**T.C.**

**YEDITEPE UNIVERSITY**

**INSTITUTE OF HEALTH & SCIENCES**

**DEPARTMENT OF PERIODONTOLOGY**

# IN VITRO SIMULATION OF IMPLANT SURFACE DECONTAMINATION WITH DIFFERENT INSTRUMENTATION TOOLS IN A SURGICAL APPROACH

**MASTER THESIS**

**NAMEER AAL JABRO, PERIODONTOLOGY**

**ISTANBUL - 2023**

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Nameer Aal Jabro, Periodontology

ADVISOR

Assoc. Prof. Dr. Ebru Karaca

ISTANBUL - 2023

# TEZ ONAYI FORMU

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Tez Sahibi: Nameer Aal- Jabro

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Bu çalışma jurimiz tarafından kapsam ve kalite yönünden Yüksek Lisans Tezi olarak kabul edilmiştir.

| | Unvanı, Adı-Soyadı (Kurumu) |
|---|---|
| Jüri Başkanı: | Prof. Dr. Bahar KURU |
| Tez danışmanı: | Doç. Dr. Ebru Özkan KARACA |
| Üye: | Prof. Dr. Burcu KARADUMAN |
| Üye: | |
| Üye: | |

ONAY

Bu tez Yeditepe Üniversitesi Lisansüstü Eğitim-Öğretim ve Sınav Yönetmeliğinin ilgili maddeleri uyarınca yukarıdaki jüri tarafından uygun görülmüş ve Enstitü Yönetim Kurulu'nun ...../...../..... tarih ve ..... sayılı kararı ile onaylanmıştır.

Prof. Dr. Bayram YILMAZ

Sağlık Bilimleri Enstitüsü Müdürü

## DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

31 / 10 / 2023

Nameer AAL JABRO

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# ABBREVIATIONS

| | |
|---|---|
| **cm** | Centimeters |
| **mm** | Millimeters |
| **Hz** | Hertz |
| **KHz** | Kilohertz |
| **MPa** | Megapascal |
| **CI** | Confidence Interval |
| **RCT** | Randomized Controlled Trial |
| **cps** | Cycle Per Second |
| **OHI** | Oral Hygiene Instructions |
| **BoP** | Bleeding on Probing |
| **PPD** | Probing Pocket Depth |
| **CAL** | Clinical Attachment Loss |
| **PEEK** | Polyether Ether Ketone |
| **VPP** | Vector Paro Pro Device |
| **LOH** | Linear Oscillating Handpiece |
| **AAD** | Air Abrasive Device |
| **TB** | Titanium Brush |
| **PDT** | Photodynamic Therapy |
| **OCB** | Oscillating Chitosan Brush |
| **OFD** | Open Flap Debridement |
| **SST** | Stainless Steel Tip |
| **CFT** | Carbon Fiber Tip |
| **PT** | PEEK Tip |
| **Er: YAG** | Erbium-doped Yttrium Aluminum Garnet |

| | |
|---|---|
| **Nd: YAG** | Neodymium-doped Yttrium Aluminum Garnet |
| **GaAlAs** | Gallium Aluminum Arsenide |
| **$CO_2$** | Carbon Dioxide |
| **CHX** | Chlorhexidine |
| **CA** | Citric Acid |
| **$H_2O_2$ or HP** | Hydrogen Peroxide |
| **LPS** | Lipopolysaccharide |
| **EFP** | European Federation of Periodontology |
| **AAP** | American Academy of Periodontology |
| **HIV** | Human Immunodeficiency Virus |
| **AIDS** | Acquired Immunodeficiency Syndrome |

# ABSTRACT

**Aal Jabro, N. (2023) In Vitro Simulation of Implant Surface Decontamination with Different Instrumentation Tools in a Surgical Approach. Yeditepe University, Faculty of Dentistry, Department of Periodontology, MSC thesis, İstanbul.**

The objective of this research is to conduct a laboratory assessment of three periodontal treatment tools and evaluate their efficiency on dental implant surface decontamination. To achieve this goal, thirty ink-stained implants were inserted into standardized epoxy resin models simulating horizontal bone defects at an angle of 180°. Implants were categorized into three distinct study groups accordingly. The standardized peri-implantitis models utilized in this study do not include any visible gingival tissue, as they are simulating an open flap debridement approach for treating implant surfaces surgically. Vector Paro Pro® device (VPP) with the use of the ultra-sonic linear oscillating handpiece (LOH) along with use of three special tips designated for implant surface debridement consisting of a stainless-steel tip (SST), a carbon-fiber tip (CFT) and a polyether ether ketone (PEEK) tip; the implants were divided on these tips (with each group at n=10). An examiner who was both blinded and calibrated assessed the standardized images of treated implant surfaces using image-processing software.

The results showed that there was a statistically significant difference between the groups in terms of the areas cleaned (p:0.001; $p < 0.05$). As a result of the mean cleared area, SST group was found to be significantly higher than the CFT and PT groups ($p<0.05$). In return, the final percentage of cleared area of the SST group was determined to be significantly higher compared to the CFT and PT groups ($p < 0.05$) suggesting that within the parameters of this in-vitro study the SST group had achieved the best results in comparison to the other two groups, although even in this superior group total cleanliness was not achieved.

In conclusion, the SST group showed significant results being the most efficient decontamination method compared to the other two groups after analysis; although it is crucial to acknowledge that full decontamination was not fully achieved by that group.

**Keywords:** peri-implantitis, surgical periodontal therapy, cleaning efficacy

# TÜRKÇE ÖZET

Bu in vitro çalışmanın amacı, üç farklı periodontal tedavi aletinin dental implant yüzeylerindeki temizleme etkinliklerini değerlendirmektir.

Çalışmada geniş açılı (180°) stardardize edilmiş otuz adet epoksi rezin modele gömülü yüzeyleri boyanmış implantlar kullanıldı. İmplantlar üç farklı çalışma grubuna göre ayrıldı. Standardize edilmiş peri-implant modellerde dişeti dokusu içermeksizin, implant yüzeylerinin cerrahi olarak tedavisini amaçlayan açık cerrahi tekniği simule edilmiştir. İmplant yüzeylerinde ultrasonik doğrusal salınım yapan bir cihazın implant yüzeylerinde uygulanan farklı üç ucu, paslanmaz çelik uç (SST), karbon fiber uç (CFT), ve poli eter keton (PEEK) uç kullanılmıştır (her gruptaki örnek sayısı 10). Uygulamaları tamamlanan implant yüzeylerinin fotoğraflarının bilgisayar programı ile değerlendirilmesi çalışma gruplarını bilmeyen ve kalibre bir araştırmacı tarafından yapıldı.

Çalisma sonuçlarinda toplam temizlenen alan değerlendirilmesine bakıldığında, gruplar arasında istatistiksel olarak anlamlı bir fark olduğunu göruldu (p:0,001; p<0,05). Ortalama temizlenen alan yüzdesinin değerlendirmesine bakıldığında SST grubunun alan yüzdesinin CFT ve PT gruplarına göre istatistiksel olarak anlamlılığı yüksek bulundu ((p<0.05). Her ne kadar SST grubundaki temizlenen alan yüzdesi CFT ve PT grubuna göre yüksek olsa da, total alanın hepsinin temizlenemediği görüldü.

Sonuç olarak, çalışmanın verilerinin analizi sonucunda, SST grubu yüzey temizliğinin değerlendirildiği gruplar arasında en iyi olarak grup olarak öne çıkmasına rağmen, bu grup tarafından tüm alanın temizlenemediği görülmüştür.

**Anahtar Kelimeler:** peri-implantitis, cerrahi periodontal tedavi, temizlik etkinliği

# INTRODUCTION & PURPOSE

Dental implants have been an ongoing treatment approach for partially and fully edentulous patients worldwide along with their wide variety of designs, materials, and surgical approaches, as a standard route of care in modern dentistry which were presented by Jung et al. & Romanos et al (1,2), with increasing number of implants is being placed.

Being surrounded by tissues, and typically with any surgical type of treatment the area is prone to infections and diseases due to multiple factors which are always being studied and researched to achieve the most appropriate methods to avoid onsets, treat diseases, and preserve the implant and its surrounding tissue.

The recent guidelines from the European Federation of Periodontology (EFP) address the prevention and treatment of peri-implant diseases, which are prevalent conditions posing significant health concerns due to their impact on both the mucosa and the supporting bone around dental implants. Notably, two specific types of peri-implant diseases have been suggested: peri-implant mucositis and peri-implantitis.

Mechanical implant-surface decontamination continues to be the golden standard in the treatment of peri-implantitis as long as deficits in access to the colonized surface have not yet been overcome based on what Romanos & Weitz (3) had presented. This involves the breakdown of the biofilm formation with multiple types of curretes or ultrasonic devices made of stainless steel, carbon, or polyehter ehter ketone (PEEK); although other methods like air abrasion devices (AAD) (4,5), lasers (6,7), chemical (8–12), and photo-dynamic therapy (13,14), have also proven their effectiveness, and recently the titanium brushes (15), have been introduced into therapy in order to achieve the most optimal method of treatment based on each situation by comparing results of the different methods.

In the light of this knowledge, this studys aims is the comparison of three common methods for surface decontamination of implants using an in-vitro model involving three different mechanical approaches at a simulated horizontal bone defect representing an open flap site to increase the available data on efficacy and to confirm existing results.

# 1. INTRODUCTION

## 1.1. Peri-Implant Tissue

Dental implant procedures embody a comprehensive strategy aimed at achieving restorative outcomes. Over the years, advancements in the field of implant dentistry have positioned implant-supported restorations as the premier solution for replacing missing teeth in individuals with partial or complete tooth loss (16,17). This holistic approach necessitates a well-thought-out treatment plan, particularly addressing all the main distinct aspects from treatment planning until the final placement of prosthetic supra-structure. As the comprehension of implant procedures enhances over time, guidelines for ensuring long-term success have been established and continue to evolve.

The epithelial tissue observed at the wound edges around implants is morphologically and phenotypically like oral epithelium, mirroring the epithelium around neighboring teeth. Considering these findings, the primary role of the epithelium during the healing phase is to shield the exposed connective tissue and form a barrier like the junctional epithelium found at the groove level. Conversely, the connective tissue acts to halt tissue movement towards the apical epithelium (18). According to Berglundh et al. (19), the halt in apical movement of the epithelial tissue might be a result to the interplay between the soft tissue and the titanium oxide layer on the implant. Consequently, this epithelium can expand around the implant, demonstrating a supra-alveolar attachment.

Research by Cochran et al. (20) illustrated the adherence of epithelial cells and fibroblasts to both smooth and textured titanium surfaces, validating that the union between connective tissue and epithelium can prevent migration across the titanium surfaces. Further studies assessing diverse implant systems have later discovered analogous binding properties between the mucosa and the titanium surface, specifically in the areas of connective tissue and the junctional epithelium (21).

The orientation of fibers in the gingival mucosa around natural teeth and peri-implant tissues is different (Figure 1.1), which may contribute to the susceptibility of peri-implant tissues to peri-implantitis, an inflammatory condition. A breakdown of these differences and their implications can be considered regarding the following:

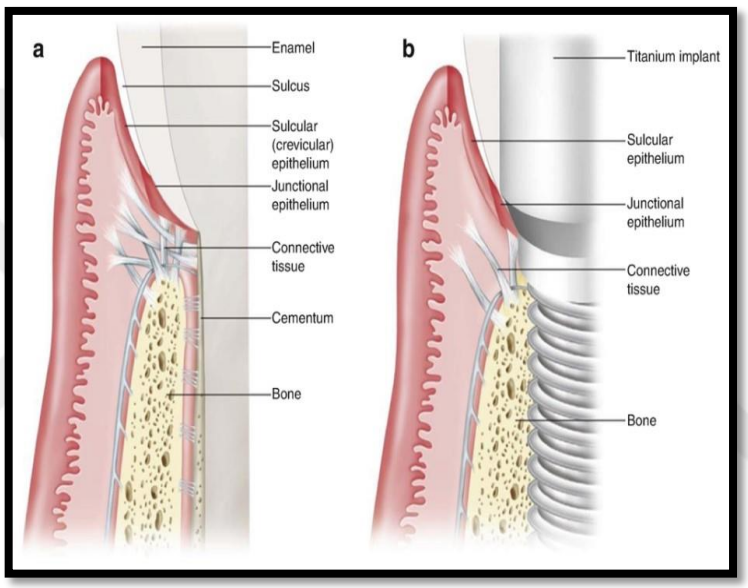
- Fiber Composition and Orientation

    - The gingival mucosa around natural teeth and implants shares morphological features but differs in connective tissue composition, collagen fiber orientation, and vasculature (22).
    - In natural teeth, collagen fibers are inserted directly into the cementum at perpendicular angle; while surrounding implants, the fibers orient parallel to the implant surface (23).
    - The differences in collagen fiber orientation between natural periodontal and peri-implant soft tissue are fundamental, and understanding the underlying mechanisms can help enhance soft tissue integration around implants (24).

- Anatomical Differences

    - The biologic width for implants is different from that for natural teeth, with fewer gingival fiber groups found around implants. Specifically, there are two types of gingival fiber groups around a tooth (circular and peri-osteo-gingival fibers) are present around implants, with no periodontal fibers present (25).
    - The peri-implant sulcus differs from the periodontal sulcus, with the peri-mucosa composed of different epithelial layers and underlying connective tissue (26).

Stable soft tissue integration around implant abutments is crucial for attenuating pathogen penetration, protecting underlying bone tissue, and preventing peri-implantitis (27). These differences in orientation and anatomical structure could make the site more susceptible to peri-implantitis as these differences could affect the tissue's ability to resist bacterial infection and inflammation, which are central to peri-implantitis development and progression.




**(Figure 1.1)** The Peri-implant tissue anatomical structure (a) next to a natural tooth surrounding tissue structure (b).

### 1.2. Peri-implant Health

A healthy peri-implant mucosa consists of connective tissue surrounded by either non-keratinized epithelium (lining mucosa) or keratinized epithelium (masticatory mucosa) (28). According to the outline of the 2017 consensus report by the World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions, periodontal health is characterized by the absence of erythema, bleeding on probing, swelling, and suppuration (29). Also, the observed clinical signs of inflammation, such as bleeding on probing (BoP), are not expected (30). It is important to point out that the evaluation of peri-implant health should not rely solely on probing depths, as normal or reduced bone levels can be present (31). However, in the context of peri-implant health, probing depths are typically expected to be $\leq 5.0$ mm (31). An assessment of peri-implant health should involve both clinical examination and radiographic findings (29,31). Under clinically healthy conditions, there should be no classical signs of inflammation, such as the redness, swelling, suppuration, or BoP, in the peri-implant tissues (29,30,32).

### 1.3. Peri-implant Diseases

In 2018, Klinge et al. (33), reported a global placement of 12 to 18 million implants each year, and the most common issue associated with implants is peri-implant diseases or infections. There are significant similarities between periodontal diseases and peri-implant diseases. Both are microbial dental plaque biofilm-related conditions presented through clinical signs of inflammation and BoP (31). Peri-implant diseases are considered to share a similar pathogenesis of inflammation with periodontal diseases, starting as peri-implant mucositis and potentially progressing to peri-implantitis, although the process is not yet fully understood (34). Peri-implant diseases affect peri-implant tissues, including peri-implant mucosa, and can extend to the supporting bone, potentially leading to implant failure (31,34,35).

## 1.4. Etiology

The microbial dental plaque (biofilm) is the primary origin of periodontal as well as peri-implant diseases or infections (35). Other contributing factors such as the absence of keratinized mucosa around the implant, excessive occlusal forces, presence of titanium particles in peri-implant tissues, bone necrosis, overheating, micro-motion, or bio-corrosion may also play a role in peri-implant diseases (32). Diseases associated with biofilm trigger an inflammation pathway in both the soft and hard tissues around an osseo-integrated implant, which eventually results in the loss of bone as it progresses (36). Reports indicate that these diseases occur in 1.4% to 53.5% of people with an installed implant or multiple ones (37,38).

Over the years several peri-implant disease definitions and classification have been presented such as the 1987 and 1999 classifications by the American Academy of Periodontology (AAP). In 2018, Caton et al. introduced a new classification, (Table 1.1) based on these diagnostic criteria for both periodontal and peri-implant conditions and diseases to provide accurate case definitions (31).

In 2018, the EFP alongside the AAP introduced a new classification scheme for periodontal and peri-implant diseases and conditions. This update was propelled by the integration of novel scientific evidence. The classification aimed to replace the previous classification system established in 1999, and it involved not only periodontal diseases but also peri-implant diseases and conditions such as peri-implant mucositis and peri-implantitis (31).

The classification grants a standardized technique about clinical and radiographic investigation of an implant, but it does not share any information in relation to management of peri-implantitis and its prognosis (39).

| Periodontal Diseases and Conditions | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Periodontal Health, Gingival Diseases and Conditions | | | Periodontitis | | | Other Conditions Affecting the Periodontium | | | | |
| Periodontal health and gingival health | Gingivitis: Dental biofilm-induced | Gingival diseases: Non-dental biofilm-induced | Necrotising periodontal diseases | Periodontitis | Periodontitis as a manifestation of systemic disease | Systemic diseases or conditions affecting the periodontal supporting tissues | Periodontal abscesses and endodontic-periodontal lesions | Mucogingival deformities and conditions | Traumatic occlusal forces | Tooth and prosthesis related factors |
| Peri-implant Diseases and Conditions | | | | | | | | | | |
| Peri-implant health | | Peri-implant mucositis | | Peri-implantitis | | Peri-implant sof and hard tissue deficiencies | | | | |

**Table 1.1** Classification for multiple periodontal diseases.

### 1.5. Peri-implant Mucositis

Peri-implant mucositis is a common complication in dental implantology, it is defined as a reversible inflammatory reaction in the soft tissues surrounding a functioning implant, with no accompanying bone loss (40). It shares similarities with gingivitis around natural teeth, often presenting with clinical signs such as redness, swelling, BoP, and increased pocket depth around the implant site. The diagnostic definition of peri-implant mucositis includes the presence of peri-implant signs of inflammation such as redness, swelling, and bleeding, along with no additional bone loss following initial healing (41).

When that is left untreated, peri-implant mucositis can progress to more severe conditions, such as peri-implantitis, which may lead to implant failure. Therefore, early detection and prompt management are crucial in maintaining the long-term success of dental implants (42,43).

Peri-implant mucositis is primarily a plaque-associated inflammatory soft tissue response with visible signs of inflammation and BoP, and peri-implantitis, which involves inflammatory soft tissue response along with concurrent bone loss around peri-implant tissues (31).

- The average prevalence of peri-implant mucositis according to implant -based and subject-based levels were found to be 29.48% and 46.83% respectively, in one study (44).
- Another systematic review reported a showed average prevalence of 43% (range: 19-65 %) for peri-implant mucositis disease (45).

## 1.6. Peri-implantitis

Peri-implantitis is a disorder that arises in the tissues surrounding dental implants, characterized by inflammation in the mucosal area surrounding the implant, coupled with ongoing bone-loss (46,47).

In the clinical setting, tissue inflammation is often identified by BoP, along with the on-going loss of bone identification radiographically. Studies on peri-implantitis require case definitions and threshold values to distinguish preimplant health from peri-implant tissue disease whether it is mucositis or peri-implantitis. It should be noted that, while case definitions for peri-implantitis vary considerably between studies (48).

Several classifications for peri-implantitis have been presented over the years of literature such as Stuart F's 2012 classification (49). The classifications of peri-implant diseases, including peri-implantitis, underwent collaborative revision by the AAP and the EFP during the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. The results of this workshop were released as the 2017 Classification of Periodontal and Peri-Implant Diseases and Conditions, which is the most recent official classification system for these conditions.

The 2017 Classification serves as the most recent and comprehensive framework to guide diagnosis, treatment planning, and personalized patient care in the management of peri-implant diseases, including peri-implantitis. According to Peri-implantitis is classified into based on the presence of peri-implant signs of inflammation, radiographic evidence of bone loss following initial healing, and an increase in probing depth as compared to probing depth values collected after the placement of the prosthetic reconstruction (29). (Table 1.2)

| Implant health category | Inflammation/soft tissue, probing depth (PD), bleeding on probing (BOP) suppuration (exudate) | Bone Loss (BL) | **Notes/clinical application** All implant categories: recommend Baseline probing depth and radiograph at placement, restoration, and at one-year post load of implant-borne restoration/prosthesis |
|---|---|---|---|
| **Peri-implant health** | Absence of inflammation, BOP, swelling, and suppuration | No BL < 2.0 mm | Absence of BL beyond the crestal bone level changes from remodeling at one year. Monitor and **recall at least every six month.** |
| **Peri-implant mucositis** | Inflammation, BOP, plaque pathological factor | No BL < 2.0 mm | **Record Gingival Index** 1-3: Mild, moderate, severe **Treat, reevaluate, and recall in three Months.** |
| **Peri-implantitis** | Inflammation, BOP, plaque pathological factor; note any increase in PD from previous exam | Subsequent Progressive BL > 2.0 mm | **Early:** PD > 4 mm, BL < 25% of Implant length **Moderate:** PD > 6 mm, BL 25%-50% Of implant length **Advanced:** PD > 8mm, BL > 50% of implant length **Treat and recall in three months** |
| **Peri-implantitis in absence of previous examination** | Inflammation, BOP, and/or Any suppuration; PD ≥ 6mm and/or recession | Radiographic BL ≥ 3.0 mm | Make baseline PD and radiograph, Diagnosis of peri-implantitis. **Treat and recall three months** |

**Table 1.2:** World Workshop 2018 Classification of Peri-implant Health & Diseases.

- When compared with peri-implant mucositis, the lesions at periimplantitis sites (case definition: BoP+, suppuration, radiographic bone loss) included more neutrophil granulocytes and larger proportions of B cells (CD19+) (50).
- Like periodontitis, the lesions at peri-implantitis sites were also dominated by plasma cells and lymphocytes (51–53), but characterized by larger proportions of polymorphonuclear leukocytes and macrophages (54,55).
- Moreover, peri-implantitis lesions were characterized by larger area proportions, numbers and densities of plasma cells, macrophages, and neutrophils, as well as a higher density of vascular structures outside and lateral to the cellular infiltrate (56).

### 1.7. Prevalence of Peri-implant Diseases

In general, peri-implant disease prevalence is increasing worldwide, affecting 28-56% of patients with dental implants according to Sahrmann et al. (35). Peri-implant mucositis was found steadily to be more frequent than peri-implantitis. In a meta-analysis, by Derks and Tomasi (44), it was found that an average prevalence of 43% and 22% for peri-implant mucositis and peri-implantitis, respectively. The confidence intervals of the estimates, however, were large, mostly due to the heterogeneity of case definitions used in the included studies.

### 1.8. Risk Factors and Modifiers of Periodontal Health

Multiple systemic conditions and scenarios have been suggested by Jepsen et al. (57) and Darby et al. (58), that alter the periodontal condition and increase risk of periodontitis/peri-implantitis. The most recent classification of the periodontal diseases confirms the sheer amount of risk factors and how the dentistry field necessitates full knowledge by the practitioners of these conditions.

The systemic diseases and risk factors are diabetes mellitus, tobacco smoking, obesity & nutrition, osteoporosis, stress, menstrual cycle, pregnancy, medications (such as oral contraceptives, anticonvulsants, immunosuppressants, and calcium channel blockers), HIV/AIDS, and other systemic diseases and developmental and acquired conditions affecting the periodontal supporting tissues.

There are also, patient-related, environmental-related, and practitioner-related factors that affect the peri-implant health Patient risk factors which involve socio-economic status, substance use disorders, diet and dietary supplements, mental health disorders, and insufficient home dental care or understanding of the need for treatment (58).

Host response alteration via gene expression is an arising risk factor as some individuals may have a genetic predisposition to gingival diseases, making them more susceptible to periodontal diseases despite maintaining good oral hygiene practices (59). Practitioner-related factors may include the low frequency of professional dental cleanings, misuse of digital technology, lack of surgeon's experience and wrong placement of dental implants (60).

## 2. TREATMENT APPROACHES

Many key differences that impact the care of periodontitis and peri-implantitis have been distinguished, the theoretical basis for peri-implantitis treatment is established on the successful approaches developed for the treatment of periodontitis. Therefore, a step-by-step approach may be more convenient, as it has been suggested for the treatment of periodontitis in the recent guideline by Sanz et al. (61).

According to Lindhe et al. (62), a crucial element for successful non-surgical and surgical treatment of peri-implantitis is the mechanical cleansing of implant surfaces. However, various mechanical techniques have shown inconsistent effectiveness, indicating that this remains a dynamic and ongoing field of research.

The recommended involvements should be provided as part of the non-surgical step of peri-implantitis which comprise of the following:

- Oral hygiene instructions (OHI) and motivation.
- Risk factor control.
- Prosthesis cleaning/removal/modification including controlling biofilm retentive factors.
- Supragingival and sub-gingival instrumentation.
- Related periodontal therapy as needed.
- Regenerative surgeries.
- Implant surface modifications.

## 2.1. Decontamination Methods During Surgical Intervention

Decontamination methods are intended to remove bacterial biofilm from the implant surface and pocket area as well as achieve re-osseointegration. Several methods of treatment have been recommended for the decontamination of peri-implant area after surgical exposure of the site. Mechanical, chemical and/or additional photodynamic therapy have been used to eradicate infection and to create suitable environment for bone regeneration and possible re-osseointegration (63,64).

## 2.2. Mechanical Methods

Mechanical instruments have been used for the decontamination of implants including metallic and non-metallic curettes, ultrasonic scalers with multiple tips (65). As well as several hand (i.e., titanium and Teflon curettes) and power-driven instruments have been developed (i.e., glycine powder, ultrasonics, titanium, and chitosan brushes) with the aim to optimize biofilm removal without altering the implant surface (66).

Maintaining a smooth surface of titanium without pits and scratches can prevent plaque accumulation (67). Therefore, it is substantial that instrument selection should depend on tip designs that are not bulky (to avoid unnecessary tissue manipulation), and the design should facilitate manipulation by the clinician.

### 2.2.1. Curettes

Choosing the right tools for eradicating biofilms surrounding dental implants is a pivotal factor in ensuring the enduring success of peri-implantitis management (68). A variety of curettes exist for this purpose, including those made from stainless steel, others coated with titanium, plastic curettes, carbon-fiber curettes, and Teflon curettes.

Stainless steel–tipped instruments have been found to be damaging to a titanium surface and can be manually applied (69). Similarly, there are also non-metallic instruments such as plastic, carbon, graphite, Teflon, resin-strengthened and non-reinforced resin curettes.

In a study provided by Mellado-Valero et al. (63), they noted that the use of metallic curettes has been shown to alter surface roughness, which could potentially favor bacterial elimination from implant surfaces, especially when used alongside Photodynamic Therapy (PDT) as compared to laser irradiation alone.

The metallic instruments produce surface alteration on implant surfaces like irregularities and substance removal (70), while titanium curettes showed less damaged at the SEM analysis presented by Louropoulou A, et al. (71).

On the other hand, a variety of nonmetallic, plastic, graphite, nylon, or Teflon-coated instruments are available and have been proven to be safe to use on titanium implant surfaces (79).

Pure titanium and titanium nitride curettes revealed slight alteration due to mechanic working traces without altering the implant surfaces when they used with optimum forces as suggested by Mengel R, et al. (70) and Lang M, et al. (72).

A titanium curette and a rubber cup with flour of pumice are suitable for cleaning implant surfaces (73,74). After the removal of calculus, polishing with a rubber cap and toothpaste, commercial implant polishing pastes, and tin oxide have been shown to be safe for titanium surfaces (70,75).

In one study by Ramaglia et al. (76), where they compared different approaches with use of plastic curette, stainless-steel curette, ultrasonic tip and an AAD. The study demonstrated that a plastic curette and air-powder-water spray did not alter the implant surface compared to the other groups, but these instruments have left some deposits in which they should be removed by irrigation to avoid any adverse tissue healing.

In a study by Huang, Yu-Shan et al. (77), where they compared titanium curettes, plastic curettes reinforced by carbon, carbon fiber tip attached to an ultrasonic scaler , and AAD using glycine-based powder. The study noted that plastic curettes are relatively safe for dental implants as they tend to cause less damage to the surfaces of the substrates compared to power-driven instruments; the study suggested a cautious approach when considering the use of metallic instruments on dental implants, as they could lead to surface alterations which in turn may affect the biofilm formation on the implant.

A study by Augthun et al. (78), the researchers compared three types of implants and each implant was treated with a certain method; plastic and metal curettes, a diamond polishing device, ultra-sonic device, and an AAD using sodium hydro-carbonate powder were implemented. Results had displayed incomplete cleaning capacity while applying the plastic curettes.

Baima et al. (79) , presented a systematic review regarding use of curettes for implant surface cleaning, particularly in the context of peri-implantitis treatment, suggests a specific view. Studies indicate that while the single use of curettes for surface decontamination has shown some effect, such as a weighted mean effect of 1.46 mm for probing pocket depth (PPD) reduction, it has been considered to result in negligible changes in marginal bone loss.

### 2.2.2. Ultra-sonic Devices

Ultrasonic scalers are applied for the decontamination of implant surfaces using multiple types of tips, they operate by generating vibrations at ultrasonic frequencies typically ranging between 25,000 to 45,000 vibrations per second, or expressed in another way, between 25 and 30 kHz (80).

Metallic ultrasonic scalers have been reported to gouge titanium (66). A plastic or rubber sleeve over an ultrasonic scaler appears not to alter titanium (81); standardized ultrasonic scalers with nonmetals tip are also appropriate for implant maintenance (82).

A study Chun KA et al. (83), evaluated the efficiency of different metallic tips of ultrasonic scalers on dental implants and found that the efficiency varied with the type of metal. Specifically, the efficiency of a stainless-steel tip was about 3 times more than the Copper tip. Similarly, a 316L stainless steel tip was about 2.7 times more efficient in comparison to a copper tip, and a bronze tip was about 1.2 times more effective than a copper tip. The research found that a bronze-alloy tip for ultrasonic scalers caused minimal harm to titanium surfaces, just as the effects observed with the copper-alloy tip.

Cha et al. (84), have implemented five mechanical instruments to check the outcomes on implant surface topography and their roughness. SEM analysis revealed that the metalic scalers tip caused more pronounced macroscopic alterations and damage of the implant surface, the PEEK tip caused remnants of plastic on implant surface, and titanium brush group changed the thread profile, while minimal sruface modification was shown in the AAD glycine-based powder group.

A study by Park JB et al. (85), revealed that using a metal-tipped ultrasonic scaler on rough surfaces results in a smoother surface with fewer irregularities and more effective bacterial removal compared to ultrasonic scalers equipped with plastic tips. Renvert et al. (86), presented research that demonstrated the comparison of ultrasonic tips to titanium curettes, there was a significant reduction in biofilm percentages from 73% to 53% ($p < 0.01$) for the groups, PPD improved from 5.1 mm to 4.9 mm for the titanium treatment targets while the ultrasonic device did no achieved an improvement in the PPD; they have also shown a decrease in BoP ($p < 0.01$). However, no differences in probing depths were observed between the two groups.

In recent years, new ultrasonic tools have been introduced which provide various tips designed for cleaning dental implant surfaces and operating with an oscillating motion, incorporating irrigation and power control (87). Nevertheless, there is a lack of information concerning the safe cleaning, decontamination, and preservation of surface biocompatibility when using this system on dental implant surfaces (88).

In a study by Sahrmann, P et al. (89), where they used an ultra-sonic device with multiple tip types such as steel, PEEK, titanium, carbon, and resin tips, the results suggested that they all caused microscopic alterations on various implant surfaces; the least change caused by resin tips and carbon tips on implant surfaces, followed by the PEEK tip.

Another study by Huang, Yu-Shan et al (77), researchers assessed four frequently utilized clinical cleaning tools for implants: titanium curette, carbon fiber reinforced plastic curettes, ultrasonic scaling equipped with carbon fiber inserts, and air polishing employing glycine powder. The researchers showed that ultra-sonic cleaning utilizing a nonmetal tip, plastic curette, and air polishing with glycine powder did not induce significant change on smooth surfaces, whereas metal instruments could potentially cause damage.

A study conducted by Koyuncuoglu et al (90), evaluated the effectiveness of ultrasonic PEEK tips in removing excess biofilm around implants. They found that these instruments were effective at removing excess cement surrounding the implants to a specific depth only. The cleaning effectiveness was particularly notable when the abutment-crown connections were 1 mm under the gingival margin. However, an increase in undetected remnants were noticed when the areas beyond 2mm apically to the margins were instrumented.

A study by Schmage et al (91), showed significant results of less than 4% remaining biofilm were obtained when applying an oscillating device with PEEK plastic tips onto implant surfaces, where similar results were achieved when compared with the group using an AAD with glycine-based powder.

Kawashima et al, investigated the decontamination efficacy of three different piezoelectric ultra-sonic scaler tips in an in-vitro study (92). Researchers evaluated carbon, plastic, and metallic tips and found that carbon and plastic tips produced clean and smooth implant surfaces. At the end of the study, they concluded that using non-metal tips attached to piezoelectric scalers was appropriate for decontamination inf peri-implant diseases.

In addition, while various strategies, such as mechanical scraping with specific tips for ultrasonic scalers and different materials for curettes, have been tried, none have shown definitive efficiency in restoring peri-implant health, and their lack of a pure agreement regarding the most satisfactory approach for treatment (93) . Concluding that although ultrasonics are among the multiple approaches used for implant surface decontamination, there is no consensus that deems them superior to other methods.

### 2.2.3. Air Abrasive Devices

Air abrasive devices have shown to be effective and safe for maintenance procedures around implants (94,95), achieving both mechanical and chemical debridement, at the removal of both supra and subgingival biofilm.

AAD's have also been approved to be causing less discomfort to the patients compared to other mechanical debridement methods. They also have lower abrasiveness level, and require less time for treatment. The powders applied through this method can be resorbed by the organism and provide an overall improved oral health. (96–99).
In vitro studies about AADs with various materials and powders have shown that larger powder particles have more surface cleaning capacity as well as the capability to facilitate damaging impacts on the microstructure of implants surfaces (28,100); An in vitro study indicated that air powder abrasion is the most effective and least harmful cleaning method when compared to sonic scalers and curettes in various defect shapes (101).

An in-vitro analysis by Ronay V, et al. (102) evaluated the decontamination efficacy of three prevalent implant cleaning techniques: Gracey curettes, ultrasonic scaler, and AAD with glycine-based powder. The findings revealed that the percentages of uncleaned surfaces were 74.70 ± 4.89% for curettes, 66.95 ± 8.69% for ultrasonic tips, and 33.87 ± 12.59% for air abrasion. The air powder abrasive device exhibited significantly superior cleaning outcomes across all defect angles ($P < 0.0001$). Additionally, it was observed that while Gracey curettes and ultrasonic devices led to notable surface modifications, the air powder abrasive device did not cause any alterations to the surface.

Tastepe et al. (103) evaluated the cleaning efficiency of calcium phosphate hydroxyapatite and titanium oxide powders on contaminated titanium discs. Researchers concluded that each of the powder groups used had shown efficient implant surface cleaning. However, all groups revealed implant surface alterations except for the control group.

A study presented by Leung et al (4), researchers investigated the decontamination effect of glycine powder on mature oral biofilm applied onto SLA titanium implants. The researchers showed that glycine powder AAD effectively removed biofilm from the titanium surfaces including bacteria in the rough pits. The researchers had also mentioned that AAD application at defective areas of 3 mm and 6 mm distances were both successful upon that approach.

The use of air abrasives for implant decontamination has been acknowledged in various studies and there has been a consensus over this approach as to being an effective method for treating peri-implant diseases.

Sodium bicarbonate used as an abrasive powder is widely used in clinical routines and has been selected for studies because of its general prevalence in practice (104). A systematic review that evaluated air abrasion (AA) noted it as a promising method for peri-implant disease treatment, focusing on its effects on microstructural changes, cleaning effectiveness, and compatibility with the titanium surfaces (105).

### 2.2.4. Brushes

The utilization of brushes, such as titanium brushes (TB) and chitosan brushes, is an integral component in the process of decontaminating implant surfaces.

Rotating TBs were found to be superior in terms of biofilm removal according to a study by Ichioka et al (106). In which they presented a comparison between rotating titanium brushes as well as the AAD approach compared to chemical disinfection by gauze wiping the implant surfaces.

A study by Giffi et al (107) employed a spectrophotometric ink-model to assess the debridement competence of several decontamination methods including Gracey curettes, glycine air-polishing, erythritol air-polishing, TB in different bone defect settings. The findings revealed that the TB's were the most effective for debridement across all bone defect types, with 60° bone defects being the easiest to debride.

In a study by González FJ, et al (108), they investigated titanium brushes where they have demonstrated utility in addressing narrow defects, as the titanium bristles facilitate easier access to such confined spaces and can adeptly conform to the implant's structure.

In another study by Lee JT et al (109), where mechanical and chemical approaches with compared and combined using cotton cleaning groups, scalers, brushes were effective in removing bacteria from implant surfaces, and biofilm formation was effectively restrained with the use of combined brush and by hydrogen peroxide ($H_2O_2$).

Other types of brushes are Chitosan brushes for dental implants which are innovative tools used for implant surface modification and maintenance. Chitosan, a biocompatible material derived from chitin, is incorporated into brushes that aim for effective cleaning, decontamination, and modification of the implant surface.

In a recent clinical trial by Khan et al (15), where two groups consisted of one applied by titanium curettes and the other with an oscillating chitosan brush, there has been lack of an statistically significant difference in the PPD and BoP variations between the two groups as they both improved significantly; termination of peri-implant disease has been shown in 9.5% of cases in the oscillating chitosan brush (OCB) group and 5.9% in the titanium curette group and so total treatment of disease was not probable for any of the groups.

Overall, while both chitosan and titanium brushes have shown promise in implant decontamination, there is no available consensus report on them being the optimal method of decontamination as it appears that more research is needed to establish standard protocols and to fully understand their effectiveness and potential synergistic benefits when using brushes as monotherapy or in adjunct to other approaches.

## 2.3. Physical Methods

Laser and photodynamic therapy (PDT) are employed as physical methods for the decontamination of implant surfaces, especially in the context of managing peri-implantitis (110,111).

### 2.3.1. Laser Decontamination

Many different types of lasers have been investigated including but not limited to diode, carbon dioxide (CO2), neodymium doped yttrium aluminum garnet (Nd:YAG), erbium, yttrium aluminum, garnet (Er:YAG), and gallium aluminum arsenide (GaAlAs) (96).

An in vivo study by Sculean (7), where they investigated the decontamination with non-surgical approach by an Er:YAG laser, in which notable improvements in BoP, PPD, and clinical attachment level (CAL) had been achieved.

The cleaning capacity of applying Er:YAG compared to power-driven subgingival air abrasive device with trehalose powder on ink stained implant surfaces in an in vitro model was presented by Karaca & Tunar (112). However, the AAD provided more efficient decontamination outcomes in comparison to the Er:YAG laser at 30$^{o}$ and 60$^{o}$ angle defects.

The consensus on the utilization of lasers for dental implant cleansing is not fully established according to the latest peri-implant diseases guideline due to lack of abundant evidence (32). A review aimed to evaluate in vitro studies on the efficacy of lasers for this purpose, where it found that Er: YAG lasers could effectively induce bacterial decontamination, and while CO2 and GaAlAs lasers also showed this capability, effectiveness varied according to the bacterial species. However, due to varying study designs and methods, there is no agreed-upon laser type or settings for optimal bacterial decontamination of titanium implant surfaces. More research is needed to develop clear guidelines for laser use in implant decontamination (113).

### 2.3.2. Photodynamic Therapy

Photodynamic therapy (PDT) involves coating a substance like an implant surface with a particular photosensitizing agent with a known wavelength of activation. Once activated by light of the excitation wavelength in the presence of oxygen, the photosensitizer transitions from a low-energy ground state to a high-energy singlet state, causing a production in free radicals that are toxic to target cells (13).

In an in vivo study by Schär et al (14), forty patients with a single affected implant were treated by PDT with a diode laser was compared to minocycline microsphere application with 20 implants for each group, after initial debridement with titanium curettes and AAD with glycine-based powder. At the 3 and 6-month follow-up exams, all implants showed significant improvements in clinical attachment level, reduction in pocket depth, and plaque reduction. Additionally, there was no statistical difference noted between the two treatment methods used.

Based on the available evidence and the recent guidelines, there is no unanimous consensus on the use of PDT for dental implant decontamination in clinical practice. However, findings from an in vitro study by Marotti et al. (110), suggested that PDT can be an efficient method for reducing bacteria on implant surfaces, showing better decontamination compared to no treatment and similar efficacy to chlorhexidine (CHX); this study also indicated that laser irradiation without the dye used in PDT was less effective than PDT itself.

## 2.4. Chemical Decontamination

Various chemical agents including citric acid (9), chlorhexidine (10,11), hydrogen peroxide (12), and others have been proposed for implant surface detoxification. These agents can be applied locally or systemically to decontaminate implant surfaces and have shown diverse outcomes in terms of effectiveness (114,115).

Several protocols were compared for their efficacy in a model replicating a peri-implant site presented by Citterio et al (116), with a focus on mechanical versus chemical methods for decontaminating titanium dental implant surfaces coated with polymicrobial biofilms beforehand, predicting possible better results if chemicals are combined.

## 2.5. Implantoplasty

Implantoplasty is a minimally invasive surgical approach in the field of implant dentistry that involves reshaping and contouring the surface of dental implants to address issues such as overhanging components, rough surfaces, or excess threads.

This procedure is aimed at improving the implant's biocompatibility and reducing the risk/recurrence of peri-implantitis; not only does it enhance the extended period of stability of the implant, but also facilitates the establishment of healthier peri-implant soft tissues. This technique can be a valuable option in managing implant-related complications and preserving the overall health of the implant site to allow provide improved patient OH (117,118).

In the implantoplasty technique, rubber cups are employed to significantly smooth the titanium surface. They effectively reduce surface roughness by eliminating debris and softening the sharp, machined grooves found on the untreated abutment surface (119). Mombelli et al. (120), have found that using pumice and a rubber cup for implant surface polishing, along with CHX irrigation and systemic antibiotics, led to a decrease in anaerobic bacteria and bleeding scores in patients suffering from peri-implantitis.

Meta-analysis presented by Lima et al (121), demonstrated that probing depth before implantoplasty was significantly higher than after implantoplasty (mean difference = -3.37 mm, confidence interval (CI) = -4.74; -2.00). This result was confirmed in the sensitivity analysis. The probability of success of implants at 6 months of follow-up after implantoplasty was 97.5% and at 24 months of follow-up was 94.7%.

The Combination of both reconstructive periodontal surgeries and implantoplasty along with decontamination of the implant surface have also been presented in RCTs by Lasserre et al (122) and Englezos et al (123), with various success rates as results of treatment with periods of follow up of 6 months and 2 years respectively (Table 2.1)

| | | | | | |
|---|---|---|---|---|---|
| *Resective therapy with adjunctive implantoplasty* | | | | | |
| Lasserre and colleagues | RCT | 29/42<br>Test: 15/22<br>Control: 14/20<br>Test: air-polishing with glycine powder + adjunctive implantoplasty<br>Control: air-polishing with glycine powder | 6 months | Definition 1: PD reduction ≥0.5 mm + no further bone loss<br>Definition 2: PD ≤5 mm + no BOP/Sup + no further bone loss ≥0.5 mm compared to baseline radiograph | Total: 69% implants<br>Test: 70% implants, 67% patients<br>Control: 68% implants, 64% patients<br>Total: 21% implants<br>Test: 15% implants, 13% patients<br>Control: 26% implants, 7% patients<br>$p = 0.294$ |
| Englezos and colleagues | Prospective case series | 25/40 | 2 years | Absence of BOP + PD <5 mm + no further bone loss | 75% (30/40) implants |

**Table 2.1:** Success rate of combined method of reconstructive therapy with implantoplasty.

## 3. MATERIALS AND METHODS

This study design had been granted and acknowledged by the Institutional Scientific Review Board (approval number: 520/2023). This in-vitro study was carried out in Yeditepe University's Dental Faculty in the Department of Periodontology, Istanbul, Turkey.

### 3.1. Sample Size Calculations

The power analysis for this experiment and study was carried out using statistical software[1], drawing on data from a previous in vitro study carried out by Sahrmann, et al (35). This analysis revealed an effect size (d) at **0.627** for the cleaning efficacy parameter, and with a standard deviation of **3.7**. An Alpha (α) error of **0.05** and a Beta (β)power of **0.80** were used. Based on this, it was concluded that a minimum of 10 samples would be needed in each group for the study.

### 3.2. Standardized Study Model Preparations

Standardized cylinder-shaped epoxy resin[2] models were made according to the materials guideline when mixing and pouring into their molds, followed by 24 hours of material setting for all models. (Figure 3.1). The thirty prepared models were then marked to achieve the most center point with a permanent red marker[3]. (Figure 3.2)

**Figure (3.1):** The preparation of the epoxy resin models into their molds.

1 **G*Power** program Version 3.0
2 **Epoart, Polisan®**, Kocaeli, Turkey.
3 **Staedtler** permanent Lumocolor, Germany

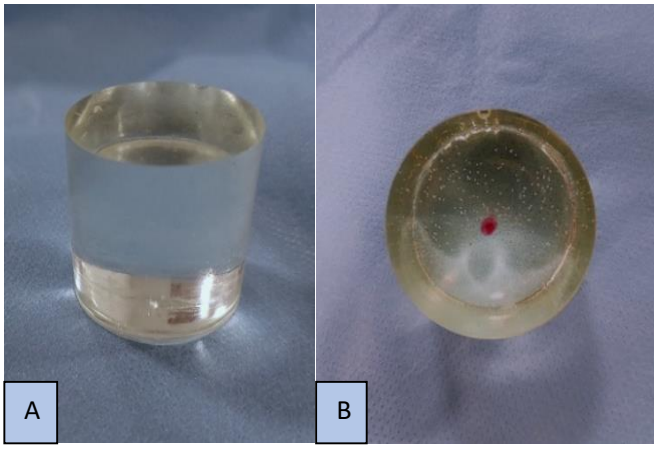
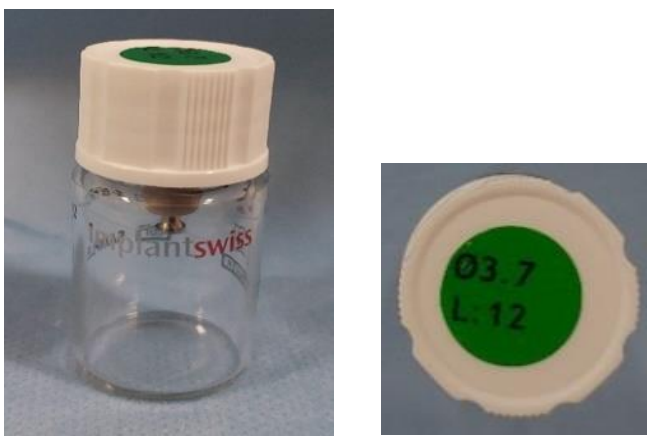



**Figure (3.2):** (A) The standardized study model (B) Marking made at the center of the model with the use of a periodontal probe[1].

### 3.3. Implant Insertion

Thirty titanium implants[2] were used in this study (Figure 3.3). Previously to the application part of the study, a standardization session was achieved with the implants by being inserted parallelly by using the periodontal probe and a marker for reference to act as an actual point of insertion into the study model according to the desired simulated vertical defect. (Figure 3.4)




**(Figure 3.3)** Dimensions of the implants

[1] **UNC-15** periodontal probe, HU-Friedy, USA

[2] **Novodent implantswiss®** 3.7mm diameter and 12mm in length.

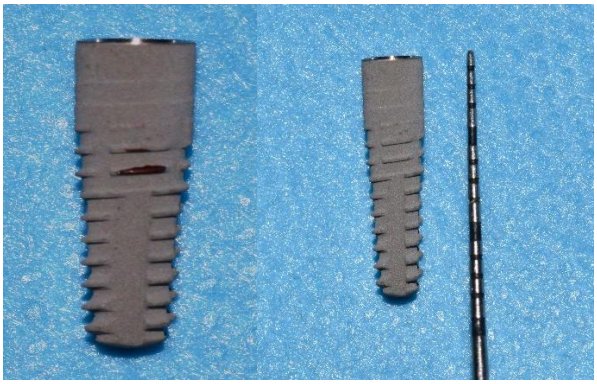


**Figure 3.4:** Reference of length desired marked on an implant

Implant surfaces were then managed by one single operator (N.J), at which each implant was coated with permanent ink[1] until it was completely and homogeneously covered. The implants were then kept at room temperature for the ink to dry for 24 hours to represent the plaque layer. Every inserted implant abutment slot was also marked from the inner abutment slot with the same permanent ink as the representative operating side of the surface decontamination. The implants were then carefully installed into the models with extra care to avoid any contact to the working side of the implant and made sure that the coronal part was at 6mm which was also double-checked again with the periodontal probe to confirm the total height, therefore resembling a horizontal bone defect in an open flap site with 6 mm of the treated surface exposed. (Figure 3.5) using the brand's own implant set (Figure 3.6)

1 **Staedtler** permanent Lumocolor, Germany

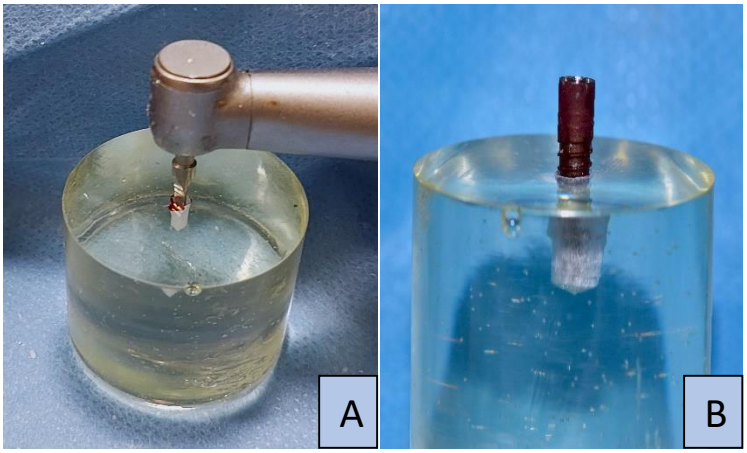



**Figure (3.5):** (A) The implant screw slot preparation and installed (B) The defect is exposed at 6mm.

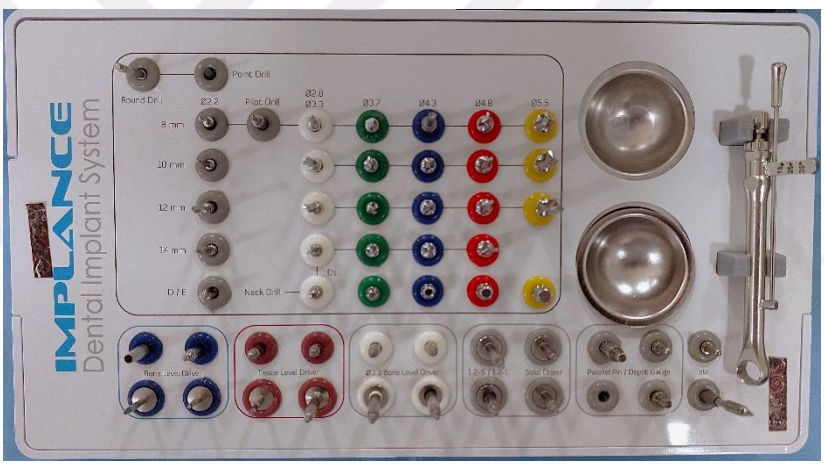



**Figure (3.6):** The implants installation set

The implant placement was carried out using the pilot from the installation set as a pinpoint followed by 2.2 Ø, 2.8 Ø and 3,7 Ø drills respectively; after preparation the implants were placed at installed at 35 torque.

### 3.4. Treatment Groups

Thirty models with inserted implants were randomly divided into three groups. Special care was taken for the working side of the implant. The slot driver was also marked as the reference of the working side and then each group was treated with different root instrumentation tools and were grouped as follows:

1. **Group (SST):** An ultrasonic device1 with linear oscillating handpiece (LOH) and a curved stainless-steel tip (SST) were used in the first group (n= 10)
2. **Group (PT):** LOH with a Polyether Ether Ketone (PEEK) tip were used in the second group (n= 10)
3. **Group (CFT):** LOH with a curved carbon-fiber tip (CFT) were used in the third group (n= 10)

All three ultrasonic tips were used in connection with the same ultrasonic device (Figure 3.7) and the same LOH, which is the specially designed handpiece for linear vertical oscillating movement for 20 seconds for each implant of each group according to an in-vitro study by Karaca & Tunar (112). Along with the use of the previously mentioned tips as shown. (Figure 3.8)

**Figure (3.7)** The ultrasonic device used in this study.

[1] **Vector® Paro Pro**, Dürr Dental SE, Bietigheim-Bissingen, Germany

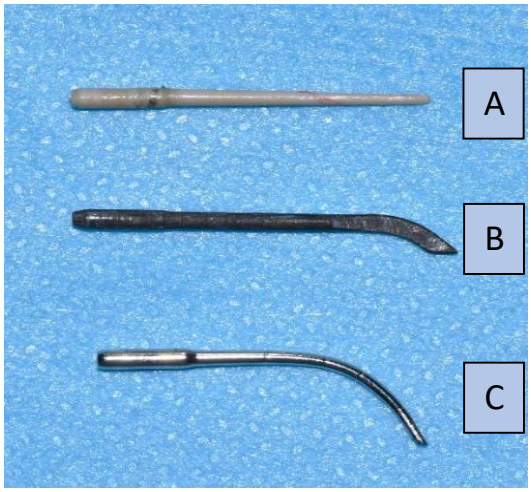



**Figure (3.8):** (A) PEEK tip, (B) Carbon (CFT) tip, (C) Stainless Steel tip

**Group SST:**

Ultra-sonic device with a LOH, with a curved stainless-steel scaler tip (SST) was applied on the implant surfaces for the first group (Figure 3.9). The application duration was 20 seconds which is marked with a timer. The tip was kept parallel to the implant surfaces with the debridement being done with horizontal strokes. The application was performed in a standardized manner in a single session, starting from the bottom of the defect and moving coronally, and care was taken to feel and trace all the thread surfaces, by making a circular sweeping motion circumferentially and along the implant. The ultra-sonic device was used at 80% operating power with a continuous stream of distilled water delivered from the water tank of the device.

The operating frequency of the ultra-sonic device with the LOH was between 25-35 kHz with frequency variable at 50hz - 60hz based on the tip used. Total operating wattage at 230 Watt. The water outflow of VPP was 30 ml of fluid per minute. Total fluid container capacity is 600 ml. No additional lateral force was used to perform during application.

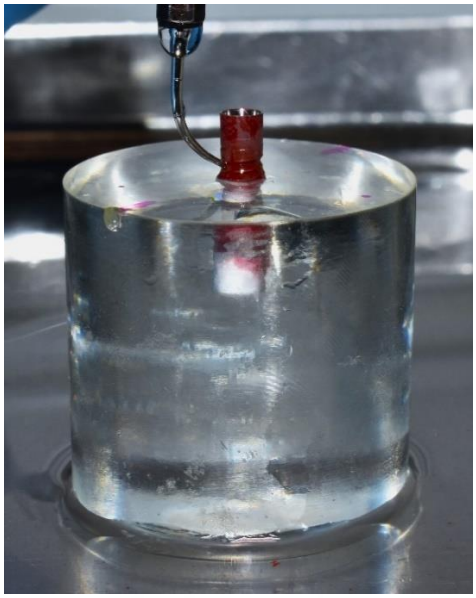


**Figure (3.9):** The application of SST group

**Group PT:**

In the second group, the ultrasonic device equipped with an LOH, and a PT was used on the implant surfaces as shown (Figure 3.10). The procedure lasted for 20 seconds, timed precisely. The tip was placed parallel to the implant surfaces, executing debridement through horizontal strokes. This process was carried out in a uniform manner during a single session, commencing from the base of the defect and progressing coronally. Effort was made to navigate and engage all the thread surfaces by performing a circular sweeping motion both circumferentially and along the implant. The ultra-sonic device operated at 80% power, supplying a continuous flow of distilled water from its tank.

The operating frequency of the ultra-sonic device with the LOH handpiece ranged from 25-35 kHz, with a variable frequency of 50hz - 60hz depending on the tip employed. The total operating wattage stands at 230 Watts, with a water discharge rate of 30 ml per minute from the ultra-sonic device. The device's water container has a capacity of 600 ml. No extra lateral force was exerted during the application.

**Figure (3.10):** The application of PT group

**Group CFT:**

For the third group, an ultrasonic handpiece featuring a carbon-fiber tip (CFT) onto the LOH was used on the implant surfaces (Figure 3.11). The application spanned 20 seconds, monitored with a timer. The tip alignment was kept parallel to the implant surfaces while performing debridement using horizontal strokes. This was done methodically in a one-off session, initiating from the defect's bottom, and advancing coronally. There was a conscious effort to cover all thread surfaces by enacting a circular sweeping gesture both around and along the implant. The ultra-sonic device functioned at 80% of its power, providing an uninterrupted stream of distilled water from its reservoir.

The operational frequency of the ultra-sonic device when paired with the LOH ranged between 25-35 kHz, with a frequency alteration between 50hz - 60hz based on the tip selected. The voltage was at 230 Watts, and the ultra-sonic device discharged water at a rate of 30 ml per minute. The water storage capacity of the device is 600 ml. There was no additional lateral force applied during the procedure.

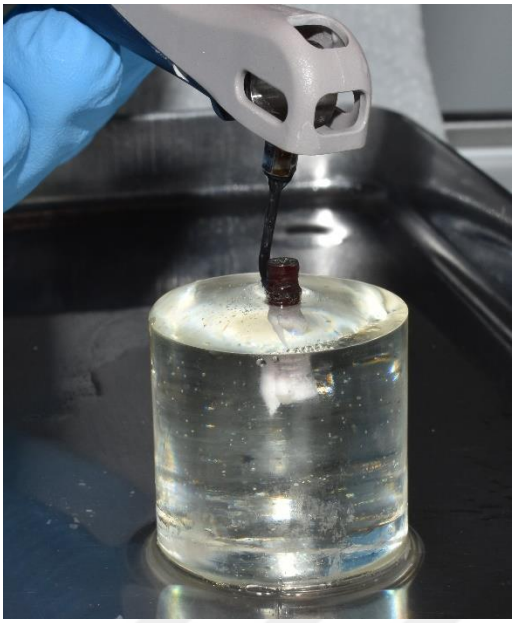


**Figure (3.11):** The application of CFT group

### 3.5. Evaluation of the Surface Cleanliness

Following the use of various mechanical instrumentation techniques across the groups, the implants were carefully removed from the models. Any remaining ink particles that were not adhered were delicately washed away using water and air spray. These groups would eventually be evaluated after instrumentation according to the surface area cleanliness according to the amount of ink removed.

Procedure was applied by using photo editing computer software[1] after photography is made with in accordance with a previously published in-vitro study by Sahrmann, et al (35) in which a DSLR camera[2] using a macro-lens[3] and a ringed flash[4] and a tripod for stability at a standardized 31.4 cm distance, ISO 100, aperture f/32, exposure time 1/250 s.

1 **ImageJ**, 1.46r, National Institutes of Health, Bethesda, Maryland, USA
2 **Nikon** D5600, Nikon, Tokyo, Japan
3 **Sigma** 105mm 1:28 Macrolens, Japan
4 **Meike** MK-14EXT, Hong Kong

The cleaned surface area was measured via computer software to detect the ratio of ink removed amount of ink present based on each treatment group.

The captured photos were assembled and formatted into a macro view using graphic design software. Subsequently, the surfaces of the implants were examined for any remaining stains through these digital images. (Figure 3.12)

**Figure (3.12):** Implant section of the working site

The traces of ink stains on the implant surfaces were identified using image processing software. While measuring the work site, the scale was calibrated using the length of a nearby UNC-15 periodontal probe to ensure accurate size measurement. (Figure 3.13.A). The aid of the computer software allowed us to trace and mark the cleaned area and compare it in percentage with the total surface areas of the whole working side. (Figure 3.13.B)

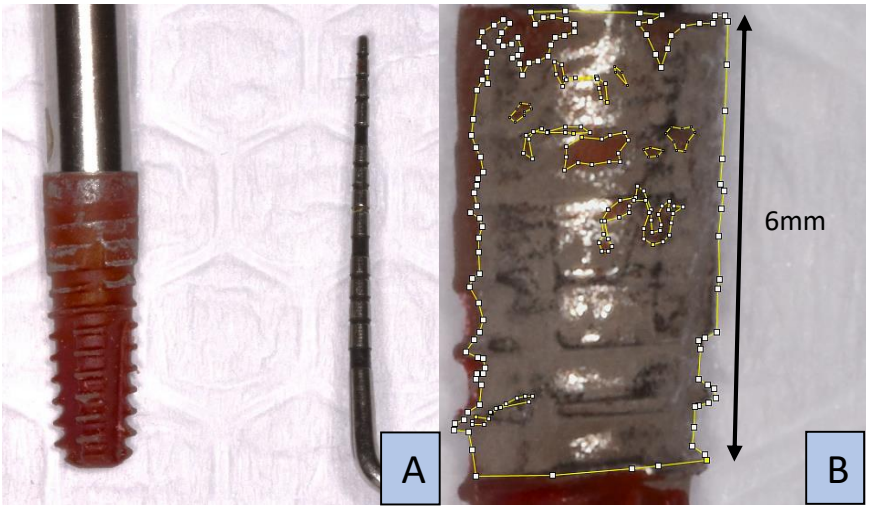



**Figure: (3.13)** (A) The real-time measurement of the scale using an adjacent known length, (B): Tracing and marking the cleaned area.

The cleaned surface area from the computer software data was listed, followed by the percentages of cleaned defect area, to be analyzed and calculated to provide a score for each approach; a cleaning score system ranging from 1 to 6 is applied based on the remaining stain amounts after recording based on a previous in-vitro study (124), which as follows:

**Score 1:** Site surface is nearly fully covered by remaining ink stain (> 95%)

**Score 2:** Surface is covered by remaining stains of more than 3 quarters of the site (75-95%)

**Score 3:** Surface is covered by remaining stains of more than half of the site (50-75%)

**Score 4:** Surface is covered by remaining stains of less than half of the site (25-50%)

**Score 5:** Surface is covered by remaining stains of less than a quarter (5-25%)

**Score 6:** Surface is nearly perfectly clean (<5%)

### 3.6 Statistical Investigations

Data of this study were analyzed in IBM SPSS program for statistical analysis. The compatibility of the parameters to the normal distribution was evaluated by the Shapiro Wilks test. Oneway Anova test was used to compare intergroup comparisons while the data was relevant, the normal distribution, and 'Tukey HSD' test was used to determine the group causing the difference.

The Kruskal Wallis test was used to compare the parameters that did not show normal distribution between groups, and Dunn's test was used to determine the group causing the difference. ICC (intraclass correlation coefficient) was calculated for the first and second measurement agreements. Significance was valued at the level of $p<0.05$.

## 4. RESULTS

The residual ink staining was measured in all implant photos in this present study. Statistically significant difference was found in terms of cleaned area measurements. (p:0.001; p <0.05). The evaluation for pairwise comparison the cleaned area after Tukey HSD test, the mean cleaned area of the SST group was found to be significantly higher than the CFT (p:0.001) and PT (p:0.001) groups (p <0.05). There was no significant difference between the CFT and PT treatment groups (p: 0.974; p <0.05). Data was presented in Table 4.1, and Figure 4.1.

**Table 4.1: Evaluation of groups areas cleaned areas of the groups ($mm^2$)**

| | Cleaned Area Measurement | |
|---|---|---|
| | **Min-Max** | **Mean±SD** |
| Group SST | 18,1 - 19,5 | 18.78± 0.56[ab] |
| Group CFT | 5,5 - 8 | 6,63± 0,93 [a] |
| Group PT | 4,1 - 9,9 | 6,74± 1,71 [b] |
| p | | 0,001* |

*Oneway ANOVA test* **p <0.05*

*a (SST vs CFT).* *Tukey HSD test*

*b (SST vs PT).* *Tukey HSD test*

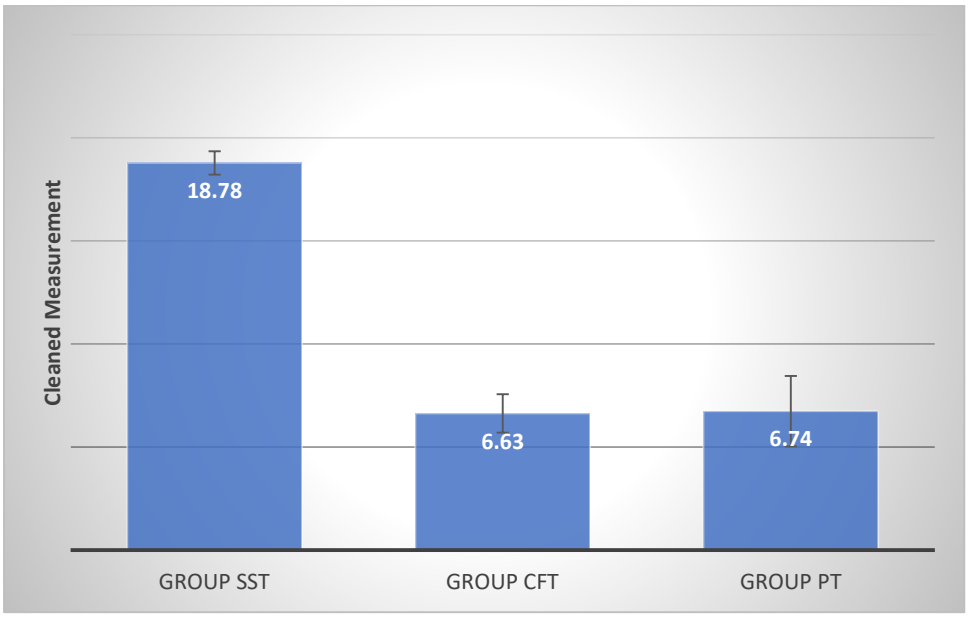



**Figure 4.1**: Visual chart representing the main cleaned data of the surfaces.

Statistically significant difference between the groups regarding the areas cleaned was found (p:0.001; p <0.05). As a result of the Tukey HSD test conducted to determine which groups the significance originates from; The mean cleared area of the SST group was found to be significantly higher than the CFT (p:0.001) and PT (p:0.001) groups (p <0.05). There was no significant difference between the CFT and PT treatment groups (p: 0.974; p <0.05).

**Table 4.2: Evaluation of the groups in terms of percentages of surface area cleaned.**

| | Surface Area Cleaned (%) | |
|---|---|---|
| | **Min-Max** | **Mean± SD** |
| Group SST | 78 - 87 | 82.50± 3.36 [ab] |
| Group CFT | 24,6 - 35,1 | 29,29± 4,11 [a] |
| Group PT | 17,7 - 43,2 | 29,44± 7,61 [b] |
| p | | 0,001* |

*Oneway ANOVA test* **p <0.05*

*a (SST vs CFT).* *Tukey HSD test*

*b (SST vs PT).* *Tukey HSD test*

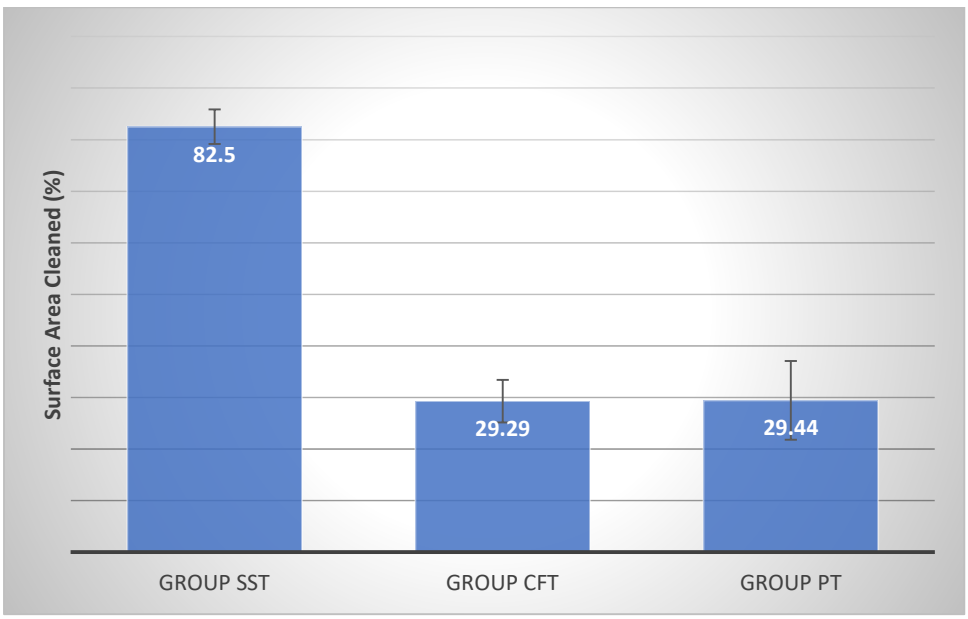



**Figure 4.2**: Visual chart representing the percentage of cleaned surfaces.

There was a statistically significant difference amongst the groups in terms of the percentages of the cleaned area (p:0.001; p <0.05). As a result of the Tukey HSD test conducted to determine which groups the significance originates from; The percentage of cleared area of the SST group was found to be significantly higher than the CFT (p:0.001) and PT (p:0.001) groups (p <0.05). There was no significant difference between the CFT and PT treatment groups (p:0.998; p <0.05).

**Table 4.3: Evaluation of groups in terms of cleaning scores**

| | Cleaning Score | |
|---|---|---|
| | **Min-Max** | **Mean±SD (Median)** |
| Group SST | 5 - 5 | 5±0 (2) [ab] |
| Group CFT | 2 - 3 | 2.9± 0.289 (4)[a] |
| Group PT | 2 - 3 | 2.8± 0.51 (4)[b] |
| p | | 0,001* |

*Kruskal Wallis test* **p <0.05*

*a (SST vs CFT).* *Dunn's test*

*b (SST vs PT).* *Dunn's test*

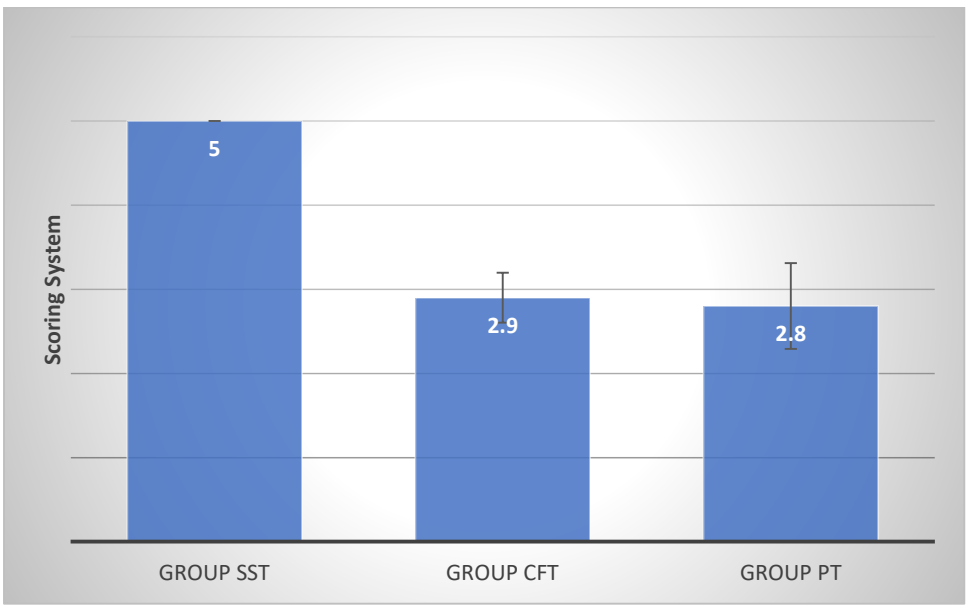



**Figure 4.3**: Visual chart representing the scoring of cleaned surfaces.

Statistically significant difference among the groups in terms of cleaning scores was detected (p:0.001; p <0.05). As a result of Dunn's test conducted to determine which groups the significance originates from; The mean score of the SST group was found to be significantly higher than the CFT (p:0.001) and PT (p:0.001) groups (p <0.05). There was no significant difference between the CFT and PT treatment groups (p:1.000; p <0.05).

There was a 95.3% agreement between the first and second measurements in the SST group, 92.6% in the CFT group and 98.9% in the PT group. The two measurements were taken at an interval of six hours. Overall, the level of agreement between the first and second measurements was 99.9% (Table 4.4).

**Table 4.4: Evaluation of first and second measurement compliance**

| | **Scoring System** | |
|---|---|---|
| | **ICC** | **%95 CI** |
| Group SST | 0,953 | 0,823 - 0,988 |
| Group CFT | 0,926 | 0,733 - 0,981 |
| Group PT | 0,989 | 0,958 - 0,997 |
| Total | 0,999 | 0,997 - 0,999 |

*ICC: Intraclass correlation coefficient* **p<0.05*

## 5. DISCUSSION AND CONCLUSION

There is a consensus among different sources that there is no universally accepted standard treatment protocol for peri-implant diseases. Despite the lack of a universal protocol, various organizations and studies have proposed different treatment approaches. The EFP S3 guideline (32) focused on the prevention and treatment of peri-implant mucositis and peri-implantitis through interdisciplinary approaches, and that the treatment protocol will vary depending on whether the peri-implant disease is peri-implant mucositis or peri-implantitis (125); although overall the current gold standard being followed for periodontal disease treatment is mechanical debridement of implant surfaces whether in non-surgical or surgical methods (41).

Mechanical means of decontamination have proven effective in eliminating calculus deposits and residual debris. However, the presence of undercuts along with grooves and porosities on the roughened implant surface can make achieving a sterile surface challenging (126); other approaches like chemical, photodynamic measures, and laser therapy, have been advocated for implant surface decontamination post-surgical exposure to eradicate infection, eliminate inflammation, and allow bone regeneration leading to possible re-osseointegration (127). Aswell as the implementation of implantoplasty, and electrolysis have been suggested to promote predictable clinical and radiographic outcomes (126).

On the other hand, mechanical methods would still have the effect of changing implant surfaces as shown by multiple studies (128–130), which leaves us in search for the optimal method of decontamination and keeping the surfaces intact considering all the methods and approaches of different materials.

Peri-implantitis has been suggested to cause a significant increase in implant failure rates over time. Long-term studies have been aimed at evaluating whether the implant failure rates match the supposed high prevalence of peri-implantitis (131).

This study had achieved to show that the SST group where a linear oscillating handpiece with a stainless-steel tip provided the most efficient decontamination of the ink-stained surfaces of the implants in comparison to the other two tips (PT & CFT) with the same handpiece, which were applied in an in-vitro study model, representing a horizontal bone defect simulating an open-flap debridement approach in surgical methods. Although this method provided the best method overall with a statistically significant difference compared to the other two tools, it did not achieve the optimal cleaning efficiency desired.

Chun et al. (83), carried out an in-vitro study where they have compared multiple metallic ultra-sonic tips (Stainless steel, 316 L steel, bronze, and copper tips) onto titanium disks placed into epoxy resin blocks. The results showed that the cleaning efficiency of the stainless-steel tip is around 3 times higher than copper tip, the 316 L tip is about 2.7 times higher than that of copper tip, and the bronze tip is about 1.2 times higher than that of copper tip; the initial statement that the SS tip provided the most efficient cleaning approach agrees with our study. On the other hand, results presented were not using the same scoring system as our study used nor did it provide the results in percentage to relation to the cleaning area as our study had as well as the lack of similar simulated bone defect.

In another study by Park et al. (132), they compared multiple treatment groups using an ultrasonic device including two different steel tips from different manufacturers, a carbon tip, and a plastic tip in relation to the removal of lab-cultured adhered bacteria. The two metallic tip treatment groups provided a result of 23.1 ± 24.2 and 26.7 ± 30.6 respectively while the untreated implant surface showed 46.4 ± 59.4 after washing the surface with a brush and dentifrice; the plastic tip however made the best result of the groups of 18.0 ± 25.1. The researchers applied different parameters than our study did, as they used bacteria cultured and attached onto implant surfaces rather than ink-removal; they also followed a protocol of applying 40 strokes only when cleaning rather than having a working time for each site as our study did which is conflicted with our study leading to different results.

In a study by Koyuncuoglu et al. (90), the researchers carried out an in-vitro study testing excess cement removal around implant abutments to measure the cleaning efficacy of (PEEK) ultrasonic tips after cementation. Implants were placed into stone models with abutment heights of 1-2 and 2.5-4 mm and then the results were analyzed through computerized planimetric technique. The results showed that efficient cleaning was achieved at the shallow area of 1-2 mm while it failed to achieve full cleanliness at sites deeper than 2.5mm. Although this study applied the usage of a PEEK tip as our study did, the parameters were different and were aimed at removal of cement rather than ink; there was a smaller area of work compared to our study as they did not aim for an open-flap debridement approach as our study had. These factors are potentially the reason in which it cannot be compared directly to our study and results.

Kawashima et al. (92), aimed to observe the efficacy of metal, carbon, and plastic tips in implant abutment cleaning in an in-vivo study. The results showed that all three groups removed the calculus efficiently as well as no significant difference in plaque removal between the three groups. Although the researchers applied the same treatment groups similar to this study, there were clear differences in the results, and this could be associated to multiple factors such as the difference of material of surface being cleaned, the difference of exposure & accessibility between in-vivo and in-vitro studies, different scoring system, as well as the time applied cleaning each working site. In that study the researchers applied 60 seconds for each site at a smaller working area, but in this study, we used 20 seconds for each site. Application of working time could potentially change the outcome of each study significantly.

Three different in-vitro studies carried out by Sahrmann et al. (35), Keim et al. (101) and Giffi et al. (107), in which they represented various bone defects ($30^{\circ}$, $60^{\circ}$& $90^{\circ}$) on models and proceeded to evaluate the efficacy of multiple approaches. Although the researchers aimed for an artificial defect similar to this study, it had been carried out with different defect angles. The evaluated parameters and defect angulations were different, these discrepancies prevented us from comparing the results of our study with these studies.

These results should be read carefully because in-vitro studies have some limitations. These in-vitro studies may not reflect the same efficiency of implant surface decontamination when compared to an approach done intra-orally due to the anatomical variations; the mouth-opening factor, saliva and blood presence and other factors may lead to various results. The Ink attachment to implant surfaces is also not widely documented in the available literature; however, it is likely that this process is more controlled and reliant on the physical and chemical properties of the ink and the implant material. Unlike bacteria, ink does not have the biological mechanisms to actively adhere or respond to the surface environment.

Furthermore, the different models used in in-vitro studied would vary in the shape of defect, as well as the mold specification leading to possible varying exposures for cleaning approaches leading to potential difference in the efficiency of the cleaning process. Epoxy-based composites can be used to develop models with a wide interest in safe, cost-effectiveness, anatomically, and mechanically similar models as the human bone (133–135).

In conclusion, within the parameters of this study, this is the only available in-vitro study that evaluated the cleaning efficacy of implant surfaces in which it implemented a horizontally-simulated bone defect ($180^{\circ}$) with the use of three treatment groups consisting of stainless steel, carbon fiber, and PEEK tips attached to an ultra-sonic device; these parameters make this study difficult to compare to parameters and results of other studies as further research is required with the same parameters. The stainless-steel tip provided the most efficient result compared to the carbon-fiber and the PEEK tip groups. The SST group, being the most efficient still did not achieve full cleanliness of the working site most notably at the apical middle parts and so regardless the method of approach is, care should be taken into this region at the surgical open-flap debridement intervention.

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## 7. CURRICULUM VITAE

### Personal Information

| | | | |
|---|---|---|---|
| **Name** | Nameer | **Surname** | Aal-Jabro |

### Education

| Degree | Department | Institution Name | Graduation Year |
|---|---|---|---|
| **Master** | Periodontology | Yeditepe University | 2023 |
| **Dental Internship** | General Dentistry | Jordan University Hospital | 2020 |
| **Bachelor's Degree** | Dentistry – DDS | Yerevan State Medical University | 2018 |
| **Highschool** | International Baccalaureate (IB) | Amman National School | 2012 |

### Languages

| Language | Grade |
|---|---|
| English | TOEFL: 94 |
| Turkish | C1 Level |
| Arabic | Native Speaker |

### Work Experience

| Position | Institute | Duration (Year) |
|---|---|---|
| Periodontology Clinical Attachment | Jordan University Hospital | 2020-2021 |
| Dental Internship (General Dentistry) | Jordan University Hospital | 2019-2020 |
| General Dentist | Private Sector Dental Clinic | 2018-2019 |

### Computer Skills

| Program | Level |
|---|---|
| Microsoft Office | Intermediate |
| Adobe Photoshop | Basic |

**Scientific Work Experience**

**The articles published in the journals indexed by SCI, SSCI, AHCI**

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**Articles published in other journals.**

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**Proceedings presented in international scientific meetings and published in proceedings book.**

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**Journals in the proceedings book of the refereed conference / symposium**

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**Others (Projects/ Certificates/ Rewards)**

| **Certificates** | **Year** |
|---|---|
| CPR Course | 2020 |
| Suturing Workshop | 2019 |
| Current Issues of Medical Science | 2015 |