l'épaule [B] et zone sous-épaule avec des spirales [C]) et analysés avec un logiciel de traitement d'image.

Résultats

Pour les implants de test, AIR a montré une efficacité de près de 100 % dans les deux zones supérieures (A/B) par rapport à une efficacité de 80 à 90 % avec US. Pour les implants de contrôle, les résultats de AIR et US étaient presque de 100 % dans la zone A, mais seulement de 55 à 75 % dans la zone B. Pour les deux implants, AIR a montré une efficacité statistiquement significativement plus élevée que US ($p < 0{,}05$).

Discussion

Dans les limites du modèle in vitro actuel, une nouvelle conception d'implant dentaire macrostructurée et microrugueuse avec une nouvelle conception de rainure verticale coronale montre une capacité de nettoyage similaire par rapport à une surface lisse et travaillée. En général, il est possible de dire que la capacité de nettoyage des implants dentaires dépend de différents facteurs, tels que la surface de l'implant et la méthode de nettoyage. Cependant, les résultats de cette étude suggèrent que la nouvelle conception d'épaule présente une capacité de nettoyage similaire à une surface lisse et travaillée. Il convient toutefois de noter qu'il s'agit d'une étude in vitro qui ne reflète pas nécessairement les conditions dans le corps humain. D'autres études sont donc nécessaires pour confirmer la pertinence clinique de ces résultats.

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