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Chapter 3

The effects of mechanical instruments on contaminated titanium dental implant surfaces: a systematic review

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Introduction

After successful osseointegration and in order to be functional, oral implants must pierce the mucosa and enter the oral cavity, thus establishing a transmucosal connection between the internal and external environment. The implant components that are in contact with the soft tissue and are exposed to the oral environment are smooth. Hence, preservation of implant health implies keeping smooth surfaces clean (Mombelli, 2002). Plaque accumulation induces inflammatory changes in the soft tissues around them, which may lead to the loss of supporting bone and ultimately implants loss (Esposito et al. 2010). Long term maintenance care, especially for the high risk groups, is essential to reduce the risk of peri-implant infections (Atieh et al. 2012). If peri-implantitis is diagnosed, a therapeutic intervention should be initiated as soon as possible (Esposito et al. 1999).

Ideally, the instruments used to effectively clean smooth surfaces should cause minimal or no surface damage, should not create a surface that is more conducive to bacterial colonisation, and should not affect the implant-soft tissue interface. If, however, the soft tissue attachment is disrupted, the instrumentation procedure should maintain a surface that is conducive to re-establishment of the soft tissue seal (Kuempel et al. 1995).

In case of peri-implantitis, the implant threads, which generally have a roughened surface to promote osseointegration, can become exposed to oral micro-organisms and bacterial colonisation of the titanium surface can occur, leading to the loss of osseointegration. The treatment of peri-implantitis includes among others the decontamination of the surface exposed to the biofilm to eliminate inflammation and to render the exposed surface biocompatible, with re-osseointegration as the ultimate goal.

In a recent systematic review (Louropoulou et al. 2012), the effects of different mechanical instruments on the characteristics and roughness of smooth and structured (i.e., rough) titanium surfaces were evaluated. Non-metal instruments and rubber cups were found to cause minimal or no damage to smooth implant surfaces. Similarly, non-metal instruments and air-abrasives were the instruments of choice for structured surfaces when maintenance of the surface integrity was required. Metal instruments and burs were recommended only in cases that required smoothing of the surface roughness.

Whereas this review addressed in detail the issue of surface alterations, it still remains unclear how effective mechanical instruments are at cleaning contaminated titanium implant surfaces. Surface alterations may be of secondary interest if the means of instrumentation prove to be ineffective in removing accretions.
Therefore, the aim of this comprehensive review was to systematically evaluate, based on the existing literature, the ability of different mechanical instruments to clean contaminated titanium surfaces.

**Materials and Methods**

This systematic review was conducted according to the guidelines of Transparent Reporting of Systematic Reviews and Meta-analyses (PRISMA-statement) (Moher et al. 2009).

**Search strategy**

Three internet sources were used to identify publications that met the inclusion criteria: the National Library of Medicine, Washington, D.C. (MEDLINE-PubMed), the Cochrane Central Register of Controlled Trials (CENTRAL) and EMBASE (Excerpta Medical Database by Elsevier). The search was conducted up to May, 2013 and was designed to include any published study that evaluated the efficacy of mechanical instruments on cleaning contaminated titanium surfaces. To achieve this goal, a comprehensive search was performed. All reference lists from the selected studies were manually searched by two reviewers (A.L & G.A.W) for additional papers that met the eligibility criteria. The terms used in the search strategy are presented in Box 1.

**Screening and selection**

Papers written in English were accepted. Letters, human case reports and reviews were not included in the search. The titles and abstracts were first screened independently by two reviewers (A.L & G.A.W) for eligibility. Following selection, full-text papers were carefully read by the two reviewers. The papers that fulfilled all of the selection criteria were processed for data extraction. Disagreements were resolved by discussion. If disagreements persisted, the judgment of a third reviewer (D.E.S) was decisive. The following eligibility criteria were used:

- Controlled studies
- Titanium surfaces of dental implants or implant components, discs, strips or cylinders simulating such surfaces
- Contamination of the titanium surfaces, including biofilm grown with a standardised technique, a single bacterial species or bacterial products, such as lipopolysaccharide (LPS), or/and calcified deposits
• Treatment with mechanical instruments, including curettes and/or scalers, (ultra)sonic instruments, titanium brushes, air abrasives/polishers, rubber cups/points and burs/polishers
• Outcome parameters for surface cleanliness, including residual biofilm (RB) area, residual lipopolysaccharide, colony forming units (CFU) and scanning electron microscope (SEM) observations.

Assessment of heterogeneity
The following factors were evaluated to assess heterogeneity:
• Titanium surfaces
• Surface contamination method
• Treatment performed
• Outcome variables
• Funding

Box 1. Search terms used for PubMed-MEDLINE, Cochrane-CENTRAL and EMBASE. The search strategy was customized according to the database been searched.

{〈Subject〉 AND 〈Adjective〉 AND 〈Intervention〉}

{〈Subject: (dental implants [MeSH terms] OR (dental implant OR {/dental OR oral} AND implant)[textword])〉
AND
〈Adjective: (biofilms OR dental plaque OR dental deposits [MeSH terms] OR smooth OR structure OR texture OR roughness OR surface OR biofilm OR plaque index OR dental plaque OR plaque OR dental deposit* OR biocompatibility [textword])〉
AND
〈Intervention: (dental scaling OR decontamination OR laser [MeSH terms] OR ultrasonic OR curette OR scaling OR laser OR polishing OR debridement OR curettage OR air abrasion OR air polisher OR cleaning OR instrumentation OR decontamination OR air powder OR bur OR brush [textword])〉}
Quality assessment

Two reviewers (A.L & D.E.S) scored the methodological quality of the studies selected for analysis. Assessment of methodological quality was performed as proposed by the RCT checklist from the Dutch Cochrane Centre (2009) and was further extended using quality criteria obtained from the CONSORT statement (Schulz et al. 2010), the Delphi List (Verhagen et al. 1998), the Jadad scale (1996), the ARRIVE guidelines (Kilkenny et al. 2010) and the position papers by Moher et al. (2001) and Needleman (2002). Most of the proposed criteria were combined as described by Louropoulou et al. (2012).

Data extraction and analysis

The data were extracted from the selected papers by two reviewers (A.L & D.E.S). Disagreements were resolved via discussion. If the disagreement persisted, the judgment of a third reviewer (G.A.W) was considered decisive. After a preliminary evaluation of the selected papers, considerable heterogeneity was found in the study characteristics, instruments used, outcome variables and results. Only few studies presented quantifiable data. Consequently, it was impossible to perform valid quantitative analyses of the data or a subsequent meta-analysis. Therefore, a descriptive presentation of the data was adopted.

In order to evaluate the sample size of the included studies, the Mead’s resource equation was used. This equation is often used for estimating sample sizes of laboratory experiments. It may not be as accurate as using other methods in estimating sample size, but gives a hint of the appropriate sample size where parameters such as expected standard deviations or expected differences in values between groups are unknown or very hard to estimate (Kirkwood et al. 2010). The Mead’s resource equation is: \[ E = N - B - T \], where \( N \) is the total number of included units (minus 1), \( T \) is the number of treatment groups, including the control group, (minus 1), \( B \) is the blocking component (minus 1) and \( E \) is the degree of freedom, which should be equal to or more than 10.

Grading the ‘body of evidence’

The Grading of Recommendations Assessment, Development and Evaluation (GRADE) system proposed by the GRADE working group was used to grade the collected evidence and to rate the strength of the recommendations (Guyatt et al. 2008).
Results

Search and selection
The PubMed-MEDLINE, Cochrane-CENTRAL and EMBASE searches identified in total, 1,893 unique papers using the specified search terms (Figure 1). The initial screening of the titles and abstracts resulted in 20 full-text papers that met the inclusion criteria. After reading the full-text articles, six of the papers were excluded. Table 1 shows the reasons for exclusion. Additional hand-searching of the reference lists from the selected studies did not yield any additional papers. Fourteen papers were ultimately processed for data extraction.

Assessment of heterogeneity
Information regarding the study characteristics is provided in Table 2. The table includes a short summary of the study design, the results of the selected studies and the authors’ conclusions. Eleven of the included studies (Parham et al. 1989; Zablotsky et al. 1992; Dennison et al. 1994; Pereira da Silva et al. 2005; Schwarz et al. 2005, 2009; Nemer Vieira et al. 2012; Schmage et al. 2012; Tastepe et al. 2013; Idlibi et al. 2013; and John et al. 2014) had an in vitro design. Two studies (Gantes & Nilveus 1991; and Speelman et al. 1992) were in situ studies using an animal model and one (Kawashima et al. 2007) was an in situ study in humans.

Titanium surfaces and surface contamination
The titanium surfaces that were evaluated varied between the selected studies. Both smooth and structured titanium surfaces were used. Implant abutments/bodies with polished/machined surfaces or titanium discs/sheets/cylinders simulating those surfaces were evaluated in eight studies (Gantes & Nilveus 1991; Speelman et al. 1992; Dennison et al. 1994; Pereira da Silva et al. 2005; Kawashima et al. 2007; Nemer Vieira et al. 2012; Schmage et al. 2012; Idlibi et al. 2013). Five studies (Schwarz et al. 2005, 2009; Schmage et al. 2012; Tastepe et al. 2013; John et al. 2014) used titanium discs with sand-blasted and acid-etched surfaces (SLA) and two studies (Nemer Vieira et al. 2012; Schmage et al. 2012) used titanium implants and titanium discs respectively with an acid-etched surface. Implant bodies and implant specimens produced from bodies with titanium plasma-sprayed (TPS) surfaces were used in two studies (Parham et al. 1989; Dennison et al. 1994). Pereira da Silva (2005) studied surfaces blasted with aluminium oxide particles of different diameters, and Zablotsky et al. (1992) and Schmage et al. (2012) used titanium strips or discs with a grit-blasted titanium alloy surface.
The methods of surface contamination also differed between the selected studies. Lipopolysaccharide from *Escherichia coli* or *Porphyromonas gingivalis* was used in two studies (Zablotsky et al. 1992; Dennison et al. 1994, respectively). Four studies used single-species biofilm, such as *Streptococcus mutans* (Schmage et al. 2012), *Streptococcus sanguis* (Pereira da Silva et al. 2005; Nemier Vieira et al. 2012) or *Actinomyces viscosus* (Parham et al. 1989). Eight studies used an *in situ* model to contaminate titanium surfaces with supragingival plaque by placing titanium discs in splints in the mouth of either beagle dogs (Gantes & Nilveus 1991; Speelman et al. 1992) or volunteers (Schwarz et al. 2005, 2009; Tastepe et al. 2013; Idlibi et al. 2013; John et al. 2014). Finally, in one study subgingival plaque was left to accumulate on healing abutments placed in the mouth of patients with implants (Kawashima et al. 2007). The period of plaque accumulation varied considerably between the studies from 24 hours up to 16 days.

**Treatment**

Metal (stainless-steel) curettes were evaluated in two studies (Speelman et al. 1992; John et al. 2013). Non-metal curettes/scalers and rubber cups with pumice were evaluated in two studies (Speelman et al. 1992; John et al. 2013). (Ultra)sonic scalers were tested with metal (Speelman et al. 1992; Schmage et al. 2012) and non-metal tips (Gantes & Nilveus 1991; Zablotsky et al. 1992; Kawashima et al. 2007; Schmage et al. 2012), while two studies (Schwarz et al. 2005; Kawashima et al. 2007) used the Vector™ ultrasonic system with a PEEK (polyether etherketone fibre) tip. Rotating titanium brushes were tested in one study (John et al. 2013). The air powder abrasive system was the instrument mostly evaluated, as it was tested in nine out of the fourteen included studies (Parham et al. 1989; Zablotsky et al. 1992; Dennison et al. 1994; Pereira da Silva et al. 2005; Schwarz et al. 2009; Nemier Vieira et al. 2012; Schmage et al. 2012; Tastepe et al. 2013; Idlibi et al. 2013). A sodium bicarbonate powder was used in the majority of the studies (Parham et al. 1989; Zablotsky et al. 1992; Dennison et al. 1994; Pereira da Silva et al. 2005; Schwarz et al. 2009; Nemier Vieira et al. 2012), while amino acid glycine powders were tested in four studies (Schwarz et al. 2009; Schmage et al. 2012; Tastepe et al. 2013; Idlibi et al. 2013). Finally, three other powders (TiO2 powder, hydroxyapatite sintered powder and calcium phosphate powder) were used in one study (Tastepe et al. 2013). Speelman et al. (1992) tested a composite bur (Stainbuster®) in combination with sodium bicarbonate powder and Schmage et al. (2012) tested a prophylaxis brush (Sonic Flex Clean®). Differences were observed in the treatment time and treatment mode (e.g., number
of stokes, distance of the tip from the surface, and angulation of the tip). No study was found evaluating the cleaning efficacy of titanium curettes.

**Funding**

Six studies (Parham et al. 1989; Zablotsky et al. 1992; Dennison et al. 1994; Pereira da Silva et al. 2005; Schwarz et al. 2005; Idlibi et al. 2013) were supported by a non-industrial funding and two (Zablotsky et al. 1992; Schwarz et al. 2009) were supported by an industrial grant. In four studies (Pereira da Silva et al. 2005; Kawashima et al. 2007; Nemer Vieira et al. 2012; Idlibi et al. 2013), the authors declared no conflict of interest. In five studies (Speelman et al. 1992; Dennison et al. 1994; Schwarz et al. 2009; Schmage et al. 2012; Idlibi et al. 2013), some of the materials used were donated by companies. Two studies (Tastepe et al. 2013; and John et al. 2014) provided no information about funding.

**Outcomes**

The outcome variable for five studies (Parham et al. 1989; Gantes & Nilveus 1991; Speelman et al. 1992; Kawashima et al. 2007; Schmage et al. 2012) was SEM observations. Idlibi et al. (2013) evaluated the quantity of residual biofilm by quantification of the total protein content and scanning electron microscopy. Four studies (Schwarz et al. 2005, 2009; Tastepe et al. 2013; John et al. 2014) used the residual biofilm areas and one study (Zablotsky et al. 1992) the residual LPS levels. Nemer Vieira et al. (2012) reported on the percentage of bacterial removal, Pereira da Silva et al. (2005) evaluated the colony forming units (CFU) before and after treatment and Dennison et al. (1994) used a radioimmunoassay to evaluate the removal of endotoxin. The results of all studies are presented in Table 2. Only two studies (Kawashima et al. 2007; Tastepe et al. 2013) provided information regarding the validation of the evaluation method (Table 3).

Speelman et al. (1992) evaluated the effectiveness of scaling with metal and plastic scalers and ultrasonic scalers with metal tips at cleaning the buccal surface of abutments with a machined surface contaminated with plaque and calculus. SEM photographs were taken and abutments were assigned a “cleanliness” score ranking from 0 (unused abutment) to 5 (surface not clean). The authors reported that although a 90 s treatment with metal, plastic or ultrasonic instruments with metal tip appeared clinically to result in a clean surface, the SEM analysis showed a surface that was still covered to various extents with thin layers of amorphous materials, calculus, and/or bacterial colonies. None of these cleaning methods created
a cleanliness score better than 3 and none of them appeared to be superior to the other. In the same study single polishing with a composite bur (Stainbuster®) in combination with sodium bicarbonate powder was found to have the least cleaning potential (score 5), while weekly rubber cup polishing with pumice for 10 s once a day for three months resulted in the highest surface cleanliness (score 1,2).

John et al. (2014) compared the effectiveness of a rotating titanium brush to that of a stainless steel curette on SLA titanium discs contaminated with supragingival plaque. Both cleaning procedures showed a significant decrease in residual plaque areas. However, the mean residual biofilm area in the titanium brush group (8.57% ± 4.85%) was significant lower than in the curette group (28.99 ± 5.51%), while being gentler to the implant surface than the metal curette.

Schmage et al. (2012) evaluated the cleaning efficacy of different cleaning instruments, among which non-metal curettes (plastic, carbon), sonic and ultrasonic scalers with non-metal (PEEK, carbon) tips, air-abrasive with amino acid glycine powder and rubber cup with pumice, on titanium discs with four different surfaces: polished, acid-etched, grit-blasted/acid-etched and grit-blasted. The specimens were contaminated with a monoclonal biofilm of *Streptococcus mutans*. The best cleaning was seen with (ultra)sonic scalers with a PEEK tip and the air abrasive with amino acid glycine powder on all implant surfaces, whereas the poorest cleaning was seen with the non-metal curettes and the rubber cup with pumice.

Kawashima et al. (2007) evaluated the treatment of polished implant abutment surfaces with three piezoelectric scalers with metal, plastic or carbon tip (Vector™ scaler), in vivo. After one week of plaque accumulation in the mouth of patients that underwent implant treatment, the subgingival area of the abutments was treated for 60 s with the three ultrasonic scalers. After instrumentation, the abutments were removed and the amount of remaining plaque and calculus in the mesial proximal area was estimated using the same ranking score as in the study of Speelman et al. (1992). The authors reported that all three instruments successfully removed plaque from the abutment surfaces. All piezoelectric scalers resulted in a cleanliness score better than 3.

Schwarz et al. (2005) tested the Vector™ system with a carbon-fibre tip and polishing fluid (HA particles < 10 μm) on titanium discs with SLA surfaces contaminated with supragingival plaque. Cleaning efficacy was evaluated by measuring the residual biofilm (RB) area. Treatment with the Vector system resulted in a significant decrease in initial biofilm covered (IPB) area (mean RB: 36.8 ± 4.5% versus mean IPB: 97.5 ± 0.9; p< 0.001).
Sonic scalers with plastic tips were also tested in two other studies (Gantes & Nilveus 1991; Zablotsky et al. 1992). Gantes & Nilveus (1991) used a sonic plastic scaler for less than 5 s on titanium cylinders with a highly polished surface contaminated with supragingival plaque and concluded that this instrument was able, based on SEM observations, to completely remove plaque from the surface of highly polished titanium. In Zablotsky et al. (1992), a sonic scaler with plastic tip was used on grit-blasted titanium alloy strips contaminated with \textit{E. coli} LPS. The residual LPS levels were measured. A 60 s application with the plastic sonic scaler tip resulted in significantly reduced residual LPS levels compared to the untreated control (63 mean residual LPS counts/min/mm\(^2\) versus 197 counts/min/mm\(^2\); \(p < 0.05\)). This study also evaluated the detoxifying effects of a 30 s application of an air powder abrasive system with a sodium bicarbonate powder. This treatment removed significantly greater amounts of LPS compared to the plastic sonic scaler (12 LPS counts/min/mm\(^2\) for air abrasive versus 63 LPS counts/min/mm\(^2\) for the plastic scaler; \(p < 0.05\)).

Dennison et al. (1994) used the air abrasive with sodium bicarbonate powder on cylindrical implants with TPS or machined surfaces contaminated with \textit{P. gingivalis} LPS for a single (60 s) and a repeated treatment (120 s) and showed that the air abrasive resulted in a significant reduction in endotoxin levels compared to the baseline on both surfaces. On TPS surfaces, the air abrasive removed 84.2\% of the endotoxin after one treatment and 91.8\% after the second treatment (\(p < 0.05\)). On the machined surface, the reduction was 98.5\% and 99.4\%, respectively (\(p > 0.05\)). The air abrasive was shown to be more effective in removing endotoxin from machined than TPS surfaces.

Parham et al. (1989) showed that a 5 s application of the air-abrasive with a sodium bicarbonate powder on implant specimens with TPS surfaces contaminated with \textit{A. viscosus} resulted in complete removal of bacteria.

Pereira da Silva et al. (2005) investigated the efficacy of a decontamination protocol for bacterial removal from titanium surfaces contaminated with \textit{S. sanguis} using a high-pressure sodium bicarbonate device for 60 s. They used titanium sheets with three different levels of surface roughness. Group 1 was composed of titanium sheets with a machined surface, and group 2 and 3 of titanium sheets blasted with aluminium oxide particles with different diameters: group 2 was blasted with 65-\(\mu\)m particles (moderate rough surface) and group 3 with 250-\(\mu\)m particles (very rough surface). The colony forming units were counted before and after treatment, and no viable cells were detected after treatment in all of the surfaces.
examined. Nemer Vieira et al. (2012) used a similar high-pressure sodium bicarbonate device for 60 s on implants contaminated with S. sanguis, with either a machined or an acid-etched surface. Removal of all bacterial cells was observed regardless of the surface roughness.

Schwarz et al. (2009) used the air abrasive with sodium bicarbonate or amino acid glycine powders with different particle sizes (range of mean particle size 20-75 μm) on titanium discs with a SLA surface contaminated with supragingival plaque at two distances and two angulations for single (20 s) and repeated treatments (40 s). The residual biofilm (RB) areas (%) were assessed. Comparable mean RB areas were observed within and between groups after single (RB: 0.0 ± 0.0 % to 5.7 ± 5.7%) and repeated treatments (RB: 0.0 ± 0.0 %). The authors concluded that all of the powders investigated were equally effective in cleaning the SLA titanium surfaces.

Tastepe et al. (2013) also tested the air abrasive on intraorally contaminated SLA titanium discs. Four different powders were used: titanium dioxide (TiO2), amino acid glycine powder (particle size 20-65 μm), hydroxylapatite sintered (HA) and calcium phosphate powder. All powders decreased the initial amount of biofilm significantly, although the TiO2 powder was not as efficient as the others. All applications resulted in remnants of the powder particles left or impacted on the surface.

Finally, Idlibi et al. (2013) evaluated the efficacy of an air abrasive with amino acid glycine powder (mean particle size: 20 μm) in removing biofilm formed in situ on machined titanium discs. A 60s treatment of the machined surfaces with the air abrasive resulted in significant decrease in the amount of biofilm. The average percentage of residual biofilm in relation to the untreated control was 2.5%.

Quality assessment and grading the ‘body of evidence’

The quality assessment of the various studies is presented in Table 3. Of the fourteen studies that evaluated the cleaning efficacy, ten were considered to have a high potential risk of bias and four were considered to have a moderate risk. Most of the studies used titanium discs, sheets or strips, which are considered to be less clinically representative. Five studies provided data regarding randomisation of the treatment, but no study provided data regarding the allocation concealment.

Regarding the sample size of the included studies, twelve studies used an adequate sample size, as it was calculated by the reviewers using the Mead’s resource equation, while two studies (Parham et al. 1989; Gantes & Nilveus 1991) did not fulfill the abovementioned
criteria. However, exclusion of these studies does not affect the outcome of the review.

The following criteria were used to rate the quality of evidence and strength of the recommendations according to GRADE (Guyatt et al. 2008, GRADE working group): potential risk of bias, consistency, directness, precision of the estimate and publication bias. There were sufficient available data regarding the use of air abrasive with sodium bicarbonate or amino acid glycine powder to clean titanium surfaces. The available data were consistent, indirect and rather precise and had a high potential risk of bias. As a result, the strength of recommendation was considered to be weak. The data reporting on the cleaning efficacy of the other mechanical instruments were limited, which made grading of the evidence not feasible. A formal testing for publication bias, as proposed by Egger et al. (1997), could not be used owing to insufficient statistical power because of the limited number of studies evaluating each instrument and the lack of sufficient quantitative data.

Discussion

The present review focused on the effectiveness of different mechanical instruments to clean contaminated titanium implant surfaces. This issue has been approached mainly by in vitro experiments. Metal (stainless steel) curettes were found to be ineffective in removing calcified deposits from machined surfaces (Speelman et al. 1992), but effective in removing non-calcified deposits from SLA surfaces (John et al. 2014). Different non-metal curettes were found to be ineffective in removing bacteria as well as calcified deposits from smooth as well as rough titanium surfaces (Speelman et al. 1992; Schmage et al. 2012). Similar results are reported in the literature and in the case of cylindrical implants with a TPS surface and screw-shaped implants with a machined surface (Augthun et al. 1998). This study showed that it was impossible to remove the plaque from the depth of the screw-like threads or the plasma-sprayed surfaces with plastic curettes. The inadequate effect of these instruments has been attributed to their limited flexibility, which prevents exact placement and application, particularly in the case of threaded implants (Augthun et al. 1998). These results are also corroborated to a certain extent by the findings from two other studies that evaluated the effectiveness of plastic curettes in combination with chlorhexidine gluconate (CHX) to remove supragingival biofilm grown on titanium discs with Osseotite or SLA titanium surfaces (Schwarz et al. 2006 and 2005, respectively). Subsequent to instrumentation, the mean residual plaque biofilm area was 58.5 ± 4.9% for the Osseotite and 61.1 ± 11.4 % for the
SLA surfaces, which showed the inability of the plastic curette to effectively clean implant surfaces, even in combination with CHX.

The Vector scaler, a piezoelectric scaler with a carbon tip, seems to be effective in removing biofilm from SLA (Schwarz et al. 2005) and polished titanium surfaces (Kawashima et al. 2007). These results are supported to a certain extent by the findings from one other study that evaluated the effectiveness of an ultrasonic scaler with the same carbon tip in combination with chlorhexidine gluconate (CHX) to remove plaque biofilm grown on titanium discs with Osseotite surfaces (Schwarz et al. 2006). Sato et al. (2004) compared the effectiveness of the Vector scaler to that of conventional piezoelectric scalers with a metal and with a plastic tip to remove artificial debris from abutments with a polished titanium alloy surface in vitro. After 60 s, removal of artificial debris was significantly better when using the Vector system compared to the conventional scalers with metal and plastic tips. However, these results are different to that of Kawashima et al. (2007) who compared the effectiveness of the same piezoelectric scalers on the same abutments in vivo. No significant differences were observed between the scalers after treatment for 60 s. These authors (Kawashima et al. 2007) concluded that all scalers produced clean surfaces. The apparent discrepancies may be due to the differences between removing artificial debris and plaque and the inherent differences between in vitro and in vivo settings. The friction during removal of the treated abutments from the mouth of the patients in order to be microscopically evaluated may have affected the amount of remaining biofilm on the surface.

(Ultra)sonic scalers with metal tip were quite effective in removing plaque from polished and highly polished surfaces (Gantes & Nilveus 1991; Kawashima et al. 2007). However, these results should be used with caution. In a systematic review evaluating the effect of different mechanical instruments on titanium implant surfaces (Louropoulou et al. 2012), (ultra)sonic scalers with metal tips were found to cause major damage to smooth surfaces. The surface roughness produced by these instruments may promote new biofilm formation and impede the preservation of implant health.

A rotating titanium brush seems to be an effective instrument for mechanical cleansing of SLA surfaces, while inducing no surface alteration (John et al. 2014). These results are supported to an extent by the findings from another study that assessed the effect of rotating titanium brushes in combination with four chemical agents on titanium surfaces covered by a Staphylococcus epidermidis-based biofilm. Three different titanium surfaces were used: SLA surfaces, specimens mimicking Ti-Unite™ surfaces and specimens mimicking OsseoSpeed™
surfaces. The combination of the titanium brushes with the chemical agents resulted in a greater reduction of the biofilm compared to the use of the same chemical agents alone (Gustumhaugen et al. 2014).

All studies evaluating the cleaning efficacy of an air powder abrasive reported consistent results. This device when used with a sodium bicarbonate powder was found to be very effective in removing bacteria and bacterial products from machined, SLA, grit-blasted and TPS titanium surfaces. All studies reported more than 84% removal of bacteria or bacterial products irrespective of the surface type. When comparing the air-abrasive with sodium bicarbonate powder to a plastic curette (Augthun et al. 1998) or a sonic scaler with a plastic tip (Zablotsky et al. 1992), the air-abrasive was found to be more effective than the other treatment modalities, independent of the surface characteristics. These results are in agreement with a recently published literature review focusing on the air abrasive (Tastepe et al. 2012). The authors of this review reported: “In vitro cleaning efficacy of air powder abrasive treatment on titanium strips, discs or implants is high.” Promising results for the air abrasive were also reported in a review evaluating the decontamination of infected implants by mechanical, chemical and physical methods (Meyle et al. 2012). This review included in vitro, animal and human studies and the authors concluded that “for decontamination of infected implant surfaces air-abrasive treatment seems to work”.

Beside the classical sodium bicarbonate powder, good results are also reported for other powders. A less abrasive amino acid glycine powder seems to be effective in removing single bacteria species and plaque from titanium discs with smooth and structured surfaces (Schwarz et al. 2009; Schmage et al. 2012; Tastepe et al. 2013; Idlibi et al. 2013). Moreover, this powder has been found to be gentler to the implant surface than the sodium bicarbonate powder. Repeated use of the different amino acid glycine powders on SLA surfaces (density = 2.16 g/cm³) was not associated with any surface alterations compared to a sodium bicarbonate powder (density = 1.61 g/cm³), which resulted in a flattening of the sharp-edged elevations of the surface after repeated treatments (Schwarz et al. 2009). Similarly, the air-polishing treatment with glycine powder of titanium abutment surfaces caused no detrimental surface alterations on the smooth surface, while an increased surface roughness with crater formation was observed when a sodium bicarbonate powder was used (Cochis et al. 2012). When comparing the air-abrasive with amino acid glycine powder with different hand, sonic and ultrasonic instruments with metal and non-metal tips, the air abrasive with amino acid glycine powder was found to be equally effective as a sonic instrument with a
PEEK tip on both smooth and structured surfaces (Schmage et al. 2012).

The powder seems to be an important parameter for the efficacy of the air abrasive. The use of an air abrasive device without powder (only water) resulted in significantly less biofilm removal compared to the use of the same device with different powders (Tastepe et al. 2013). However, deposition of powder particles has been observed on the treated surfaces (Mouhyi et al. 1998; Tastepe et al. 2013). The latest study (Mouhyi et al. 1998), in which failing implants were cleaned with an air-abrasive with sodium bicarbonate powder, showed that although a clean surface was observed on SEM, the elemental composition of the original surface was not re-established. This treatment resulted in a marked contamination with sodium (38%), which was found as deep as 87 nm into the implant, and only 1% of titanium could be detected on the surface (Mouhyi et al. 1998). The residual powder particles may interfere with cell responses and thus, affect the biocompatibility of the treated titanium surface.

Limitations

Reviewing the literature for studies on mechanical cleaning of titanium dental implant surfaces retrieved limited evidence. Only thirteen studies were identified addressing this issue. Most instruments were evaluated in only one or two studies. The majority of the studies used titanium discs, sheets, strips and cylinders simulating the surface of implant bodies or abutments. Although these specimens mimic exactly the microstructure of the surface, the macrostructure (threads shape) are not identical. As a result of these differences, the cleaning of actual implant surfaces may be more difficult.

In almost all studies that used biofilm contamination, the titanium surfaces were contaminated with non-mineralised supragingival plaque. However, the composition of the subgingival plaque may vary and mineralised deposits may be present in clinical cases. Only one study (Speelman et al. 1992) used surfaces contaminated with plaque and calculus and showed the inability of the tested instruments to adequately remove mineralised deposits. Several of the studies used bacterial products (e.g., LPS) and single species-biofilm to contaminate the surfaces. These contaminants may not adequately represent actual clinical situations compared to in situ biofilm growth.

The impact of sponsorship may be an important issue, as there is literature showing that industry sponsorship may affect biomedical research outcomes (Popelut et al. 2010). In the present review, two studies (Zablotsky et al. 1992; Schwarz et al. 2009) were supported by an
industrial grant. In the study of Schwarz et al. (2009) the air abrasive system and the powders used were provided by a grant of the manufacturer, while the study of Zablotsky et al. (1992) was supported in part by the implant company. Furthermore, in four studies (Speelman et al. 1992; Dennison et al. 1994; Schmage et al. 2012; Idlibi et al. 2013), the implant specimens used were donated by the implant companies. Two studies investigated the effectiveness of a commercial device, the Vector™ scaler (Schwarz et al. 2005; Kawashima et al. 2007). In the first study the authors declare no conflict of interest, while the second one was supported by a non-industrial grant. In a systematic review on the treatment of peri-implantitis (Esposito et al. 2012) the authors report that in the trials sponsored by manufacturers “there might be some commercial ‘pressure’ to evaluate some interventions and not others”.

Quantifiable results are fundamental for effective comparisons of study outcomes (Field et al. 2010). In five studies SEM observations were used to evaluate the cleaning effect of the different instruments. This method is clearly not quantitative and thus does not allow us to draw any definitive conclusions.

Randomization and allocation concealment are aspects shown to have a great impact on bias. However, for the quality appraisal of the studies included in this review (Table 3), neither allocation concealment or sequence generation (randomization) were considered as items to be used to estimate the risk of bias. Although the authors of this review recognize that this is an important issue, they are also aware that reporting on randomization and allocation concealment in the dental literature has not been a critical item up until the recent past. Therefore, including these items would result in an overestimation of the risk of bias. From the fourteen studies included in this review, only six (Schwarz et al. 2005, 2009; Schmage et al. 2012; Tastepe et al. 2013; Idlibi et al. 2013; John et al. 2014), provided information about the randomization. All are recent studies that are published starting from 2005. None of the included studies provided information about the concealment of allocation. It should, however, be emphasized that for future studies it is imperative that researchers provide information on these important aspects.

Different instruments, among which mechanical instruments, have been suggested for the decontamination of implant surfaces. All of these methods have been associated with advantages and disadvantages, with no definitive gold standard. This finding does not mean that all current treatments are ineffective (Esposito et al. 2012), but there is still no consensus among clinicians regarding the best available treatment. The term “contamination” is ambiguous. Most clinicians use this term to imply the transfer of microorganisms or bacterial
products, such as polysaccharide, onto the implant surfaces. Any contamination of the titanium surface significantly reduces the surface free energy, which is believed to compromise the biocompatibility of the implant (Kasemo 1983; Sennerby et al. 1989). Thus, the removal of plaque biofilm or bacterial products from the implant surfaces constitutes an important element in the prevention and treatment of peri-implant infections. It should, however, be kept in mind that instruments used to remove contaminants may also leave deposits on the treated surfaces. Air abrasive powders, the Vector™ scaler and non-metal instruments were found to leave deposits on the treated surfaces (Louropoulou et al. 2012). Whether such residues influence healing events is still unknown.

In this systematic review an attempt was made to evaluate the available evidence on mechanical instruments and their cleaning efficacy on titanium implant surfaces in a controlled manner (Table 4). The conclusions are based mainly on *in vitro* studies and refer to observations at a microscopic level. In clinical situations, there are factors that render the accessibility of the titanium surfaces more difficult, such as the design of the implant, the design of the suprastructure and the soft and hard tissues surrounding the implants. In a clinical setting, the cleaning efficacy of the instruments may, thus, be more limited. Although complete biofilm removal should not be expected, especially in clinical situations when sufficient access to the surface is sometimes difficult, some mechanical instruments have been proven to reduce the amount of biofilm present on the surface satisfactory. This decrease in the bacterial load may be enough to re-establish equilibrium between the peri-implant microbiota and the host defense and thus, a stable clinical situation over time (Mombelli, 2002).

**Conclusions**

- Metal curettes seem to be ineffective in removing calcified deposits from machined surfaces but effective in removing non-calcified deposits from SLA surfaces.
- Non-metal curettes seem to be ineffective in removing bacteria from polished/machined, acid-etched and grit-blasted titanium surfaces.
- (Ultra)sonic scalers with metal tip seem to be effective in removing plaque from polished titanium surfaces. In the presence of calcified deposits, the cleaning potential of these instruments appears to be very limited.
- (Ultra)sonic scalers with non-metal tip seem to be effective in removing single bacteria species and non-calcified deposits from polished and highly polished titanium surfaces. Controversial results are presented for grit-blasted surfaces.
• The Vector™ scaler with a carbon tip seems to be effective in removing plaque from polished and SLA titanium surfaces.
• Rotating titanium brushes seem to be effective in removing non-mineralised deposits from SLA surfaces.
• Single use of rubber cup with pumice on both smooth and rough titanium surfaces does not clean these surfaces effectively.
• Air powder abrasive with either sodium bicarbonate or amino acid glycine powder appears to clean machined, SLA, TPS and grit-blasted titanium surfaces effectively.

Different surfaces may require treatment with different instruments. When choosing the most appropriate instruments for each surface other parameters should also be taken into account like the localization the surface, the accessibility of the surface, the alterations produced by the instrumentation and the effect of instrumentation on the biocompatibility of the treated surface. It is obvious that an instrument would be of no value if it renders the surface non-biocompatible.

*Implications for further research*

In this systematic review an attempt was made to evaluate the available evidence on mechanical instruments and their cleaning efficacy on titanium implant surfaces in a controlled manner. Although the formulation of concrete conclusions appears to be difficult, this review clearly points out that some mechanical instruments may be valuable instruments in the maintenance of implants and the treatment of peri-implantitis. As this systematic review has shown that mechanical instruments cannot be expected to achieve complete biofilm removal, combination treatments should also be tested. Mechanical instruments could be combined with chemical agents for killing the bacteria remaining on the titanium surfaces. Well-performed in vitro and eventually in vivo studies with adequate sample size and appropriate design to allow comparisons are necessary in order to establish an evidence-based protocol for the use of mechanical instruments in the maintenance of implants and the treatment of peri-implantitis.

*Practical Implications*

The available data suggested that the air abrasive may remove plaque effectively from machined, SLA and TPS titanium surfaces. Positive results were also observed for ultrasonic scalers with non-metal tip on polished and SLA surfaces and rotating titanium brushes on SLA surfaces.
Acknowledgements

Declaration of interest
The authors declare that they have no conflict of interest.
The research was self-funded by the authors and their institution

Authors’ contributions:
A. Louropoulou contributed to the conception, design, acquisition, analysis, interpretation of data, drafted the manuscript.
D.E. Slot contributed to the design, analysis, interpretation of data, critically revised the manuscript for important intellectual content.
G.A. van der Weijden contributed to the conception, design, analysis, interpretation of data, critically revised the manuscript for important intellectual content.

All authors gave final approval and agree to be accountable for all aspects of the work in ensuring that questions relating to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
References


The effects of mechanical instruments on contaminated implant surfaces

Chapter 3


* Studies included in the review
**Figure 1.** Databases search and literature selection

**Table 1.** Overview of the studies that were excluded after full-text reading and the reason for exclusion

<table>
<thead>
<tr>
<th>Reason for exclusion</th>
<th>Authors (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not controlled and non-standardized biofilm growth</td>
<td>Bain (1998)</td>
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<td></td>
<td>Mouhyi et al. (1998)</td>
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<td></td>
<td>Augthun et al. (1998)</td>
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<td></td>
<td>Matsuyama et al. (2003)</td>
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<tr>
<td>Contamination with ink</td>
<td>Sahrmann et al. (2013)</td>
</tr>
<tr>
<td>Combination of mechanical and chemical treatment/</td>
<td>Baumhammers et al. (1975)</td>
</tr>
<tr>
<td>no mechanical instruments</td>
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</tbody>
</table>
Table 2. Summary of studies evaluating the cleaning efficacy of mechanical instruments on titanium surfaces

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Component/ Surface(s)/ Contamination</th>
<th>Treatment/ Control (n = # of treated surfaces)</th>
<th>Outcome parameter</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>John et al. (2014)</td>
<td>Titanium discs SLA surface Contaminated with supragingival plaque by placement of splints in volunteers</td>
<td>- Rotating titanium brush (n = 30) - Metal curette (n = 30) - Pre-treatment control (n = 60)</td>
<td>Residual biofilm areas</td>
<td>Both cleansing procedures showed a significant decrease in residual biofilm areas. The rotation titanium brush was more effective in removing plaque than the steel curette.</td>
</tr>
<tr>
<td>Idlibi et al. (2013)</td>
<td>Titanium discs Machined surface Contaminated with supragingival plaque by placement of splints in volunteers</td>
<td>- Air abrasive with amino acid glycine powder (n = 20) - Contaminated and untreated control (n = 20)</td>
<td>Percentage of residual biofilm Total protein content</td>
<td>The air abrasive showed the best efficacy at removing oral biofilm. The percentage of residual biofilm was 2.5% of the untreated control.</td>
</tr>
<tr>
<td>Nemer Vieira et al. (2012)</td>
<td>Titanium implants Machined surface Acid-etched surface Contaminated with Streptococcus sanguis</td>
<td>- Air abrasive with sodium bicarbonate powder (n = 20) - Pre-treatment control (n = 20)</td>
<td>Percentage of bacterial removal</td>
<td>After the application of the decontamination protocol, all bacterial cells were removed from the tested implants, regardless of surfaces roughness.</td>
</tr>
<tr>
<td>Tastepe et al. (2013)</td>
<td>Titanium discs SLA surface Contaminated with supragingival plaque by placement of splints in volunteers</td>
<td>- Air powder abrasive with four different powders: (1) TiO2 powder (n = 6) (2) Amino acid glycine powder (n = 6) (3) HA powder (n = 6) (4) Calcium phosphate powder (n = 6) - Pre-treatment control (n = 24)</td>
<td>Residual biofilm areas</td>
<td>The calcium phosphate, HA and amino acid glycine powders can almost totally remove the biofilm from the titanium surfaces. The TiO2 powder is less efficient.</td>
</tr>
<tr>
<td>Author (year)</td>
<td>Component/ Surface(s)/ Contamination</td>
<td>Treatment/ Control (n = # of treated surfaces)</td>
<td>Outcome parameter</td>
<td>Conclusions</td>
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<tr>
<td>Schmage et al. (2012)</td>
<td>Titanium discs Polished surface Acid-etched surface Grit-blasted/acid-etched surface Grit-blasted surface Contaminated with <em>Streptococcus mutans</em></td>
<td>- Plastic curette (n= 20) - Carbon curette (n= 20) - Prophylaxis brush (n= 20) - Rubber cup with paste (n= 20) - Sonic scaler with PEEK tip (n= 20) - Ultrasonic scaler with PEEK tip (n= 20) - Ultrasonic scaler with carbon curette (n=20) - Ultrasonic scaler with metal tip (n= 20) - Air abrasive with amino acid glycine powder (n= 20) - Non contaminated and untreated control (n= 20)</td>
<td>SEM observations Ranking score: 1 (no bacteria or remaining particles) to 3 (many remnants of bacteria of particles)</td>
<td>The best cleaning was found for the air abrasive and the sonic scaler with PEEK tip on all implant surfaces. The carbon curette provided the worst cleaning.</td>
</tr>
<tr>
<td>Schwarz et al. (2009)</td>
<td>Titanium discs SLA surface Contaminated with supragingival plaque by placement of splints in volunteers</td>
<td>- Air powder abrasive with amino acid glycine or sodium bicarbonate powder (n=128) - Pre-treatment control (n=128)</td>
<td>Residual biofilm areas</td>
<td>All powders investigated were equally effective.</td>
</tr>
<tr>
<td>Kawashima et al. (2007)</td>
<td>Healing abutments Polished surface (Ti-6Al-4V) Contaminated by subgingival plaque by placement in the mouth of patients</td>
<td>- Ultrasonic scaler with metal tip (n= 7) - Ultrasonic scaler with plastic tip(n= 7) - Ultrasonic scaler with carbon tip (n= 7) - Contaminated and untreated control (n= 21)</td>
<td>SEM observations Ranking score: 0 (untreated abutment) to 5 (surface not clean)</td>
<td>The modified remaining plaque and calculus scores differed significantly when the treatment groups compared to controls. No significant differences were observed between the treatment groups.</td>
</tr>
<tr>
<td>Schwarz et al. (2005)</td>
<td>Titanium discs SLA surface Contaminated with supragingival plaque by placement of splints in volunteers</td>
<td>- Ultrasonic scaler with PEEK tip and polishing fluid (n=20) - Pre-treatment control (n=20)</td>
<td>Residual biofilm areas</td>
<td>Specimens treated with the ultrasonic scaler showed a significant decrease in biofilm covered areas.</td>
</tr>
<tr>
<td>Pereira da Silva et al. (2005)</td>
<td>Titanium sheets Machined surface Titanium surface blasted with 65 μm aluminum oxide particles Titanium surface blasted with 250 μm particles Contaminated with <em>Streptococcus sanguis</em></td>
<td>- Air abrasive with sodium bicarbonate powder (n= 21) - Contaminated and untreated control (n= 9)</td>
<td>Colony forming units</td>
<td>After application of the decontamination protocol no viable cells were detected for all surfaces examined.</td>
</tr>
<tr>
<td>Author (year)</td>
<td>Component/Surface(s)/Contamination</td>
<td>Treatment/Control (n = # of treated surfaces)</td>
<td>Outcome parameter</td>
<td>Conclusions</td>
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</table>
| Dennison et al. (1994)| Implant bodies TPS surface, Machined surface Contaminated with *Porphyromonas gingivalis* LPS   | - Air powder abrasive with sodium bicarbonate powder (n = 6)  
- Pre-treatment control (n = 6)                          | Radioactive endotoxin (radioimmunoassay)                                                                       | Significant decrease in endotoxin levels after treatment on both titanium surfaces.  
Air abrasive was more effective in removing endotoxin from machined than from TPS surfaces. |
| Speelman et al. (1992)| Healing abutments Machined surface Contaminated with plaque and calculus by placement in beagle dogs | - Metal curette (n = 4)  
- Plastic scaler (n = 4)  
- Ultrasonic scaler with metal tip (n = 5)  
- Single polishing with composite bur and sodium bicarbonate powder (n = 5)  
- Rubber cup with pumice (n = 3)  
- Non contaminated and untreated control (n = 1) | SEM observations  
Ranking score: 0 (untreated abutment) to 5 (surface not clean) | The weekly rubber cup polishing resulted in the highest surface cleanliness.  
The single polishing with composite bur resulted in the lowest surface cleanliness followed by the plastic scaler.  
None of the three scaling methods created a cleanliness score better than 3. |
| Zablotsky et al. (1992)| Titanium strips Grit-blasted titanium alloy surface Contaminated with *Escherichia coli* LPS | - Sonic scaler with plastic tip (n = 3)  
- Air powder abrasive with sodium bicarbonate powder (n = 3)  
- Contaminated and untreated control (n = 3) | Residual LPS levels measured by liquid scintillation spectrometry | Both treatments resulted in significantly less amounts of LPS compared to the untreated control.  
The air powder abrasive removed significantly greater amounts of LPS than the sonic plastic scaler. |
| Gantes et al. (1991)  | Titanium cylinders Highly polished surface Contaminated with supragingival plaque by placement in beagle dogs | - Sonic scaler with plastic tip (n = 6)  
- Contaminated and untreated control (n = 2) | SEM observations | The sonic plastic scaler was able to completely remove the contaminants from the surface of polished titanium. |
| Parham et al. (1989)  | Implant specimens TPS surface Contaminated with *Actinomyces viscosus* | - Air powder abrasive with sodium bicarbonate powder (n = 4)  
- Contaminated and untreated control (n = 4) | SEM observations | Specimens treated with the air abrasive system showed 100% removal of bacteria. |

TPS, titanium plasma-sprayed; SLA, sand-blasted and acid-etched; LPS, lipopolysaccharide; SEM, scanning electron microscope; PEEK, polyether ether ketone fiber; TiO2, titanium dioxide; HA, hydroxylapatite
Table 3. Methodological quality scores of the selected studies

<table>
<thead>
<tr>
<th>Quality criteria</th>
<th>External validity</th>
<th>Internal validity</th>
<th>Statistical validity</th>
<th>Author’s estimated risk of bias</th>
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<tbody>
<tr>
<td>Author (year)</td>
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<td>Quality criteria</td>
<td>External validity</td>
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<td>Author’s estimated risk of bias</td>
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<tr>
<td></td>
<td>Representative surface *</td>
<td>Validation of the evaluation method</td>
<td>Reproducibility data provided</td>
<td>Sequence generation (randomization)</td>
</tr>
<tr>
<td>Author (year)</td>
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<tr>
<td>Schwarz et al. (2005)</td>
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<tr>
<td>Gantes et al. (1991)</td>
<td>+</td>
<td>?</td>
<td>-</td>
<td>?</td>
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<tr>
<td>Parham et al. (1989)</td>
<td>-</td>
<td>?</td>
<td>NA</td>
<td>-</td>
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</tbody>
</table>

+ : yes, - : no, ? : not specified/unclear
* : Items used to estimate potential risk of bias
NA: not applicable, visual assessment without scoring of the outcome
¹ The authors of the review calculated the sample size of all the include studies by using the Meads’s resource equation
Table 4. Summary of the outcomes of the included studies

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<tbody>
<tr>
<td>Surface</td>
<td>SLA§</td>
<td>Machined</td>
<td>Acid-etched</td>
<td>SLA</td>
<td>Polished Acid-etched</td>
<td>SLA</td>
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<tr>
<td>Contamination</td>
<td>Plaque biofilm</td>
<td>Plaque biofilm</td>
<td>Single species biofilm</td>
<td>Plaque biofilm</td>
<td>Single species biofilm</td>
<td>Plaque biofilm</td>
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<td>Treatment</td>
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<tr>
<td>Metal curette</td>
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<td>Non-metal curette</td>
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<td>0</td>
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<tr>
<td>Ultrasonic with metal tip</td>
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<tr>
<td>Ultrasonic with non-metal</td>
<td>+/-</td>
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<tr>
<td>Vector scaler with carbon</td>
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<tr>
<td>Rotating titanium brush</td>
<td>+</td>
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<tr>
<td>Air abrasive with sodium</td>
<td>+/-</td>
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<tr>
<td>Air abrasive with HA powder</td>
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<tr>
<td>Air abrasive with calcium</td>
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<tr>
<td>Rubber cup with pumice</td>
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<td>0</td>
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</tbody>
</table>

+: positive effect reported and statistically significant difference compared to control
+/:- positive effect reported, without statistical analysis
0: no statistically significant difference compared to control or observation without statistical analysis with surface still (partially) covered with biofilm
TPS, titanium plasma-sprayed; SLA, sand-blasted and acid-etched; LPS, lipopolysaccharide; HA: hydroxylapatite
<table>
<thead>
<tr>
<th>Author</th>
<th>Surface</th>
<th>Contamination</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kawashima et al. (2007)</td>
<td>Polished SLA</td>
<td>Plaque biofilm</td>
<td>0</td>
</tr>
<tr>
<td>Schwarz et al. (2005)</td>
<td>Grit-blasted</td>
<td>Plaque biofilm</td>
<td>0</td>
</tr>
<tr>
<td>Pereira da Silva et al. (2005)</td>
<td>Machined TPS</td>
<td>Single species biofilm</td>
<td>+</td>
</tr>
<tr>
<td>Dennison et al. (1994)</td>
<td>Machined TPS</td>
<td>LPS</td>
<td>+</td>
</tr>
<tr>
<td>Speelman et al. (1992)</td>
<td>Grit-blasted</td>
<td>Plaque biofilm</td>
<td>+/-</td>
</tr>
<tr>
<td>Zablotsky et al. (1992)</td>
<td>Highly polished</td>
<td>LPS</td>
<td>+</td>
</tr>
<tr>
<td>Gantes et al. (1991)</td>
<td>TPS</td>
<td>Plaque biofilm</td>
<td>+</td>
</tr>
<tr>
<td>Parham et al. (1989)</td>
<td></td>
<td>Single species biofilm</td>
<td>+</td>
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</tbody>
</table>

**Note:**

- +: positive effect reported and statistically significant difference compared to control
- +/-: positive effect reported, without statistical analysis
- 0: no statistically significant difference compared to control or observation without statistical analysis with surface still (partially) covered with biofilm

TPS, titanium plasma-sprayed; SLA, sand-blasted and acid-etched; LPS, lipopolysaccharide; HA: hydroxylapatite