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COMPARISON OF OSTELL VALUES, INSERTION AND REMOVAL TORQUE VALUES BETWEEN SHORT AND LONG IMPLANTS

DOCTOR OF PHILOSOPHY THESIS

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Ahmet Decani

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM - American Society for Testing and Materials

ATH - Acceleration Time History

CAD - Computer-aided Design

Ca - Calcium

CAM - Computer-aided Manufacturing

Cm - Centimetre

Co - Cobalt

Cr - Chromium

CT - Computerized Tomography

CSR- Cumulative Survival Rate

FRCs - Fiber-reinforced Polymer Composites

HA - Hydroxyapatite

HCL - Hydrochloric Acid

H2SO4 - Sulfuric Acid

Hz - Hertz

IAN - Inferior Alveolar Nerve

ISQ - Implant Stability Quotient

IT: Insertion torque

OH - Hydroxide

MAO - Micro-arc Oxidation

MM - Millimetre

MO - Molybdenum

NB - Niobium

N - Number of Sample

Ncm - Newton Centimetre

NiTi - Nickel Titanium

Ni - Nickel

RFA - Resonance Frequency Analysis

RT: Removal Torque

SD - Standard Deviation

SLA - Sandblasted and Acid-Etched

Ta - Tantalum

TCP - Tricalcium Phosphate

Ti - Titanium

TiO_2 - Titanium Dioxide

TPS - Titanium Sprayed Plasma

V - Vanadium

Zr - Zirconium

ABSTRACT IN ENGLISH

Decani A. (2022) Comparison of Ostell Values, Insertion and Removal Torque Values between Short and Long Implants. Yeditepe University, Institute Of Health Sciences, Department of Oral and Maxillofacial Surgery, PhD Thesis. Istanbul

One of the best treatment option for replacing missing teeth is dental implants and survival rates of dental implants vary depending on many factors such as surface properties of implants, patient habits, prosthetic factors and bone density. Bone density is a determining factor in dental implant treatments especially in short dental implants. The literature showed that implant losses were more experienced in areas with low bone density due to peri-implant forcing and tensions. The purpose of this study was to compare Ostell values, the insertion and removal torque values of 5-mm short implants and 10-mm standard size implants into two different types of bones (D2 and D4 bone densities). A total of 40 dental implants 4.3 mm diameter and 5 mm (n=20) and 10 mm (n=20) in length were placed into the same polyurethane bone block which imitates the structure of D2 and D4 bone type. While inserting and removing the implants, the torque values were recorded at each iteration, and the mean values were calculated from start to finish. The torque values for insertion were calculated until the implants reached the bone level. Primary stability was measured after implant insertion using Resonance Frequency Analysis (RFA). Statistical Package for the Social Sciences (SPSS) was used to analyse the data. Results of this study showed that the insertion torque value of 5 mm length implant in D2 bone (35) was not statistically lower than the insertion torque value of 10 mm length implant in D2 bone (36.5). However, the insertion torque value of 5 mm length implant in D4 bone (2) was found to be statistically lower than the insertion torque (IT) value of 10 mm length implant in D4 bone (3). The removal torque (RT) value of 5 mm length implant both in D2 bone (15.5) and D4 bone (6.3±1.05) was not statistically lower than the removal torque value of 10 mm length implant in D2 bone (18) and in D4 bone (6.7±1.15). However, the Implant Stability Quotient (ISQ) value of 5 mm length implant in D2 bone (50±19.04) and in D4 bone (41.8±8/84) was found to be statistically lower than the ISQ value of 10 mm length implant in D2 bone (66.5±2.22) and in D4 bone (54.5±2.06). The current study concluded that the 5-mm implants may be used as an alternative to augmentation techniques in the mandibular posterior region, but they were not reliable in the maxillary posterior region. Further studies with larger samples and prospective clinical studies are necessary to validate the current findings.

Key Words: Implant Stability, Mandibula, Maxilla, Insertion and Extraction torque

ABSTRACT IN TURKISH

Decani, A (2022). Kısa ve Uzun İmplantların Ostell Değerleri, Yerleştirme ve Çıkarma Tork Değerlerinin Karşılaştırılması. Yeditepe Üniversitesi, Sağlık Bilimleri Enstitüsü, Ağız Diş ve Çene Cerrahisi Anabilim Dalı Doktora Tezi. İstanbul.

Eksik dişlerin yerine konması için en iyi tedavi seçeneklerinden biri dental implantlardır ve dental implantların hayatta kalma oranları implantların yüzey özellikleri, hasta alışkanlıkları, protetik faktörler ve kemik yoğunluğu gibi birçok faktöre bağlı olarak değişmektedir. Dental implant tedavilerinde özellikle kısa dental implantlarda kemik yoğunluğu belirleyici bir faktördür. Literatür, peri-implant zorlama ve gerilimler nedeniyle kemik yoğunluğunun düşük olduğu bölgelerde implant kayıplarının daha fazla yaşandığını göstermiştir. Bu çalışmanın amacı, 5 mm uzunluğundaki kısa implantların ve 10 mm standart boyutlu implantların Ostell değerlerini, yerleştirme ve çıkarma tork değerlerini iki farklı kemik tipinde (D2 ve D4 kemik yoğunlukları) karşılaştırmaktır. D2 ve D4 kemik tipi yapısını taklit eden aynı poliüretan kemik bloğuna 4,3 mm çapında, 5 mm (n=20) ve 10 mm (n=20) uzunluğunda toplam 40 adet dental implant yerleştirildi. İmplantların takılıp çıkarılması sırasında her seferinde tork değerleri kaydedildi ve baştan sona ortalama değerler hesaplandı. Yerleştirme için tork değerleri, implantlar kemik seviyesine ulaşana kadar hesaplandı. Primer stabilite, implant yerleştirildikten sonra RFA kullanılarak ölçüldü. Verilerin analizinde SPSS kullanıldı. Bu çalışmanın sonuçları, 5 mm uzunluğundaki implantın D2 kemiğe (35 n/cm) yerleştirme tork değerinin, D2 kemiğe 10 mm uzunluğundaki implantın yerleştirme tork değerinden istatistiksel olarak daha düşük olmadığını gösterdi (36,5 n/cm). Ancak 5 mm uzunluğundaki implantın D4 kemiğe yerleştirme tork değeri (2 n/cm), 10 mm uzunluğundaki implantın D4 kemiğine yerleştirme tork değerinden (3 n/cm) istatistiksel olarak daha düşük bulundu. 5 mm uzunluğundaki implantın hem D2 (15,5 n/cm) hem de D4 kemikte (6,3±1,05 n/cm) çıkarma tork değeri, 10 mm uzunluğundaki implantın D2 kemikte (18 n/cm) ve D4 kemikte (6,7±1,15 n/cm) olan değerlerinden istatistiksel olarak düşük bulunmadı. Ancak D2 kemikte (50±19.04 n/cm) ve D4 kemikte (41.8±8/84 n/cm)

5 mm implantın ISQ değeri D2 kemikte (66.5±2,22 n/cm) ve D4 kemikte (54,5±2,06 n/cm) 10 mm implantın ISQ değerinden istatistiksel olarak düşük bulundu. Mevcut çalışma, 5 mm implantların mandibulaposterior bölgede ogmentasyon tekniklerine bir alternatif olarak kullanılabileceği, ancak maksiller posterior bölgede güvenilir olmadığı sonucuna varmıştır. Mevcut bulguları doğrulamak için daha büyük örneklemler ve prospektif klinik çalışmalar gereklidir.

Anahtar Kelimeler: İmplant stabilitesi, Mandibula, Maksila, Yerleştirme ve Çıkarma Torku

1. INTRODUCTION AND PURPOSE

According to the American Association of Oral and Maxillofacial Surgeons, between the ages of 35 and 44, periodontal disease, a failed root canal, tooth decay, or an accident cause the loss of at least one permanent teeth in 69 percent of individuals. In addition, 26% of adults who are 74 years old lose every tooth. As a result, according to the records for dental implants, between 100,000 and 300,000 dental implants are placed annually, which almost equates to the number of artificial hip and knee joints that are installed. (1,2).

Due to the recent growth of the global market for dental implants and the rising demand for cosmetic dentistry, researchs on techniques, dental implant designs and materials increase every year and expectations is more expantion for future (3-6). Moreover, dental implants have become increasingly important in recent years, particularly for restoring toothless areas using prosthetic and surgical methods For missing teeth replacement and provide the ideal. implants have become a pretrial treatment methods for this issue. While dental implants offer numerous benefits to both the dentists and the patient, they are both financially and time-consuming to implement[7]. In order to place dental implants in a patient, both horizontally and vertically adequate bone must be present. If it is not placed correctly, failures in the implants is possible. Today, thanks to advanced technology and a variety of bone augmentation procedures, the areas where dental implants can be used, or indications, have expanded (7,8). Short dental implants placements can be a better alternative method for being less invasive surgical procedure (9). Bone density is a determining factor in short dental implants and the survival rates of in maxilla are lower. Primary stability, defined as the interface of the implant facial with the surrounding bone, is a predictor of the implant's capacity to maintain its health over time and hence the therapy's effectiveness (10). Analysis of resonance frequency (RFA) is one of the primary ways for assessing the osseointegration, and it gives essential clinical objective information regarding implant durability (11). In addition, the most important clinical indicators for primary stability of dental implants is insertion torque (IT)(12,13). The torsional power necessary for the removal of an implant is called "the value of removal torque", and it has been extensively utilized by a variety of researchers to determine the interaction between surrounding bone of the implant and the implant surface (13, 14).

The objective of this study was to evaluate the insertion and extraction torque values for implants of two distinct types of bones with Ostell values of 5 mm short implants and 10 mm standard size implants (D2 and D4 bone densities).

2. GENERAL INFORMATION

2.1. Dental Implants

Dental implants are one option for replacing missing teeth. Their use in the treatment of total and partial edentulism has developed into a regular therapeutic option in dentistry. (8). Dental implants offer several advantages over traditional fixed partial dentures. For instance, dental implants have high rate of success (above 97 percent for 10 years), a lower risk of endodontic problems and caries in neighbouring teeth, improved bone maintenance in the edentulous site and reduced sensitivity of neighbouring teeth (14).

A dental implant is an alloplastic structure that is placed into the oral tissues under the mucosa and/or periosteum, as well as within or through the bone, this provides maintenance and sustenance for a removable or fixed dental prosthesis. Exodontia also known as oral surgery is considered the oldest dental profession, followed by implant dentistry. Around 600 AD, the Mayans used shell fragments as implants to replace mandibular teeth. Moreover, in 1809 J. Maggiolo implanted a gold implant tube into a new extraction site. In addition, in 1930 Strock brothers used Vitallium screws to maintain missing teeth. In the 1940s, Formiggini (the father of modern implantology) and Zepponi invented a post-type endosseous implant. Dahl invented the subperiosteal implant in Sweden in the 1940s. Strock invented a two-stage screw implant that did not require a permucosal post in 1946. After the implant had healed completely, the individual crown and abutment post were attached. Ankylosis was the term used at the time to describe the desired implant interface. Dr. Linkow pioneered blade implants, now known as endosseous implants, in 1967. After Dr. Branemark, accidently invented the dental implants, they became an irreplaceable method (15).

Throughout history, people have attempted to develop a variety of methods for replacing missing teeth that would serve the same functional and aesthetic. One of these methods is implant treatment. Implants are substitutes which are inserted on living tissues in the human body to perform various functions. Dental implants are screw shaped objects that are designed to be substitute of the teeth by inserting them on the bone, into the mucosa, or in the bone (Figure 2.1.) (16). These treatments aim to restore phonetic, aesthetical, functional, and psychosocial integrity. (17) Different degrees of integration were discovered in the connection between the implant surface and the bone. It has been showed that normal bone tissue and bone residues, as well as hematoma that occurs during the implantation stage, can be found in this interface. These findings drew attention to the concept of osseointegration, which occurs between the titanium surface of implants and the bone. (12, 18,19)

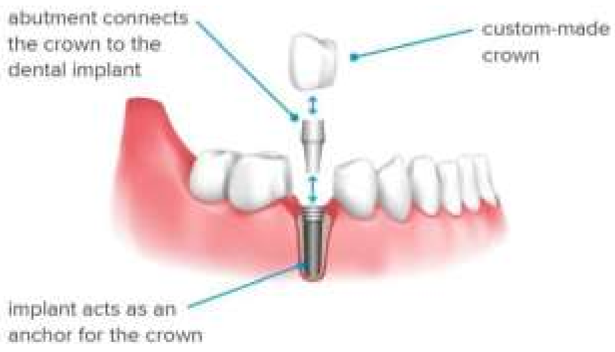


Figure 2.1. Dental Implant

2.2. Dental Implant Evolution

Ancient Egyptians employed carved seashells and/or stones embedded in the human jawbone as dental implants to replace missing teeth. Noble metal implants intended to resemble natural roots are another early implant that has been described. (19). Dental implants have also been around for a very long time—more than 2,000 years—since the earliest civilizations in South and North America, as well as in parts of the Middle East and the Mediterranean. These cultures may have employed carved stone, shells, bones, and gold to fill up the gaps left by missing teeth, according to archaeological findings. (5).

The earliest documented evidence of dental implants date to the Mayan culture, which flourished approximately 600 AD, according to excavations conducted in Honduras in the 1930s. A mandible with implants was discovered. Three shell pieces with tooth forms on them were inserted into the sockets of the specimen's missing three lower incisor teeth. Then, it was found that two of the implants had firm bone development around them. (6). Xenografts and allografts were used in the Middle Ages for dental implantation. However, because it was linked to infectious infections and occasionally even fatalities, this technique did not become widespread. (6).

The history of modern dental implants began during World War II, when Dr. Norman Goldberg was serving in the military and employing metal dental restorations to replace various body parts (20). In 1948, they worked along with Dr. Aaron Gershkoff to develop the first successful sub-periosteal implant (20). They were the first to teach the procedures in dental schools and dental societies around the world, and this success laid the foundation for implant dentistry (20).

A breakthrough in dental implantology occurred in 1957 when Per-Ingvar Brnemark, a Swedish orthopaedic surgeon, started researching bone healing and regeneration. He discovered that bone tissue could grow around titanium (Ti) and could adhere to the metal surface effectively without experiencing any rejection (21). Branemark therefore coined the term "osseointegration" and carried out a large number of additional investigations on both animal and 34-year-old human volunteers. In 1965, he implanted the first titanium dental implants in a patient who had lost all of his teeth as a result of severe chin and jaw abnormalities. Four titanium fixtures were placed by Branemark into the patient's jaw, and several months later, a fixed set of prosthetic teeth was built on top of the fixtures (6). After more than 40 years, the patient's dental implants finally failed (4-6). Over 7 million Branemark System implants have now been placed, and hundreds of new companies have begun to produce dental implants as a result of the various studies Branemark published on the usage of titanium implants. His invention had a significant impact on dentistry (21).

In 1982, the US Food and Drug Administration legalized the use of titanium dental implants, and in 1983, Dr. Matts Andersson created the Procera (Nobel Biocare, Zurich, Switzerland). This also covered the production of dental crowns with high precision and repeatability utilizing computer-aided design and manufacturing (CAD/CAM). After the mid-1980s, further notable improvements in dental implantology were oriented on esthetic restorations. Recent developments in dental implantology have focused on techniques and materials to advance characteristics. (5, 6). After that, in 1992, the development of modern ceramics started, and since then, dental implant firms have added ceramic surface treatments and ceramic-like elements to implants to enhance osseointegration (5). Presently, 450,000 Osseo integrated dental implants are inserted yearly, with a 95 percent success rate and few risks or issues. (5,6).

2.3. Implant Materials

Today's implant materials must be designed to last for the duration of the patient's life (16). A surface chemistry which can create cell change of the interface is a must for an ideal implant (16). Non-adherent fibrous capsules form on implants that do not meet these requirements, and cause an interface instability. Infection wear worn particles and toxic substance release, or uncontrolled surface degradation can all result in the formation of a fibrous capsule which separate the implant from normal tissues. To put it another way, an ideal implant is one that acts similarly to host tissue (16).

2.3.1. Solid Metals and Alloys as Biomaterials

Metallic implant materials should have two main characteristics to make them suitable to apply and as well as biologically and mechanically compatible (23). First, a bio-compatible metallic material should cause a minimal adverse tissue reaction by using only inert alloy components. It should be combined with passive protective layers, which prevent the metal ion release into the environment (24). Elements which can be toxic or may cause allergic reactions, such as V, Ni or Co, should be avoided, while Ti, Nb, Zr, and Ta are the best nominees. A mechanically compatible metallic material, on the other hand, must have a mixture of high mechanical resistance and low elastic modulus. If these properties are not present at the same time, the implantation will fail due to implant loosening and cause implant failure (25).

As an example of a never-ending search for metal implant materials to improve biological and mechanical compatibility, Ni-free Ti-based shape memory alloys combined with the low-stiffness superplastic behaviour of NiTi with the biocompatibility of pure titanium. These Ni-free superplastic alloys are part of the metastable ß-type titanium alloys, that they can closely imitate plateau-like bone behaviour by inducing a body-cantered cubic ß phase under stress (26). The new group of materials become a part of the family of more traditional low-modulus near-ß and ß-type titanium alloys, which also contain non-toxic elements like Zr, Nb, and Ta but lack super elasticity (27).

2.3.2. Metals

For a long time, metallic implant materials have had enormous clinical importance in the medical field. Titanium and alloys, cobalt–chromium alloys, aluminium alloys and zirconium–niobium is among the metal alloys used for medical applications (28). The rapid growth and development of the biomaterial field has made opportunities for the development of many metal-based medical products, like craniofacial plates and dental implants. The rapid growth and development of the biomaterial field has created opportunities for the enhancement of many metal-based medical products, such as craniofacial plates and dental implants (29). Though other classes of materials can be used to create biomaterials, engineers consider metals to be the most important. Metal-based materials for biomedical applications are chosen based on their outstanding biocompatibility, useful properties, suitable corrosion resistance, and great prices (27). The metal type used in biomedical applications is determined by the implant's functions and the biological environment. The most common alloy used in all metal implants, from cardiovascular to otorhinology, is 316L type stainless steel (316L SS).

Metal mechanical properties are critical when creating load-bearing dental and orthopedic implants. Co–Cr–Mo alloys, on the other hand, are used when the implant needs high wear resistance, like artificial joints. When compared to ceramics and polymeric materials, metals' have increased fatigue limits and tensile strength which allow them to design implants to tolerate high mechanical loads. Metals have higher ultimate tensile strength and elastic modulus than polymers, yet decreased strains at failure. Metals, on the other hand, have lower strengths and elastic moduli, as well as higher strains to failure, when compared to ceramics (30). When a metal-based biomaterial is implanted in the biologic medium, the surface of the material can change and degrade, releasing some by-products. Interactions between the metallic implant surface and cells or tissues occur as a result of this releasing process (29). This factor has prompted modern researchers to place a premium on understanding the surface properties of metallic products in order to develop biocompatible materials.

2.3.3. Dental implants with porous titanium coating

Dental and orthopedic implants must have complicated topography. Implant surface topography and roughness are crucial for bone adhesion and biological fixation. Most exterior structural elements maintain implant bonding until bone forms and adheres to it (31). Dental implant surface modification and coating generate 3D nano and microscale porous structures to promote bone and implant integration. During implant loading, large stress concentrations develop in the bone for endosseous screw-shaped implants (threaded implants), especially around the superior-most threads (31).

Porous implants may distribute force across a wider area of the bone-interfacing implant surface, reducing peri-implant bone stresses. Short porous implants have better stress distribution in cancellous bone than solid implants (32). Deporter et al. inserted porous Ti-coated cylindrical dental implants in canine mandibles and femora. Higher porosity coatings increased bone ingrowth. Porous-surfaced implants with lengths of 7, 9, and 12 mm have also been used effectively to complement fixed partial dentures and as free-standing implants (34).

Common coating processes have downsides. Delamination and poor coating-to-substrate adhesion have been found in coating systems (35, 36). Porous coatings don't alleviate mechanical mismatch between implant and bone. Researchers and developers have produced totally porous dental implants or monolithic solid cores with a porous surface.

2.3.4. Fiber-reinforced polymer composites

Fiber-reinforced polymer composites are used in a variety of dental applications. The implant materials, which are typically titanium and its alloys, zirconia (37), or FRCs (38), should be biocompatible and have proper surface feature that induce bone formation around the implant (39). It should also have an appropriate design, high hydrophilicity, and a suitable surface roughness. Aside from these materials, most dental treatments use alumina, gold, silicate cements, amalgam and acrylic resins to restore decayed teeth. Due to cosmetic expectations and long term toxicity potency of silvery mercury amalgam, gold and amalgam are not suitable materials for anterior teeth restorations but can be used for posterior regions. The most preferred materials for anterior tooth treatment are Acrylic resins and silicate cements (40). However, due to their poor mechanical properties, they have a short term service and are prone to clinical damage. Dental composite resins are replacing these materials in the restoration of posterior and anterior teeth. The matrix polymer in dental composite resin is BIS–GIM and the fillers are barium glass, quartz, and colloidal silica (40). To prevent premature polymerization, inhibitors like butylated trioxytoluene or 2,4,6-tri-tert-butylhenol and low-viscosity liquids like triethylene glycol dimethacrylate can be used. Urethane dimethacrylate resin is another popular dental composite resin. Similarly, glass fibre is widely used as a filler material in dental composite resins due to its ability to impart wear resistance, high stiffness, and strength (41). Furthermore, the glass fibres reduce shrinkage during resin polymerization as well as variation between the thermal expansion coefficients of the composite resin and the teeth. To create a strong bond between fillers and resin, silane-coupling agents are used.

2.3.5. Metals and alloys

Titanium and titanium alloys 4 vanadium – 6 aluminium Cobalt, chromium, and molybdenum are three elements that make up the metal cobalt, chromium, and molybdenum (42). Out of all the implant materials titanium is the most frequently used (42). This is mainly due its resistant to attacks by organism-produced fluids. In addition, titanium is considered suitable for dental implant design mainly due to its high resistance to loads and corrosion, as well as its good biocompatibility with bone structure (43). Titanium becomes passive in the tissue and a titanium oxide layer forms on the surface. Coating pure titanium with hydroxyapatite, foreign body reaction was reduced, and a successful rescue process was detected (44). A typical implant material should include the following characteristics:

- Be neither cytotoxic nor carcinogenic.
- Does not cause any allergies.
- Must be biocompatible.
- Remain resistant to pressures and avoid changes.
- Act as a bio-adhesive.
- Be cost-effective.
- Must be sterilisable.
- Abrasion resistance.
- Easy to shape.

2.3.6. Titanium in Biocompatibility

Biocompatibility is a material's capacity to evoke an appropriate host reaction (39, 45). Biocompatibility is the fundamental reason for titanium's appeal. High corrosion resistance makes titanium and alloys biocompatible. The material's surface oxide layer provides high corrosion resistance and electromagnetic protection. Titanium's exceptional osseointegration with bone and capacity to generate a calcium phosphate-rich layer resembling hydroxyapatite are further biocompatibility requirements (46).

In vitro, animal, and in vivo testing show titanium's biocompatibility. Literature shows that titanium corrosion products concentrate in lymph nodes and organs, causing galvanic adverse effects (47). Researchers reported titanium allergies (48-50). Biocompatibility nowadays means 'less toxicity' Because titanium has little ion emission, this term suits titanium's response in soft tissue (51).

Urban et al. (48) found that corrosive chemicals might be extensively dispersed throughout the body but did not generate toxic consequences in individuals with hip/knee prosthesis. Titanium has no mutagenic or harmful effects, according to in vitro research (48). Surface features like metal emission and protein binding affinity influence metallic implants' biocompatibility (51). A research comparing chromium-cobalt (Co- Cr-Mo) and titanium implants indicated that chromium was released more than titanium (52). Biofilm composition and metal ion release influence implant alloy bioreactivity. Titanium's protein structure and minimal ion release in human fluids make it biocompatible (52).

Implant surface qualities affect the biological reaction to them. Today, implant-tissue interface is the key concern (53). External aspects include chemical properties, crystallization, heterogeneity, roughness, and wettability. Each parameter affects biology. Plasma, ion implantation, hydroxyapatite coating, and laser enhance titanium implant surface properties (53, 54).

2.4. Types of Dental Implants

Intramucosal inserts, subperiosteal implants, endosseous (endosteal) implants, transosseous (trans-mandibular) implants and are the four fundamental types of dental implant designs that have been improved to be used in clinical dentistry (46).

Subperiosteal implants are used when the crests are highly resorbed, and the vertical bone height is insufficient. Without a suitable oral mucosa, partial and total prosthetics can be worn. These implants were used in the 1940s, and their success rate was reported as 93% for 5-year follow up. Over time, a series of changes were implemented to more evenly distribute the incoming forces. Body of the implant was extended towards the lateral of the ramus and the retromolar region and which was a change. Furthermore, the implant was coated with hydroxyapatite to improve the connection between the bone and the implant. The researchers were able to raise the bone and provide enough bone for the implant by using autogenous bone graft on an atrophic area, obtaining a 3-dimensional model using CT (computerized tomography), applying the implant to this model, and carrying out the surgical process in one step (15).

Intramucosal inserts were proposed by GustauDahi in 1943. These implants are mushroom-shaped titanium structures and commonly used in maxillary prosthetics. These are used when the labial extension of the prosthetic is kept short, or when the palatinal section is not desired and retention is required due to atrophic maxilla. Nonetheless, such implants are not widely used nowadays (15,16).

In regard to endosseous (endosteal) implants, the tooth roots in this case are replaced by cylinders, screws, or blades made of titanium or ceramic material. The implant is surgically placed into the jawbone, which aids in the retention of the artificial teeth. As a result, these implants are completely embedded within the jawbone, under soft tissue. Artificial teeth, on the other hand, are not directly connected to endosteal implants. Consequently, after inserting the dental implant into the jawbone, a post is attached to the implant. The artificial tooth is then firmly affixed. These types of implants have recently received attention, and various implants are constantly promoted by various companies. Endosseous implants are now available in a variety of brands around the world. Root-shaped screwed or cylindrical implants are the most commonly preferred. In comparison to other implants, these are more effective (16).
In addition, transosteal implants was developed in 1973, it is especially used on toothless and severely atrophied mandibles. These implants are used who have had cyst or tumour formation, trauma in mandibula, or who have progressive level of defect due to surgical operation. However, these implants can only be used for the lower jawbone and therefore, generally they are not first choice due to its complicated and time-consuming surgery. The fitting procedures includes attaching a metal plate to the bottom of the surgery jaw, with screws running through the jawbone and posts embedded within the gum tissue. An incision is made beneath the chin to secure the plate with screws and posts on top, to which the artificial teeth are attached. These implants, however, are expensive because they must be custom-made to be fit in the width and height of the jawbone. This ensures that the implant is properly fitted to the individual(15,16).

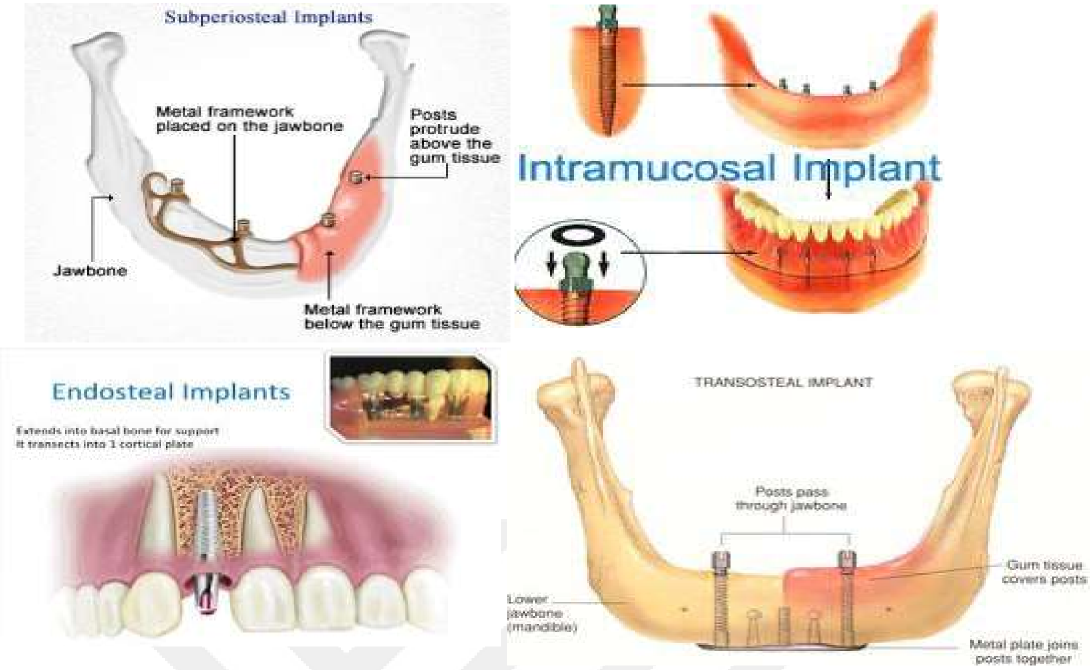


Figure 2.2. Types of Dental Implants

2.5. Classification and Effects of Implant Surface Modification

The surface properties of the dental implant are known to affect the osteoblastic cell adhesion and differentiation (55, 56). Surface energy, roughness, chemical composition and topography are all examples of surface properties. Surface roughness is frequently modified in dental implants to modulate bone apposition (57, 58). In addition, surface roughness is classified as macro, micro, and nanometer-sized texture. Mechanical anchorage to bone is aided by macro- and micrometer roughness (51). Moreover, nanometer roughness influences protein adsorption and osteoblastic cell adhesion. It has the ability to influence the rate of osteointegration (53, 54,59,60). To achieve the desired surface topography, various of surface treatments can be used. The titanium various and surface modifications of commercially available implants vary; understanding these disparities assists dentists to make a knowledgeable decision in implant selection for their patients. Implant surface characteristics includes 1) unprocessed implants, 2) implants with processed surfaces such as acid-etched, sandblasted, polish, and implants with coated surfaces such as plasma spray.

2.5.1. Surface Alteration Methods for Implants: Physical and Subtractive

The first surface alteration method is machined. This is where the implant is machined in one of the following methods: turned, milled, or polished. Sandblast is another surface alteration method for implants.

2.5.2. Acid-etched surfaces

Studies have demonstrated that acid etching promotes the growth of bone around implants. Acid etching can be done using baths of 2% hydrofluoric acid and 10% nitric acid or hydrochloric acid and sulfuric acid (HCL/H_2SO_4). Acid-etching at high temperatures produces a more uniform micro-rough surface compared to TPS surfaces, which increases bone-implant contact (61). The acid-etching technique not only increases surface area but also enhances bone-implant interaction by eliminating leftover materials from the metal surface (62,63). Prior to this, 3.25x4 mm polished titanium and acid-etched (HCL/H_2SO_4) (Osteotite) implants were tested for torque on rabbit femoral bones. The torque resistance values for polished Ti and osteotite after a two-month recovery time were 20.5 Ncm and 4.95 Ncm, respectively. When the surface is acid etched, the torque resistance value increases by about four times. The study's findings showed that connecting with the bone is enhanced by rough surfaces (64). Buser et al. (65) found that much higher torque values were necessary to remove implants that had been acid-etched and sandblasted. Before and after the acid-etched and sandblasted implants were loaded, Cochran et al. (62) also noticed a reduction in bone resorptions along the implant's neck. Furthermore, titanium's mechanical characteristics could be diminished by chemical treatments. For instance, acid etching could result in hydrogen embrittlement and tiny surface cracks on titanium, reducing the wear resistance values of the implants (66).

2.5.3. Sandblasted and Acid-Etched (SLA) Surfaces

The process of SLA roughens the surface with a strong acid following sandblasting. SLA technique can be an alternative to TPS coating and used to improve surface chemistry and topography. This procedure combines acid-etching and grit-blasting to promote surface roughness and osseointegration (67, 69). Histomorphometric and biomechanical testing reveal higher reverse torque (69,70). Following these results, SLA implants were employed for early loading in clinical investigations within 6 weeks. Three-year clinical follow-up showed 98% implant success (71,72,).

Straumann introduced SLA implant surfaces in 1997. SLA surfaces aren't coated. Spraying sand on implants creates microroughness. Surface acid creates 2-4 mm microholes. Medium-roughness SLA implant surfaces. The implant's roughness is uniform. One study found that osteoblast-like cells had more alkaline phosphatase activity on SLA surfaces than TPS surfaces (73).

2.5.4. Surfaces coated by plasma spray

Typically, plasma spraying results in the formation of a thick layer of materials like titanium and hydroxyapatite (HA) (Ti). The coating procedure involves applying materials that have been thermally melted to the implant surface (68,74). In theory, plasma spraying improves the roughness of the surface of the implant, increasing its surface area (68,74). Layers of calcium phosphate that are predominantly made of hydroxyapatite are typically used to cover metal implants. Following implant implantation, released calcium phosphate in the peri-implant region increases bodily fluid saturation and causes biological appetite to build up onto the implant surface. For the purpose of promoting osteogenic cell adhesion and proliferation, that biological apatite layer may function as a matrix with endogenous proteins (74).

The process of bone revival for the implant's surrounding bone is developed as a result of this layer. Titanium implants bind to bone tissue more quickly when calcium phosphate is present. When compared to titanium implants without calcium phosphate coatings, clinical success is known to be higher (75, 76). The danger of the coating delaminating, even if it is securely adhered to the bone tissue, is one of the most critical issues with plasma spray coating. This raises the likelihood of failure. Due to the plasma spray's activity not reaching the appropriate level when the dental implants are not the proper size, coating delamination happens. Multiple studies have found that the covering might loosen, especially when implants are inserted into solid bone (77, 78).

2.5.5. Surfaces coated by ceramics

The ceramic industry views micro-arc oxidation (MAO) as a cutting-edge surface coating technique. It is an electrochemical process that coats porous surfaces like metals and ceramics with a high-voltage electrolyte solution. By modifying the content and concentration of Ca and ions, the MAO technique covers the surface (79, 80). Because the Ca and PO3 ions in the electrolyte during the MAO technique might boost the bioactivity potential of metal alloys like titanium, this process is significant in terms of biomedical procedures (81).

During this procedure, a Ti sample immersed in the electrolyte receives a positive voltage, and titanium anodization results in the formation of an oxide layer on the surface. A micro-arc is seen when the applied voltage is raised to a specific level at the location where the oxide layer starts to deteriorate (non-conductor degradation). Ti ions and OH ions in the electrolyte start to flow in the reverse direction when non-conductor deterioration starts, instantly mending the damaged oxide layer. The new layer has a closely connected porous structure that is perfect for bioactive surfaces (81). The MAO method has recently been recognized as one of the best surface modification techniques for enhancing the biological response of Ti implants (82,83).

Due to the potential for an implant to be placed at various horizontal levels, elleman et al. (87) classified implants with vertical heights of 8 mm or less in the bone as short implants. Additionally, research on short or very short implants—implants with a length of less than 7 mm—have been published (90, 91). According to earlier study, short implants can range from 5 to 10 mm in length (92). Publications have not yet agreed upon a definition for this (93, 94).

2.6. What are Short Implants?

As discussed earlier in the literature review implants are now widely used to replace missing teeth in many cases. Dental implant applications have a higher success rate when the alveolar bones have sufficient vertical and horizontal dimensions. It is not possible to insert dental implants in cases where these dimensions are insufficient, and it is common practice to place dental implants after providing sufficient bone height through superior surgical methods such as sinus lifting, bone augmentation, IAN lateralization. Although there have been may successful study results for such procedures, it is well known that they have high patient morbidity and complication risk with while also increased treatment time and cost (84). Short implants, were first introduced in 1979 as 7-mm implants by the Branemark system and described as shorter than 10 mm by some researchers, while the others defined 8 mm was the upper limit (85-89).

Telleman et al. (87) defined implants with vertical heights of 8 mm or less in the bone as short implants, owing to the possibility of an implant being inserted on different horizontal levels. In addition, studies have been published on implants shorter than 7 mm in length, referred to as short or extra short implants (90, 91). Based on previous research, there is a wide interval of 5-

10 mm to define short implants (92). Publications have yet to reach an agreement on such a definition (93, 94).

Figure 2.3. Dental Implants Sizes

2.6.1. Surface Properties of Short Implants

There have been numerous studies comparing long implants versus conventional implants, but no agreement has been reached as of yet (85). Because osseointegration and primary stability are lower with short implants, they fail more often (86).Short implants had much lower failure rates, according to research done by Pommer et al. (96) on the first year of functioning loaded implants. Bahat (97) found a failure rate of 9.5 percent in a clinical investigation that classified implants shorter than 7 mm as short implants; longer implants had a failure rate of 3.8 percent. Improvements to the surface characteristics of short implants, along with an increase in the number and depth of grooves, were said to facilitate osseointegration between newly created implant systems and bone (97).

In circumstances of low bone density, machinized macro-surface implants are reportedly harmful (98). Machined surfaces can be separated from processed surfaces with less torque (3). In the near term, the implant surface porosity that develops enables a stronger link to form between the bone and the implant (98). Modifications to the implant surface, according to Deporter et al. (99), have a considerable impact on the success and survival rates of the implant. According to reports, short implants with changed surfaces that are inserted into bones using the proper surgical technique and thickness perform better (100).

Malo et al. (101) claim that because of the features of the surface, anodic oxidized surfaced short implants have a success rate of about 95% after being put to low density bone after a year. However, it was asserted that the implant's height was unrelated to the low success rates of the procedure, only with the implant's external characteristics (101). It was shown that surfaces with better surface properties were more resilient to implant tension pressures. (100) When comparing short and long implants with machined surfaces, a greater failure rate was observed (104).

It was discussed if machined surfaces implants should be at least 11-133 mm tall and 3.75 mm or 4 mm in diameter for a better prognosis (65). By comparing different implant sizes that had been roughened by TiO2, Gotfredsen and Karlsson (104) found that the roughened exteriors had better bone survival. Implant exterior and implant design were not as superior to one another in terms of short implant survival rates, according to Atieh et al. (92).

2.6.2. Short Implants Bone Properties

Implant success depends on bone density (105). Short implants are utilized to replace atrophied posterior molars (106). Some studies advise against placing short implants in the posterior maxilla due to insufficient bone density (88, 94). Short implants in this location are coupled with lengthy implants for restorations. The results are ambiguous (101). Short mandible implants were more successful than maxilla implants (107).

Short implants on maxilla and mandible have 87 and 100% success rates, respectively (108). Even though the maxilla clinical findings are ambiguous, at least three year outcomes are needed for the mandible (109). A meta-analysis found no difference between mandible and maxilla (90). Despite investigations and analyses, there is no consensus on short implant survival rates for mandibula and maxilla (110). When the vertical alveolar bone height is insufficient but the bone breadth is sufficient, short implants can be used in the mandibular and maxillary posterior areas. Non-invasive alternatives to augmentation (88).

2.6.3. Advantages of Short of Implants

Short implants are better than regular ones. Short implants require less vertical bone grafting, reducing treatment time, cost, and morbidity. There is a lesser surgical risk of perforating the maxillary sinus, inducing paraesthesia owing to dental nerve injury, triggering impairment due to osteotomy overheating, and hurting adjacent tooth roots. According to several research, short implants put in the natural bone had the same survival rate as normal implants (105,106). Short implants have a lower survival rate and unexpected effects (113).

2.6.4. Osseointegration

In order to accomplish and maintain clinically asymptomatic severe attachment of alloplastic elements in bone during functional loads, osseointegration is characterized as a time-dependent healing process (114,115). Without any involvement of tough or connective tissue between the implant surface and bone, the histologic appearance was comparable to a functional ankylosis. The reliance of the various parts of an equation that contains the following determines the success of any implant technique in the main (116). The first week of ossification shows signs of steoblastic migration. For one month, the osteophytic phase lasts (121). The fibrocartilaginous callus turns into bone during the second phase, which is known as the osteoconductive phase. This change takes place in the third month, and as a result, more bone builds up on the implant's outside. The most bone covers the implant surface in the fourth month after implant placement (121). The osteo-adaptive phase, which starts in the fourth month, is the third stage. At this point, remodeling starts, and the area around the implant continues to build bone. The woven bone thickens and changes into lamellar bone during this stage (121). Remodeling is the last phase of osseointegration. This is long-lasting and essential for implants to last longer (122). The primary stability and osseointegration of an implant are essential for its success (90). Primary stability, which is necessary for osseointegration, is the absence of motion of the implant after it has been implanted (123-125).

1. The implant material's biocompatibility
2. The implant surface's and designs' macroscopic and microscopic natures (117)
3. The implant bed's status in terms of both health and morphology (bone quality)
4. The surgical technique in general (118, 119)
5. Uninterrupted healing phase (120)
6. Conditions of loading

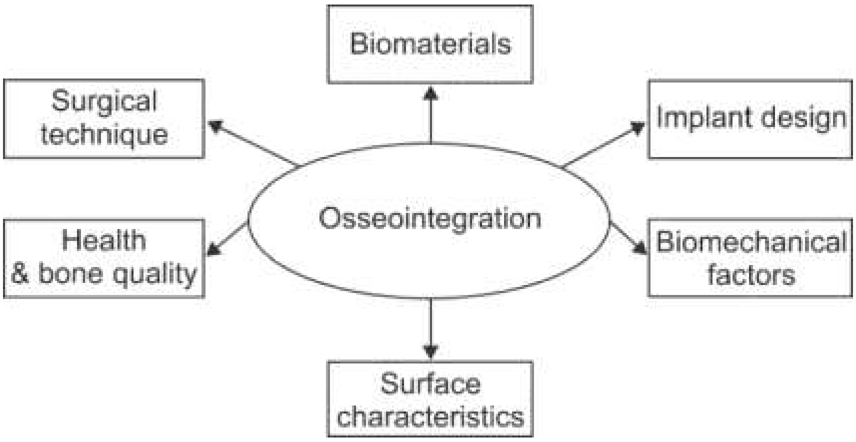


Figure 2.4. Osseointegration

2.6.5. Osseointegration Biological Phases

Osteo-phytic phase is the first of three biological phases for osseointegration, and it happens after the implant has been placed. Coagulation results from blood filling the gap between the implant and the bone (121). There is minimal to no bone contact with the implant. Cells and extracellular fluid make up the remaining components. During this phase, molecules are produced and collagen synthesis is controlled. These mechanisms are controlled by the secretion of cytokines (121). Additionally, cytokines can modify cell proliferation and control the metabolism of the bone. During the first week, inflammatory cells begin to develop. In response to foreign antigens, these cells manifest. On the third day, vascular development starts at essential organs. By the conclusion of the third week after implant placement, there has been a noticeable improvement in vascular growth. Following it, cellular activation, differentiation, and proliferation start (121).

The first week of ossification sees osteoblastic migration. For one month, the osteophytic phase lasts (121). The fibrocartilaginous callus turns into bone during the second phase, which is known as the osteoconductive phase. This change takes place in the third month, and as a result, more bone builds up on the implant's outside. The most bone covers the implant surface in the fourth month after implant placement (121). The osteo-adaptive phase, which starts in the fourth month, is the third stage. At this point, remodeling starts, and the area around the implant continues to build bone. The woven bone thickens and changes into lamellar bone during this stage (121). Remodeling is the last phase of osseointegration. This is long-lasting and essential for implants to last longer (122). The primary stability and osseointegration of an implant are essential for its success (90). Primary stability, which is necessary for osseointegration, is the absence of motion of the implant after it has been implanted (123-125).

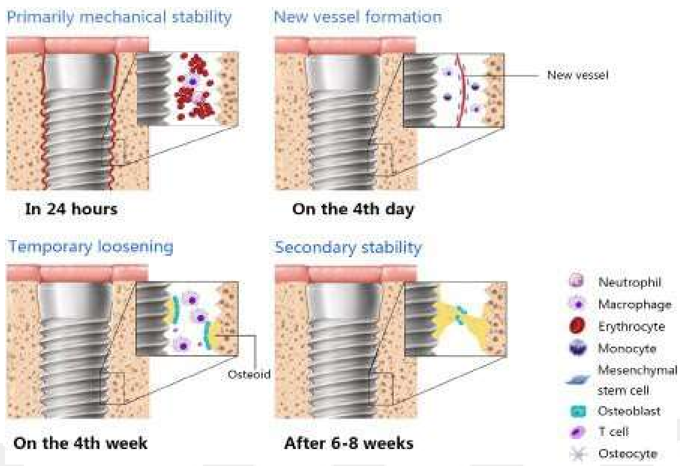


Figure 2.5. Osseointegration Biological Phases

2.7. Implant Stability

Since the beginning of the osseointegration concept, which was defined as "a direct functional and structural contact between the living bone and the surface of an implant", dental implants have become increasingly popular. Schroeder and colleagues stated that osseointegration must be achieved and maintained in order for dental implants to be successful and functional (126). The "primary stability" during implant insertion is the key factor to determine the osseointegration success (127,128). It is related to bone structure, implant design (type, length, and diameter), and surgical technique (129). Primary stability is an important factor to measure implant stability and to determine the loading protocol. It enables clinician to decide loading time (130).

2.7.1. What is Implant Stability?

Implant stability can be defined as the following factors:

- Mechanical stability, also known as primary stability is achieved as a result of firm placement of an implant in bone. In other words, holding implant in place. It is the first resistance to micro mobility and micro motion of a dental implant after it is placed in the bone (131).

- Biological stability, also known as secondary stability, can be defined as new bone formation around the implant and its integration with bone. The process of osseointegration results in biological stability. In an ideal world, sufficient secondary stability would be achieved in as soon as possible, to allow patients to gain function with their implant-retained restorations (131).

When the bone quality and quantity is sufficient, generally primary stability is high even after immediate implant placement. Among other things, this is the result of mechanical compression of the bone during implant placement, and in the short term it frequently decreases (132). In addition, biological stability (secondary stability), on the other hand, does not play a role directly in primary stability (133).

When there is sufficient osseointegration, new bone formation around implant becomes visible and increase in time. It is the decisive determinant if the implant-supported restoration can endure the functional forces and integrate the patient's dentition (132).

2.8. Primary Implant Stability

Implant insertion stability is a substantial factor for determination of implant treatment success. Surgical technique for implant insertion, implant type, height and diameter, the quality and quantity of bone where the implant will be planned to place are determinant factors for primary stability. When there is not sufficient primary stability, implants make micromovements and disrupt recovery. Clinical failure is unavoidable once the implant begins to move (134-137). Two crucial elements in obtaining primary stability are the degree of attachment between the implant and the bone and the compression stress between the two. According to several studies, thick cortical bone provides higher stability for implants than trabecular bone does. The implant cavity may be created using a hand piece to have a smaller diameter than the implants, and the implants can then be put into the cavity. As a result, the implant is placed firmly inside the cavity. Despite the stability benefits, this may also result in bone ischemia or bone necrosis (134). Mechanical forces match the implants' weak primary stability, increasing the likelihood of early failure, claim Gapski et al. (138). Primary stability is also important in early loading regimens. If stability is sufficient, functional loadings may be applied right away. This is due to the possibility of insufficient primary stability when implants are implanted in spongious bone; as a result, enough time should pass before loading (138).

2.8.1. Implant Stability Measurement Methods

The achievement of primary stability is the first step toward osseointegration. Additionally, primary stability might provide some insight into the osseointegration process (139). Stability is measured using the techniques listed below:

1. Torque insertion test
2. Torque extraction test
3. Implatest
4. Periotest
5. Percussion examination
6. RFA (resonance frequency analysis)
7. Dynamic model evaluation

2.8.2. Torque insertion test

While installing implants with an electronic motor, torque values are calculated (140). According to Colomina, torque quantity can be used to understand bone quality and implant stability (141). The applied torque may be measured safely while the implant is being inserted into the prepared cavity. It has become a well-liked technique for immediate loading (141). Ottoni et al. (142) also found that torque and ISQ values of implants are high in patients with good bone quality. On the other hand, Friberg et al. (143) asserted that there is no connection between ISQ and insertion torque.

In their investigation into the relationship between insertion torque values and bone quality, O'Sullivan et al. (137) found that while there was no statistically significant difference between types 2 and 3 bones, the torque value for type 4 bones dramatically dropped. Ottoni et al. claim that the instantaneous loading can be carried out when the insertion torque is greater than 32 Ncm and that the risk of failure increases if the insertion torque is less than 20 Ncm.

Furthermore, the insertion torque test is a reliable and simple method to assess implant stability (142).

2.8.3. Torque extraction test

Extraction torque testing was defined as releasing the link between the bone and implant through a reverse torque movement (144). Researchers claim that the only reliable way to assess bone development and maturation around implants is with a torque test. It was determined that this test may be used to assess how long the region between the bone and the implant could withstand the maximum shear force. In addition to implant design, the quality of the bone between the implant and the surrounding tissues affects the measurement degrees that are disclosed (145). Torque tests are still utilized today, although for ethical reasons, neither in vitro nor in vivo testing is feasible. These are the tests' most significant flaws (10).

2.8.4. Impla-test

Impla-test test was developed by Dario et al. in 2002. (146). It requires digitally tracking the stability of the implant. The accelerometer is mounted on a structure and used with a device to record results in the impulse test, which is also frequently used in engineering and structural analysis. During recording, the device's moving mechanism stimulates the accelerometer, which subsequently transmits that signal to the implant. The data obtained (ATH data) is enlisted when the device's tip makes contact with the implant. When the device's tip is still in touch with the implant, the recorded data is not evaluated. Following data analysis, a plot is displayed on the device's screen, and the stability of the implant is assessed using this plot. If there is enough osseointegration, the plot's curve becomes smoother before the curve varies, indicating that there was insufficient osseointegration (146,147).

2.8.5. Periotest

Siemens developed the Periotest instrument at the University of Tubingen in the 1980s, and it is now produced by (Bensheim, Germany). Its objective is to quantitatively assess the mobility of the teeth and the diminished periodontal tissues surrounding them (148). There are three types of it: the Periotest Classic, Periotest S, and the recently released wireless Periotest M. (Figure 6). In Periotest S, the measured data can be saved. A noninvasive diagnostic technique called Periotest evaluates the integrity of the implant surface and the bone (149-151). A mechanical process, periotestis is controlled and powered by electricity. The measurement process, which lasts 4 seconds, involves 16 percussive hits from the device's moving tip on the implant or tooth. The pressure-sensitive movable tip component measures the period of contact between the implant and the tooth. The Periotest value increases as the contact time lengthens. When implants or teeth are movable, high values are undesirable. Shorter contact times and a lower Periotest value indicate that the stability is satisfactory. Periotest values can change depending on the dentist's use, the recording's location, and the device's orientation. Additionally, the dynamic properties of the implant may alter following abutment installation and implant loading, affecting the Periotest values. Consequently, some experts think that this approach is inappropriate for evaluating osseointegration (151,153).

Table 2.1. Osseointegration Biological Phases

Periotest Value Interval	**Interpretation**
-8 to 0	Sufficient osteointegration implant can be loaded
+1 to +4	Clinical examination is necessary, implants may not be loaded
+10 to +50	Osteointegration is not enough, the implant should not be loaded

Figure 2.6. Periotest M and periotest classic

2.8.6. Percussion examination

A subjective procedure, percussion examination is said to be. Analyzing the sound the implant makes when it is struck by the back of a hand instrument is a simple process. If there is mobility, it can be heard from the blunt sound the implant makes. When the sound is feeble, it indicates that the implant has not yet undergone osseo-integration and is instead encased in fibrous tissue (144).

2.8.7. Resonance Frequency Analysis (RFA)

Resonance frequency analysis is a technique created by Meredith et al (127). It is a technique for electronically assessing implant stability. It is objective and non-intrusive. In multiple in vivo experiments, this technique statistically quantifies osseointegration (127,134,139,153). It was thought that because implant systems are constantly changing, standard procedures are inadequate. It was necessary to create a tool that objectively and non-invasively increased implant stability. They gave the measuring instrument the name OsstellTM (Figure 8). Later, the device underwent adjustments, and it was rebranded as Osstell Mentor TM. The investigation revealed the following advantages of the device:

1. Osstell enables the measuring of the implant's stability and bone quality as well as the gathering of data regarding the loading time of the implant.
2. The improvements and alterations in the vicinity of the implant are assessed, and the right amount of time for restoration is chosen. The ability to anticipate potential mistakes makes it easier to take preventative measures. In this way clinical failure is prevented.
3. The implant's clinical effectiveness can be assessed. This enables selecting from a variety of implants.
4. Ostell measurement findings and patient data can be retained in the same file. This is advantageous to the doctor in terms of keeping an eye on the patient and following the law (128, 135).

The primary stability of the implant is assessed using ISQ measurements. The ISQ scores are between 1 and 10. The readings, however, fall within the typical range of 55 to 80. According to several research, the mandible has higher values than the maxilla. ISQ > 70 indicates high stability, 60-69 indicates medium stability, and 60 indicates low stability. When the ISQ value is 60, loading the implant temporarily is dangerous. Even though it was emphasized that

traditional loading may be performed for implants with ISQ values between 60 and 69, implants with ISQ values over 70 can be loaded right away without a doubt (145).
Primary stability measurement values (ISQ) are directly related to the implant's placement procedure and the quality of the bone in which it is implanted. There are four main kinds of bones in a human mouth. Lekholm and Zarb (154) categorised these categories as follows:
It is a thick, compact bone that is a little spongy. It is frequently noticed in the front part of the toothless jaw.
D2: The bone is thick, spongy, and compact. It is located in the palatinal region of the maxilla, the posterior and anterior portions of the mandible.
D3: The bone is small, spongy, and compact. It is located in the anterior and posterior parts of the maxilla.
D4: The bone is typically spongy, thin, and full of gaps. It occurs more frequently in the back of the maxilla.

Figure 2.7. Ostell TM

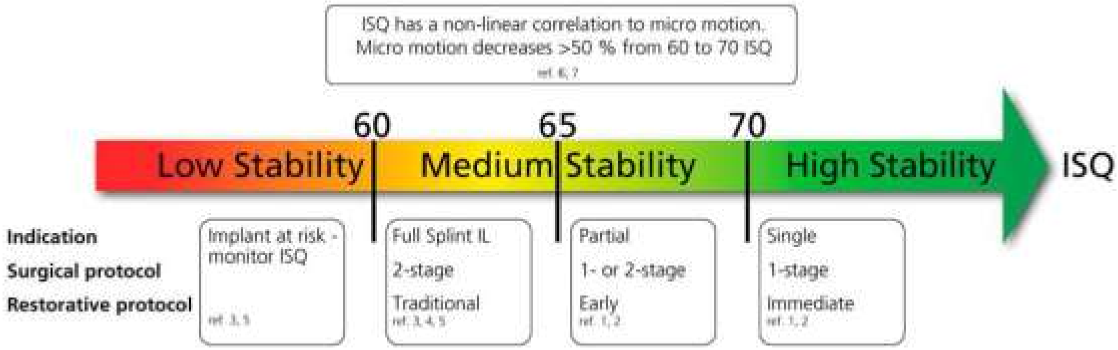


Figure2.8. Ostell ISQ Scale

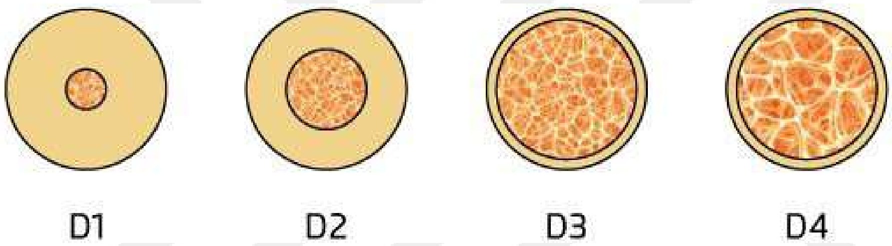


Figure 2.9. Types of bone (Lekholmand Zarb,1985)

2.8.8. Dynamic model evaluation

Dynamic model assessment was developed in 1996. (146). Here, a pendulum-shaped hammer is utilized to hit the implant, resulting in vibration. When you hit anything with the hammer, the piezoelectric crystal within will send out a voltage signal. A force-time graph is generated based on the input data. Area under the force-time curve is a measure of the pushing force. The data changes as it is affected by the force's intensity and location. There have been reports that this measurement is particularly challenging in implants with poor stability (15

3. MATERIALS AND METHODS

All studies were done at Marmara University's Göztepe Mechanical Engineering Department. The sample size for this study was n=40 with a 0.9 effect size at 80% statistical power and 5% significance.

3.1. Preparing the sample materials

Bone level implant helps provide optimal collar cohesiveness and gingival profile. Implants with SLA surface treatment, aluminum oxide particles, and acid interfered with osseointegration. 40 (Implance, Dental Implant system, AGS Medikal Salk Ürünleri, San. Tic. Ltd. ti.) conical-shaped implants with internal hexagon connection (4.3x5 mm and 4.3x10 mm) were used for this in vitro study (Figure 3.1 and Figure 3.2).

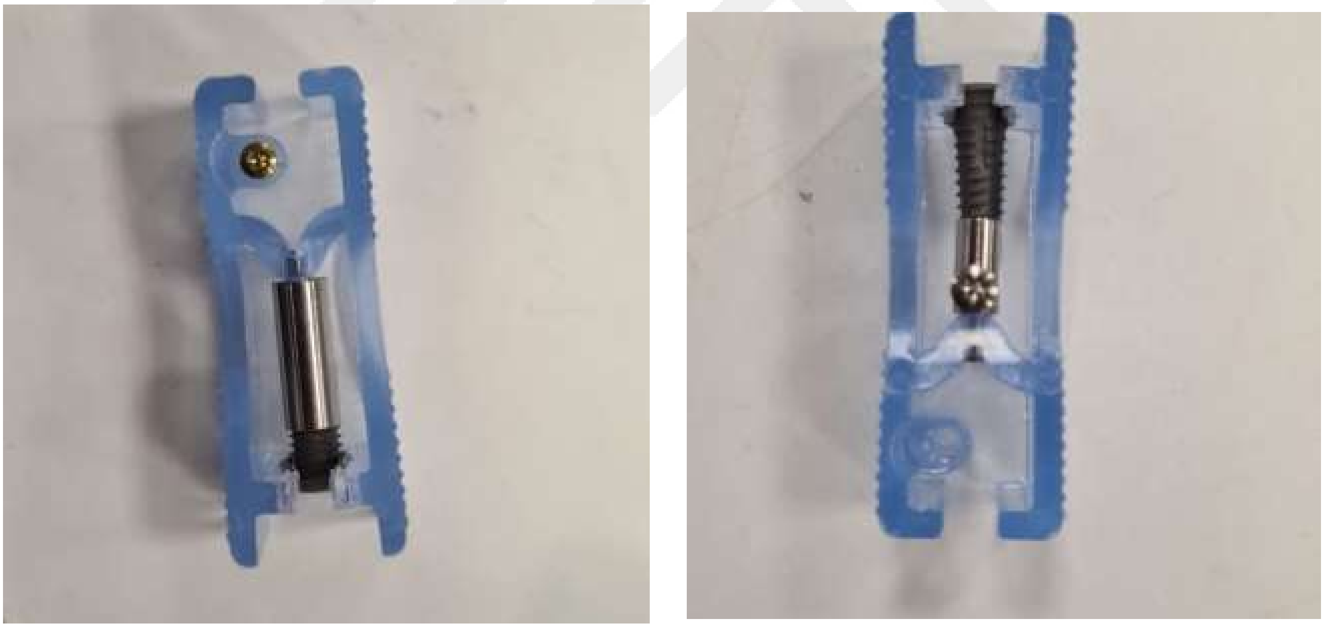


Figure 3,1. Short implant with diameter and length 4.3x5 mm and standard size implant with diameter and length 4.3x10 mm (Implance, Dental Implant system, AGS Medikal Sağlık Ürünleri, San. Tic. Ltd. Şti.)

Group 1: 4.3mm x 5mm implants (n=20).
Group 1A: 4.3x5mm implants in D2 polyurethane blocks (n=10)
Group 1B: 4.3x5mm implants in D4 polyurethane blocks (n=10)
Group 2: 4.3mmx10mm implants (n=20).
Group 2A: 4.3x5x10mm implants in D2 polyurethane blocks (n=10)
Group 2B: 4.3x10mm5mm implants in D4 polyurethane blocks (n=10) (Figure 3.3)

3.2. Polyurethane Block

The polyurethane blocks (#1522-03: Sawbones, Malmö, Sweden), which imitate the bone structure of D2 and D4 (PCF05), were utilized to put implants using the standard procedure (Figure 3.1The rigid polyurethane foam known as Standard Specification for Rigid Polyurethane Foam for Use as a Standard Material for Test Orthopaedic Devices for Instruments has been approved and recognized by the American Society for Testing and Materials (ASTM F-1839-08) as a standard for evaluating tools and mouth implants for comparative testing of bone screws. The polyurethane block was developed in a stimulated D2 and D4 bone density (#PCF20, #PCF05: Sawbones, Malmö, Sweden). With this closed cell polyurethane foam, the torque of stripping, insertion, and screw pull out are all periodically evaluated. .

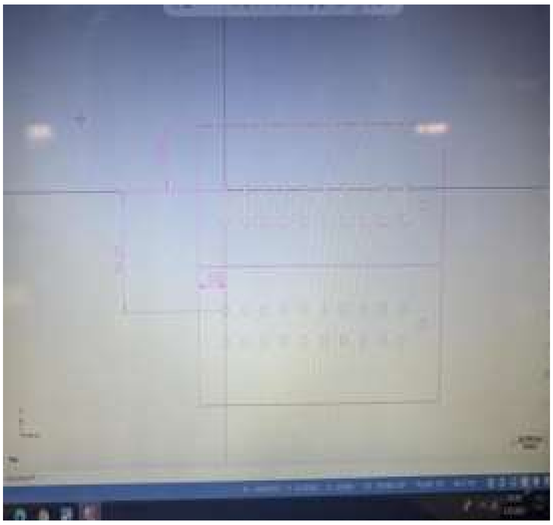
Figure 3.2. Sawbones, PCF05(D4) polyurethane bone (#1522-03: Malmo, Sweden)

.

Figure 3.3. Johnford VMC-850 model CNC Milling machine (Taichung City, Taiwan)

The blocks' implant slots were cut using a computer-controlled CNC milling machine (Johnford VMC-850 type CNC Milling machine, Taichung City, Taiwan) and digital drawings and instructions. There were gaps of 3 cm from the top of the bone block, 2 cm from each side, and 1 cm between each slot. This resulted in a negligible margin of error for implant slots caused by angular stresses between different osteotomies.

The ultimate drill diameter to put the implant was determined to be 4.3 mm during the drilling technique, and it was used for both D2 and D4 bone types with 600 rpm speed and 35 N/cm torque (Figure 19). By drilling holes inside the implants, the FANUC series O-M robotic (FANUC, Oshino-mura, Minamitsuru-gun, Yamanashi Prefecture, Japan) was able to manage them accurately (Figure 20). The implant was placed using the Implance surgical kit (AGS Medikal Ürünleri th. hr. Tic. ti.) after the artificial blocks were prepared.



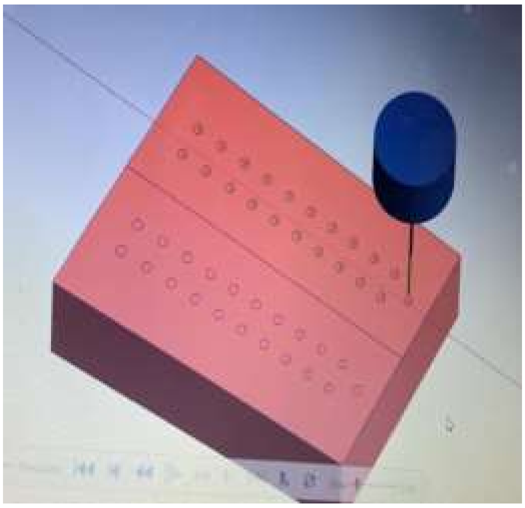


Figure 3.4. Digital drawings made on the computer connected to the CNC Milling machin

Figure 3.5. Implant slots opened to PCF05 and PCF020 bone type

Figure 3.6. IMPLANCE conventional surgical kit (Trabzon, Turkey)

Figure 3.7. Woodpecker physio dispenser (Guilin, China)

3.3. Insertion Torque, Removal Torque and Resonance Frequency Analysis

Using a physio-dispenser from the Woodpecker brand (Guilin, China), the torque values of the implants' insertion and removal were measured. As the implants were being inserted and removed, the torque values at each turn were measured, and all values were rounded throughout. Once each implant has reached bone level, the calculation of the insertion torque values has finished. The results from the physio dispenser were compared to the results from the calibrated Geratech Digital Torque Wrench (Germany) brand torque tool, which was received from the Marmara University Faculty of Technology. This allowed for the verification of the results.

Figure 3.8. Geratech Digital Torque Wrench torque tool (Germany)

The smartpeg (type 57; Gothenburg, Sweden) was put on the implants, and the resonance frequency study of the implants was carried out. With the Penguin RFA equipment (Integration Diagnostics Sweden AB, Gothenburg, Sweden) held about 1 cm from the smartpeg affixed to the implants, resonance frequency analysis measurements were made. The observed values are given in ISQ units. Three measurements were made for every implant. The implants' peak, left, and right points were all measured, and the average was calculated. The investigations were conducted with great care, including using the same operator, measurement tools, ambient circumstances, and methodology throughout.

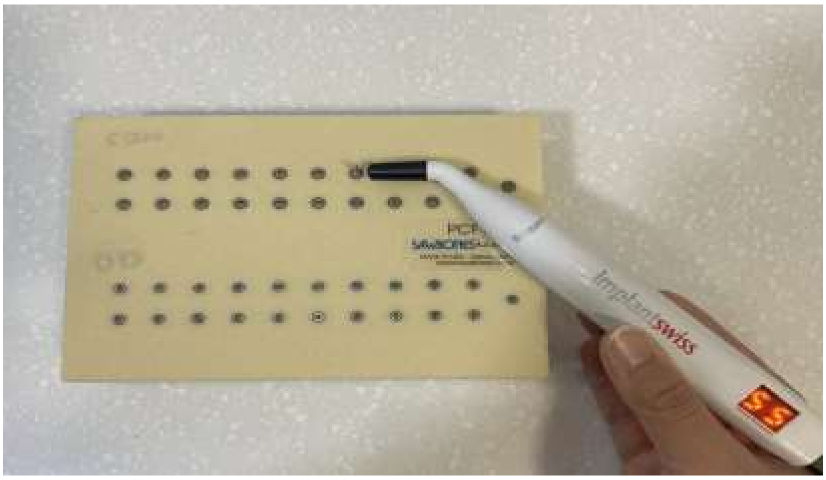


Figure 3.9. Type 57 smartpeg; Gothenburg, Sweden

Figure 3.10. Penguin RFA (Integration Diagnostics Sweden AB, Gothenburg, Sweden)

3.4. Statistical Analysis

Data were analysed in this study using both descriptive and inferential statistics. The descriptive statistical techniques of mean, standard deviation, cross-tabulation, and frequencies are all employed to characterize the data. Prior to determining the dependent and independent variables, its main objective was to understand the variables included in the data. Additionally, the Mann Whitney Test was utilized in this study to look at group differences; a significant difference was shown by a p-value of 0.05.

4. RESULTS

This study compared the main stability (ISQ values), insertion and extraction torque values, and two types of bone densities of 5-mm short implants and 10-mm standard size implants (D2 and D4).

4. 1 Comparison of measurements by groups:

4.1.1 Insertion torque value in D2 bone

A non-statistically significant difference (p0.05) was discovered when the Mann Whitney U test was used to compare the insertion torque values between the groups. The insertion torque value for a 5 mm short implant (35 n/cm) in D2 bone density was not significantly different from that of a 10 mm standard implant (36.5 n/cm).

Table 4.1. Comparison of insertion torque value by implant length in D2 bone.

Groups	Bone type	Implant length (mm)	Median value Insertion Torque (n/cm)	Value of mw u	p value
Group 1A	D2	5	35	24	0.24
Group 2A	D2	10	36.5	24	

4.1.2 Insertion torque value in D4 bone

Comparing insertion torque values between groups with the Mann Whitney U test indicated a statistically significant difference (p=0.01). 5 mm short implant insertion torque in D4 bone (2 n/cm) was statistically lower than 10 mm standard implant (3 n/cm).

Table 4.2. Comparison of insertion torque value by implant length in D4 bone.

Groups	Bone type	Implant length (mm)	Median value Insertion Torque (n/cm)	Value of mw u	p value
Group 1B	D4	5	2	17	0.01
Group 2B	D4	10	3	17	

4.1.3 Implant Stability Quotient ISQ in D2 bone

Using the Mann Whitney U test, differences in ISQ values between groups were discovered (p=0.024). 5 mm implant in D2 bone (5019.04 n/cm) had a lower ISQ value than 10 mm implant in D2 bone (66.52.22 n/cm).

Table 4.3. Comparison of ISQ value by implant length in D2 bone.

Groups	Bone type	Implant length (mm)	Mean±SD ISQ (n/cm)	Value of F	p value
Group 1A	D2	5	50±19.04	27.52	0.024
Group 2A	D2	10	66.5±2.22		

4.1.4 Implant Stability Quotient ISQ in D4 bone

Using the Mann Whitney U test, a statistically significant difference (p0.001) was detected between the groups' ISQ values. The ISQ value of a 5 mm implant in D4 bone (41.88/84 n/cm) was lower than a 10 mm implant (54.52.06 n/cm).

Table 4.4. Comparison of ISQ value by implant length in D4 bone.

Groups	Bone Type	Implant length (mm)	Mean±SD ISQ (n/cm)	Value of F	p value
Group 1B	D4	5	41.8±8.84	17.92	0.001
Group 2B	D4	10	54.5±2.06		

4.1.5 Removal torque value in D2

The Mann Whitney U test indicated no statistically significant difference between groups' removal torque values (p0.05). 5 mm implant in D2 bone (15.5 n/cm) was not statistically lower than 10 mm implant (18 n/cm).

Table 4.5. Comparison of removal torque value by implant length in D2 bone.

Groups	Bone type	Implant length (mm)	Median value Removal Torque (n/cm)	Value of mw u	p value
Group 1A	D2	5	15.5	32.5	0.19
Group 2A	D2	10	18		

4.1.6 Removal torque value in D4

A non-statistically significant difference (p0.05) was detected between group removal torque values using the Mann Whitney U test. The 5 mm implant in D4 bone (6.31.05 n/cm) had the same removal torque as the 10 mm implant (6.71.15 n/cm).

Table 4.6. Comparison of removal torque value by implant length in D4 bone.

Groups	bone type	Implant length (mm)	Median±SD Removal Torque (n/cm)	Value of mw u	p value
Group 1B	D4	5	6.3±1.05	0.66	0.44
Group 2B	D4	10	6.7±1.15		

5. DISCUSSION AND CONCLUSION

This study compared the main stability (ISQ values), insertion, and extraction torques of 5-mm short implants and 10-mm standard implants in two kinds of bones (D2 and D4 bone densities).

Advanced surgical procedures include sinus elevation, IAN nerve lateralization, and bone augmentation might give patients problems during and after the procedure. Short dental implants may be a better treatment choice in terms of less intrusive surgery and patient satisfaction, say experts. Short dental implants fail less often than lengthy ones, according to study (111,112).

Lengthier implants provide superior crown-to-implant ratios and larger surface area for osseointegration, reducing occlusal stresses.

Reduced implant length may be countered by better implant designs and microstructured implant surfaces that enhance the integratable surface area. It would retain the bone-implant interface (100). The crestal section of the implant body absorbs most of the load, whereas the apical portion gets very little stress, and anchoring was not significantly enhanced by extending implant length from 7 to 10 mm (102). The key to spreading prosthetic loads to bone-implant contact may not be implant length. However, posterior location in the mouth, increased crown height, and low bone density of the atrophic jawbone offer substantial hazards that might affect the longevity of short dental implants. It's been said that bone density speeds up dental implant processes. Short dental implants in the maxilla had worse survival rates, while implants in the mandible, which has better bone density and stronger mechanical properties, put less stress on the bone. In past studies, implant losses occurred due to peri-implant stresses and tensions in locations with poor bone density (150). In this investigation, D2 bone blocks mimicking mandibular bone density and D4 bone blocks mimicking maxillary bone density were used.

With advances in implant design and surface properties, this concept has grown unclear. Studies call implants smaller than 10, 8, 7, and 6 mm short (7,8,15,16). In addition, "ultrashort implants" or "extra-short implants" with intra-bony lengths no longer than 6 mm are becoming more popular (11,12).

The debate over whether implant length affects clinical success continues (19,20,21,22). Previous systematic reviews generally included implants longer than 8 or 10 mm as a control group (2,35). Compared to extra-short implants (6 mm), 8 mm or longer implants in native or rebuilt bone are the control group. In other words, we compare the clinical results of tiny (5 mm) implants to those of longer (10 mm) implants, which were the control group with acceptable clinical outcomes (172,173).

Clinical performance of short dental implants has improved due to advances in implant design and surface features that ensure stronger primary stability and wider bone-to-implant contact, as well as focused surgical procedures and personalized prosthetic restorations (100). In this study, SLA implants were chosen over machined implants for high placement and extraction torque and ISQ values. A grooved implant was chosen because specialists thought it would have excellent primer stability.

Continuous, unbiased, quantitative monitoring is essential to check the implant's stability. Microscopic or histologic investigation was once the gold standard for osseointegration assessment. Due to its invasiveness and ethical concerns, alternate techniques of testing, such as torque of cutting resistance, insertion torque, and removal torque, have been developed (174). Invasiveness of the procedures led to the selection of insertion torque, removal torque, and RFA parameters for the current study's implant stability assessment.

Insertion torque test measures the force needed to put the implant into the slot. It is currently commonly used for quick loading (131,136). Ottoni asserted in 2005 that implants in patients with high bone quality have high torque and ISQ (142). However, Friberg et al. said insertion torque and ISQ are unrelated (143).

Sullivan et al. investigated insertion torques according to bone quality and found no statistically significant difference between D2 and D3 bone, whereas D4 values declined significantly (156).

Ottoni et al. found that implants with a placement torque of more than 32 Ncm can be loaded immediately, but those with less than 20 Ncm may fail (142). Supposedly, the insertion torque test is a straightforward and reliable way to determine implant stability (157).

In vivo, Trisi et al. observed a link between insertion torque, peri-implant bone density, and micro-movement. Bone density increases insertion torque and reduces micro-movement (158). In a review, Li et al. and Berardini et al. found no difference in implant failure rate or crestal bone resorption with low or high insertion torque. They also showed that dental implants put in low-density bone can have greater bone volume (BV) and bone-implant contact (BIC) than traditional osteotomies, suggesting this may aid with osseointegration (159,160).

The insertion torque test is an accurate and simple method for assessing implant stability, according to Ottoni et al (142). Similarly, Türkylmaz et al. and Farré-Pagè et al. showed a statistically significant connection between primary implant stability and insertion torque (161, 162).

Fernando et al. (133) studied how bone quality affects the primary and secondary stability of single short implants in the posterior. Short dental implants were put into diverse bone types to assess primer and secondary stabilities. They placed 39 implants with 4.1 mm diameters and 6 mm heights in 18 patients' posterior maxillae and mandibles. To test primer stability, they measured placement torque and resonance frequency. According to the data, the placement torque and ISQ values of implants in D4 bone were much lower than in D1 and D2 bone. In addition, 5 and 10 mm implants were put, removed, and tested for primary stability in D2 and D4 bone types. The results show a statistically significant difference between D2 and D4 bone types in insertion, extraction, and ISQ values, with D2 being much higher. The current study found a statistically significant difference between D2 and D4 bone insertion and extraction torque, with D2 being substantially greater. Also seen with 5mm implants.

Alghamdi et al. (132) examined the extraction torque and ISQ of 40 short dental implants with varying diameters and heights on bovine ribs with D2 bone density. They chose implants with diameters of 4.8 and 6.2 mm and heights of 5 and 7 mm. In their study, 4.8x5-mm implants had a mean ISQ of 45.08, whereas 4.8x7-mm implants had a substantially higher 46.75. Similarly, 6.2x5-mm implants' mean ISQ value was 50.5, whereas 6.2x7-mm implants' was 51.57. In the same study, maximum extraction torque values for implants were published. Implants with a diameter of 4.8 mm and a height of 5 mm had a mean maximum extraction torque of 24.99 N.cm, whereas implants with the same diameter and a height of 7 mm had a value of 25.97 N.cm. Implants with a diameter of 6.2 mm and a height of 5 mm had a mean maximum extraction torque of 27.77 N.cm, whereas those with the same diameter but a height of 7 mm had a value of 28.98 N.cm. They found that preserving implant heights and diameters enhanced ISQ and extraction torque.

Implants with insertion torque values more than 32 N cm can be loaded immediately, while the failure rate may be higher with values less than 20 N cm, said Ottoni et al (142). The placement torque test is a user-friendly technique to measure implant stability, they say. In this study, the mean insertion torque for 5 mm implants in bone type D2 was 34 N cm, whereas it was 36 N cm for 10 mm implants. In the current study, the extraction torque for 5-mm implants on D2 bone was 16 N.cm compared to 17 N.cm for 10-mm implants. The ISQ for 5-mm implants put on D2 bone was 51 N.cm, compared to 67 N.cm for 10-mm implants.

These options make early loading feasible. Mean insertion torque for 5-mm implants in D4 bone was 2 N.cm, however it was 3 N.cm for 10-mm implants. In this study, the extraction torque for 10-mm implants was 6 N.cm, while it was 6 N.cm for 5-mm implants on D2 bone. In this study, the extraction torque for 10-mm implants was 6 N.cm, while it was 6 N.cm for 5-mm implants on D2 bone. The ISQ for 5-mm implants put on D2 bone was 55 N.cm, compared to 41 N.cm for 10-mm implants. These studies imply that early loading of dental implants may induce failure.

Experts believe that resonance frequency measurement is the best way to evaluate primer stability (ISQ). Levels of ISQ 60 are harmful and shouldn't be loaded soon. Implants with ISQ values between 60 and 69 can handle traditional loading, whereas those over 70 can handle quick loading (139).

The amount of torque needed to unscrew an implant from bone depends on how well it contacts the bone. Implants may be more stable with higher removal torque (163).

Torque testing was said to be the sole way to accurately measure bone growth at implant sites. According to reports, this test can establish the maximal shear force between the bone and implant. In addition to implant shape, implant contact with surrounding tissues affects these measurements (162).

According to Ivanoff et al., larger torque rotation forces necessary to remove implants may enhance bone-implant contact, leading to higher osseointegration strength. (164). The removal torque values for screw-shaped implants put in rabbit tibiae for 6 weeks, 3 months, and 6 months were unaltered. Removal torque values for cancellous bone (femoral intra-articular implants) at 3 months and 6 months were likewise unaltered (10). The results support the idea that an improved design improves early implant loading and osseointegration. Similar findings were seen with rabbit tibia removal torque (165, 166). Gehrke and Marin discovered no regular association between ISQ and removal torque, but correlations when converting averages to percentages for each time period (167). This is consistent with Cehreli's study, which found a statistically significant association between cutting torque or insertion torque and resonant frequency analysis, indicating that ISQ values were frequently related with removal torque values. Surface An earlier study indicated that surface alterations influenced removal torque, thus identical implants were employed (168). Our investigation indicated that the removal torque of short dental implants put using the D2 OD method was much higher than that of short implants placed using the traditional procedure (mean = 1.570.6 N/cm).

Meredith suggested resonance frequency analysis in 1998 as a noninvasive diagnostic method for assessing implant stability and bone density (127). RFA is used to evaluate the main stability of dental implants. Implants with ISQ 60 are dangerous and shouldn't be loaded in the short term. Traditional loading may be done for implants with ISQ values between 60 and 69, but instantaneous loading for implants beyond 70. In low-density bone types such as D4, these reference values may shift, and implants with ISQ values >40 do not have failed implant stability (134,139).

Primary implant stability depends on implant design, bone density, and surgery (11,168,169). Low implant micro-movement, especially during early healing, facilitates direct bone ingrowth to the implant surface (170). Research shows a linear link between implant height and ISQ scores (171,172). In this investigation, Sim and Lang linked ISQ values to bone structure and implant length (171). However, O'Sullivan et al observed no connection between implant shape and primary stability (172). In this study, identical bone and tissue implants were compared. Compared to tissue-level implants, bone-level implants showed somewhat higher ISQ and removal torque values. When implant stability was compared in different bone types, type II bone with 1 mm cortical bone had the highest ISQ values (172). This conclusion is similar to that of Akca et al., who found implant shape affected bone quality less (173). Implant design, surgical technique, and substrate type affect primary stability, say Elias et al (3).

González-Serrano et al. (174) studied the main stability of short dental implants. On cow ribs, which imitated D3 and D4 bone types, they put short dental implants with the same diameters and heights. Thirty of the 60 implants had a single-helix design and 30 had a double-helix design. The main stability of double-helix implants was higher than that of single-helix implants, according to resonance frequency analyses. Double-threaded short implants exhibited greater PS in D3 and D4 bone than single-threaded short implants.

In another study, Calvo-Guirado et al. (175) compared the main stability, marginal bone loss, longevity, and success of 4-mm-long implants to conventional implants supporting fixed prostheses. In resonant frequency analysis used to assess primer stability, 4-mm implants had lower ISQ than 10-mm implants. Short dental implants (8 mm or less) supporting single crowns or fixed bridges are a feasible treatment option for individuals with impaired ridges, with similar radiographic and clinical success rates. More long-term data from more implants and patients are needed to corroborate these findings.

In addition, Benliday et al. (170) employed 147 implants on 38 patients with an average age of 48.3 years. Mean loading times for conventional implants were 36.6 12.9 months and 39.4

13.5 months for short implants. Standard implant survival rates after three years were 98.4% and 96.5% for short implants, but the difference was not statistically significant. Short implants exhibited less bone loss than conventional ones. At 30 months, loss was 0.790.72 mm for regular implants and 0.51 0.54 mm for short implants. These values were 0.420.36 mm and 0.660.63 mm 5 years following implant insertion. The authors proposed brief implants as an option to bone augmentation, although research is currently restricted. Bruggenkate et al. (177) studied 253 Straumann (Basel, Switzerland) implants and found recovery time to be 4 months. After 72 months, they observed a 94% implant survival rate and a 6% failure rate for maxilla and mandible implants. 164 Gulje et al. (178) inserted 60 4x6 mm AstraTech (Gothenburg, Sweden) implants on mandibular areas. Clinical and radiological outcomes were the same for 6-mm short and 11-mm standard-length implants during a 5-year period. Dynamic model assessment was developed in 1996. (146). Here, a pendulum-shaped hammer is utilized to hit the implant, resulting in vibration. When you hit anything with the hammer, the piezoelectric crystal within will send out a voltage signal. A force-time graph is generated based on the input data. Area under the force-time curve is a measure of the pushing force. The data changes as it is affected by the force's intensity and location. There have been reports that this measurement is particularly challenging in implants with poor stability (155).

Short implants exhibited decreased failure rates in the first year of functional loadings, according to Pommer et al. (96). In a clinical investigation, 7-mm implants had a failure rate of 9.5%, whereas lengthier implants had a failure rate of 3.8%.

When comparing short and regular dental implants, Rokn et al. (157) found no changes. In other trials, marginal bone loss, prosthesis failure, and complications were comparable across short and regular dental implants. Short implants have a higher failure risk because to their lesser bone connection. Misch et al. (182) found that 85.3% of 2837 posterior short implants from 1991 to 2003 were effective (152). Their investigation found that short implants can sustain permanent restorations in posterior partial edentulism. Das Neves et al. (93) and Esposito et al. (109) revealed that brief implants are an effective alternative to sophisticated augmentation procedures. Their results show that short implants are better than vertical bone grafting for resorbed mandibles. In a research comparing lengthy and short dental implant treatments, Kotsovilis et al. (160) found that short implants were equally as successful. Short rough-surface implants are not less successful than standard rough-surface implants for replacing missing teeth in totally or partially edentulous individuals, according to their study.

Malo et al. (101) studied 127 patients who had 217 implants and 165 fixed prostheses. Their study found that 7 mm short implants had high success rates (95 percent at the patient and implant levels) one year after loading, demonstrating that small implants are a realistic idea. Longer follow-ups are needed to corroborate these findings. In comparable trials, Espesito et al. (161) showed marginal bone loss of 1 mm for short implants and 1.2 mm for long implants. Renouard et al. (88) followed 96 short dental implants for two years and discovered a 0.44 mm mean marginal bone loss, which is safe. Short and wide-diameter implants had equal survival rates to lengthier and standard-diameter implants, they said. In areas with bone resorption, injury, or trauma, short implants may be unfavorable. While implant failure rates may be greater in these circumstances, results should be compared to bone grafting, sinus lifting, and alveolar nerve transposition.

Jain et al. (185) compared preferred dental implants to bone density and features. Their research found that bone type affects the success of short dental implants, with D3 and D4 having the highest failure rates. Inferior bone quality and low implant heights hampered implant stability and healing, they said. They concluded that short implants may be a viable treatment strategy in atrophic ridge patients to avoid invasive surgery. Improved implant surface geometry and texture result in a larger implant surface in contact with bone, improving osseointegration.

Numerous studies have compared lengthy implants to conventional implants, but there's no consensus (95). 2 mm of bone loss around a 6-mm implant is almost half the implant's length and should be treated clinically differently. To help clinical interpretation, short dental implants should be compared to standard implants in resorbed posterior jaws. In systematic reviews, Chiapasco et al. found that implant survival rates in the augmented maxillary sinus were 95% (follow-up, 6-144 months), that in vertical distraction osteogenesis procedures was 95.9% (follow-up, 6-72 months), and that in the maxilla and mandible reconstructed with onlay bone grafts were 79.5% (follow-up, 6-240 months) and 94.8% ((follow-up, 6-240 months) They chose simple methods(186). The ISQ value of a 5 mm-long implant in D2 and D4 bone was statistically lower than a 10 mm-long implant in both bones.

According to the author, no study has compared the main stability (ISQ values), insertion and extraction torque values of 5-mm short SLA implants with 10-mm standard size SLA surface implants into two distinct types of bones (D2 and D4 bone densities).

This study's limitations allow the following conclusions:

• A 5 mm implant in D2 bone had the same insertion torque as a 10 mm implant.

• 5 mm implant insertion torque in D4 bone was statistically lower than 10 mm implant insertion torque in D4.

• A 5 mm implant in D2 bone had a lower ISQ value than a 10 mm implant.

• A 5 mm implant in D4 bone had a lower ISQ than a 10 mm implant.

• A 5 mm implant in D2 bone did not have a lower removal torque than a 10 mm implant.

• A 5 mm implant in D4 bone did not have a lower removal torque than a 10 mm implant.

•

This study found that bone type affects implant survival more than implant length.

• The results show that 5mm small implants are an appropriate alternative to 10mm long implants to avert advanced operations.

• Larger samples and prospective clinical investigations are needed to confirm present findings.

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8. CURRICULUM VITAE

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