T.C. YEDITEPE UNIVERSITY

FACULTY OF DENTISTRY

DEPARTMENT OF PERIODONTOLOGY

THE EFFECTS OF DIFFERENT MECHANICAL INSTRUMENTATIONS ON IMPLANT SURFACES

DOCTOR OF PHILOSOPHY THESIS

Dt. Müge MÜEZZİNOĞLU

SUPERVISOR
Prof. Dr. Bahar KURU

Co-Advisor
Assoc. Prof. Dr. Ogül Leman TUNAR

Istanbul, 2023

THESIS APPROVAL FORM

Institute : Yeditepe University Institute of Health Sciences

Programme : Periodontology

Title of the Thesis : The Effects of Different Mechanical Instrumentations on Implant Surfaces

Owner of the Thesis : Müge MÜEZZİNOĞLU

Examination Date : 14 / 07 / 2023

This study have approved as a Doctorate Thesis in regard to content and quality by the Jury.

	Title, Name-Surname (Institution)
Chair of the Jury:	Prof. Dr. Bahar KURU (Yeditepe University)
Supervisor:	Prof. Dr. Bahar KURU (Yeditepe University)
Co-Advisor	Assoc. Prof. Dr. Ogül Leman TUNAR (Yeditepe University)
Member/Examiner:	Prof. Dr. Funda YALÇIN (Istanbul University)
Member/Examiner:	Prof. Dr. Burcu Karaduman (Biruni University)
Member/Examiner:	Prof. Dr. Zeynep ÖZKURT KAYAHAN (Yeditepe University)
Member/Examiner:	Doç. Dr. Ebru ÖZKAN KARACA (Yeditepe University)

APPROVAL

This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dated ..... and numbered .....

Prof. Dr. Bayram YILMAZ

Director of Institute of Health Sciences

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.

06 / 07 / 2023

Müge MÜEZZİNOĞLU

ACKNOWLEDGEMENTS

With all the effort made and attention paid this thesis work has been such a devotion to me and my dedicated supervisor Prof. Dr. Bahar KURU, co-advisor Assoc. Prof. Dr. Ogul Leman TUNAR, Assoc. Prof. Dr. Ebru ÖZKAN KARACA, Assist. Prof. Dr. Hazel Zeynep KOCABAŞ, Assist. Prof. Dr. Tuğçe CEYHANLI and Assist. Prof. Dr. Ece Deniz YARIMOĞLU ÖKTEN. They have been sincerely giving and always there whenever I needed them. For the most part it is a great honor to be their doctorate student and I am willing to take our scientific relationship forward.

I am thankful to Ebru OSMANOĞLU as she performed the statistical analyses for our thesis study, Turgut AZOV since he helped me shooting implant photographs and also İrem AKYÜZ who performed the collage of implant photographs.

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LIST OF SYMBOLS AND ABBREVIATIONS

APAD	Air Powder Abrasive Device
NUS	Newtron Ultrasonic Scaler
VUS	Vector Ultrasonic Scaler
Er:YAG	Erbium-doped Yttrium Aluminium Garnet
BC	Before Christ
AD	Anno Domini
HA	Hydroxyapatite
mm	Millimeter
PEEK	PolyEtherEtherKetone
PAEK	Polyaryletherketone
Hz	Hertz
Cps	Cycles Per Second
CO_2	Carbon Dioxide
Nd:YAG	Neodymium-doped Yttrium Aluminium Garnet
Er, Cr:YSGG	Erbium, Chromium-doped; Yttrium, Scandium, Gallium, Garnet
Nm	Nanometer
psi	Per Square Inch
μm	Micrometer
ml	Milliliter
kPa	Kilopascal
$cm^{3.}$	Centimeters Cubed
LEDs	Light Emitting Diodes
kHz	Kilohertz
W	Watt
SD	Standard Deviation

ABSTRACT

Muezzinoglu, M. (2023) The Effects of Different Mechanical Intrumentations on Implant Surfaces. Yeditepe University, Faculty of Dentistry, Department of Periodontology, PhD thesis, İstanbul. The aim of this study is in vitro evaluation of the effects of different mechanical treatment instruments on titanium implant surfaces. For this purpose, thirty ink-stained implants which are inserted in standardized epoxy resin models with narrow defect angulations (30°) are used in three different study groups. The standardized peri-implantitis models are covered by a non-transparent custom-made mucosa mask to provide the visual display of gingiva for simulating of non-surgical mechanical therapy. An air powder abrasive device using trehalose powder with a special nozzle for subgingival application (APAD) (n=10), an ultrasonic device with a special designed implant tip (NUS) (n=10), and an ultrasonic device with a subgingival tip (VUS) (n=10) were used. A blinded and calibrated examiner evaluated the standardized photographs of instrumented implant surfaces with image-processing software. The total cleaned area of APAD group was found significantly higher than both NUS (p:0.020, $p<0.05$) and VUS (p:0.022, $p<0.05$) groups. The average percentage of cleaned area of APAD group was significantly higher than both NUS (p:0.017, $p<0.05$) and VUS (p:0.044, $p<0.05$) groups. Within the limits of this in vitro study the air abrasive device demonstrated better cleaning performance than the two different power-driven ultrasonic devices, although, complete surface cleanliness was not achieved in any of the three instrumentation methods during non-surgical treatment simulation of peri-implant defects. Further microbiological and clinical research are needed to confirm the clinical relevance of the *in vitro* findings.

Key words: peri-implantitis, non-surgical periodontal therapy, surface roughness

TÜRKÇE ÖZET

Muezzinoglu, M. (2023) Farklı Mekanik Aletlerin İmplant Yüzeylerindeki Etkileri. Yeditepe Üniversitesi, Diş Hekimliği Fakültesi, Periodontoloji Anabilim Dalı, PhD tezi, İstanbul. Bu in vitro çalışmanın amacı mekanik tedavide kullanılan farklı aletlerin titanyum implant yüzeylerindeki temizleme etkinliklerinin karşılaştırılmasıdır. Çalışmada dar defekt açılı (30°) standardize epoksi rezin modelle gömülü otuz adet yüzeyleri boyanmış implant kullanıldı. Peri-implant yıkım gerçekleşmiş implant defektlerinin cerrahi olmayan mekanik tedavilerini simule edebilmek için modeller transparan olmayan özel bir mukoza maskesi ile örtüldü. Hava-toz aşındırıcı cihaz ve subgingival enstrümentasyon için kullanılan özel ucu (APAD) (n=10), implant yüzeyleri için özel geliştirilmiş bir ucu olan ultrasonik bir cihaz (NUS) (n=10) ve subgingival uygulamalarda kullanılabilen uca sahip bir diğer ultrasonik cihaz (VUS) (n=10) araştırmada kullanıldı. Uygulamaları tamamlanan implant yüzeylerinin fotoğrafları bilgisayar programı ile değerlendirildi değerlendirildi. Toplam temizlenen alanların değerlendirilmesine bakıldığında APAD grubunun temizlenen alan ortalamasının ($p:0.010$, $p<0.05$) NUS ($p:0.020$, $p<0.05$) ve VUS ($p:0.022$, $p<0.05$) gruplarına göre anlamlılığı istatistiksel olarak yüksek bulundu. Ortalama temizlenen alan yüzdesinin değerlendirilmelerine bakıldığında APAD grubunun ortalama temizlenen alan yüzdesinin ($p:0.013$; $p<0.05$) NUS ($p:0.017$) ve VUS ($p:0.044$) gruplarına göre istatistiksel olarak anlamlılığı yüksek bulundu. Sonuç olarak, üç cihaz da tamamen yüzey temizliği göstermemiş olmasına rağmen, subgingival başlığa sahip hava-toz aşındırıcı cihaz diğer ultrasonik cihazlara göre daha iyi temizleme etkinliği göstermiştir. Klinik ve mikrobiolojik olarak bu farklı yüzey temizleme metodlarının sonuçlarının değerlendirildiği ileri çalışmalara ihtiyaç olduğu görülmüştür.

Anahtar kelimeler: peri-implantitis, cerrahi olmayan periodontal tedavi, yüzey pürüzlülüğü

1. INTRODUCTION and PURPOSE

The use of dental implants is an acceptable treatment alternative with predictable outcomes and high long-term success rates to improve patient's oral aesthetics, function and phonetics (1,2). Implant materials, design and surface topographies affect the success of osseointegration (3). Various implant surfaces have been introduced starting from glabrous machined surfaces to more rough surfaces which are created by coatings or blastings with different substances, acid applications, or by combinations of these applications over the years (4). An optimal implant-surface design should consider both surface roughness for an ideal osseointegration and post-operative hygienic care at the same time. Despite the ever-increasing rate of success in implant therapy, widespread use of different varieties of implants throughout the world has brought some problems and complications. Biological challenges in implant therapy are described to as peri-implant mucositis or peri-implantitis (5). Peri-implant mucositis is the inflammation of surrounding soft tissues, whereas peri-implantitis is the both soft tissue inflammation and destruction of the bone. Also, peri-implantitis is an important problem for the implant treatment. On the other hand, peri-implantitis has become a global health problem due to the high increase in dental implant application and lack of a clearly accepted standard treatment protocol. A great variety of treatment approaches such as implant surface debridement with curettes (6), laser therapy (7) and air abrasive device systems (8) has been proposed. Decontamination of implant surfaces is a significant factor for the achievement of peri-implant disease treatment. Many decontamination methods have been reported inadequate and therefore, this is a dynamic and noticeable research area in modern dentistry.

In recent years, a new generation of power-driven instrument has been introduced. This system gives the opportunity to obtain a most caring instrumentation on the tooth surface (9). It performs a small amplitude nonelliptical vibration movement with a special fluid which causes less pain on patients (10). Irrigation flow rate and power of the device can be managed. But there is insufficient data about the usage of this system in the treatment of peri-implant diseases.

The air abrasive devices have also been used in mechanical periodontal treatment. This device offers an improved air polishing with one powder jet handpiece, two replaceable nozzles and different prophylaxis powders to achieve minimally invasive management of biofilm. Many studies have documented that the powders which are used in air abrasive devices can alter the roughness on tooth surfaces and surface characteristics on dental implant surfaces (11,12). The powders which are being used in air abrasive devices are glycine, erythritol, sodium bicarbonate, aluminium trioxide, calcium carbonate, chlorhexidine gluconate and trehalose powder (11–15). The trehalose powder is a noncariogenic disaccharide approved also in food processing (14) and can be also used in dentistry for both supragingival and subgingival areas. The manufacturer delineates that trehalose powder is a highly water-soluble powder with a pH of 6.4 (16). Established *in vitro* trials by manufacturer state that the abrasive effect of trehalose powder on tooth surface is as low as a glycine powder and have particle diameters of 25-35 μm (16). However, the information in literature about the use of trehalose powder on titanium implant surfaces is limited. One of the recent studies has documented that the so-called new generation air abrasive device is more efficient in cleaning implant surfaces than the Er: YAG (erbium-doped yttrium aluminium garnet) laser (17). Cleaning potential of this air powder abrasive device using trehalose powder on implant surfaces were investigated in this study (17).

There is also another ultrasonic device which has been introduced in recent years. This device offers different tips for dental implant surfaces and has an oscillating movement with irrigation and power control (18). However, there is also paucity of knowledge for the use of this system around dental implant surfaces regarding safe cleaning, decontamination and the maintenance of the biocompatibility of the surface (19).

In the light of these literature reviews, the aim of this study is to evaluate the cleaning potential of three different mechanical instrumentation tools used in the non-surgical treatment of titanium implant surfaces.

2. LITERATURE REVIEW

2.1. History of Dental Implants

The history of dental implants has a huge evolution through time. Dental implants have been used in humans to replace missing teeth which are lost because of dental and periodontal diseases. The Egyptians used a gold ligature wire to stabilize teeth in approximately 2500 BC (before christ) (20,21). Afterwards, the Etruscans made trials with gold bands attaching animal teeth to rehabilitate oral function in humans; they also used oxen bones to replace missing teeth in about 500 BC (20,21). In the meantime, the Phoenicians also used gold wires to stabilize teeth without periodontal support; these people carved out teeth to create a fixed bridge by binding them with gold wire around 300 AD (anno domini) (20,21). The first knowledge of dental implants is belonged to the Mayan population who lived in 600 AD. Mayans used shell pieces as implants for the replacement for mandibular teeth (20–22). An implant from stone was prepared by Honduran culture and placed in the mandible in 800 AD (20,21).

In 1687, the first reference of dental application was made by Charles Allen (23). In those times, teeth were taken from the poor people or the corpses aiming to achieve allotransplantation (21,24). But this method disappeared later on due to the secondary infections such as syphilis and tuberculosis (24).

French dentist Jourdan Maggiolo is the first person to publish the technique of dental implants in his book "Le Manuel de l'Art du Dentiste" in 1809 (20,22,25). He wrote a method about implanting three branched 18 karat gold alloy into the jawbone and installing porcelain crown (20,22,25).

In 1905, Dr. Scholl produced a root-form, porcelain implant (24,25). Edwin Greenfield thereafter developed a hollow cylindrical implant design and drilling systems which are being used in present (20–22,24). He was also the first dentist who reported the implant treatment failures occurred because of infections (24).

In the 1930s, Dr. Alvin Strock and Dr. Moses Strock practiced chromium-cobalt alloy orthopedic screw fixtures (20,21,25,26). They implanted these screws in both humans and dogs in the same manner as physicians' placing implants in the hip bone. They found out that these screws were providing anchorage and support in dental treatment (20). The Strock brothers were also the first dentists achieved success in placing endosteal implants (20‑22,25,26). Afterwards, Dr. Pinkney Adams was granted by the U.S. patent office for inventing a cylindrical endosseous implant and a healing cap with a smooth gingival collar in 1938 (20‑22). Then, in the 1940's, Dr. Manlio Formiggini (Father of Modern Implantology) and Dr. Zepponi invented a post-type endosseous implant (20,21). This implant had a spiral stainless-steel design which has helped bone to grow into the its metal surface (20,21). Afterwards, Dr. Perron Andres changed Formiggini's spiral design as including a solid shaft (20‑22).

After the modification of the spiral design by Dr. Perron Andres, studies focused on placing subperiosteal implants, their design and loading components. Dr. Raphael Chercheve created burs for an easy insertion of the implant (20–22). Then, in Sweden, Dr. Gustav Dahl worked on the subperiosteal implants in the 1940's while these developments were continued (20,21,26). The design of this implant system was laying over the crest of the alveolar ridge with its flat abutments and screws (20,21). Dr. Aaron Gershkoff and Dr. Norman Goldberg developed Dahl's implant design from 1947-1948 (20,21,26). Afterwards, in 1950, Dr. Lew, Dr. Bausch, and Dr. Berman researched the subperiosteal implant design (20,21).

In 1967, Dr. Leonard Linkow introduced two different variations of the blade implants that could be placed in both the maxilla and mandible (20,22,24,26). Currently the blade implants are known as endosseous implants (20,22,24,26).

In 1978, Dr. Per-Ingvar Brånemark introduced titanium root-form implant system made from pure titanium with a two-stage approach (20–22,26–28). These implants were placed to patients by him previously in 1965 (20,21,25). First patient of Brånemark had missing and misaligned teeth, he implanted four implants into the mandible (21). These implants had a six months duration of integration and were survived for the next 40 years (21,25,26,29). He also found that the bone was attached to the titanium surface of the implants and fractures

occurred between bone and bone, not in between the bone and the implant (20–22,25,26). As a result, Brånemark introduced a term called “osseointegration” which can be defined as “a direct structural and functional connection between living bone and the surface of a load carrying implant” (20–22,25–27). Many different types of implants such as tapered-form implants were invented after the Brånemark’s cylindrical implant by several implant companies (20–22,25,26).

Dr. Andre Schroeder and Dr. Reinhard Straumann were also important dentists of implantology from Switzerland (20,21,25). They did experiments with metals which were used in orthopedic surgery to have fabrication of dental implants (20,21,30). Many dentists used the endosseous root-form implants as the customary implant in the middle of the 1980’s (20,21). In early 1980’s, Dr. Hilt Tatum developed the titanium alloy omni R implant with horizontal fins and Dr. Gerald Niznick developed a hollow basket implant which was the core-vent implant (20,21). Niznick continued to improve other implant systems called screw-vent which had hydroxyapatite (HA) coating, bio-vent and micro-vent (20,21). Afterwards, Dr. Driskell invented a titanium alloy endosseous stryker “root form” implant with hydroxylapatite coating (20,21).

In 1985, introduction of the integral implant system with titanium-plasma-spray to enhance surface area and an intra-mobile part to simulate the mobility of natural teeth was made (20,21,25). These implants were planned to be placed in a one-stage approach (20,21,25,26).

In 1992, some companies started to manufacture implants to enhance osseointegration. Implants made from PolyEtherEtherKetone (PEEK) revealed good results in osseointegration (20). Ceramic implants had osteoconductive features. The most used ceramics deemed as bioactive are hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) (HA), tricalcium phosphate ($Ca_3(PO_4)_2$) and bioglasses and they can initiate a chemical bond with bone (3,31,32). Implants can be made of fully ceramic or a ceramic coating can be applied (3). Biesbrock et al. suggested that HA-coated implants could be more feasible in cases where more impetuous and advanced bone-implant contact needed or when short implants are going to be applied (3).

On the other hand, there are polymer implants which can be made of polyurethane, polyamide fibers, polymethylmethacrylate resin and polytetrafluoroethylene (3,33). They were expected to imitate the movement of the periodontal ligaments around implants (3,34). However, there are no statistical differences between these flexible and other rigid implants for transferring stress safer to bone (35). But utilization of these materials as a coating layer is eliminated due to their mechanical features, deficiency of adhesion to periodontal tissues and adverse immunologic responses (3).

Under the light of these historical evolution and current knowledge, titanium and its alloys have become a preference for production of dental implants. They ensure a thriving solution in replacement of missing teeth, with more than two million dental implants used globally in a year (36,37). However, the use of dental implants to improve patient's oral function, aesthetics and phonetics is an acceptable treatment alternative with foreseeable implications and high long-term success rates (2). It is an advanced and multidisciplinary treatment for achieving a restorative goal in partial or fully edentulous patients. Despite all the advances in years, there are still some controversial topics and conditions that are subject to debate. Once an implant diagnosed as diseased and left untreated, it is likely that the disease will progress accompanied with bone destruction (38).

2.2. Peri-implant Tissues

The soft and hard tissues surrounding dental implants are called peri-implant tissues. The soft tissue part is called peri-implant mucosa and it develops during the wound reformation phase (39,40). Peri-implant mucosa is a non-keratinized oral barrier epithelium with basal lamina and hemidesmosomes surrounding the implant surface (41,42). There are inflammatory cell infiltrates in the connective tissue part of this epithelial barrier to represent host's defense (41,42). The epithelial barrier and the existence of inflammatory cells effectuate a soft tissue seal dividing peri-implant attachment from the oral cavity (41,42). The hard tissue part makes a contingence with the implant surface (39,40). The part of peri-implant mucosa facing implant includes two different portions (39,40). The first is called "coronal portion" and lined by barrier epithelium and sulcular epithelium, a similar

epithelium with the junctional epithelium (39,40). The sulcular epithelium around implants is continuous with the junctional epithelium and ensures an epithelial unity between the implant and gingiva (41). The height of peri-implant mucosa is about 3 to 4 millimeters (mm) and has an about 2 mm long epithelium around the implant surface (39). There are small clusters of inflammatory cells, which are T and B lymphocytes, inside of the barrier epithelium of connective tissue (39). About 60% of the intrabony implant part is in relationship with mineralized bone (39). But during the healing process, bone modelling may occur with some decrease in the marginal bone level (39).

The second part is called “apical segment” and implant surface has directly contact with the connective tissue (39,40,43). In general, the peri-implant surrounding tissues are similar to the periodontium unit. But in the tissues surrounding the natural tooth has quite unique structure such as presence of cementum and alveolar ligament. Mineralized bone grows in close along the implant surface and therefore, dental implants lack a periodontal ligament (39,43). But it is possible to detect fibers like dentogingival fibers which are functionally oriented perpendicularly to the implant surface (41). The collagen fibers surrounding dental implants are localized parallel to the implant surface (39,43) (Figure 2.1.).

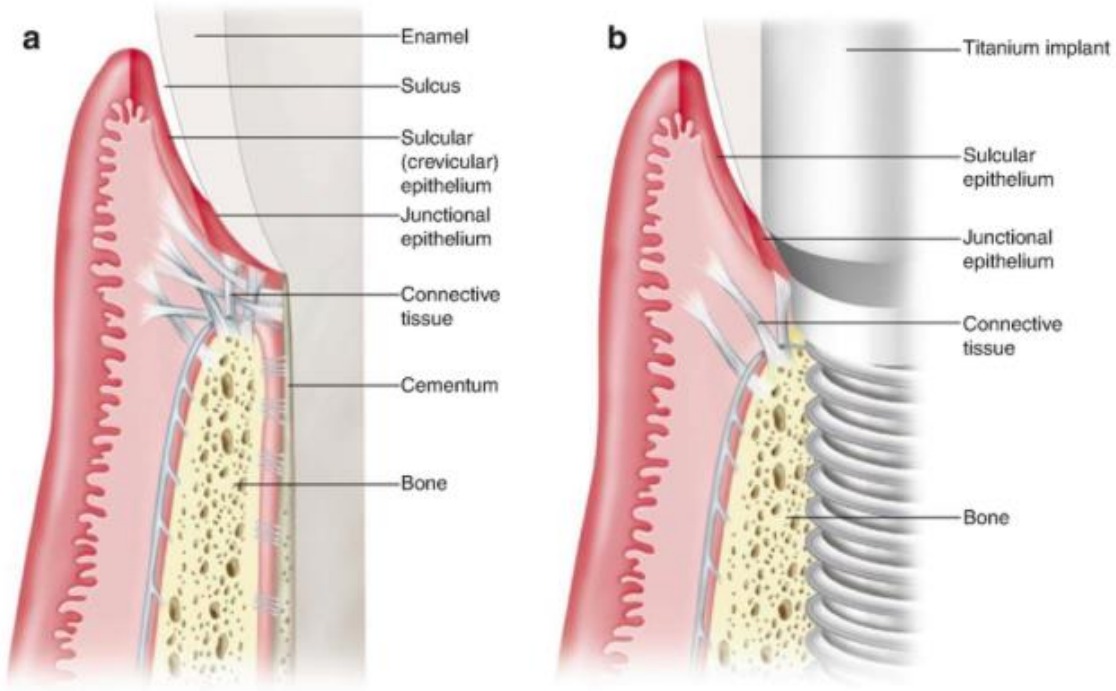

Figure 2.1. The structural differences between teeth and dental implants (43)
(a), Schematic illustration of periodontal tissues around natural tooth; (b), Schematic illustration of periodontal tissues around dental implant

The fibers around dental implants are supracrestal gingival fibers (41). These connective tissue fibers are mostly located in parallel and perpendicular orientation (41).

Overall, it can be briefly stated that:

- Keratinized tissue around the implants provides resistance to initiations through the change of gingival fiber alignment from parallel to perpendicular to the surface
- Similar but longer epithelial attachment with hemidesmosomes and basal lamina
- Peri-implant mucosa contains more collagen fibers in comparison to gingiva but less fibroblasts and blood vessels
- No periodontal ligament area between implant and surrounding bone jeopardizing the vascular nourishment
- Peri-implant inflammation proceeds rapidly due to lack of periodontal ligament barrier

- High risk for peri-implant diseases and low healing capacity compared to natural tooth.

2.3. Osseointegration and Type of Implants

Osseointegration plays an important role in implant treatment and the health of peri-implant tissues which is related with the survival of dental implants. Osseointegration was described as “a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant” (3,27). According to Zarb and Albrektsson, the term of osseointegration is a clinically rigid fixation between alloplastic implant material and bone tissue, which is uneventful and asymptomatic healing process by time (44). The resembled histological appearance was a functional ankylosis without connective tissue existence between bone and implant surface (44). They also described osseointegration as the attachment of lamellar bone with implants not including intervening fibrous tissue (45). A biological and physiological barrier is provided by the soft tissue barrier surrounding implants to protect the bony anchorage (46). The micro-architecture of the titanium surfaces can affect the gingival fibroblasts (46).

The responses of bone, connective tissue and epithelium to endosteal implants with titanium implants are searched by Schroeder et al. (47). They found that the bone executes itself by “ankylosis”, without an intermeddling layer of connective tissue to the surface of the implant and continues attached to it when placed under functional loading over periods (47). And also, the fibers of the connective tissue in the midst of the bone and the epithelium interpolate between bone tissue and the titanium implant surface, seem to be functionally oriented (47).

Implant materials, designs and surface topographies affect the progress of osseointegration (3,45,48). Implant materials can be divided into three groups; metals, ceramics, polymers (3). Titanium implants are the most commonly used types because of their minimal toxicity, corrosion resistance, high mechanical resistance and biocompatibility (48). They show better long-term clinical results (48). Yet, the clinical evidence for zirconia

implants is currently limited but they show promising results in high success rates and low marginal bone loss (49). Zirconia implants show different surface and material characteristics than titanium implants (49). It was suggested that using zirconia implants in sites with reduced vertical bone was suggested by the literature (49). But the current trend in biomedical research is the improvement of materials for regenerative medicine based on bioceramics (50). Bioceramics play a critical role in tissue regeneration because of their effect on cell differentiation and proliferation in the implant region (50). The interaction of osteogenic cells with ceramics enables good bone integration and regeneration, however, ceramic implants have worse mechanical properties than metal implants (50). The polymer implants which are mainly composed of PEEK have satisfying biocompatibility (51,52). PEEK belongs to a group of high-performance thermoplastic polymers called polyaryletherketone (PAEK) (51). They do not integrate with any biological tissue because of their biologically inert and hydrophobic characteristic (51). They also have similar elasticity with cortical bone (51). But there are limited studies in the literature about polymer implants, they cannot be constructed into monolithic structures, and they are radiolucent which can limit the ability of assessment with radiographs (52).

On the other hand, biomaterials can be classified in three groups according to the type of biologic response they initiate in the periodontal tissue (3,53,54). These groups are biotolerant, bioinert, bioactive (3,53,54).

Biotolerant materials are accepted materials and not rejected from periodontal tissues, but they are encircled by a capsule form of fibrous layer (3). These materials are some metals as stainless steel, zirconium, gold, cobalt-chromium alloys, niobium, tantalum and some polymers as polyethylene, polyamide, polymethylmethacrylate, polytetrafluoroethylene, polyurethane (3).

Bioinert materials can authorize the construction of bone on their surfaces (3). They authorize the bone and tissues enclosing implant surface to re-grow and congregate without causing any negative immune response (3). These materials are some metals as pure titanium, titanium alloy and ceramics as zirconium oxide, aluminium oxide (3).

Also, bioactive materials can authorize the construction of bone on their surfaces, but with a different process (3). They stimulate an advantageous biological response from the body on implantation (3). The most used examples of this bioactive material types are ceramics as hydroxyapatite, tricalcium phosphate, bioglass, fluoroapatite, brushite, carbon: vitreous pyrolytic, carbon silicone and calcium pyrophosphate (3).

Bioinert and bioactive materials are called osteoinductive materials because they both can initiate the formation of bone (3). The chemical compositions of these three types are shown in Table 2.1. (3).

Table 2.1. Classification of implant materials (3)

Biodynamic activity	Chemical composition		
	Metals	Ceramics	Polymers
Biotolerant	Gold Cobalt-chromium alloys Stainless steel Zirconium Niobium Tantalum		Polyethylene Polyamide Polymethylmethacrylate Polytetrafluoroethylene Polyurethane
Bioinert	Commercially pure titanium Titanium alloy (Ti-6Ai-4V)	Aluminium oxide Zirconium oxide	
Bioactive		Hydroxyapatite Tricalcium phosphate Tetracalcium phosphate Calcium pyrophosphate Fluoroapatite Brushite Carbon:vitreous, pyrolytic Carbon-silicone Bioglass	

2.4. Peri-implant Health

The healthy peri-implant mucosa is consisted of connective tissue which is also surrounded with a non-keratinized epithelium (lining mucosa) or keratinized (masticatory mucosa) (39). The clinically visual signs of inflammation and bleeding on probing are not expected in peri-implant health (55–58). Also, peri-implant health cannot be evaluated only with probing depths, because it may have normal or reduced bone level (56). On the other

hand, probing depths are important in peri-implant health and expected to be ≤ 5.0 mm in general (56). It is necessary to evaluate peri-implant health with both clinical and radiographic findings (56,59). Under clinically healthy conditions no signs of inflammation exist (i.e., erythema, swelling and suppuration, bleeding on probing) in peri-implant tissues (58–60). According to these data, requirements of peri-implant health are:

- Nonexistence of clinical signs of inflammation
- Nonexistence of bleeding on probing or suppuration
- Nonexistence of increase in pocket depth compared to previous examinations
- Nonexistence of bone loss beyond crestal bone level (60).

2.5. Peri-implant Diseases

In 2018, Klinge et al. reported that 12 to 18 million implants are being placed in a year around the world (61). The most common problem of implants are peri-implant diseases or infections. The prevalence of peri-implant diseases is increasing worldwide, and it has been shown that 28-56% of patients with dental implants have this serious problem (55). There are many resemblances among the periodontal diseases and peri-implant diseases. They are both microbial dental plaque biofilm associated diseases and characterized with clinical signs of inflammation and bleeding on probing (56). Peri-implant diseases assumed to have the same pathogenesis of inflammation with the periodontal diseases, which start with peri-implant mucositis and precede to peri-implantitis, however, the process is not clear yet (62). Peri-implant diseases affect the peri-implant tissues, which includes peri-implant mucosa and may spread supporting bone and cause the failure of implant (55,56,62).

As previously stated, microbial dental plaque biofilm is the main etiologic factor of both the periodontal and peri-implant diseases or infections (55,63–65). Also, other predisposing factors such as nonexistence of peri-implant keratinized mucosa, overload of occlusal forces, existence of titanium particles in peri-implant tissues, necrosis of bone, overheating, micro-motion or bio-corrosion could be responsible for peri-implant diseases (60). The biofilm can accumulate on dental implant surfaces and lead to peri-implant diseases classified as peri-

implant mucositis and periimplantitis (59,66). Peri-implant mucositis is described as mostly plaque-associated inflammatory soft tissue response with clinically visual signs of inflammation and bleeding on probing. It can be reversed if the plaque is eliminated (56). Peri-implantitis is described as a plaque-associated inflammatory soft tissue response with concurrent bone loss around peri-implant tissues (56).

Caton et al. published a new classification table according to these diagnostic criteria for periodontal and peri-implant conditions and diseases to be able to make correct case definitions in 2017 (Table 2.4.) (56).

Table 2.2. The schematic scheme which is published by Caton et al. in 2017 (56)

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

Also, Berglundh et al. published peri-implant conditions and diseases as a new classification paper and can be shown in Table 2.5. (59).

Table 2.3. The schematic scheme which is published by Berglundh et al. in 2018 (59)

Peri-implant Diseases and Conditions Consensus Report
Peri-implant Diseases and Conditions
Peri-implant health
Peri-implant mucositis
Peri-implantitis
Peri-implant soft and hard tissue deficiencies

2.5.1. Peri-implant Mucositis

Peri-implant mucositis is a peri-implant mucosal inflammation without continuing marginal bone loss (60). Dental plaque biofilm accumulates without disruption, peri-implant mucositis develops due to a deprivation of symbiosis among the biofilm and host immune inflammatory response (56,60). Additional factors such as history of periodontal disease and smoking could affect the onset and progression of peri-implant mucositis (60). The major aspect of peri-implant mucositis is bleeding on probing but erythema, swelling and suppuration may or may not to be present (58–60). It is characterized by an inflammatory lesion which is an infiltrate rich in vascular structures; plasma cells and lymphocytes are located lateral to the junctional epithelium (59). Another clinical aspect of peri-implant mucositis is the increase in probing depths compared to baseline (58,59). In the past, there are many different diagnostic criteria for peri-implant mucositis (Table 2.4) (67).

Table 2.4. Diagnostic criteria for peri-implant mucositis (Table is adapted from the literature of Figuero et al.) (67)

Author / year	**Mucositis definition**
Heitz-Mayfield et al. 2011	Bleeding on probing and no bone loss
Thone-Muhling et al. 2010	Bleeding on probing and/or gingival index ≥ 1 on at least one site and no bone loss in the previous 2 years
Ramberg et al. 2009	Bleeding on probing
Porras et al. 2002	Plaque, probing depth ≤ 5 mm and evidence of inflammation by modified bleeding index
Felo et al. 2011	Bleeding on probing, modified gingival index > 1.5, modified plaque index > 1.5 and probing depth ≤ 3 mm
Ciancio et al. 1995	Bleeding on probing, modified gingival index > 1.5 and modified plaque index > 1.7

Currently, up to date criteria have been published by American Academy of Periodontology and European Federation of Periodontology, peri-implant diseases study group in 2017 (58,68). According to 2017 World Workshop, peri-implant mucositis diagnostic criteria should have; clinical signs of inflammatory disease and radiographic images should be investigated to exclude bone level changes (58). Clinically visual diagnostic signs of peri-implant mucositis are:

- Visually localized swelling and redness,
- Bleeding on probing or drop bleeding, suppuration,
- Increase in probing depths,
- Nonexistence of bone loss beyond crestal bone level (the bone level of supra structure should not be > 2.0 mm after the first year of installation) (58).

Peri-implant mucositis is assumed to be a risk factor and a pre-requisite for peri-implantitis (56). History of periodontitis, smoking, insufficient oral hygiene, and diabetes are important risk factors for peri-implantitis (56,62). But to be noticed, peri-implant mucositis could be existed for a long time without developing to peri-implantitis (42).

2.5.2. Peri-implantitis

Peri-implantitis is a peri-implant biofilm related pathological situation, eventuating in peri-implant tissues and characterized by inflammation in peri-implant mucosa and advanced supporting bone loss (60). In peri-implantitis, bleeding on probing, suppuration, increased probing depths in comparison to the previous evaluations and bone loss beyond crestal bone level are present (58–60). The main etiological factor of peri-implantitis is the deposition of microbial dental plaque biofilm and the risk factors include severe periodontitis, insufficient oral hygiene and absence of regular supportive peri-implant treatment (60). On the other hand, smoking, diabetes, existence of submucosal cement or placement of implants and unfavorable superstructures limiting the plaque control may affect the progress and onset of peri-implantitis (60). The main difference among peri-implant mucositis and peri-implantitis is the supporting bone loss (56,58,59). There are many different peri-implantitis definition in

the literature and most of them involve the existence of bleeding on probing, deep probing depths and bone loss shown in Table 2.3. (67).

Table 2.5. Diagnostic criteria for peri-implantitis (Table is adapted from the literature of Figuero et al.) (67)

Author / year	Peri-implant disease definition
Schar et al. 2013	Probing depth 4-6 mm, bleeding on probing at one or more sites and radiographic bone loss of 0.5-2 mm
Renvert et al. 2011	Probing depth ≥ 5 mm, bleeding on probing/suppuration and radiographic bone loss > 3 mm
Renvert et al. 2009 **Persson et al. 2010**	Probing depth ≥ 4 mm, bleeding on probing/suppuration and radiographic bone loss < 2.5 mm
Renvert et al. 2008	Probing depth ≥ 4 mm, bleeding on probing/suppuration, bone loss < 1.8 mm (three threads) and the presence of *P. gingivalis, P. intermedia, F. nucleatum, T. forsythia, A. actinomycetemcomitans* and *T. denticola*
Renvert et al. 2006	Probing depth ≥ 4 mm, bleeding on probing/suppuration, bone loss fewer than three threads and the presence of *P. gingivalis, P. intermedia, F. nucleatum, T. forsythia, A. actinomycetemcomitans* and *T. denticola*
Schwarz et al. 2004, 2006	Moderate (> 4 mm) to advanced (> 7 mm) probing depth, bone loss, bleeding on probing/suppuration, plaque index < 1 and keratinized mucosa
Karring et al. 2005	Probing depth ≥ 5 mm, bleeding on probing, radiographic bone loss = 1.5 mm and exposed implant threads
Aghazadeh et al. 2012	Probing depth ≥ 5 mm, bleeding on probing/suppuration, radiographic bone loss ≥ 2 mm and angular peri-implant bone defects ≥ 3 mm
Schwarz et al. 2011	Probing depth > 6 mm and radiographic bone loss > 3 mm
Roos-Jansaker et al. 2007	Bleeding on probing/suppuration and bone loss more than three threads
Deppe et al. 2007	Probing depth > 4 mm or bleeding on probing; vertical bone loss
Schwarz et al. 2009	Probing depth > 6 mm and radiographic bone loss > 3 mm
Romeo et al. 2005, 2007	Probing depth > 4 mm, bleeding on probing/suppuration and peri-implant radiolucency

Today, according to 2017 periodontal and peri-implant disease classification, proposed peri-implantitis diagnostic criteria should include bleeding on probing with bone loss (58). The diagnostic criteria of peri-implantitis are summarized as the following:

- Clinically visual inflammatory changes,
- Bleeding on probing or drop bleeding, suppuration,
- Increasing probing depths,
- Advanced bone loss after 1 year following the placement of the implant and in the nonexistence of initial radiographs and probing depths, bone loss of ≥ 3 mm and/or probing depths of ≥ 6 mm (58).

The peri-implant region is more susceptible to microorganisms than the periodontium (63,66). On the other hand, the bacteria presented inside this biofilm is very resistant to topical disinfectants and systemic antibiotics (55). The biofilm should be controlled by patients with standard prophylactic means (i.e., tooth brush, dental floss, interdental brush) and dentists with regular maintenance therapy (63). Besides history of periodontitis, smoking and insufficient oral hygiene, are admitted as risk factors for peri-implant diseases since host response is very important in the disease pathogenesis (17,69). The presence of soft and hard tissue deficiencies occurring during the healing process after tooth loss is also a critical importance (56,59). Extended deficiencies could occur if there are combinations of the deprivation of periodontal support, endodontic lesions, longitudinal root fractures, weak buccal bone plate, buccal or lingual tooth position, traumatic extraction, injury, pneumatization of maxillary sinus, treatments with medications, having systemic diseases, agenesis of teeth and stress of removable prosthesis (56,59).

2.6. Treatment Strategies of Peri-implant Diseases

Different treatment modalities have been proposed for peri-implant diseases in years. These therapeutic approaches primarily aim to remove microbial dental plaque biofilm from the implant surfaces (17,63,70–74). Yet, prevention from peri-implant diseases is also a key aspect in the management of these diseases (60). Prevention is possible with an appropriate

multidisciplinary treatment planning, assessment of risk factors, maintenance program for peri-implant tissue health (60). An integrated approach (periodontal, surgical and restorative) including a restoratively driven implant positioning and hygiene-driven restorations as well as the maintenance of periodontal and peri-implant health is the basis for prevention. The therapeutic approaches on the other hand are mechanical debridement, adjunctive antimicrobial therapy and surgical procedures in advanced cases (64,92,94,95). Both in peri-implantitis and peri-implant mucositis, mechanical approaches are performed and they are of critical importance (17,42,43,65,66,71–74). Therefore, non-surgical mechanical therapy and maintenance therapy are suggested to achieve success in peri-implant disease treatment. Besides the mechanical therapy, the adjunctive effects of antimicrobials (local or systemic antimicrobials) and both mechanical and antimicrobial effects of devices such as dental lasers and air abrasive devices and surgical procedures have been stated as the treatment tools of peri-implant diseases (75–78).

2.6.1. Mechanical Therapy

Although therapy of peri-implantitis is more advanced and complex then the therapy of peri-implant mucositis, due to the loss of supportive bone (65), the initial mechanical treatment approaches are similar in both diseases (5,6,17,43,65,72–74). Mechanical therapy can be performed with special curettes, power-driven devices, dental lasers, rubber cups, various types of brushes and air abrasive devices (72,74,79). Based upon the literature, there is no evidence to identify one of them as the gold standard (60). Recently, Herrera et al. published a clinical practice guideline of prevention and treatment of peri-implant diseases. Related to this guideline, adding air abrasive devices and/or diode lasers to conventional treatment of peri-implant diseases is not recommended (60).

Treatment of peri-implant mucositis with early intervention aims to prevent the process of peri-implantitis (42,65,74). The first step to achieve this aim is to eliminate the biofilm and risk factors such as smoking, radiation therapy, diabetes, insufficient oral hygiene, lack of maintenance therapy, design of prosthesis, excess cement and inadequate soft tissue levels (65). The biofilm can be eliminated with mechanical debridement using curettes, power-

driven devices, dental lasers and air powder abrasive devices alone or in combination with local and/or systemic antimicrobial therapy (15,17,65,74). There is evidence in the literature which shows mechanical debridement in combination with irrigation with antimicrobials is more effective than the mechanical debridement alone (65,70,71,74). The results of recent studies showed that mechanical implant surface decontamination in peri-implant diseases should be supported with chemical irrigation, however, further long-term research is needed for confirmation (80).

Mechanical debridement around implants requires special instruments and care to maintain and regain biocompatibility to debride effectively without surface alterations and leftovers. Stainless-steel curettes, titanium curettes, plastic curettes, carbon-fiber curettes and teflon curettes can be applied for mechanical debridement (67).

It is important to avoid leaving material remnants on implant surface when performing mechanical debridement (81). The titanium remnants released from implant surface have introduced foreign bodies in the peri-implant tissues after using an instrument or device, (81). For this reason, a brush made of natural chitosan (poly-N-acetyl glycosaminoglycan) with a flexible shaft is developed (81). This brush is a non-toxic and bio-absorbable material which has bacteriostatic and anti-inflammatory characteristics (81). The chitosan brush is being used with a customized oscillating dental hand piece (81). In patients with progressive lesions, mechanical therapy alone is not adequate and surgical access may be needed (17,43,65,74).

Wohlfahrt et al. investigated the effect of the aforementioned novel chitosan brush for the non-surgical therapy of mild peri-implantitis (82). This investigation included case series and concluded that chitosan brush is confidential to use and seems to have benefits in the non-surgical therapy of mild peri-implantitis (82)

The key of the success in treatment of peri-implant diseases is the mechanical decontamination (17,83–87). Although there is no gold standard protocol in treatment of peri-implant diseases, studies have shown that both in surgical and non-surgical treatment

approaches, debridement of implant surfaces is the essential process for the maintenance of implant health (10–13,38,67,72,74,78,80,83–113). The search for the most efficient debridement method and new instruments are continuously being developed.

2.6.1.1. Currettes

Selection of proper instruments for the removal of biofilms during non-surgical peri-implant therapy is critical for the success of long-term peri-implantitis management (57,114–118). There are several types of curettes such as stainless-steel curettes, titanium-coated curettes, plastic curettes, carbon-fiber curettes and teflon curettes (67).

In an *in vitro* study by Fox et al. have compared the surface roughness of pure titanium implants after scaling with different types of curettes (119). Titanium alloy, stainless steel curette and plastic curettes were used to evaluate the in vitro effects of hand scaling on pure titanium implants (119). Plastic curettes produced insignificant alteration such as scratches, cuts and gouges of the implant surfaces, while titanium alloy and stainless-steel curettes significantly altered the implant surface (119). This alteration may lead to contamination of implant surface and increase corrosion and plaque accumulation (119).

The titanium-alloy and stainless-steel curettes have been studied on titanium surfaces for debridement (118,120). Subsequently, pure titanium curettes and titanium nitride (TiN) curettes were found to leave only slight working traces and not alter the implant surfaces in optimum forces (63,118). It is substantial to select appropriate instrument due to the alterations of surface roughness that may increase the biofilm accumulation (103,109). Also, there are studies showing that using rubber cup, plastic curette and air polishing units leave implant surfaces unchanged (103,106). But plastic curettes cannot reach the macro and micro porosity of dental implant surfaces resulting in higher residual biofilm levels after treatment (95).

Muthukuru et al. evaluated the efficiency and reliability of non-surgical treatment of peri-implantitis (121). They showed that locally delivered antibiotics as an adjunct to mechanical

debridement result in greater decrease in bleeding on probing and probing depths compared to mechanical debridement with curettes. Er:YAG laser was found to result in greater decrease in bleeding on probing when compared to mechanical debridement with curettes. Air abrasive devices reduce bleeding on probing greater than mechanical debridement with curettes, but the present information is not considered sufficient for recommending whether or not any of the evaluated treatments are the gold standard (121).

2.6.1.2. Power-Driven Instruments

There are two types of power-driven devices as ultrasonic and sonic (122). Ultrasonic devices or scalers have high vibration movement with a frequency range of 25.000-42.000 Hertz (Hz) on the tip (122). Ultrasonic scalers transform electrical energy into ultrasonic-waves with piezoelectricity or magnetostriction (122). On the other hand, sonic devices are air turbine devices which have low frequencies in a range of 3000-8000 cycles per second (Cps) (122). Conventional sonic and ultrasonic scalers with metal tips are used in the treatment of peri-implant diseases, however, it is known that they may induce modifications and roughen the implant surfaces (123). Due to these limitations of conventional ultrasonic devices, serious engineering work in this area is still in progress to develop specially designed piezoelectric ultrasonic devices (123). Recently, new metal tips made of copper alloy and ultrasonic devices have been introduced (101). The most appropriate tips of ultrasonic devices for mechanical debridement are carbon fiber, silicone and plastic tips for implants (76).

Today, piezoelectric devices have become as popular as other power-driven devices which have high frequency oscillating movement for mechanical debridement with metal tips or probes (124). The tips of power-driven devices have a range of shapes and designs, but these tips are less sharp than manual hand instruments (124). Power-driven devices provide less sensitive tactile feedback to the dentist than manual hand instruments (124). The power-driven devices have an irrigant that flows over the working tip providing a reduction in frictional heat occurred during debridement and the clearance of the debris from the working area (124).

Studies have shown that ultrasonic devices have the same efficacy as hand instruments (76). In a study by Hussain et al., researchers have assessed whether there is consensus in the choice of treatment for peri-implant diseases (125). They have asked 35 periodontology professionals to fill a questionnaire and professionals agreed that there is no singled out decontamination method shown to be more effective than the others for mechanical implant debridement (125). However, in a systematic review, it is concluded that mechanical debridement as a non-surgical approach with different instrumentation methods is found effective in healing peri-implant inflammation and reducing pocket depths (126).

In an *in vitro* study, Schmidt et al. investigated the surface characteristics of implants and the formation of biofilm after using different decontamination methods and instrumentations (127). They had seven instrumentation groups in their study: stainless steel curettes, titanium curettes, air abrasive device, ultrasonic device and plastic-coated curettes to be evaluated on 35 titanium implants embedded into plastic models (127). Bacterial colonization was investigated after debridement under scanning electron microscope (127). No significant differences were found between the groups in terms of surface characteristics (127).

In the *in vitro* study of Baek et al., researchers investigated reliability and efficacy of novel ultrasonic scaler tips, conventional stainless-steel tips and plastic tips on implant surfaces (101). They found that, novel metallic copper alloy ultrasonic scaler tips may slightly induce modifications on implant surfaces, resembling plastic tips (101). It is concluded that, novel ultrasonic scaler tips and plastic tips are more suitable instruments for the treatment of peri-implant diseases.

Another *in vivo* study of Kawashima et al. evaluated three different piezoelectric ultrasonic scaler tips in the treatment of peri-implant diseases (128). They used carbon, plastic and metallic tips and found that carbon and plastic tips produced clean, smooth implant surfaces (128). As a conclusion, researchers stated that piezoelectric scalers with non-metal tips were appropriate for decontamination in peri-implant diseases (128).

Nart et al. assessed the clinical and radiographic consequences of implants treated by different non-surgical debridement methods with systemic antibiotic administration (129). They used ultrasonic debridement, air abrasive device and metronidazole for mechanical decontamination of peri-implantitis lesions (129). They found out that non-surgical therapy of peri-implantitis has efficiency to arrest advanced bone loss, decrease probing pocket depths as well as suppuration together with radiographic bone fill (129).

Irshad et al. investigated the role of implant surface decontamination alone or in combination with systemic antibiotics on the clinical and microbiological parameters (99). They concluded that implant surface debridement with ultrasonic scaler improved the clinical parameters of peri-implantitis and adjunctive use of systemic antibiotics promoted mucosal recession and reduced bleeding on probing (99).

There are few researches about the recently introduced ultrasonic devices in the literature which has horizontal vibration and suspension of hydroxyapatite particles and water (130). Sato et al. assessed the comparative effects of new generation ultrasonic scalers, conventional scalers and plastic scalers on implant surfaces (106). The researchers showed that the new generation ultrasonic scalers and conventional ultrasonic scalers are helpful for decontamination and no damage was found on implant surfaces compared to plastic scalers (106).

A pilot study of Karring et al. investigated the efficiency of peri-implantitis treatment with novel ultrasonic devices, the new generation ultrasonic scalers and carbon-fiber curettes (108). They compared the baseline and 3 months measurements of bleeding on probing (108). The study revealed greater decrease in bleeding on probing following the treatment with new generation ultrasonic scaler than carbon-fiber curettes, there was no significant difference between these two methods (108). As a result, further research is needed to investigate the possible role of new generation ultrasonic scalers.

2.6.1.3. Laser Therapy

Lasers have been suggested for the decontamination and cleaning of implant surfaces (131). Diode, carbon dioxide (CO_2), neodymium-doped yttrium aluminium garnet (Nd:YAG), erbium-doped yttrium aluminum garnet (Er:YAG) and erbium, chromium-doped; yttrium, scandium, gallium, garnet (Er, Cr: YSGG) lasers are being used in peri-implant diseases (132). Lasers could do photobiomodulation which describes reduction of inflammation and stimulation of cell proliferation as well as mechanical ablation and decontamination (132).

Diode and Nd:YAG lasers can be only used on soft-tissues (132). Wavelengths of these lasers are between 800-1,100 nanometers (nm) and can be transmitted through water, absorbed in the blood and tissue pigments (132). Nd:YAG lasers are free running pulsed lasers with short duration pulses and diode lasers are being used in a continuous wave mode (132). Both of these two lasers have a risk to produce thermal damage, but Nd:YAG lasers have higher risk because of the free running pulsed mode and they are contraindicated in treatment of implant surfaces (132).

CO_2 lasers have wavelength between 9,300-10,600 nm and they can be used on peri-implant soft tissues (132). The CO_2 lasers have the highest absorption levels in dental minerals such as hydroxyapatite and calcium phosphate and should be avoided from direct contact with hard tissues (132). The CO_2 lasers also could be used in a continuous wave or pulsed (132).

Er:YAG and Er, Cr:YSGG lasers firstly target water or hydroxide ion (OH^-) and secondly minerals (132). Er:YAG lasers have a 2,940 nm wavelength and Er, Cr:YSGG lasers have a 2,780 nm wavelength (132). Both of them have free running pulsed emission modes (132). Erbium lasers could be used in both hard and soft tissue and they are more appropriate than other lasers for the debridement around implants due to their friendly mechanism of action (132).

The Er:YAG lasers are useful in dental treatments because of their wavelength highly absorbable in water (131). There are available data in the literature which showed Er:YAG lasers have bactericidal effects (133). The data from recent *in vitro* studies have shown that Er:YAG lasers may be appropriate for the decontamination of implant surfaces because they did not increase implant body temperature (134).

Kreisler et al. evaluated the bactericidal effects of the Er:YAG lasers on implant surfaces in an *in vitro* study (131). They incubated titanium implant plates with *Streptococcus sanguins* and evaluated the colony units and temperature elevations after Er:YAG laser treatment (131). The microbiological and microscopy results of this study proved that the Er:YAG lasers have a high bactericidal effect on implant surface and critical temperature threshold is not exceeded (131)

Saffarpour et al. investigated the potential implant surface alterations after decontamination with Er:YAG lasers, photodynamic treatment and chlorhexidine in an *in vitro* study (135). It is concluded that, Er:YAG lasers and photodynamic therapy did not change the implant surfaces (135).

Another *in vitro* study of Giannelli et al. assessed the effects of Er:YAG lasers and ultrasonic scaler on implant surfaces contaminated with subgingival plaque (136). This study showed that an ultrasonic scaler with metal tip has less success than the Er:YAG laser decontamination. Both methods were found efficient for restoring sufficient osseoconductivity (136).

A recent study of Karaca and Tunar investigated the cleaning efficiency of an air abrasive device with trehalose powder on implant surface compared to Er:YAG laser applications using two different bone defect angulations in an *in vitro* study (17). They used 40 ink-stained implants which were mounted in epoxy resin models with 30° and 60° angulated defects (17). They concluded that the air abrasive devices showed better cleaning efficiency than the Er:YAG laser and special instrumentational care is necessary at the apical part of the peri-implant bone defect (17).

Hakkı et al. investigated the efficiency of different cleaning methods and temperature changes on the implant surfaces in vitro (97). They used plastic curette, titanium curette, carbon curette, titanium brush, Er:YAG laser, ultrasonic scaler, air abrasive device with citric acid and implantoplasty (97). It is concluded that the most successful method for debridement of the implant surfaces was the use of air abrasive device and Er:YAG laser. When hand instruments were compared, titanium curettes were found more successful than both plastic and carbon curettes (97). The temperature on implant surfaces was higher after hand instrumentation (97).

In a study of Takasaki et al., the efficiency of Er:YAG lasers on implant surface debridement in peri-implant infections were evaluated (137). They induced experimental peri-implant infections in dogs and treated with Er:YAG laser or a plastic curette (137). The laser group revealed a leaning to produce greater bone-to-implant contact than the curette group showing commitment in the treatment of peri-implantitis (137).

Renvert et al. studied the treatment efficiency of air abrasive devices and Er:YAG lasers in patients with severe peri-implantitis (91). Although the results of this study were limited, similarities between the two procedures were pointed (91).

Schwarz et al. searched the clinical effects of Er:YAG lasers for non-surgical treatment of peri-implantitis in a pilot study (134). They compared the mechanical debridement with Er:YAG laser, plastic curette and antiseptic agent application. The results showed that treatment with both Er:YAG lasers and curettes may result in a statistically significant decrease in probing depths and an increase in clinical attachment levels (134). In another study by Schwarz et al., they assessed clinical and histopathological healing process of peri-implantitis lesions after non-surgical treatment with Er:YAG lasers (138). It is concluded that a single application of Er:YAG laser may not be adequate to maintain failing implants (138).

2.6.1.4. Air Abrasive Devices

Air abrasive devices are introduced for an efficient and safe treatment of peri-implant diseases in 1980’s and recently they are gaining popularity in the treatment of peri-implant

diseases (83,109). They can decontaminate the implant surfaces and can be used as an alternative option to curettes, sonic and ultrasonic devices (76,88). Air abrasive devices require the use of an abrasive powder and work with a stream of compressed air to remove microbial dental plaque (139). These devices apply a mixture of water, air and abrasive powder at pressures in a range of 65 to 100 pounds per square inch (psi) (139). In the literature, *in vitro* studies proved that air abrasive devices have superior or equal decontamination effects when compared to other debridement methods (83,84,86,88,89,91,93,96,98,99,102,104,140). They have advantages of achieving both mechanical and chemical debridement, removing both supra and subgingival biofilm, causing less discomfort to patients than other mechanical debridement methods, having lower abrasiveness level, requiring less time for treatment and having powders which can be resorbed by the organism (83,88,89,98,104,109,140).

Air abrasive devices can clean the dental implant surfaces without causing any serious damage (109). This qualification is related with the particle sizes of powders being used in air abrasive devices (83,84,86,88,93,102,104,109,140). The first developed powder was the sodium bicarbonate which was extremely abrasive on dental implant surfaces (83,102,104,109). Afterwards, a less abrasive amino acid glycine powder was introduced to minimalize the damage on dental implant surfaces which have 20-65 micrometers (μm) particle size (84,88,102,104). Since the introduction of amino acid glycine powders, other low abrasive powders which are aluminium trioxide and calcium carbonate are developed (104). Aluminium trioxide has 2 to 5 μm particle diameter size and calcium carbonate have 25-65 μm particle size (88). Thereafter, an erythritol powder with chlorhexidine gluconate was introduced (104). Chlorhexidine helps to reduce inflammation parameters (84). More recently, trehalose powder is developed (93). These powders are important because their remnants are expected in peri-implant tissues and they might affect the biocompatibility of dental implant surfaces and biologic responses during healing (104). Amino acid glycine can reduce bacterial recolonization in 24 hours and does not change implant surface (98,102). Glycine is an endogenous substance which can be resorbed by the organism (89). Trehalose powder is a very efficient disaccharide in decontamination of implant surfaces (140). The surface decontamination with these systems is expected to restore the initial implant surface

properties and help re-osseointegration after treatment (88). Because of this, it is important to use bioactive and osteoconductive powders as cleaning powders (88).

Due to the paucity of information in the literature about conventional air abrasive devices and risk of powder attachment to the implant surface, a new generation air abrasive device is developed recently using trehalose powder (139–141). Subgingival cleaning of root and implant surfaces can be completed smoothly and without interruption by quickly swapping the two nozzles (supragingival and subgingival nozzles) (140,141). Both nozzles have ability to rotate 360° degrees for enabling access to all regions of the oral cavity (141). The subgingival nozzle has a narrow and flexible structure (141). Working range of this nozzle is 11.7 mm and this length facilitates access to pockets >8 mm deep. This air abrasive system can be used with a special powder (141). The powder which is used with this instrument is a trehalose powder with 30 μm particle size. Kruse et al. investigated clinical parameters after using this system to remove subgingival biofilm in 44 patients (140). Their control group received cleaning with a sonic scaling device (140). As a result, they concluded that none of the two decontamination methods proved superior clinical effects on bleeding on probing, pocket depths and clinical attachment levels but patients were more comfortable with air abrasive device (140). Another study of Kruse et al. investigated the superiority between subgingival debridement with trehalose powder and sonic scaling device in 44 patients (93). They concluded that subgingival debridement with trehalose powder shows different clinical outcomes than sonic scaling device. Sonic scaling device was less comfortable than air abrasive device (93).

Schwarz et al. assessed the efficiency of air polishing on peri-implant inflammation compared with control treatments such as using adjunctive antiseptic and antibiotic therapy (112). They reported that, while using glycine powder in air abrasive devices was as effective as the control treatments at peri-implant mucositis sites, it may improve the efficiency of non-surgical treatment of peri-implantitis over the control treatments, however, complete healing was not achieved (112).

Sahrmann et al., in their *in vitro* study assessed three different instrumentation methods on implant models using a bone-defect-simulating model with 30°, 60° and 90° angulations (90). The instruments used in this study were gracey curettes, ultrasonic devices and air abrasive devices including glycine powder (90). They found that air abrasive devices including glycine powder is an efficient treatment alternative for the decontamination (90).

Ronay et al. also investigated *in vitro* cleaning efficacy of gracey curettes, ultrasonic device and an air abrasive device including glycine powder on implant models with the same defect angulations but covered with a hand-made artificial mucosa mask (92). They concluded that a complete surface decontamination could not be achieved regardless of the method used, however, the air abrasive devices showed a better cleaning efficacy for all defect angulations than the other methods (92).

John et al. evaluated the efficiency of an air-abrasive device in non-surgical treatment of peri-implantitis in a clinical study (142). They found out that non-surgical therapy of peri-implantitis using air abrasive device and carbon curette resulted with a decrease in probing depths and gain in clinical attachment level after 12 months of healing (142). The decrease in bleeding on probing were significantly higher in the air abrasive device group in comparison to carbon curette group (142). They concluded that air abrasive device may be more effective for non-surgical treatment of peri-implantitis than carbon curettes (142).

Sahm et al. also investigated the efficiency of an air abrasive device for non-surgical treatment of peri-implantitis in a randomized controlled clinical study (143). They compared the treatment with air abrasive device including amino acid glycine powder and carbon curette in 30 patients (143). It was concluded that both treatment methods revealed comparable but limited gain in clinical attachment level at 6 months and air abrasive device group showed significantly higher decrease in bleeding on probing than carbon curettes (143).

Lupi et al. investigated clinical signs after treatment with air abrasive device using amino acid glycine powder and manual surface debridement with plastic curette followed by

chlorhexidine administration (84). They applied these treatments to a total of 46 patients which have 88 implants in total (84). They investigated plaque index, bleeding index, probing depth, clinical attachment level and bleeding score in each patient (84). The bleeding scores, probing depth, plaque index and bleeding on probing was improved after 3 and 6 months of treatment with air abrasive device and glycine powder (84). The glycine group was seemed more effective treatment method than the traditional debridement treatment with plastic curettes and chlorhexidine method in the maintenance of peri-implant health (84).

Al Ghazal et al. compared the efficiency of two different debridement methods on maintaining peri-implant soft tissue health over a period of 12 months (144). One group was treated with air abrasive device using low abrasive glycine powder and the other group was treated with titanium curettes (144). They indicated that maintaining or improving peri-implant hygiene over 12-month period plays a role in reducing the level of inflammation (144). Also, both debridement methods were showed to have success in reducing peri-implant inflammation (144).

Tan et al. evaluated clinical results, perception of patients and cost-effectiveness of repeated periodontal therapy with air abrasive devices compared to hand instruments and/or power-driven instruments for implant survival rates in a systematic review (145). According to the data they have collected from the literature, repeating subgingival decontamination with air abrasive devices might play a role in improving clinical results compared to hand instruments and/or power-driven devices in implant survival rates (145).

Riben et al. evaluated the clinical treatment efficiency of air abrasive powder device with glycine powder and ultrasonic device on peri-implant mucositis (146). They included 37 patients who were diagnosed with peri-implant mucositis and concluded that treatments with air abrasive powder device with glycine powder and ultrasonic device are both effective in non-surgical treatment of peri-implant mucositis (146).

Based on the above literature review, this study was designed to investigate the cleaning performances of an air powder abrasive device using trehalose powder, an

ultrasonic device with a special designed implant tip and an ultrasonic device with a subgingival tip in the non-surgical treatment of titanium implant surfaces.

3. MATERIALS AND METHODS

This *in vitro* study was conducted in Yeditepe University Faculty of Dentistry department of Periodontology. The study design was approved by Institutional Scientific Review Board (approval number 413).

3.1. Sample Size Calculations

Prior to the study, the power of the study was performed with a statistical software program[1] by using a previous in vitro study conducted with Sahrmann et al. (55). According to this calculation the effect size (d) was found 0.627 for the efficacy of cleaning potential parameter (standard deviation was measured as 3.7), α error was 0.05, power (β) was 0.80 used. According to minimum sample size, it was found 10 samples in each working group.

3.2. Standardized Model Preparations

In this study the standardized 30 models were prepared by clear polymethacrylate resin[2] which had narrow defect morphologies with 30° opening angulations (55).

An empty rectangle shaped plastic tray was filled with silicone putty impression material[3], thereafter the cylindrical shaped glass beakers were immediately placed inside this impression material. After 4 minutes 45 seconds, these cylindrical shaped glass beakers were removed from the silicone putty impression. The obtained impression vessel was then ready for using to have study/working models.

The polymethacrylate resin has prepared according to manufacturer instructions. The polymethacrylate resin consists of 2 different components as base and activator. According to guideline, 100 unit of base and 60 unit of activator were bled with a mixer (Figure 3.1).

[1] G*Power program Version 3.0
[2] Epoart, Polisan®, Kocaeli, Turkey
[3] Zhermack Zetaplus Soft Putty, Badia Polesine, Italy

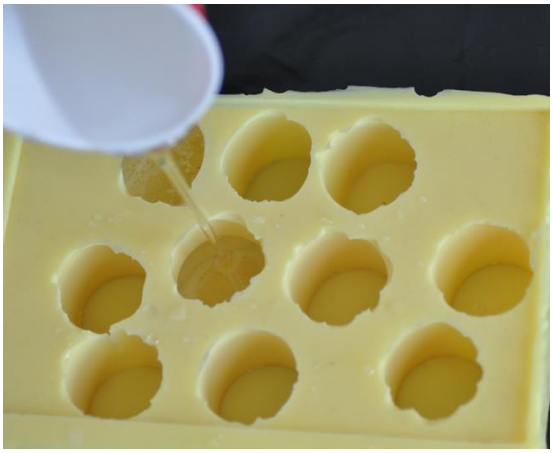

Figure 3.1. Model preparation from clear polymethacrylate

Thereafter, the polymethacrylate resin poured into the holes of impression vessel. After 24 hours, the cylindrical shaped polymethacrylate resin working models were prepared.

The special designed stainless-steel bur (which have 30° working angulation) and hand piece were used with parallelometer[1] for creating the defect angulations on each model. For creating the defect angulation, a parallelometer device[1] and its milling machine was used in a range of 25-35 kHz (Figure 3.2).

[1] Amann Girrbach APF 400, Koblach, Austria

Figure 3.2. The paralellometer device with milling machine

A special designed stainless-steel bur (which have 30° working angulation and 6 mm height) was inserted the milling machine and work on the center of the study model till the bottom line of the angled burr (Figure 3.3, 3.4).

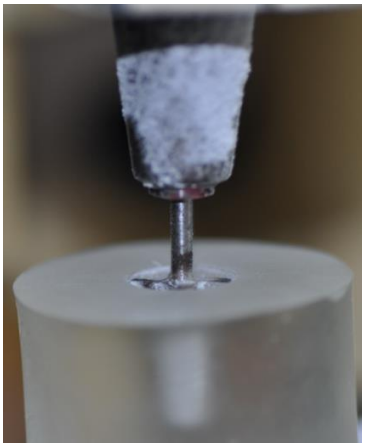

Figure 3.3. Preparation of defect morphologies with 30° opening angulations using 30° burr and a part of milling machine

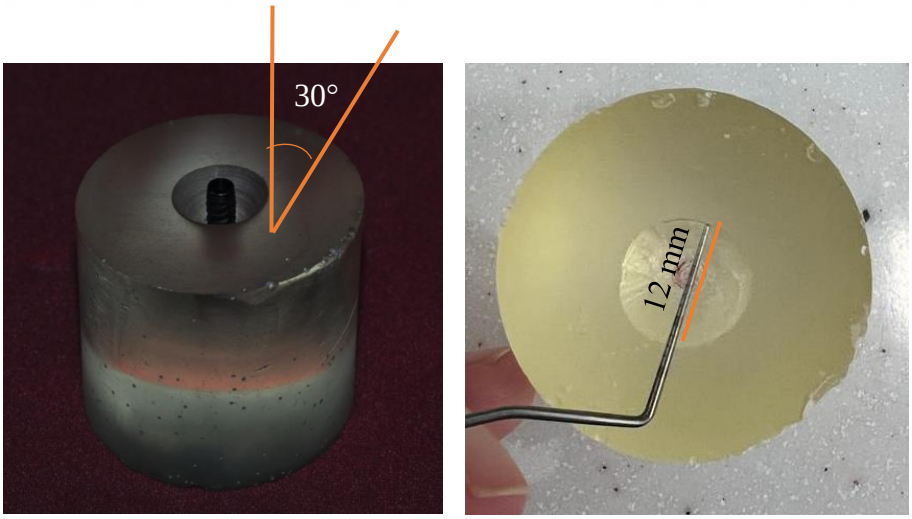

Figure 3.4-3.5. Schematic illustration of the defect models with 30° and 12 mm width

The height of defect on each model was 6 mm and the width of defect was 12 mm according to the diameter of implant simulating a circumferential peri-implantitis defect (Figure 3.3). Then, drilling was done from the center of defect with one implant burr which

has the same diameter (3,75 mm) and height (13 mm) with implants. 30 implants[1] with these measurements were placed in the center of these standardized models (Figure 3.5) (147).

Figure 3.6. Placement of the implants in center of standardized models

Implants with complete roughened titanium (65% hydroxyapatite + 35% calcium phosphate) surface were coated with water-insoluble, non-covering ink stain[2] to stimulate an optically visible biofilm (Figure 3.6) (9).

Figure 3.7. Coating implant surfaces with ink stain

[1] Mode Rapid Implant®, Istanbul, Turkey
[2] Staedler permanent Lumocolor®, Nürnberg, Germany)

Before the insertion, 6 mm of the implants were covered with a sellotape to avoid any contiguity between the implant surface and mucosa mask. And after the insertion, the upper edge of the implant margin was leveled as same with the top plane of the standardized resin model (Figure 3.7) (37).

Figure 3.8. Implant margins leveled as same with the top plane of resin models

Abutments were placed on all implants since all the implant surfaces were embedded in the defect and would then be joined with a mucosa mask to cover their surfaces and the way of working and disassembly has been facilitated.

To simulate the soft tissue, cover of oral environment, models was covered by a non-transparent hand-made mucosa mask[1]. The mask was applied with dental impression mixing dispensing gun[2] with 2 minutes waiting time for each model. (Figure 3.8, 3.9).

[1] Gingifast Elastic®, Zhermack®, Badia Polesine, Italy

[2] Elite HD+®, Italy

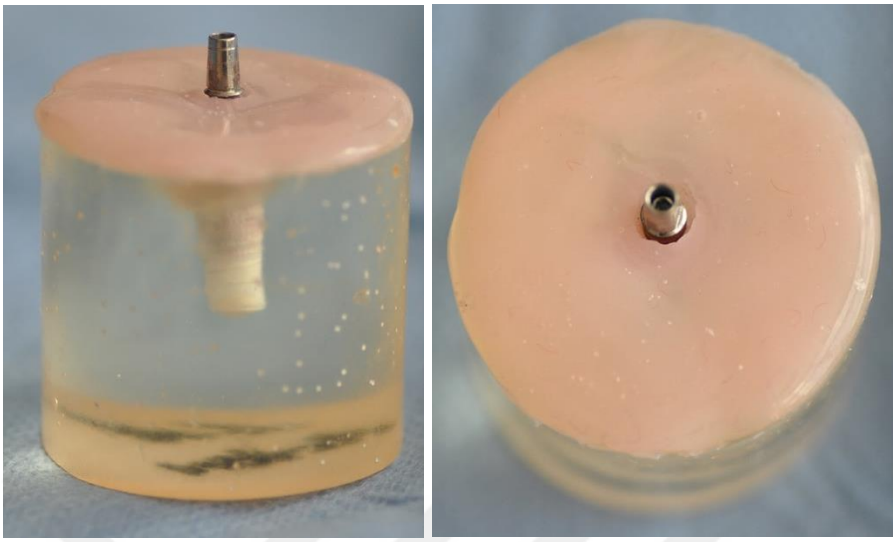

Figure 3.9-3.10. Covering top of the models with a non-transparent custom-made mucosa mask

3.3. Study Groups and Design

Standardized resin models were divided into three groups and three different mechanical instrumentation techniques were used on the implant surfaces as follows:

Group 1	Air Powder Abrasive Device (APAD) group	n=10
Group 2	Ultrasonic Scaler 1 (Newtron® Ultrasonic Scaler (NUS)) group	n=10
Group 3	Ultrasonic Scaler 2 (Vector® Ultrasonic Scaler (VUS)) group	n=10

Group 1: An air powder abrasive device (APAD)[1] and a special perio nozzle for subgingival instrumentation[2] with trehalose powder[3] which has 30 μm grain size were used (Figure 3.10, Figure 3.11).

[1] Powder jet unit MyLunos®, Dürr Dental SE, Bietigheim-Bissingen, Germany

[2] Lunos® Perio Tip, Dürr Dental SE, Bietigheim-Bissingen, Germany

Figure 3.11. 30 µm grain size trehalose powder

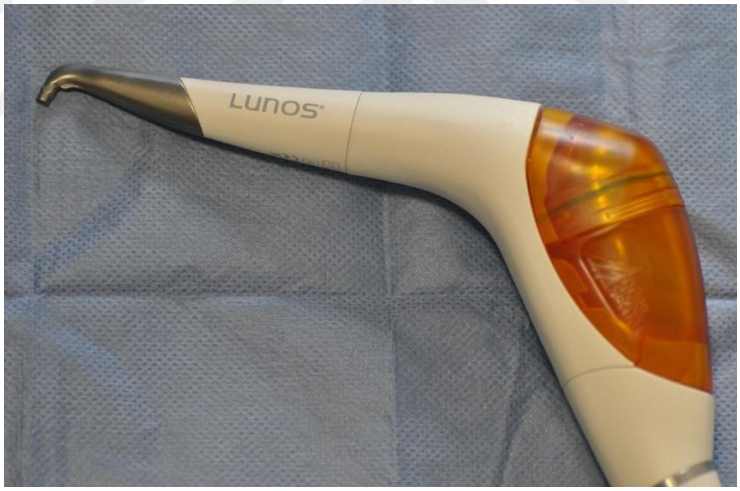

Figure 3.12. The air powder abrasive device

The tip of APAD was placed the created pocket of the defect and applied on each implant surface for 120 seconds with perio nozzle tip which was parallel to the implant surfaces. Horizontal sweeping movements were performed with the nozzle tip on each implant defect surface. A new nozzle tip was used for each working model, then discarded. (Figure 3.12). The working length of nozzle tip is 11.7 mm. The water pressure of this device is maximum 200 kPa and water output flow is 70 ml in per minute. The air pressure of APAD is maximum 400 kPa. The powder unit capacity is 40 cm[1].

[1] Lunos Prophy Powder Perio Combi®, Dürr Dental SE, Bietigheim-Bissingen, Germany

Figure 3.13. Instrumentation with the air powder abrasive device

Group 2: The first ultrasonic scaler application was performed with an ultrasonic device (NUS)[1] with a special designed implant tip[2] (IP2L tip) (Figure 3.13, 3.14). Application was performed for 120 seconds under water cooling, with horizontal sweeping movements. (Figure 3.15, 3.16). The scaler tip was parallel to implant surfaces. The tip is left angled. Horizontal sweeping movements were starting from the bottom of the peri-implant defect to upper surface of implant. The NUS was used at green LEDs light on. This setting has a very low to low power. The operating frequency range of NUS is 28-36 kHz. The maximum amplitude of NUS is 200 μm. Total operating watt is 150 W. The water output flow was 40 ml in per minute and NUS is working with mains water system. No additional lateral force was used to perform during application.

[1] Newtron® P5 XS Bled, Acteon®, France.

[2] IP2L tip, Acteon®, France.

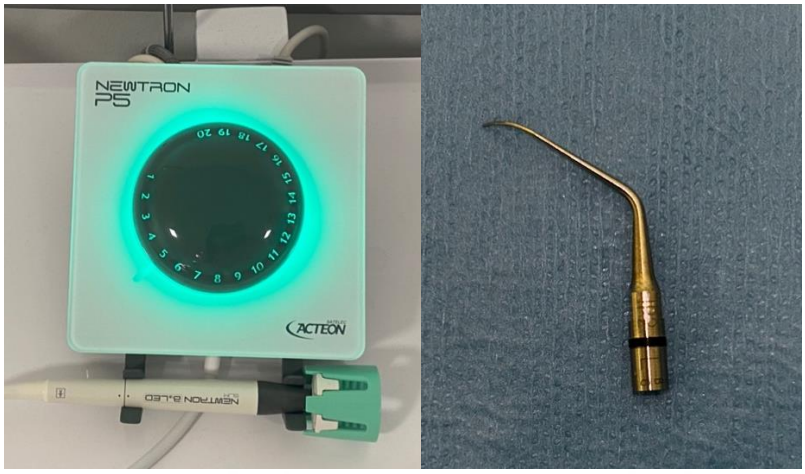

Figure 3.14. The ultrasonic scaler (NUS) device and IP2L tip

Figure 3.15. The IP2L tip

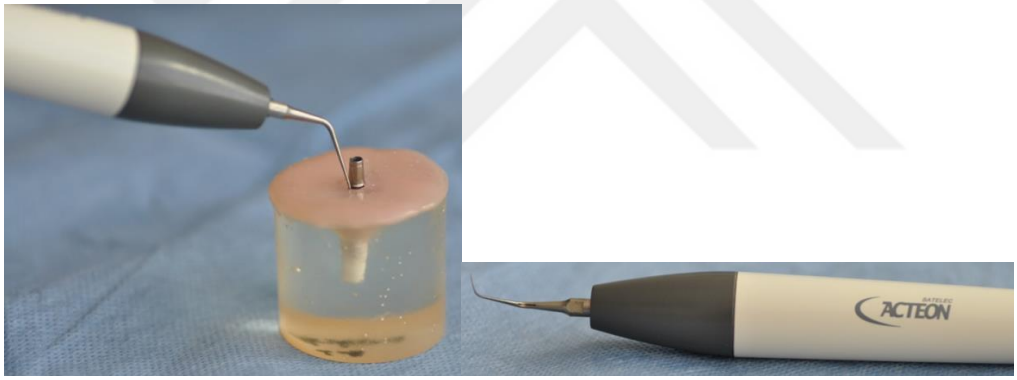

Figure 3.16-3.17. Instrumentation with an ultrasonic device with special designed tip

Group 3: The second piezoelectric ultrasonic device (VUS)[1] with P1 tip[2] applied on the implant surfaces (Figure 3.17). The application duration was 120 seconds. The tip was kept parallel to the implant surfaces (Figure 3.18). The application was performed in a standardized manner, starting from the bottom of the defect, and care was taken to feel and traced all the thread surfaces, by making a circular sweeping motion circumferentially and along the implant. The VUS was used at 4 LEDs light on and 80% full operating power with a constant stream of distilled water[3] coolant delivered from the water tank of the device (Figure 3.19). The operating frequency of VUS with scaler handpiece is between 27-32 kHz.

[1] Vector® Paro Pro, Scaler hand piece, Dürr Dental SE, Bietigheim-Bissingen, Germany
[2] P1 tip, Dürr Dental SE, Bietigheim-Bissingen, Germany
[3] Sterile distilled water, Koçak farma, Turkey

The amplitude of VUS differs according to the tips used and is between 20-120 μm. Total operating watt is 230 W. The water outflow of VUS was selected at 3 LEDs light on and fluid consumption is 45 ml of fluid per minute for 3 LEDs light on. Total fluid container capacity is 600 ml. No additional lateral force was used to perform during application.

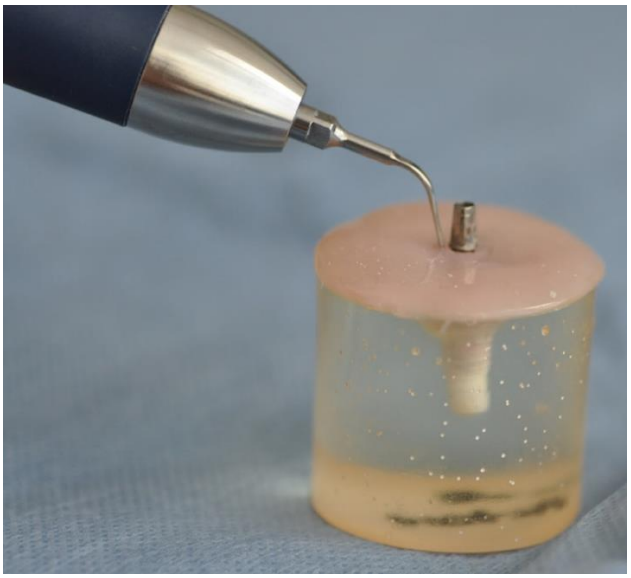

Figure 3.18. The ultrasonic scaler (VUS) device

Figure 3.19. Instrumentation with P1 tip of VUS device

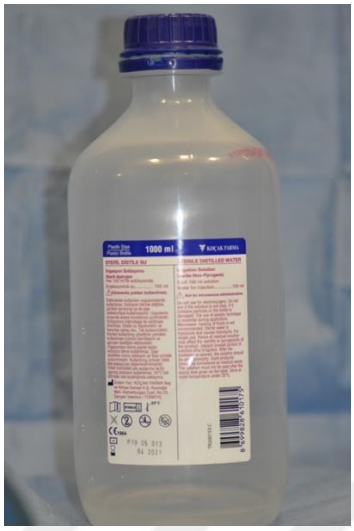

Figure 3.20. Distilled water

3.4. Evaluation of the Surface Cleanliness

After the application of different mechanical instrumentation methods of the groups, implants were gently ejected from the models and unengaged ink particles were removed cautiously with water and air spray.

Digital photographs were shot vertically to the implant axis with a DSLR camera[1] and macro lens[2] with standardized parameters (objective 105 mm macro, 2 units of 500-watt paraflash photography light[3]). Series of photographs was taken to the implants since the whole implant surface was digitally collaged like panoramic view. Each implant was photographed 12 times from every 30° angle (148). The rotational references of the implants were performed based on the lines on the implant driver (Figure 3.20).

[1] Nikon D810®, Tokyo, Japan
[2] Tamron® SP AF 90mm f/2.8 Di Macro Lens, USA
[3] Hensel®, Germany

Figure 3.21. The rotational references of implants on the implant driver

Taken photographs were collaged (implant driver part was excluded) and designed as a panoramic view by a graphic designer program[1] (Figure 3.21). Thereafter, implant surfaces were investigated for residual stain with these digital photographs.

[1] Adobe Photoshop®, USA

Figure 3.22. The collaged photograph of implant excluding implant driver

The remnants of ink stains on the implant surfaces are detected using by an image processing software[1] (Figure 3.22) (17). During measurements the scale was set with the length of the implant (13 mm) as perform the real size measurement (Figure 3.23).

Figure 3.23. The detection of remnant ink stains on implant surface with image processing software

[1] ImageJ® 1.46r, National Institutes of Health, Bethesda, Maryland, USA

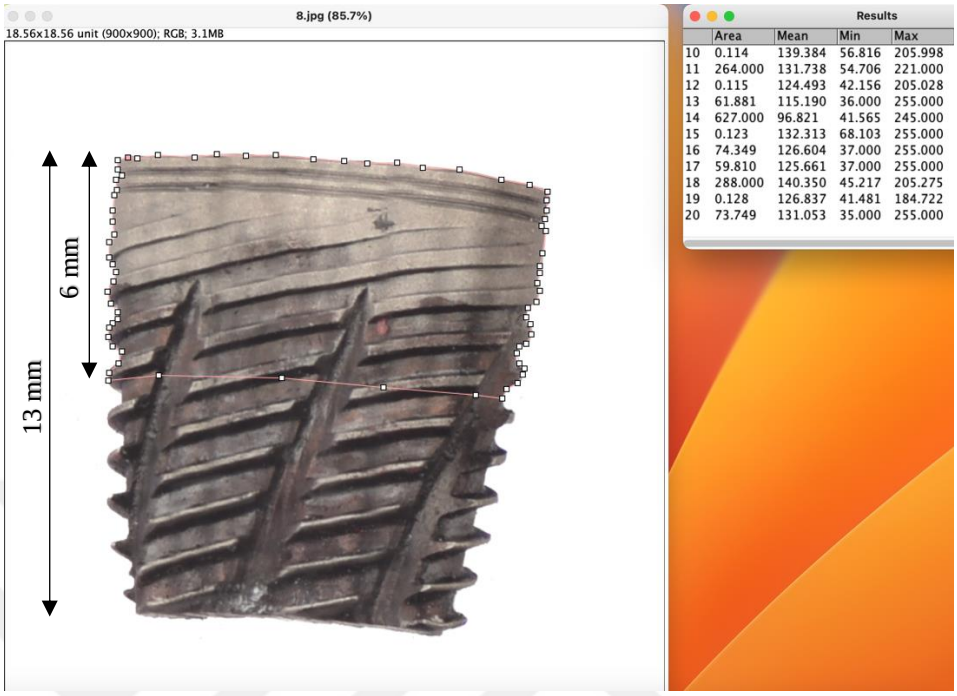

Figure 3.24. The setting of scale and measurements of cleaned area

The cleaned surface area, the percentages of cleaned defect area and also scoring from 1 to 6 is made according to the residual stain amounts were calculated by these panoramic images (147).

The score of surface cleaning were describe below.

- Score 1: indicates a surface nearly fully covered by residual ink stain (>95%)
- Score 2: indicates a surface that is covered by residual stain for more than $^{3}/_{4}$ (75-95%)
- Score 3: indicates a surface that is covered by residual stain for more than a half (50-75%)
- Score 4: indicates a surface that is covered by residual stain for less than a half (25-50%)
- Score 5: indicates a surface that is covered by residual stain for less than 25% but considerable residual stains (5-25%)
- Score 6: indicates nearly perfectly clean surfaces (<5%)

3.5. Statistical Analysis

The analyses of data were performed with IBM SPSS Statistics 22 program. Significant statistics for continuous variables were proffered as arithmetic mean ± SD and median. The pertinence of normal distribution was calculated with Kolmogorov-Smirnov and Shapiro Wilks tests and parameters was found as normal distribution. Intergroup comparisons were evaluated with Oneway Anova test, Kruskal Wallis test and for determining the group which causes difference Tamhane's T2 test and Tukey HSD test were used. Statistical significance was accepted at $p<0.05$ level.

4. RESULTS

In this *in vitro* study, the residual ink staining was observed in all implant surfaces following mechanical surface cleaning methods. Statistically significant difference was found in terms of total cleaned area between the 3 study groups (p:0.010, p<0.05). After Tamhane's T2 test evaluation for pairwise comparison the total cleaned area of the APAD group was significantly higher than both NUS (p:0.020, p<0.05) and VUS (p:0.022, p<0.05) groups. There was no significant difference between the NUS and VUS groups (p:1.000; p<0.05). Data are shown in the Table 4.1 and Figure 4.1.

Table 4.1. Evaluation of the total cleaning areas of the groups (mm^2)

	Cleaned Area
	Mean±Standard Deviation (SD)
APAD	32,58±10,30[ab]
NUS	23,92±4,00
VUS	24,00±3,63
p	0,010*
Oneway ANOVA test	**p<0.05*
a (APAD vs NUS)	*Tamhane's T2 test*
b (APAD vs VUS)	*Tamhane's T2 test*

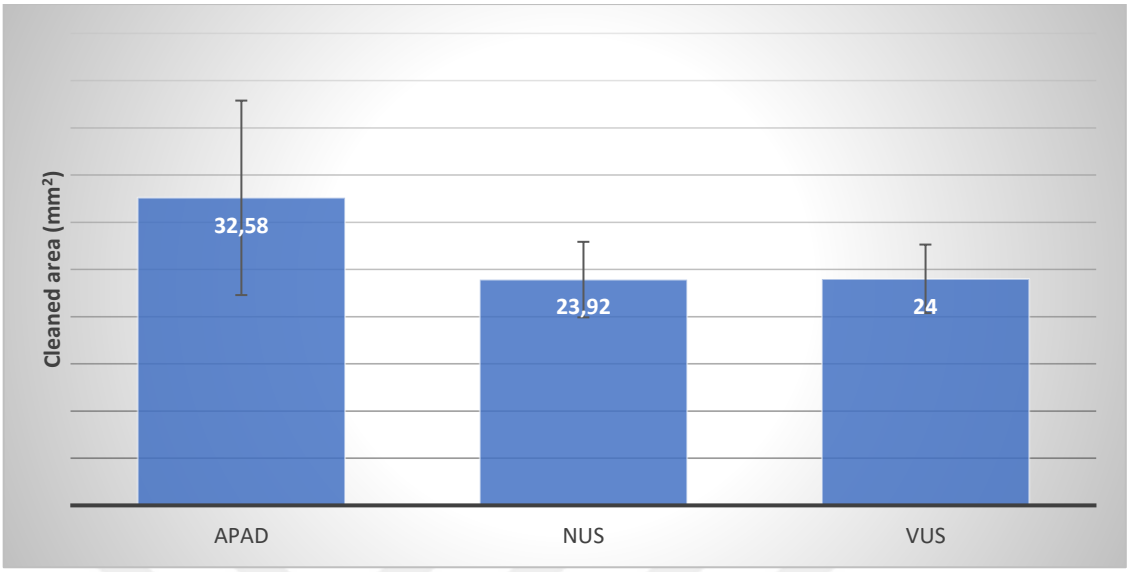

Figure 4.1. The graphic of total cleaned areas (mm^2) between three groups

Statistically significant difference was found between 3 study groups in terms of total cleaning percentage of the defect area of the implant surfaces. (p:0.013; p<0.05). After Tukey HSD test evaluation average percentage of cleaned area of the APAD group was significantly higher than both NUS (p:0.017) and VUS (p:0.044) groups. There was no significant difference between the NUS and VUS groups (p:0.914; p>0.05). Data represented in the Table 4.2 and Figure 4.2.

Table 4.2. Comparisons of the total cleaned area percentages of the implant surfaces

	Percentages of Cleaned areas
	Mean±Standard Deviation (SD)
APAD	42,77±8,86[ab]
NUS	34,20±4,42
VUS	35,37±5,53
p	0,013*
Oneway ANOVA test	**p<0.05*
a (APAD vs NUS)	*Tukey HSD test*
b (APAD vs VUS)	*Tukey HSD test*

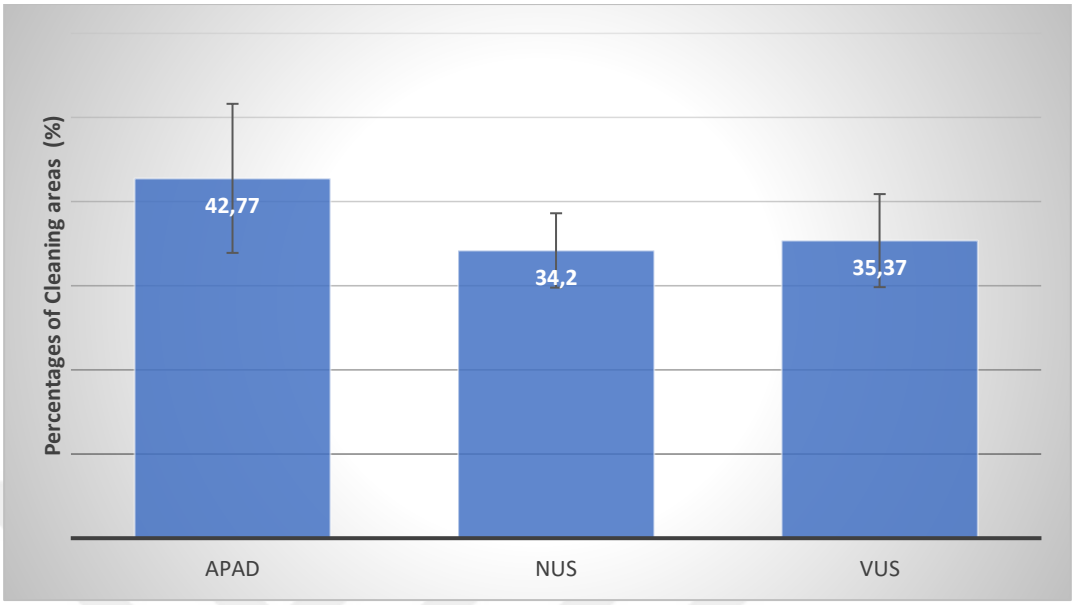

Figure 4.2. The graphic of cleaning area percentages between three groups

There was no statistically significant difference between the groups according to their cleaned area scores (p>0.05). The data are represented in the Table 4.3.

Table 4.3. Comparisons of the cleaned area scores

	Cleaned area scores
	Mean±Standard Deviation (SD)
APAD	3,90±0,31 (4)
NUS	4,0±0 (4)
VUS	4,0±0 (4)
p	0,368

Kruskal Wallis test

Representative photographs of the groups

Representative photographs of the study show the macro differences between the groups (Figure 4.3.). It is clearly seen that the APAD application maintains the appearance SLA coating, similar to the matte surface of the untreated implants without making a macro change on the areas where the dye was removed. On the other hand, it was observed that

the matte surface appearance disappeared in both NUS and VUS applied areas and the tips caused a shiny appearance in the worked areas.

In addition, it was observed that all devices provided less cleaning in areas close to the base of the defect. Also, the APAD group provided a better cleaning in the areas between the threads.

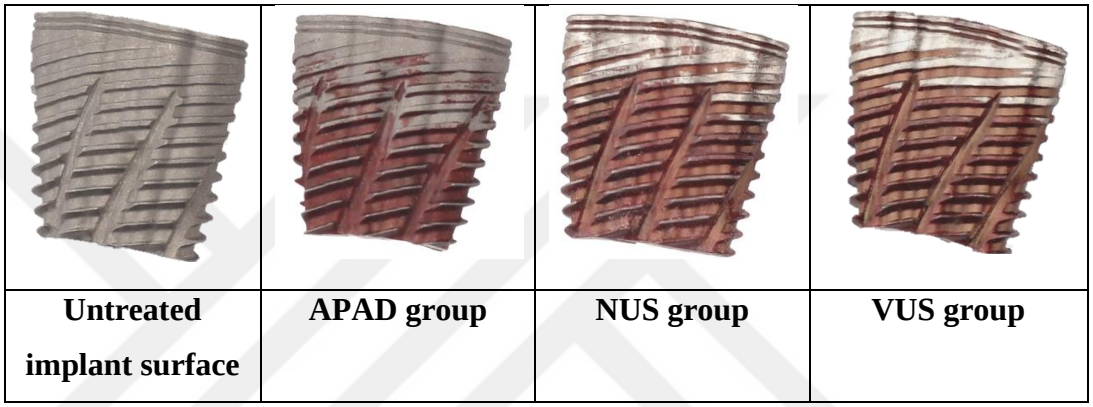

Figure 4.3. Comparison scheme of the working groups.

5. DISCUSSION and CONCLUSION

Mechanical debridement of implant surfaces remains the gold standard in peri-implant diseases. It is essential to achieve biologically acceptable implant surface to reduce and prevent peri-implant infections. Non-surgical peri-implant treatment is a key stone for success in peri-implant diseases. Mechanical debridement of the implant surface is also a key factor during surgical therapy; both in regenerative treatment which the defect is infused and resective treatment which peri-implant pocket is resolved (38). Nevertheless, there is no universally accepted standard treatment protocol for peri-implant diseases. Therefore, this study evaluated three mechanical debridement devices and a new air abrasive cleaning powder on the exposured surfaces of implants stained with ink in an *in vit*ro peri-implantitis model. The results could guide for clinically applicable approaches in peri-implant diseases.

Peri-implant diseases contaminate the implant surface and therefore, mechanical and/or chemical decontamination of implant surfaces to upgrade the prognosis of dental implants are strongly recommended (60,67,94,125,149–152). However, there are studies showed that some mechanical or chemical debridement approaches may change the implant surfaces (17,63,83,86,97,101–103,106,109,119,127,131,153–155). The search for the least harmful and effective debridement method is continuing to be searched and *in vitro* studies aim to find out the most appropriate approach for long term implant health. For now, there is no alternative to treat and prevent the peri-implant diseases without surface decontamination (67,80,126)

Curettes, power-driven devices, special brushes, air abrasive devices and lasers can be used as a part of non-surgical mechanical treatment in peri-implant diseases (17,142,156–160). Some treatments usually provided reductions in probing depths, bleeding on probing and clinical attachment levels because of the removal of biofilm related peri-implant disease modifying factors (93,140). Since, there is a lack of information for a standard treatment protocol and no consensus for the therapy of peri-implant diseases, this is an important subject matter for researchers to investigate (161). The main reason for implant failure is the untreatable forms of peri-implant diseases with concurrent supporting bone loss (162).

Therefore, this study evaluated the cleaning potential of a power-driven air abrasive device with abrasive trehalose powder, ultrasonic scaler with a special designed implant tip and piezoelectric ultrasonic device with special designed implant tip on ink-stained implant surfaces in an *in vitro* model with angulated defect morphologies. Residual stain remnants were assessed on the implant surfaces in all study models after the debridements. As a result, the air abrasive powder device with treahalose powder showed better cleaning performance than the both ultrasonic and piezoelectric ultrasonic devices ($p<0.05$). Although the total cleaning performance of air abrasive powder device was better, a thorough cleanliness was not provided.

Treatment of peri-implant diseases through mechanical approaches, and cleaning, decontamination surface changes of various instrumentations on implant surfaces have been an active area of research for years (60,79,125,149–152,161–163).However, according to the latest treatment guideline written by using the systematic and metanalysis of randomized control trials in the literature, we have a long way to go for achieving successful outcomes to lower the prevalence of peri-implant diseases. As the biological aspect of implant failure etiologies peri-implantitis treatment is rather challenging whereas peri-mucositis is reversible with early intervention. The number of studies to be included in such systematic reviews and metanalysis to reach a consensus is still very limited due to the high risk bias of the performed researches. The number of study materials as well as the method appropriate for the aim of the research are of critical importance. In this study, new generation ultrasonic devices with special implant tips and a recently introduced air abrasive device were tested by using standardized study models and working protocol.

Although there is inadequate data to recommend air abrasive powder devices for the treatment of peri-implant diseases, air abrasive powder devices are considered as one of the alternatives for implant surface debridement due to their safety and friendly mechanism of action (86). In this study we found that air abrasive device with trehalose powder revealed the best cleaning performance on implant surfaces without any detectable surface changes on photographs. Previous studies showed that air abrasive powder devices have an equal cleaning efficiency compared to other mechanical debridement approaches such as the use

of sonic scalers (93). Also, in Sahrmann et al. study, using a similar method with our study, images of the implant surfaces showed that the cleaning efficiency of air powder abrasive devices was enhanced in wide defects and there were no surface alterations compared to curette and ultrasonic device (164). Other *in vitro* studies in the literature reported that air abrasive devices with small particle powders have less harmful effects on implant surfaces (89,92,101,106,126–128,159,164).

Recent literature on power-driven and air abrasive devices for decontamination of implant surfaces were mostly studied on discs and investigated the cleaned areas of flat surfaces excluding defect morphologies (102). There were limited studies in the literature mimicked peri-implantitis defect morphologies (83,92,164). In the study of Sahrmann et al., they investigated three different instrumentation methods using gracey curettes, ultrasonic device and air abrasive device with abrasive glycine powder in a bone defect-simulating models with 30°, 60° and 90° angulations (164). They found out that air abrasive devices with abrasive glycine powders were appear to be constitute for an effective treatment option for the implant decontamination. Air abrasive device group had least residual ink remnants ($11.3 \pm 5.4\%$) and it is followed by ultrasonic device group ($18.5 \pm 3.8\%$) and gracey curette group ($24.1 \pm 4.8\%$) on implant surfaces (164). Narrow defect models with 30° angulation as it is in our study model showed more residual ink remnants than wider defect models with 60° and 90° angulations in simulation peri-implant defect models (164). Matsubara et al. showed that two small-sized particles glycine (20-65 μm) and erythritol (14 μm) powders have less cleaning capacity than large-sized sodium bicarbonate (75-300 μm) (83). But due to the surface damages by large-sized particles, trehalose powder with 30 μm particle sized was preferred as the test material in this study. In a study of Wei et al., researchers compared different sized particle abrasive powders (glycine, sodium bicarbonate, calcium carbonate) in a 60° angulated peri-implantitis defect model (86). They also found out that small-sized glycine powder had less cleaning efficiency and surface alterations on implant surface than the large-sized sodium bicorbanate and calcium carbonate (25-65 μm) powders (86). Ronay et al., investigated the cleaning potential of gracey curettes, ultrasonic devices and an air abrasive device including glycine powder on implant models with 30°, 60° and 90° defect angulations covered by a hand-made artificial mucosa mask and ink-stained implants (92).

They concluded that a complete surface decontamination could not be succeeded in any of the instrumentation applied, however, the air abrasive device resulted with a better cleaning efficacy for all defect angulations (92). Also models with similar 30° defect angulations covered by a hand-made artificial mucosa mask were used to avoid the visual control of the cleaning and to simulate both soft tissue covering of peri-implant defect during mechanical debridement. Implants were ink-stained to represent microbial plaque biofilm in this our study. Ink-staining could be more recalcitrant to remove from implant surfaces, however, residual staining has advantage of being easily assessed in the photographic evaluations (104).

In another study of Ronay et al., researchers investigated the localization of ink-stainings (147). They created hand-made standardized models from polymethacrylate resin with 30°, 60° and 90° defect angulations and used a steel gracey curette, an ultrasonic device with steel tip and an air abrasive powder device with glycine powder (147). After application of these three methods, digital photographs were taken from implants and residual staining remnants were calculated with a custom-programmed planimetrical software (147). According to these calculations, researchers made a grading for each implant ranging from score 1 to 6 and found out that apically facing threads of implants were the least clean group which was scored as 1, machined surface area of implants were the most cleaned group scoring as 5 (147). The highest scoring was made to air abrasive powder device and highest score was between 2 and 4 (147). In our study, scoring was also done but according to calculations of cleaned areas, almost all implants except one scored as 4.

Nart et al. investigated the 12-month clinical and radiographic consequences of treatment of peri-implantitis lesions with ultrasonic devices and air powder abrasive device with abrasive glycine powder (129). The researchers applied supra and subgingival treatment on patients who were diagnosed with peri-implantitis and both clinical and radiographic outcomes were noted after 12 months (129). They concluded that non-surgical therapy of peri-implantitis was efficient in preventing advanced bone loss, reducing pocket depth and suppuration and achieving radiographic bone fill (129). In another pilot study of Karring et al., researchers investigated the clinical effectiveness of the new generation ultrasonic linear

oscillating system with carbon fiber tips (Vector® Paro) and carbon-fiber curettes in the treatment of peri-implantitis (165). Researchers compared the baseline and 3 months measurements of bleeding on probing clinically (165). They found that there was a greater reduction in bleeding on probing after treatment with this ultrasonic system, but suggested that further research should be carried out to evaluate the possible role of ultrasonic devices (165). As a result, our study aimed to provide a significant contribution to the literature regarding cleaning potential of two different ultrasonic scaler which revealed similar but less cleanliness.

In an *in vivo* study of Kawashima et al., researchers evaluated the efficacy of three different piezoelectric ultrasonic scaler tips (carbon, plastic and metallic tips) in the therapy of peri-implant diseases (128). Abutment surface characteristics were assessed with scanning electron microscope after debridement with these tips and it is stated that non-metal tips were causing less surface alterations than metallic tips (128). The carbon tip and plastic tip groups left more smooth surfaces than metallic tip group revealed similar cleaning efficiency as metallic tip on abutments (128). Similar alterations occurred with subgingival tip and peri-implant tip on implant surfaces in our study, assessed on photographs APAD group had smooth surfaces because of its plastic tip. Accordingly, cleaning potential comparison between the two different ultrasonic scalers with their tips and air abrasive device with subgingival tip revealed. Air abrasive device with subgingival tip caused no surface alteration on the implant surface compared to ultrasonic scalers presenting a shiny and clear view after instrumentation.

Further research is necessary to compare the cleaning effects and alterations of implant surface after applying trehalose powder and other small-sized abrasive powders under standardized provisions as well as between the tips of new generation ultrasonic scalers. Moreover, besides clinical evaluations for microbial changes and recolonization on implant surfaces, the identification of the relationship of implant surface changes and regenerative treatment consequences are of interest.

In conclusion, within the limits of this study, the air abrasive device with subgingival trehalose powder provided better cleaning efficiency than the two different power-driven ultrasonic devices, although complete surface cleanliness was not succeeded in any of them. Regardless of the cleaning method, the residual remnants of ink-stained surfaces especially towards the apical region of the defects show that special care for debridement or instrumentation is needed at the base of the peri-implant bone defect.

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7. CURRICULUM VITAE

Personal Informations

Name	Müge	**Surname**	MÜEZZİNOĞLU

Education

Degree	Department	The name of the Institution Graduated From	Graduation year
Doctorate			
Master			
University	Yeditepe University	Faculty of Dentistry	2017
High school	İstek Acıbadem Anadolu Lisesi	-	2012

Languages	**Grades (#)**
English	YDS: 72,50

All the grades must be listed if there is more than one (KPDS, ÜDS, TOEFL; EELTS vs),

Work Experience (Sort from present to past)

Position	Institute	**Duration (Year - Year)**
		-
		-

Computer Skills

Program	**Level**

***Excellent , good, average or basic**

Scientific works

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

Articles published in other journals

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

Journals in the proceedings book of the refereed conference / symposium

Others (Projects / Certificates / Rewards)
