BIOMEDICAL DESIGN FOR IMPROVING THE PRIMARY STABILITY OF DENTAL IMPLANTS IN POOR BONE QUALITY

by

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ABSTRACT

BIOMEDICAL DESIGN FOR IMPROVING THE PRIMARY STABILITY OF DENTAL IMPLANTS IN POOR BONE QUALITY

Like so many other discoveries, clinically reliable dental implants were preceded by a serendipitous observation, rather than a logical chain of experiments, leading to the final product. In an attempt to film the microcirculation of rabbit bones, Branemark noticed that the metallic cap at the end of a fiber optic cable embedded in the bone of an experimental animal had apparently become fused to the bone after remaining in situ for some days. This observation led him to postulate that the metal of the end cap, namely titanium, had properties that could be valuable in the construction of dental implants. In order to test his hypothesis, Branemark and his collaborators began a series of experiments, first in animals and later in humans, which led to the development of the first reliable dental implant. The development of new systems has been accelerated in last years and implants became a treatment modality in modern dentistry. Eventhough there are many types of implants available in the medical applications, some developments are required regarding the need of improving the success of surgical interventions. The research implemented to use titanium which is well documented to provide all necessary mechanical and bio-compatibility requirements. The focus is to propose a new implant design, not conical or cylindrical designs which are actual designs applied, but a new design which will resemble the tooth anatomy as with roots, thus increase the primary stability and open new indications to implant applications. The results of the study indicates promising positive future directions but further controlled clinical invivo research is needed for better understanding the action mechanism of the developed implant design. After the modifications are applied by the data collected from controlled clinical invivo research will be realized, developed implant design can open new treatment indications in implant dentistry.

Keywords: Implant, Dental, Primary Stability, Design, Prototype, Titanium.

ÖZET

KEMİK KALİTESİNİN DÜŞÜK OLDUĞU DURUMLARDA DİŞ İMPLANTLARININ BİRİNCİL KARARLILIĞININ ARTIRILMASINA YÖNELİK BİYOMEDİKAL İMPLANT TASARIMI

Birçok buluşta olduğu gibi, diş implantların temel gelişimide mantıksal deneyler zinciri yerine rastlantısal bir gözlem sonucu gerçekleşmiştir. Tavşan kemiklerinde mikro kan dolaşımını filme almaktayken, Branemark adlı araştırıcı fiber optik kablonun ucundaki metal başlığı, operasyon bölgesinde bir kaç gün unutunca, metal ucun kemiğe kaynadığını gözlemlemiştir. Bu gözlem kendisine titanyum metalinin diş implantlarının kullanımında avantajlı bir malzeme olabileceğini düşündürmüştür. Bu hipotezini denemek için Branemark ve arkadaşları önce hayvanlarda sonra insanlarda deney serileri gerçekleştirerek, ilk güvenilir diş implant sisteminin gelişimini sağlamışlardır. Yeni sistemlerin geliştirilmesi son yıllarda hızlanmış ve bu gelişmelerle birlikte diş implantları modern dişhekimliği uygulamaları arasındaki yerini almıştır. Medikal sektörde çeşitli uygulamalarda başarıyla uygulanan farklı implant türleri olmakla beraber halen bu cerrahi uygulamanın başarısını artırmaya yönelik yeni gelişmelere ihtiyaç duyulmaktadır. Yapılan bilimsel çalışma tüm mekanik ve biyouyumluluk özellikleri sağlayan titanyum metali kullanılarak gerçekleştirilmiştir. çalışmanın amacı yeni bir biyomedikal diş implant tasarımı önererek, güncel kullanılan konik veya silindirik implant tasarımlarının dışında, doğal diş anatomisini andıran kök oluşumunda bir tasarımla, birincil kararlılığı artıran bir model geliştirmektir. Bu tasarım geliştirilerek implant uygulamalarında yeni uygulama ufukları açmayı hedeflemektedir. Bu çalışmanın sonuçları gelecek için olumlu ibareler taşımakla birlikte, etkileşim mekanizmasının daha iyi anlaşılabilmesi için gelecekte kontrollü klinik bilimsel çalışmalar yapılması gereklidir. Bu yapılacak çalışmalar sonrasında geliştirilen implant tasarımı üzerinde gerekli değişiklikler yapılarak birincil kararlılığın artırıldığı implant tasarımı yeni implant uygulama alanları yaratabilecektir.

Anahtar Sözcükler: İmplant, Diş, Birincil Kararlılık, Tasarım, Prototip, Titanyum.

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1. INTRODUCTION

Anthropological discoveries in Europe, the Near East, and Central America have indicated that man attempted very early in history to replace lost teeth using homologous or alloplastic materials including human and animal teeth, carved bone, pieces of ivory, and mother of pearl. The apparent purpose for such attempts at tooth replacement was purely esthetic. In terms of chewing function, they were worthless. The Spaniard Alabucasim, around the year AD 1100, supposedly was the first to recommend re-transplantation and transplantation of teeth, suggesting that it was a medically acceptable procedure to replace missing teeth [1]. This method was in common use for centuries. Especially in the 18th century, the transplantation of teeth was fashionable in the higher social circles in France and England; the transplanted teeth were usually removed from young individuals, who were paid. Because of the very high failure rate, as well as the danger of transmission of diseases, e.g., tuberculosis and syphilis, such tooth transplantations came under increasing criticism.

With the development of the natural sciences in the 18th and 19th centuries, and the transfer of scientific knowledge and methods into the area of medicine, numerous attempts were made to replace lost teeth by means of implanting foreign materials into the jaws. By the end of the 19th century, various authors had proposed the implantation of alloplastic materials (rubber, gold, porcelain, etc.) Shaped to resemble tooth roots into artificially created alveoli [2]. Hartmann was the first to expand the indication for implants beyond single tooth replacement; he proposed in 1891 that dentures be affixed to implanted alloplastic tooth roots by means of screws. However, the large number of failures with such root-form implants led to the relatively quick demise of the procedure. It was in 1939 that Stock first attempted to change the shape of a dental implant from that of a tooth root; he used a chromium-cobalt-molybdenum alloy (Vitallium) to create a dental implant with a threaded body, which resembled a wood screw [12]. A new area of implantology began in 1947, when Formigini adopted Stockâs idea that dental implants do not need to resemble tooth roots. It reached a

climax at the end of the 1960s and early 1970s. In France, Scialom (1962) recommended needle implants, inserted into the nobe of the jaws as dipods, tripods or arranged in a row. It was Linkow who, in 1968, introduced implants in the shape of special blades [12].

Like so many other discoveries, clinically reliable dental implants were preceded by a serendipitous observation, rather than a logical chain of experiments, leading to the final product. In an attempt to film the microcirculation of rabbit bones, Branemark noticed that the metallic cap at the end of a fiber optic cable embedded in the bone of an experimental animal had apparently become fused to the bone after remaining in situ for some days. This observation led him to postulate that the metal of the end cap, namely Titanium, had properties that could be valuable in the construction of dental implants. In order to test his hypothesis, Branemark and his collaborators began a series of experiments, first in animals and later in humans, that led to the development of the first reliable dental implant [3-6].

The chain of events that led to this therapeutic breakthrough began with an astute observation, namely that titanium appeared to be capable of forming an intimate bond with bone tissue. Following this seminal observation, a series of hypotheses were formulated the objectives of which were to clarify various aspects of the observed phenomenon. Included among these were feasibility ("proof of principle") studies aimed at determining whether a titanium implant could be developed for human use. Experiments in animals indicated that titanium was biocompatible with and could achieve an intimate bond with both soft and hard tissues.

The animal experiments provided the basis for a long-term clinical trial in humans that culminated. In the eventual report by Adell [7] of 15-year results on the use of dental implants in the edentulous mandible and maxilla to support implant-borne restorations. The report, which covered 2,768 implants placed from 1965 to 1980 in 410 jaws of 371 consecutive patients, indicated that "implant stability" was achieved in 81 percent of the maxillary and 89 percent of the mandibular implants, and restorations retained in 89 percent of the maxillary and 100 percent of the mandibular cases. These

clinical results constituted a significant improvement over the results that had been achieved up to that time with other systems [8, 9].

While such clinical trials are primarily descriptive in nature, they provide essential data on survival rates and complications that can be used to determine the safety and reliability of a new therapeutic approach in a clinical setting. They also serve as a valuable source of testable hypotheses to help understand some of the underlying mechanisms that control the outcome of such trials.

In developing their implant system, Branemark and his collaborators made certain assumptions regarding the composition of the implant material, its macrostructure and microstructure, and the surgical protocol for placing the implants and later for loading them [3, 4]. Because of the need to maintain a standard protocol while collecting longitudinal data on a large number of implants within the framework of a multi-center experimental design, many of the underlying assumptions for ensuring a successful clinical outcome were not actively challenged, at least initiallv. As discussed below, some of the requirements thought to be essential for success later proved to be less critical than first assumed.

The early reports of high success rates with the Branemark implants and of the independently developed TPS (Titanium Plasma Sprayed) screws [10, 11], prompted the outgrowth of additional implant systems as well as modifications of existing ones. Since the mid 1980s, dozens of other implant systems have been marketed, some of which have undergone longitudinal trials with the results published in refereed journals, while others have been subjected to more limited testing. The development of new systems has been accelerated in last years and implants became a treatment modality in modern dentistry.

2. IMPLANT TYPES AND THEIR USES

2.1 Endosteal

2.1.1 Root Forms

Given sufficient width and height of available bone, root forms (submergible two-stage and single-stage one-piece) are the first choice in selecting an implant. The following three types are available. Press-fit (unthreaded but covered with a roughened hydroxyapatite (HA) or titanium plasma spray coating (TPS). Second type of root form implants are self-tapping implants. And the third types of implants are pretapping (threaded) implants. These may be used for fixed, fixed-detachable, overdenture, and single-tooth purposes (hex or other antirotational design required). Maxillary or mandibular, complete or partial edentulism are suitable arches. Required bone; minimum 8 mm vertical bone height, minimum 5.25 mm bone width at buccal to lingual and at least 6.5 mm bone length mesial or distal; per implant, including the spaces, mesially and distally.

2.1.2 Ramus Blade and Ramus Frame

The ramus implant is a one-piece blade made for use in the posterior mandible when insufficient bone exists in the body of this jaw. The ramus frame is a three-blade, one-piece device designed for relatively atrophied mandibles for which the subperiosteal implant, because of cost or operator preference, is not desirable. Prosthetic options are overdenture types. Suitable arche is mandibular, complete edentulism. Required bone; minimum 6 mm vertical bone height at symphysis or rami, and 3 mm bone width at buccal or lingual.

2.1.3 Transosteal Implants

These are one-piece implants. A submental skin incision is required under operating room conditions with this modality. The advantage of this type of implant is predictable longevity. These can be in single component or multiple components, staple structure. Prosthetic options for usual applications for these implant is the overdenture. Fixed bridges may be made as an alternative. Suitable arches are mandible, anterior region, complete or partial edentulism (single component may be used in the presence of teeth). Required bone; minimum 9 mm vertical bone height and 5 mm bone width labiolingually.

2.1.4 Crete Mince

These are threaded, self-tapping titanium spinals. Prosthetic options are for these thin-ridge implants add retention to long-span fixed bridge prostheses by pinning them through their pontics to the underlying bone. Suitable arch are mandibular or maxillary. Required bone; minimum 8 mm height and 2.5 mm width.

2.2 Subperiosteal

2.2.1 Complete, Universal, and Unilateral

These implants, which generally are quite reliable, may be used when insufficient bone is available for the use of endosteal varieties. However, when extreme mandibular atrophy exists, mandibular augmentation will improve the prognosis. These implants are always custom-made. They may be fabricated either by making a direct bone impression or by using the computer designed techniques. They may be used in any part of either jaw, and they will serve as abutments for a variety of superstructure designs, although the overdenture variety is strongly recommended for the complete subperiosteal implant. Prosthetic options are overdentures and fixed bridges. Suitable

arches are maxillary or mandibular arches, complete or partial edentulism. Required bone is adequate bone to support the implant.

2.2.2 Caveat

Extremely thin (pencil-like) mandibles and maxillae may permit subperiosteal implants to settle right through them. Therefore, a moderate amount of vertical bone height should be sought at minimum of 6 mm, or plans should be made to augment the inferior mandibular border or elevate the antral floor on a preventive basis.

2.3 Endodontic Stabilizer

These are highly successful tooth root-lengthening implants. One reason for their success is that they have no site of permucosal penetration because they are placed into bone through the apices of natural teeth. This implant offers a one-stage treatment for the stabilization of teeth that have inadequate crown-root ratios. Their percentage of success, when periodontal problems have been treated, approaches that of conventional endodontic therapy. Prosthetic options are crowns and fixed bridges. Suitable arches are: maxillary or mandibular; any tooth may be treated. Required bone is in direct proximity to apex-and in the long axis of the root canal 10 mm of height.

2.4 Intramucosal Inserts

These are buttonlike nonimplanted retention devices that can be used to stabilize full maxillary and partial maxillary and mandibular removable denture prostheses. They are of particular value for patients who are poor medical risks because of the simple and relatively noninvasive nature of the procedure. Prosthetic options are removable dentures, full or partial. Suitable arches maxillary, complete or partial eden-

tulism; mandibular, partial only. Required bone is minimum, but required mucosa, 2.2 mm thick (bone beneath thinner mucosa may be deepened in nonantral areas).

3. ANATOMIC FACTORS OF JAW BONE

Anatomical factors have a very important place in implant failures. There have been many studies on the implant and bone types, amount and available height. It is very essential to give the related terminology, before discussing the failures related, since mostly the failures arrive when contre-indicated patients are treated.

3.1 Bone Quality

For secure anchoring of endosteal implants, one requires not only adequate bone quantity (height, width, shape), but also density, and therefore the bone quality is of importance. With increasing age (beginning about age 45), osteoporotic alterations occur in the jaw bones; this is a physiological reduction of the trabecular density occasioned by hormonally induced insufficiency of the osteoblasts. A gross estimation of bone quality can be obtained from radiographs; however, accurate evaluation is not yet possible because the compact bony structures mask the trabecular areas, end because of the high level of variability among radiographic equipment. In most cases, the quality of bone is determined with certainty only during the surgical procedure. An experienced surgeon will recognize the bone quality as soon as the pilot hole has been drilled. Another classification of the various bone qualities was proposed in 1985 by Lekholm and Zarb [13]. It is used in combination with the classification of bone resorption also proposed by these authors. Class I is the jaw consists almost exclusively of homogeneous compact bone. Class II is the jaw which thick compact bone surrounds highly trabecular core bone. Class III is the thin cortical bone surrounds highly trabecular core bone. Class IV is the thin cortical bone surrounding loose, spongy core bone. In dense, compact alveolar bone, the drilling of the implant bed must be performed with intermittent up and down movements using relatively high rpm greater force application, and the best possible cooling.

In the loose, spongy bone of the maxilla, surgical bed preparation must be performed with extreme care and without application of force, to preclude lateral perforations and excessive widening of the implant bed. Drilling the bed for cylinder implants is performed using reduced rpm, and the final implant bed preparations are carried out in one continuous motion. This precludes unfavorable widening of the implant bed in cases of implants with press-fit anchorage. With screw-type implants, care is indicated to avoid screwing the implant itself or the thread-cutting tap too deeply into bone. In spongy bone (Classes III, IV), self tapping screws therefore have certain advantages.

The absolute thicknesses as well as the internal osseous architectures vary considerably in different segments of the maxilla and mandible. These structural differences can influence treatment planning and clinical success with dental implants. Misch [14] acknowledged this fact in his classification of four degrees of bone quality as they affect the anchoring of endosteal implants. Each of the four classes is topographically based and described from the clinical point of view, with regard to it importance and the problems it may present in implantology.

D1 is defined as thick compact bone and found in anterior segment of the atrophic edentulous mandible. The advantages of this type of bone are, good primary stability of the implants, expansive implant-bone interface and use of short implants is possible. Disadvantages of this type of bone are reduced blood supply (longer healing phase), often short bone height (implant-crown ratio) and difficult implant bed preparation (overheating).

D2 is defined as thick, porous compact bone highly trabecular core bone and found in anterior and posterior segments of mandible. This type of bone can also be found in anterior maxillary segment. Advantages of this type of bone are good primary stability, good healing tendency (blood supply) and easy implant bed preparation.

D3 is defined as thin, porous compact bone loosely structured cancellous bone and found in anterior (facial aspect) and posterior segments of the maxilla, posterior segments of the mandible and in conditions following osteoplasty of Class D2 bone.

Advantage of this type of bone is good blood supply. Disadvantages of this type of bone are difficult implant bed preparation (widening), optimum usage of available bone is necessary and reduced implant-bone interface (increased number of implants).

D4 is defined as loose, thin cancellous bone and found in maxillary tuberosittes or in conditions following osteoplasty of Class D3 bone. There is no advantage for this type of bone. Disadvantages of this type of bone are difficult implant bed preparation (primary stability), optimum usage of available bone is necessary and reduced implant-bone interface (increased number of implants).

The characteristics of the bone at the implantation site and the anatomical locations are among those factors which seem to profoundly influence implant failure rates, independently of whether implants are loaded or not. In general, but not always, higher failure rates have been reported for implants placed in maxillas and in posterior segments of both jaws. This may partly be explained by different types of bone quality and loading conditions in these locations. In fact, mandibles generally have a denser and thicker cortical layer than maxillas and the cortical layer of both jaws tends to become thinner and more porous posteriorly. Also the trabecular bone component is denser in mandibles than in maxillas and in anterior areas than in posterior locations, although an extreme range of variations has been observed in mandibles.

An interim publication evaluating early failure rates in relation to bone quality reported that implants placed in "type I bone" had higher failure rates than those placed "type 4 bone" [15]. The authors speculated that this difference was possibly due to the use of HA-coated implants in "type 4 bone" and to overheating of the compact "type I bone" when preparing the implant site. In a follow up study by the same group [16], the total number of early failures decreased and this was attributed to improved surgical skill. Most of the failures observed in "type I bone" (i.e., mandibles) occurred before implant uncovering and could be related to iatrogenic reasons (infection and over-heating).

For failures discovered at abutment connection, the rates increased as bone

density decreased (indicating that bone quality played a predominant role). In addition, the interpretation of the results is further complicated by the fact that implants of different designs (cylinders, screws, grooved cylinders and baskets) and surface coatings (HA-coated or uncoated commercially pure titanium (CP Ti) or Ti alloy) were used in specific anatomical locations. For example, hollow-basket implants, which were mainly used in mandibles where "type I bone" is more often found, contributed with 46 out of the total 69 failures. In particular, 6 of the 8 failures occurred in "type I bone" involved basket implants. Conversely, HA-coated implants were mainly used in maxillas, where the softer "type 4 bone" is more commonly found.

These findings exemplify well the complexity of the relationships between different factors concurring to implant losses. It is conceivable, as shown by Truhlar [16], that the presence of dense bone may favour early implant stabilization, which is one of the prerequisites for obtaining osseointegration in a predictable way. In addition, possible differences in healing patterns between cortical and trabecular bone may be of importance.

3.2 Bone Quantity

3.2.1 Height of Bone

The vertical extent of bone available for implantation is defined by the distance between the alveolar crest and opposing anatomic boundaries (e.g., sinuses, mandibular canal, etc.). Implants should be placed with a safety margin of 1-2 mm from such structures. Ten mm is the accepted minimal length for cylinder or screw-type implants; exceptions to this general rule may apply if compact bone is very thick, for example in the mandibular symphysis region of a severely atrophied mandible. Whenever possible, longer implants should be used to increase the bone-implant contact surface area. In addition, distal implants have to withstand the heaviest loading and are in general short due to insufficient quantity of available bone. The presence of anatomical structures, such as the maxillary sinus and the inferior alveolar nerve, also limits the amount of

bone available for implants in posterior locations.

3.2.2 Width of Bone

The width of bone is measured in the area of the planned implant placement site as the distance between the oral (lingual, palatal) and the vestibular (buccal) osseous walls at the level of the alveolar ridge. For screw-form and cylinder implants, a width of about 5 mm is required and about 2.5 mm for blade implants. After surgical placement, at least 0.5 mm of bone should remain on both the oral and vestibular aspects of the implant.

3.2.3 Length of Bone

The minimum distance as measured from axis to axis between two implants is 7 mm. Depending on the implant diameter, this corresponds to a minimum 3-4 mm distance between implants. The minimum distance between an implant and a natural tooth should be about 1.25 mm. A very important clinical question is to what extent encroachment on the maxillary sinus can be tolerated during implant placement.

As a general rule, implants should be placed no closer than 1-2 mm from the base of the maxillary sinus; failure to observe this general rule may necessitate subsequent implant removal, and can represent a risk of infection if peri-implantitis occurs. On the other hand, some authors have reported no complications after opening the sinus during implant bed preparation or even penetration of the implant itself into the sinus by 1-2 mm.

3.2.4 Classifications of the bone atrophy

There are classifications in the literature following the atrophy of the alveolar ridge. These classifications can be useful during planning and case discussion. In most cases the quality of the bone will be taken into consideration together with the degree of the resorption. The following articles summarizes the classifications Atwood 1979 [17]; Fallschussel 1986 [18]; and; Lekholm Zarb, 1985 [13]. In 1987, Misch and Judy [19] provided a classification for the partially edentulous (Classes I-IV) as well as the totally edentulous (Class V) jaw. The basis for their classification is the amount of available bone for end osteal implantation with regard to bone height, width, and length of the bony alveolar ridge. The system is applicable with the use of cylinder, screw-type, and blade-form endosteal implants. However, because screw- and cylinder-form implants are used primarily worldwide today, it seemed reasonable to modify the classification system to fit today's realities. Kennedy's classification of partial edentulousness served as the basis for the Misch and Judy classification of partially edentulous jaws. The Kennedy system was expanded to include the osseous status of the edentulous jaw segment destined to receive an implant. The four Kennedy classes are further subdivided into four subgroups (A-D).

3.2.4.1 Classification of the Edentulous Jaw. This classification was made by Misch and Judy in 1987 [19]. Group A Sufficient quantity of bone is available for anchoring all types of endosteal implants in the maxillas and in the mandible. In the mandible, dental implants are normally only placed in the interforaminal region, even with such favorable initial situations. Perio overdentures or distal cantilever bridge.

Group B Bone availability is less expansive in this group. Smaller forms of cylinder and screw implants can be placed in both the maxilla and mandible. The prognosis, however, may be less favorable depending upon the bone quality. The number of abutments should be increased in order to provide more expansive implant-bone contact area, which will provide improved load distribution.

Group C The available bone permits placement of short screw and cylinder type implants in the interforaminal region of the edentulous mandible. In exceptional cases, it may be necessary to relocate the inferior alveolar nerve. If a patient presents with this initial situation, placement of endosteal dental implants is seldom feasible. In exceptional cases, ridge augmentation or sinus lift procedures may be attempted.

Group D In these cases, the alveolar processes as well as portions of the basal bony structure are resorbed. The placement of endosteal dental implants is not possible in either case. Prosthetic treatment involving implant supported dentures can only be accomplished after preprosthetic surgery to augment the ridge.

3.2.4.2 Classification of the Partially Edentulous Jaw. This classification was made by Misch and Judy in 1987 [19]. Group A Patients in Classes I and II present with natural teeth in the anterior segments and either unilateral or bilateral free end situations. The quantity of available bone is sufficient to permit either purely implant-borne bridges or bridgework extending from natural teeth to implants. The number of implants placed will depend on the number of missing teeth as well as on the opposing dentition. Patients in this group are missing teeth or groups of teeth (Classes III and IV) and have sufficient bone for placement for screw- and cylinder form implants. The number of implants to be placed will depend upon the length of the edentulous space and the type of prosthetic superstructure that is planned. Replacement teeth may be purely implant-borne or bridgework supported by both implants and natural teeth.

Group B Class I II ; The patients in this group exhibit a somewhat reduced bone quantity that is, however, still sufficient for the placement of smaller screw and cylinder form implants. In some cases, it is indicated to use more than one implant for load distribution. Blade-form implants can also be used to advantage with this type of bone relationship. Class III IV ; Very long edentulous spaces can be restored using fixed bridgework supported by implants because the bone availability is still adequate. Some practitioners recommend the use of blade implants in such circumstances.

Group C Class I II ; Patients in this category do not have adequate bone for placement of screw or cylinder implants. In recent years, exceptional cases of this type have been treated with implants after sinus lift procedures in the maxilla or relocation of the inferior alveolar nerve in the mandible. These two procedures are currently being evaluated scientifically. Long, Class III, edentulous spaces with bone quantity that is not adequate for the placement of endosteal dental implants. In some cases, maxillary sinus lifting of mandibular nerve relocation procedures may be employed. In Class IV situations, it is only possible to use short screw and cylinder form implants, and caution is indicated because of functional as well as esthetic limitations.

Group D Extremely advanced atrophy of the bone is evident. The use of conventional, removable dentures is indicated, but is sometimes fraught with problems (e.g., paresthesia, pressure loading) because of the high location of the mandibular canal. If there is a risk of mandibular fracture, autologous bone may be used for alveolar augmentation in special cases. Extremely advanced bone resorption excludes the possibility of placing endosteal implants. Prosthetic treatment using conventional partial dentures is indicated. In special cases, i.e., those with a danger of mandibular fracture, bone stabilization can be attempted using autologous bone augmentation.

4. OSSEOINTEGRATION

The concept of osseointegration was developed by Branemark [3] in the middle of the 1960s and led to the predictable long-term success of oral implants. Osseointegration has been defined from various viewpoints, including the description of long-term clinical results, a numeric evaluation of interfacial mechanical capacity, and the morphological appearance of the tissue-implant interface [114]. One of the first definitions of osseointegration, given by Albrektsson [20], was a direct functional and structural connection between living bone and the surface of a load bearing implant.

According to Zarb Albrektsson [21] the only acceptable definition of osseointegration is based on a clinical examination. These authors described osseointegration as "a process in which a clinically asymptomatic rigid fixation of alloplastic material is achieved and maintained in bone during functional loading". This is in contrast to implants surrounded by fibrous connective tissue (fibrointegration), which have shown a clinically discernible mobility when loaded. Obviously, it is of great interest to be able to define osseointegration. According to the Dorland Illustrated Dictionary (1994, p. 1198), osseointegration is the direct anchorage of an implant by the formation of bony tissue around the implants without the growth of fibrous tissue at the bone-implant interface.

On the basis of previous suggested definitions, a provision of definitions from various viewpoints was recently given by Branemark [22]. From the viewpoint of the patient an implant fixture is osseointegrated if it provides a stable and apparently immobile support of prosthesis under functional loads, without pain, inflammation or loosening over the lifetime of the patient. From a viewpoint of macroscopic and microscopic biology osseointegration of a fixture in bone is defined as the close apposition of new and reformed bone in congruence with the fixture, including surface irregularities, so that at light microscopic level, there is no interpositioned connective or fibrous tissue and that a direct structural and functional connection is established, capable of car-

rying normal physiological loads without excessive deformation and without initiating rejecting mechanisms. From a macroscopic biomechanical point of view a fixture is osseointegrated if there is no progressive relative motion between/the fixture and surrounding living bone and marrow under functional levels and types of loading for the entire life of the patient exhibits deformations of the same order of magnitude as when the same loads are applied directly to the bone. From a microscopic biophysical point of view osseointegration implies that at light microscopic and electron microscopic levels, the identifiable components of tissue within a thin zone of a fixture surface are identified as normal bone and marrow constituents which continuously grade into a normal bone structure surrounding the fixture: that mineralized tissue is found to be in contact with the fixture surface over most of the surface within nanometers so that no functionally significant intervening material exists at the interface.

4.1 Mechanism of Osseointegration

In order for optimal bone formation to occur a coordinated series of events ranging from protein adsorption to osteoid synthesis and calcification must take place. In general categories these events can be summarized as; protein adsorption, cellular adherence, local factor product, proliferation, differentiation, matrix production and calcification.

4.1.1 Protein adsorption

Immediately upon implantation, the implant materials are conditioned by body fluids and the device becomes coated with a layer of organic and inorganic components from the plasma. These proteins, lipids, sugars, and ions adsorb to the surface of the implant, with relative affinities depending on the material. Meyer [23] demonstrated that the adsorption of lipids and proteins onto various biomaterials, including titanium, occurs within 5 minutes in vivo. Time is an important factor. Protein adsorption occurs within minutes, and even seconds. For example, the surface of a number of materials is

essentially immediately covered with the serum protein fibronectin [24]. Fibronectin, is a protein found in plasma at 2-3 mg/dl , has been found to bind almost instantaneously to a number of materials [23]. This protein allows mediating mesenchymal cell attachment. Other proteins, with similar binding-site sequences, can also adsorb to the surface. Proteins such as albumin and lgG are also adsorbed onto the material at early time points. Moreover, the composition of the proteins at the surface may be altered with time. The chemical composition of the material can influence the composition of the adsorption film. Material characteristics that are involved include: the nature of the surface charge, the surface energy, the presence of grain boundaries and the chemistry of the surface ions [25]. Changes in surface wetting profiles have direct effects on the adherence of molecules to the implant surface; resulting in poor tissue adhesion and development of peri-implant scar tissue.

4.1.2 Cellular adherence

Surface characteristics have a direct effect on cell attachment. Surface roughness and micro-topography affect cell adherence [26]. Micro-architecture in the context of the individual cell can be defined as any morphological feature that is within the dimension of the cell itself. The average length of a mesenchymal cell is about 5-12 Clm; therefore, a roughness greater than the cell length would be perceived as smooth by those cells located between adjacent peaks. It has been found that osteoblast like cells adhere more strongly to Ti surfaces [25]. Cells do not actually attach to the material itself, but to the organic material that adheres to the surface of the material. They form focal attachments through their integrinreceptors, with RGD sequences in proteins like fibronectin and vitronectin. Windeler [27] demonstrated that osteoblast like cells adhered more strongly to Ti surfaces whereas osteoclasts adhered more strongly to hydroxyapatite surfaces.

4.1.3 Local factor production

At a surgical wound site, as with any traumatic injury, the acute inflammatory response includes the release and activation of a variety of cytokines and growth factors which mediate the initial events. Many of these factors are provided by platelets, but others are released by polymorphonuclear cells and macrophages. As a result, mesenchymal cells migrate onto the clot and synthesize a collagen network which becomes the scaffold for wound repair. Soon, these cells also produce their own complement of factors, some of which act on the cells in an autocrine manner and some of which act on other cells via paracrine mechanisms. As the cells differentiate into osteoprogenitor cells and, ultimately, osteoblasts, they continue to produce and respond to local regulatory factors. Local factor production determines the quality of bone formation or the formation of fibrosis. Implant properties should promote production and release of a factor profile which enhances osteogenesis where appropriate and retards bone resorption. Itâs shown that surface roughness affects the production of local factors important in wound healing and bone formation. Both inflammatory mediators (PGEg) and growth factors (TGF-pl) are expressed in the osteogenic range on rough surfaces and not at levels which would promote bone resorption. However, on smooth surfaces, only low levels of these factors are produced, which may explain why there is a tendency toward fibrous tissue formation on these surfaces in vivo. Moreover, local factors can not only affect cells in an autocrine but also a paracrine manner and therefore influence osteogenesis at distant sites.

In addition to modulating production of local factors, surface roughness affects the way that osteoblast-like cells respond to systemic hormones. Similarly, surface roughness enhances cellular response to local factors. Also, surface roughness affects proliferation; as roughness increases, proliferation decreases [28]. Fibroblasts and epithelial cells are also affected by surface characteristics. In general, decreased proliferation precedes expression of a more differentiated phenotype, and the decrease in proliferation is associated with marked changes in cellular morphology, signaling phenotypic expression and differentiation.

4.1.4 Differentiation

The enormous number of permutations available with respect to the effects of surface energy, roughness, topography, and composition on the efficacy of implant materials has led to attempts by several laboratories to isolate one of these characteristics and closely examine its effects on cellular response in vitro. Differentiation is enhanced on rough surfaces based on stimulation of alkaline phosphates-specific activity. Alkaline phosphatase is a marker enzyme for matrix vesicles, organelles which are associated with initial mineral formation in calcifying cartilage and in woven bone. The effect of surface roughness on alkaline phosphatase is specifically targeted to these organelles, suggesting that the enhanced differentiation is to a calcifying phenotype. Production of osteocalcin, an extracellular matrix protein which modulates apatite crystal growth, also is increased on rougher surfaces in the MG63 cell model [28].

4.1.5 Matrix production

Appropriate mineral deposition is critical to ensure that subsequent iterations of the remodeling cycle on the implant surface will be optimal. Once the bone is resorbed, new bone formation will take place in an environment that is physiologically very different from the initial acute surgical wound. Matrix production is necessary for the correct interrelationship between the apatite crystals and collagen. Surface characteristics might modulate matrix production, in two general parameters: (1) collagenase digestible protein (CDP) synthesis and noncollagenase-digestible protein (NCP) synthesis and their interrelationship, collagen production; and (2) sulfate incorporation into proteoglycans.

The three dimensional structure of the extracellular matrix including the distribution and activity of matrix vesicles within the collagen network is important to the ability of the cells to support apatite formation. In addition, the amount of proteoglycan and the nature of the glycosaminoglycan side chains and their degree of sulfation, and the presence of specific noncollagenous proteins, all contribute to how the min-

eral phase is formed and organized within its organic matrix. Studies showing that osteocalcin production is modulated by surface roughness support the hypothesis that the specific interrelationship of proteins in the matrix may be altered as well. To date there are only limited studies on the effects of the surface on mineral formation.

4.2 Mechanism of action

The mechanisms by which surfaces modulate cell proliferation and differentiation are not well understood. As noted above; cells interact with the surface through integrin receptors. These receptors recognize peptide sequences in the proteins adherent to the material. For mesenchymal cells, like osteoblasts and chondrocytes, the most well-known sequence is RGD, and for this reason attempts to micromanage the response of cells by grafting RGD or similar peptides to materials has gained a degree of popularity. The amount of an attachment protein and the presentation of the RGD like peptide to the cells could modulate cell attachment in a spatial context.

Once a cell forms focal attachments, signaling pathways are activated that may result in new gene expression, leading to a change in the phenotype of the cell. Prostaglandin levels must be elevated to some degree even to initiate the differentiation response. Surface effects on wound healing and subsequent osteogenesis in vivo. In vivo studies are needed to prove the suggested theories concerning the mechanisms of how surface properties may promote osseointegration. Different surface textures (roughness plus topography) induce different contacts between the cells and the surrounding matrix, resulting in differences in the clinical outcome [29]. Macro architecture also plays a role, but micro-architecture may be an overriding variable since the removal torques of both cylindrical and screw-type implants with rough surfaces were greater than those of implants with smooth surfaces [30].

5. CRITERIA FOR SUCCESS AND FAILURE IN IMPLANTOLOGY

Before we start talking about implant design, itâs important to understand the success and the failures. Success, in general terms, can be defined as the gaining of what is aimed at. Therefore, to be considered successful, an osseointegrated oral implant has to meet certain criteria in terms of function (ability to chew), tissue physiology (presence and maintenance of osseo-integration, absence of pain and other pathological processes) and user satisfaction (aesthetics and absence of discomfort).

Obviously, every single implant has to fulfill and be tested for all the defined success criteria, otherwise it should be considered as surviving. This term applies to those implants which are still in function, but which have not been tested with respect to success criteria, or where neither criteria for success or failure are met [31, 32].

At the last NIH/AAP consensus conference in Bethesda, the following success criteria for an endosseous implant were proposed; (Steenberghe) [33];

1. Do not cause allergic, toxic or gross infectious reactions either local or systemic, 2. Offers anchorage to a functional prosthesis, 3. Does not show signs of fracture or bending, 4. Does not show any mobility when individually tested by tapping or rocking with a hand instrument, or when tested with an electronic tapping device does not reach improper values of rigidity, 5. Does not show any signs of radiolucency on an intra oral radiograph using a paralleling technique strictly perpendicular to the implant-bone surface.

From both theoretical and practical points of view, the distinction between successful and failed implants on the one hand, and failing and failed implants on the other appears crucial, as it is possible that implants might fail in a slow and gradual way.

Nonsuccessful implants are named in different terminology. Compromised successful implant term is used inflammation, hyperplasia, and fistula formation occur near an otherwise fully osseointegrated implant. Failing implant term is used when the implant is characterized by progressive bone resorption, but remains functional, Failed implant term is used when the infection persists around an implant whose function is compromised.

Terms currently used to indicate failing implants or complications are: peri-implant mucositis and peri-implantitis. Peri-implant mucositis is in term describing reversible inflammatory reaction; in the soft tissues surrounding a functioning implant, whereas peri-implantitis refers to inflammatory reactions with loss of supporting bone in the tissue surrounding a functioning implant [32].

5.1 Clinical Evaluation of Implant Success and Failure

5.1.1 Pain

Absence of pain under vertical and horizontal forces is a primary implant criterion of evaluation. Pain or discomfort is often associated with mobility and could be one of the first signs which indicate an implant failure [34]. Pain or sensitivity when chewing, tightening the abutment screw, or at percussion can be experienced, even under local anesthesia. No studies have identified the structural correlation to pain around implants. Interestingly, failed implants can also be completely asymptomatic [35]. Further, pain may reflect adverse tissue reactions not primarily related to implant mobility. For instance, in cases of implants placed over the mandibular canal, after nerve transposition or lateralization procedures, pain can reflect intraosseous oedema and pressure on the inferior alveolar nerve and may therefore be associated with perfectly stable implants. It has been suggested that persistent discomfort may be evident long before any radiographic changes.

5.1.2 Sound

It has been suggested that a subdued sound upon percussion is indicative of soft tissue encapsulation, whereas a clear crystalline sound indicates successful osseointegration. Once the clinician has verified that the abutment is properly attached to the implant, the test is conducted by hitting the abutment with a loosely held metallic instrument.

Although it is a rather subjective test without a solid scientific background, it can provide a useful indication to the examiner. It has also been suggested that a dull tone on percussion might be present long before radiographic signs of implant failure. Unfortunately, no scientific evidence has been presented yet to substantiate this hypothesis.

5.1.3 Bleeding Index

Bleeding index is the indicator for the health of peri-implant soft tissues. But implant health is not as related to gingival health as tooth. No correlations were observed between bleeding changes typical for gingivitis and/or periodontitis. Berglundh in 1994 published the study [36] on vascular topography of the periodontium and the peri implant soft and hard tissues. They observed that the gingiva and the supra-crestal connective tissue at teeth are supplied by [37] supraperiostal vessels lateral to the alveolar process and [38] vessels from the periodontal ligament. The peri-implant mucosa, on the other hand, was found to be supplied by terminal branches of larger vessels originating from the periosteum of the bone at the implant site. In both situations, blood vessels built a characteristic Â« cervicular plexus Â» lateral to the junctional epithelium [39].

It was hypothesized that bleeding could have been produced by undue force onto the periodontal explorer. These preliminary findings were recently confirmed in an animal study. Conversely, experimental findings around the ITI implants yielded

completely different results [40]. Healthy sites were characterized by complete absence of bleeding on probing, whereas both peri-implant mucositis and peri-implantitis sites showed significant bleeding (67 and 91 percent, respectively). The reason for these differences might be attributed to the different probing forces used (0.5 N versus 0.2 N, respectively). However, recent findings [41] also reported by Esposito [42] suggested that bleeding cannot be used as discriminator of a healthy or diseased peri-implant state. Peri-implant probing and bleeding index are infact supported by the Consensus report of Session C in 3rd European Workshop in Periodontology [25] and reported as enabling the assessment of the stability of the supracrestal connective tissue level over time. Itâs noted that minimum four sites per implant should be recorded, and the probing should include a fixed reference point. [25]

5.1.4 Probing Depths

The probing depth around healthy gingiva around teeth with a normal or reduced periodontal support to probing depth of health mucosa around Branemark implants were compared by Ericsson and Lindhe[43] .The results of the tissue composition of gingiva appeared to be different from that of peri-implant mucosa, resulting in different tissue resistance to probing in the two units. Hence, probe penetration is greater at implant sites than at tooth sites [43]. Several studies have indicated that stable implants generally allow probe penetration of approximately 3 mm [7, 44]. The mean values of probing depth reported for the nonsubmerged ITI system varied between 2,74 mm [44] and 3,13 mm [45]. And Lang [46] has published values of 2,12 mm and 1,87 mm for healthy mucosal conditions or mucositis. The difference of the values may be due to the differences in the implant morphology, probe form, probing pressure and the thickness of the mucosa influencing probing measurements.

A mean distance from the alveolar bone crest to the tip of the probe of 0,59 mm was found in healthy sites, 0,80 mm in sites with mucositis but only 0,25 mm in the sites with peri-implantitis. At implant sites the probe tip displaced the junctional epithelium as well as the connective tissue portion facing the abutment surface in the

lateral direction and stopped close to the bone crest. The tip of probe thus stopped within the supracrestal connective tissue portion, and occasionally rupture of some blood vessels resulted in bleeding (which will also help to explain the difference of bleeding index with implants to tooth).

Implant shape, design and surface texture may influence probe tip penetration and occasionally, even render clinical probing impossible. Also underestimation of probing depth may result. Hence it must be anticipated that clinical probing may not result in reliable assessments in all implant systems [46].

5.1.5 Mobility and Rigid Fixation

One of the clear sign of implant success and failure is implant mobility. After verifying the mobile part of the implant system and if the clinician realizes that the implant body is the mobile part, the implant is suspected to be surrounded by fibrous tissue and the implant is lost. Several different kinds of mobility have been recognized [42]; rotation mobility, lateral or horizontal mobility, axial or vertical mobility; as well as different degrees of mobility. Further, it has been suggested that slight changes of horizontal mobility can be better evaluated by means of electronic devices such as the Periotest. This procedure provides an objective method to measure the degree of mobility. It has been shown that implant and abutment length, the type of jaw treated, as well as the bone density have a major influence on Periotest values. However, despite some claims, it remains to be demonstrated if changes in Periotest scores are an early sign of implant failure, preceding radiographic changes. Implants with less than 0,5 mm of horizontal movement has been accepted to return to rigid fixation and zero mobility by Misch [47].

It has been suggested that implants should also be evaluated for possible rotational movements. Recently, it was, e.g., proposed to apply a reverse-torque test, with forces not exceeding 10Ncm, to every single implant at abutment connection to discover mobile implants [48]. With this procedure, an incidence of 4.7 percent of early

failures was reported. In the report by Sullivan [48], an increase of the reverse-torque test to 20 Ncm was shown to reduce the number of late failures. However, the figures for early failures were not reported. It is yet unclear if this method is advisable or not due to the risk of inducing an iatrogenic fracture at the bone-implant interface. Occasionally, clinically discernible mobility can be present without distinct radiographic bone changes [49]. Therefore, mobility is the cardinal sign of implant success or failure.

5.2 Radiological Evaluation

An absence of radiolucency around an implant does not mean bone is present at the interface, especially in the anterior mandible. As much as 40 percent decrease in the trabecular bone is necessary to produce a radiologically evident difference in this region, because of dense cortical bone [50].

However the presence of a radiolucent region around implant definitely represents the presence of fibrous tissue, although the amount cannot be determined precisely. There seems to be unanimous consensus that progressive marginal bone loss is a pathological sign which can lead to implant failure. However, to what extent the marginal bone resorption should progress in order to advocate treatment, and which is the appropriate treatment procedure, remains to be decided. One of the most commonly used success criteria for the evaluation of marginal bone loss was proposed by Albrektsson [51, 52]. These authors suggested using less than 1.5 mm of marginal bone loss during the 1 st year of loading and thereafter less than 0.2 mm yearly as success criteria. Some authors doubt that a firm limit for an acceptable annual bone loss can be established [53, 54]. This doubt was based on reported higher amounts of bone loss, which stabilized after 2 or 3 years without leading to loss of the implant. It has therefore been proposed that an implant should be considered failed when the marginal bone loss has reached the apical 1/3 of the implant [55]. Moreover, from a technical point of view, it is not possible to verify an annual progression in the range of 0,1 mm on radiographs [56].

There can be 2 well-distinct radiographic pictures: a thin peri-fixtural radiolucency surrounding the entire implant, suggesting the absence of a direct bone-implant contact and possibly a loss of stability, and an increased marginal bone loss. In the first case, the implant is usually found mobile when tested, whereas in the latter, the fixture can be stable. It should be considered that an abnormal rate of marginal bone loss can also be a sign of a mechanical failure (fracture of the implant) . Since the distinction between these 2 radiographic pictures is not always clear, when a suspected peri-fixtural radiolucency or excessive marginal bone loss is observed, it is recommendable to remove the prosthetic construction and check the implants for stability.

Clinically discernible mobility after bridge removal can confirm the presumptive radiographic diagnosis of implant failure. The resolution of the radiographic technique together with the projection of anatomical structures could limit the detection of a thin soft tissue layer surrounding the fixture. This could explain why, occasionally, barely perceptible clinical mobility does not correspond to appreciable radiographic changes. Conversely, due to the Mach band effect (a visual phenomenon, where the borders of adjacent areas of different photographic densities appear to have larger density differences than really exist, i.e., the presence of soft tissue around the implant is simulated), peri-implant radiolucency can, occasionally, be noted even in cases of successful implants. However, the satisfactions of the requirements for identical exposure geometry are very difficult to meet in clinical practice, particularly when compared to the in vitro situation.

Another important limitation of the radiographic examination is that only the interproximal aspects of the implant can be evaluated. It has been suggested that digital subtraction radiography might be useful to detect more subtle changes in bone density adjacent to the implant, improving both accuracy and precision. However, few data to validate this technique have been presented. It should be also observed that intraoral periapical radiographs have at least 2 x the resolving power of digital intraoral imagining. Even though it is extremely difficult to obtain accurate and reproducible bone-level measurements over time using a radiographic technique, this method seems more reliable than probing, particularly in the presence of inflamed peri-implant tissues

and bony defects, in monitoring implant conditions.

5.3 Classification of Implant Failures

The success of dental implants has been published in many longitudinal studies. The high success rate of implants has well responded by the clinicians and implantology became a treatment modality in modern dentistry. There are thousands of publications about implant systems and success, but the data regarding implant failures is limited. There can be logical aspects of this lack of information when we consider the most of the publications are made by researchers or university hospitals where all surgical and follow up procedures of implantology is exactly followed, especially for the study groups who are planned to be published in a direction of research.

We must consider that the implantology is nowadays not practiced only by specialists, but also by dentists who have passed a fast training period about only the implant system which he is introduced. So in real dental practice life the failures take more place and percentage than thatâs published in the literature. By realizing the increase in the number of implants placed and also the number of dentists who are practicing implantology, itâs an obligation for dental researchers to develop the information on dental implant failures. For scientific studies and also for well communication of clinicians between each other; the classification of failure is necessary. In dental publications, dental implant failures are classified by different clinical aspects. We will give the classifications with their clinical aspects.

5.3.1 Classification of failures according to the osseointegration concept

Esposito and his working group have proposed a classification of failures according to the osseointegration concept [42]. The table summarizes the classification. They have classified as biological failures (related to biological processes) and mechanical failures of the components (including fractures of implants, coatings, connecting

screws and prostheses). An iatrogenic failure has been defined as one characterized by a stable and osseointegrated implant, but due to malpositioning, it is prevented from being used as part of the anchorage unit. This group also includes implants which have to be removed due to violation of anatomical structures such as the inferior alveolar nerve. Another group of failures has been related to inadequate or insufficient patient adaptation (psychological, aesthetical and phonetical problems).

A biological failure can be defined as the inadequacy of the host tissue to establish or to maintain osseointegration. Such failures can further be divided according to chronological criteria in early failures (failure to establish osseointegration, i.e., an interference with the healing process) and late failures (failure to maintain the established osseointegration, i.e., processes involving a breakdown of osseointegration). Late failures can be; mechanical the result of fracture of implants, connecting screws, bridge frameworks, coatings; iatrogenic the result of nerve damages, wrong alignment of the implants; or the result of inadequate patient adaptation for phonetical, aesthetical, psychological problems. This classification is well detailed when we check the literature regarding the implant failures but the sub divisions given by this classification is not clear. Classificating the implant failures by their etiology is also an aspect I support but to what extend we can decide the osseontegration clinically has to be questioned. The invasive technique for clear confirmation of osseointegration is mostly limited to research patients. The easiest way to define the osseointegration for this purpose will be from macroscopic biomechanical point of view, which was explained in previous chapter. Another problem in this classification is the chronologique mixture of the failures. From chronologique point of view, it would be more appropriate to place iatrogenic factors in the early or primary implant failures. This problem also seen for mechanical problems whereas we can also include in late or secondary failures. The terminology used in this classification is accepted as clear and useful, but it will be more appropriate to have a classification form both etiological and chronological aspects.

5.3.2 Etio-chronologic classification of implant failures

The division of failures into primary and secondary failures is an attempt to provide a simple and practical sub-classification. In fact, this classification has been employed in most clinical studies and can be applied easily in clinical situations. One way to chronologically discriminate primary from secondary failures may be to confine all implants removed before bridge insertion (or after "appropriate" healing period) to the group of primary failures. Similarly, all failures occurring after the prosthetic rehabilitation may belong to the group of secondary failures.

5.3.3 Classification of peri-implantitis from therapeutical aspect

This classification takes base the clinical status of the peri-implant bone during the various stages of peri-implantitis [58]. There are no sharp demarcations exist between the stages described. Class 1 is slight horizontal bone loss with minimal peri-implant defects, Class 2 is moderate horizontal bone loss with isolated vertical defects, Class 3 is moderate to advanced horizontal bone loss with broad, circular bony defects, and Class 4 is advanced horizontal bone loss with broad, circumferential vertical defects, as well as loss of the oral and/ or vestibular bony wall.

This classification can serve more for treatment aspects, as mentioned in the title. As it is only classifies the bacterial related failures, and many of the factors contributing in to failures are missing, this classification will not be used. There is a difference between this classification and the previous that this classification explains more the clinical situation after the pathology, whereas the previous was for the causes of the failures. And a last point which have to be mentioned for this classification is that the difference between failing and failed implants. The terminology for this difference was given in previous chapter. This classification has more value in failing/ailing implant situation for treatment concepts.

5.4 Factors Contributing to Implant Failures

Factors contributing to implant failures are given described by Esposito in 1998 [57]. He has proposed that factors contributing to implant failures can be divided into endogenous (systemic /and local) and exogenous (operator-related and biomaterial-related). However, the boundaries of these subdivisions are obviously difficult to distinguish as several of these conditions may overlap, rendering any kind of classification too simplified. Endogenous factors are systemic and local factors. Systemic factors are patients with compromised medical status and Smoking patients (more than 10 per day). Local factors are irradiation therapy, poor bone quality/quantity, bone grafting and parafunctions. Exogenous factors can be operator-related or biomaterial related factors. Operator related factors are non-optimal operator experience, high degree of surgical trauma, bacterial contamination, immediate loading, non-submerged technique, non-optimal number of supporting implants and lack of prophylactic antibiotics. Biomaterial related factors can be non-optimal surface properties or non-optimal implant design. This study has great value in implant failure literature [57], because it has talked about the factors which were not mentioned and included in implant pathology classification. One of these factors is surgeon experience. As mentioned before the clinical researches and the longitudinal study which are showing high success rates are not really representing the actual clinical success rates of implants treatments. The implants included in these studies are placed under highly strict clinical regulations and also by experienced surgeons. The surgeon experience has great importance because implant failures are most probably to arrive when the surgical and pre/post-operatory regulations are not obeyed.

6. IMPORTANCE OF PRIMARY STABILITY

It has been suggested that oral implants should not be subject to micro movements during the healing period to achieve a direct bone to implant apposition. Experiments have clearly indicated that early micro motion can lead to differentiation of cells into fibroblasts and inhibition of bone growth. Animal studies can be altered around implants, if the mechanical conditions are changed. Newly formed supporting bone can lead to differentiated, after 4 weeks of healing, into connective fibrous tissue, when an unstable mechanical situation is induced [59]. Such tissue differentiation was found to be partly reversible after a relative stabilization of the screws. In another experimental study, in which micromotion was discontinued between 4 and 16 week, the fibrous tissue surrounding Ti and HA coated implants was replaced by bone.

In another study which have done with animal model, the vascular architecture and bone apposition around Ti and TPS surfaces have been studied. When the bone and machined implant interface was observed at low magnification, abundant newly formed blood vessels and bone (NB) were seen on the bone surface. These vessels branched out from the vascular network of the bone marrow. Higher magnification showed that the vessels were flat and growing toward the implant fixture. The vascular network consisted of venules, with a diameter of 30 to 80 jLim. The vascular bud, which terminated at the fixture surface, was finger-like. New bone had initiated from the preexisting bone. This immature bone tissue was quite polar and spongy. At higher magnification, the shagginess on the surface of the vascular resin cast indicated multiplication of the endothelium, creating an impression on the lumen side of the vascular bud.

Observation of the bone-TPS implant interface at low magnification showed a vascular network being formed between the existing bone and the implant fixture. Bone was starting to form toward the implant surface (NB). The vascular network could be seen as a fishnet-like structure consisting of flat blood vessels with a diameter of 10 to

60 m in the space between the bone and the implant. Ingrowth of the bone was so rapid that in some places, the vascular network was buried.

The surface of the implant fixture, which was subjected to proteinase digestion. At the surface of the titanium particles of the plasma spray coating, the immature bone could be seen. There was also a newly formed blood vessel (BV). At higher magnification, the arterioles (A) and venules (V) could be seen passing around the titanium particles.

The publication of Matsuo [60] by giving the 14, 30, and 120 day histologic results have shown the complexity of the healing mechanism around implants and the micromotion will damage the healing capacity .Another information about the surface difference was given also by the same group; saying the microcirculation is created in 7 days around TPS implants whereas we need 14 days for Ti implants. So the first two weeks of the bone healing after implant surgery is very essential and the micromotion may not be tolerated which can end up with fibro capsulation of the implant.

7. OCCLUSAL LOADS ON DENTAL IMPLANTS

It has been stated that overloading of an oral implant can result in loss of the marginal bone or complete loss of implants where osseointegration has been achieved [7, 61, 62]. The most convincing evidence for this theory, so far, has been presented by Sanz in 1991 [63]. In 6 patients who had implants with mobility and peri-implant radiolucency or marginal loss but without pockets exceeding 3 mm and without bleeding. They found healthy peri implant mucosa without the signs of inflammation in light and electron microscope evaluations. This result was interpreted by authors to mean that overload had caused the peri-implant breakdown.

A load on a bone deforms or strains it. This can result in mechanical fatigue damage (micro damage), but remodeling normally repairs the damage and thus keeps it from accumulating. Overloading the bone can increase the micro damage (and the repair). When bone is loaded to 1,500-2,000 (LIE (microstrain)), the bone is deformed 0.15-0.2 percent the small micro damage that occurs can be repaired, and loads influencing the bone in this interval may even result in an osseous adaptation by formation of bone (reshaping and strengthening), presumably for reducing the future functional strain within the bone. Cyclic loading of a bone resulting in a deformation of 0.2-0.4 percent ; 2,000-4,000 increases the micro damage, and loading above 4,000 (0.4 percent deformation) can overwhelm the repair mechanism, resulting in a fatigue failure (fatigue fracture of the supporting bone) of an oral implant as well [64]. In comparison, normal bone fractures at forces causing a deformation of about 2.5 percent (25,000)Lie. Apposition of bone around an oral implant, therefore, seems to be the biological response to a mechanical stress below a certain threshold, whereas loss of osseointegration may be the result of mechanical stress beyond this threshold.

The mechanism by which osseointegration is lost due to overloading of an oral implant has been explained as micro damage in the bone exceeding its repair potential [64]. This leads to replacement of the bone-implant interface with a soft tissue layer and

thus loosening of the implant [55]. In a histological study of implants losing osseointegration under experimental conditions Isidor et. al. [62], the loss of osseointegration in occlusally overloaded implants seemed to start not just as a loss of contact between the bone tissue and the implant surface but also as a resorption of bone a short distance from the implant surface. This could be interpreted to mean that the micro damage may occur not just in the bone-implant interface but rather as microfractures in the bone near the implant surface.

Thus Â« occlusal trauma Â« in oral implantology can be described as ; the clinical situation when the loading on implants exceeds the physiological range of bone adaptation which may then cause loss of osseointegration by replacement of the bone-implant interface with a soft tissue layer or/and resorption of bone at a short distance from the implant surface.

The study of Isidor to show that occlusal overload can result in loss of osseointegration of previously osseointegrated oral implants in monkeys, is a good paper to demonstrate the occlusal trauma [62]. Five screw-type implants of pure titanium were inserted in the mandibles in each of four monkeys. Two implants were placed in each of the lateral segments and one in the frontal area. After six months of healing, a fixed partial prosthesis was mounted on the two implants in one lateral segment. The prosthesis was in supra-occlusal contact with an antagonizing metal splint and caused a lateral displacement of the mandible during occlusion, therefore resulting in a lateral rather than an axial excessive occlusal load. The two implants retaining the prosthesis were brushed once a week and subgingival cleaning was performed once a month. The remaining implants were never cleaned, and additionally a cotton cord was placed passively around each of these to promote plaque accumulation. During the 18 months of observation five out of eight implants with an excessive occlusal load lost osseointegration, as shown by increased mobility and peri-implant radiolucency. An additional implant exhibited questionable mobility and peri-implant radiolucency. The clinical signs of loss of osseointegration were observed 18 weeks to 1,5 years after the occlusal overload was commenced.

Two of the mobile implants were screwed out of the jaw during demounting of the fixed prosthesis. The loaded implants in one monkey did not become mobile. On the other hand, this monkey was the only one fracturing prosthesis-retaining screws. All implants with plaque accumulation remained clinically osseointegrated, although a progressive radiographic bone loss was observed. Histological evaluation revealed that all implants with plaque accumulation were osseointegrated but exhibited a histological marginal bone loss. A dense inflammatory infiltrate was obvious in the supracrestal connective tissue and osteoclastic activity at the bone crest was apparent at the implants with plaque accumulation. In contrast, a moderate inflammatory infiltrate was observed in the supracrestal peri-implant mucosa at implants with an occlusal overload. Of the six implants available for histological analysis, two implants (in one monkey) with manifest clinical and radiographic signs of having lost osseointegration had also histologically lost osseointegration completely. The bone crest was near the margin of the implants, but a narrow zone of fibrous connective tissue was interposed between the implant and the bone. Bone resorption along the bone surface next to the zone of fibrous connective tissue was apparent. In another monkey, the implants with manifest or possible clinical and radiographic signs of having lost osseointegration were only osseointegrated in the apical half. Only a minor proportion of the implant surface was in contact with mineralized bone tissue at these latter implants. In these few areas with bone-to- implant contact, bone resorption was often observed. Also at these implants, the bone crest was near the margin of the implant. The apical termination of the epithelium along the abutment and implant surfaces could only be identified in some sections, but when identified, the epithelium extended slightly apically to the margin of the overloaded implants rather than covering the whole non-osseointegrated implant surface.

Occlusal overload on oral implants can result in complete or partial loss of osseointegration. Implants with plaque accumulation, on the other hand, may show signs of peri-implantitis with a marginal loss of bone. On the clinical and radiographical and on the histological level the features of the two events are distinctly different.

There is no doubt that implantology has opened a big wide door in treatment modalities of modern dentistry. In traditional dentistry the restoration reflects the existing oral condition of the patient. Existing natural abutments are first evaluated, and a removable or fixed restoration is accordingly fabricated. Implant dentistry is unique because a foundation of support may be added for a desired prosthodontic result. An organised treatment approach based on the prosthesis permits predictable results of therapy. Five prosthetic options are given by Misch [47]; FP-1 ; Fixed prosthesis ; replaces only the crown, looks like a natural tooth. FP-2 ; Fixed prosthesis ; replaces the crown and a portion of the root ; crown contour appears normal in the occlusal half, but is elongated or hyper contoured in the gingival half. FP-3 ; Fixed prosthesis ; replaces missing crowns and gingival color and portion of the edentulous site ; prosthesis most often uses denture teeth and acrylic gingiva, but may be porcelain to metal. RP-4 ; Removable prosthesis ; overdenture supported completely by implant. RP-5 ; Removable prosthesis ; overdenture supported by both soft tissue and implant.

7.1 Cantilever Bridge

It has been recommended that implant-supported fixed partial prostheses be supported by a mesial and a distal implant without cantilevers. Distal cantilevers, especially, are reported to be unfavorable from a biomechanical point of view and have increased the number of complications for implant-supported fixed partial prostheses [65]. From a biomechanical point of view, cantilevers will always be a risk because they increase the bending moment and therefore the stress induced in the implant-supported construction. When the number of implants and the supporting area are increased, the resistance to functional bending increases. Therefore, the risks with cantilevers can be reduced by increasing the number of supporting implants.

It has been hypothesized that cantilever length influences stress distribution, particularly on distal implants. In vitro studies have supported this hypothesis and 15mm has been indicated as the maximal length for mandibular cantilevers [66]. Only few clinical investigations on this topic are available and one study [67] reported that

prostheses with cantilevers longer than 15 mm had to be remade more often than those with cantilevers shorter than 15 mm. In other studies [68, 69] no correlation between marginal bone loss at any implants and cantilever lengths was found, even when extreme groups were compared (cantilevers <12mm and > 18 mm) [68]. In addition, the marginal bone loss was found to be greater at anterior than posterior implants [68], which is contrary to the assumption that distal implants are exposed to the highest stress concentration. However, no study relates implant failure to cantilever length and the few clinical investigations, addressing this issue, have not given a definitive answer.

7.2 Number of Implants

In partially edentulous patients more implant failures and prosthetic complications have been observed for bridges supported by 2 implants compared to 3 or more fixtures. This might be related to a more unfavorable biomechanical situation in relation to the number of supporting implants [57]. This can also be an effect of the positioning of the implants; in which the three or more implants make it possible to position the implant on a curved line Â« tripod positioning Â» , and this has been claimed to give a more optimal bone support than a linear arrangement [65]. However from a clinical point of view the available bone which permits to arrange the tripod can also support wider implants , so the surgeon has to make his choice in diameter or curvature.

The implants replacing the natural tooth, especially in posterior region are under heavy occlusal forces, so itâs evident that replacing each teeth with one implant is better. Nowadays there is a new concept of replacing molars with two implants, scientific data is not available yet for this concept; but the creation of retention areas for bacterial plaque accumulation can be the first critic for this new concept.

In the anterior region the forces acting on the implant supported prosthesis are normally less, and the bone volume is greater than the posterior regions. Therefore it can be possible to reduce the number of implants in anterior region to a few long

implants. If two teeth have to be replaced in an anterior region, two implant supported single crowns would usually be more appropriate. This will help the hygiene procedures and also support better the esthetics. But if the forces are evaluated as to appear high on these crowns, the crowns have to be connected.

7.3 Crown Root Ratio

If the implant axis is positioned at a considerable distance from the center of the occlusal/lingual surface, the forces on the implant will act in a transverse direction, and bending moments on the implant are induced [65, 70] . This means that only a small part of the implant will counteract the load, leading to higher stress levels in the implant and in the marginal areas of the peri-implant bone [65,70].

The greater the distance from the point of occlusal contact to the abutment-fixture connection, the higher the bending moment which will be induced by a transverse force. This will increase the risk of technical failures in the implant component, or, if the fixture is relatively short and the force sufficiently great, may also cause biological problems [70]

7.4 Axial Forces

Non-axial loading induces bending of the implant. This leads to increased stress levels in the portion of the implant-bone interface receiving the load. Likewise, undue stresses can also be induced in screws and in the superstructure. For that reason, it is important to strive at minimizing functional bending moments in implant-supported prostheses [71]. This means that from a theoretical point of view all forces should preferably be directed axially (perpendicular to the occlusal plane). Even vertical occlusal loads on cusp inclines produce forces in a lateral direction, therefore, that the occlusal surfaces of implant-retained prostheses should be created with a continuous flat

fossa throughout the prosthesis and with reduced cusp inclinations. This will result in less lateral forces and thereby decrease the torque exerted on the prosthesis, implants, and bone. Other recommendations for the occlusal design have been to secure bilateral and anterior posterior stability in centric occlusion, to secure slight or no latero- or mediotrusive contacts on posterior cantilever segments, and to create a balcony shape of the cingulum.

Furthermore, lighter occlusion may be advisable on implant retained partial prostheses or single crowns to reduce the risk for overloading during physiological intrusion of the teeth [72]. In general, in an actual patient it should be considered to what extent the implant-supported restoration needs to be occlusally protected compared to the eventually remaining teeth. If the teeth are hypermobile (periodontally involved) they may need as much protection as the implants. On the other hand, in a dentition with parafunctional activity and normal tooth support it will be appropriate to distribute as much force as possible to the teeth [72].

7.5 Connection Between Teeth and Implant

The periodontal ligament is missing at osseointegrated oral implants; consequently, the periodontal receptors in the ligament are also lacking. This may influence the tactile sensibility when an oral implant is occlusally loaded. It has in fact been demonstrated that tactile perception is reduced at osseointegrated oral implants compared to teeth with up to more than 8-fold higher threshold values for tactile perception [73]. In addition, it has been shown that other mechanoreceptors cannot fully compensate for the loss of periodontal receptors. It has also been shown that chewing forces placed on implant-supported fixed prostheses in patients with these prostheses were higher than similar forces placed on the teeth of dentate patients [74]. This means that the risk for occlusal overloading without warning from the receptors presumably is higher for implants than for teeth. This is also indicated by the results of a study in which patients with implant-supported fixed prostheses in both jaws showed significantly more marginal bone loss than did those with only one implant-supported fixed

prosthesis opposite a natural dentition [75].

Furthermore, in a review of the literature it was concluded that fewer implant failures including late failures are observed in partially dentate patients than in edentulous patients [52]. It has been observed that the chewing force placed on fixed partial dentures is positively correlated to the remaining periodontal ligament area [76], or in other words, that reduced periodontal support reduces the chewing force. This could mean that occlusal forces on implant-retained prostheses in patients with a periodontally compromised dentition may be reduced compared to forces in patients with normal periodontal support of the remaining teeth, and that the risk for occlusal overloading of implants in periodontally compromised patients.

Previous reports have described intramobile elements incorporated in the implants to compensate for the difference in resilience. There has been no evidence, however, showing that such resilient elements or non-rigid connections are useful [77]. On the contrary, there are reports demonstrating that shock-absorbing intramobile elements in implants are not necessary [78]. Furthermore, an in vitro study comparing axial load and bending moments on rigid and non-rigid connections did not find any significant difference [79].

Today there are in vivo studies showing very good long-term results for teeth and implants connected without resilient elements. The strongest evidence is a randomized, prospective study from Sweden. In this study, 23 patients with Applegate Kennedy Class I residual dentition in the mandible and a complete maxillary denture were treated with an implant-supported fixed partial denture in one side and a tooth-implant-supported fixed partial denture in the other side. After 5 and 10 years it was not possible to demonstrate any higher risk of implant or prosthetic failure for the tooth-implant-supported fixed partial denture compared with the implant-supported fixed partial denture [80]. Rangert explained the good results on the basis that with light bite forces the implant would support the major part of the load, but with higher bite forces-the more critical situation the supporting tooth would be fully activated and share the load with the implant [81]. If two or more implants are connected to teeth,

replacements will be mainly implant-supported, and the question has to be considered whether or not the teeth should be included [82].

8. THE FORM OF IMPLANT

8.1 Implant Type

Computerized or photoelastic stress analyses have shown that different implant designs may distribute occlusal load differently to the bone, but no clinical studies have tried to compare the prosthetic relation in prognoses of implants with various designs [83, 84]. So, even if it seems likely that implant design may influence the ability of the implant and surrounding bone to withstand occlusal forces, it has not been clarified to what extent. As tested with a removal torque test, Ti02 blasted and plasma sprayed implants have shown better anchorage in bone than implants with only a machine-produced surface. The implant design and surface characteristics plays a role in the implant surface area, which will relatively affect the loading concepts. There is a table given in next page showing how the surface area changes with implant design.

8.2 Implant Length

Itâs evident that the patient selection criteria and the experience of the praticien play a big role in implant selection. Mostly in atrophic posterior regions of mandibula and the development of sinus in maxillary posterior region ; makes the selection much more difficult where the clinician was faced to use short implants or complicated surgical procedures to increase the height of the bone available. Retrospective studies and reviews have indicated that shorter implants fail more frequently than longer ones [85]. The consequence of using short implants is a reduced amount of mineralized bone to implant contact to stabilize the implant, and in regions of poor bone quality studies have shown increased failure rates [86]. This has been interpreted as meaning that short implants are more prone to biomechanical overload and /or that peri-implantitis may require less time to affect a critical proportion of the established osseointegration.

8.3 Implant Diameter

Implant diameter is also important in prosthetic concept, as it was also important in osseointeration concept. The reason is that most standard implant types have cervical diameters from 3.5 mm to 5 mm, corresponding to the approximate mesiodistal dimension of natural premolars in the cervical/subgingival area. But this diameter does not correspond to the average mesiodistal or vestibulolingual size of the natural teeth. Premolar units would then give the best contoured prosthetic replacements. Furthermore, if the distance between the two implants is too small, there will be problems with the use of instruments and/or with oral hygiene.

A number of published reports have recommended using wider implant diameter if the jaw is wide and has a compromised bone density. This would also improve the strength between components within the implant [65]. Furthermore, experimental studies indicate that cortical stabilization bucco-lingually or bicortically should be obtained if the bone quantity or quality is compromised [87]. The surface area of implant will increase by wider diameters, longer implants and with rougeous surfaces. So the Ante law in prosthetic fixed restorations which says ; the root surface area of the abutment teeth must be larger than the surface area of the teeth missing. So itâs useful to keep in mind the surface area comparisons of different surface, length and diameter implants.

9. TOOTH ANATOMY AND STRUCTURE

Teeth (singular tooth) are small, calcified, whitish structures found in the mouths of many vertebrates that are used to tear, scrape, and chew food. Some animals, particularly carnivores, also use teeth for hunting or defense. The roots of teeth are covered by gums. Teeth are not made of bone, but rather of tissues of varying density and hardness.

Teeth are among the most distinctive (and long-lasting) features of mammal species. Paleontologists use teeth to identify fossil species and determine their relationships. Mammals are diphyodont, meaning that they develop two sets of teeth. In humans, the first set (the "baby," "milk," "primary" or "deciduous" set) normally starts to appear at about six months of age, although some babies are born with one or more visible teeth, known as neonatal teeth. Normal tooth eruption at about six months is known as teething and can be painful. Some animals develop only one set of teeth (monophyodont) while others develop many sets (polyphyodont). Sharks, for example, grow a new set of teeth every two weeks to replace worn teeth. Rodent incisors grow and wear away continually through gnawing, maintaining relatively constant length. Many rodents such as voles (but not mice) and guinea pigs, as well as rabbits, have continuously growing molars in addition to incisors [88, 89, 90].

9.1 Tooth Parts

Each tooth has two main parts, the crown and the root. The crown and the root meet at the neck of the tooth, which is normally just below the gum margin.

9.1.1 The crown

This is the part of the tooth that we see in the mouth. It is made up of the enamel, dentine and pulp. The appearance of teeth varies in shape and size. The front incisor teeth have a straight edge as a cutting tool. The canine or eye teeth are the pointed long teeth between the incisor and premolar teeth. The pre-molar and molar teeth are larger and have cusps. A cusp is the raised pointed part of the chewing surface of a tooth. The presence of large cusps on pre-molar and molar teeth marks the main difference between them and the front teeth. Pre-molar teeth (bicuspids) have two cusps. Molar teeth each have four or more cusps. The four permanent lower incisor teeth each erupt with three small cuspettes that resemble a serrated edge. These cusps wear down with use and the teeth remain with a straight edge. The four permanent upper incisors may erupt with three very small cuspettes. These are much less obvious than those on the lower incisors. They are also normally worn away to form a straight edge.

9.1.2 Enamel

The enamel is the white hard covering over the crown of the tooth. It is shaped into cusps, fissures and pits in premolar and molar teeth. It is the hardest material in the body and does not have a nerve supply. Chipping or damage to enamel only will not be painful. It also does not have a blood supply. This results in a chipped tooth remaining exactly as it is. Enamel cannot heal or repair as bone or dentine can.

9.1.3 Dentine

Dentine is a cream colored hard material that makes up the bulk of the tooth. It is covered by enamel on the crown, and by cementum on the roots. The dentine surrounds and protects the nerves and blood vessels (pulp) in the crown and roots. Dentine is alive or vital in as much as more dentine can be formed, and it can register

pain. A protective layer of secondary dentine can be layed down over the pulp. This happens in response to caries, attrition, abrasion, erosion, or fracture of a tooth, when the dentine becomes exposed. The tooth becomes sensitive to temperature changes and feels painful, when the dentine is exposed in the above mentioned ways.

9.1.4 Pulp

The nerves and blood vessels of the tooth are called the pulp. The pulp occupies the root canals, and the pulp chamber in the crown of the tooth. When it is exposed to infection by decay or injury it will die and cause severe pain. An abscess will develop on the root. The tooth will have to be extracted if a root canal treatment is not performed to save it.

9.1.5 The roots

The roots are embedded in the tooth socket in the jaw bone. The front incisor and eye-teeth each have a single root. Pre-molar teeth (bicuspids) have one or two roots. The molar teeth can have two or three roots. Each root has a root canal for the nerves and blood vessels to pass through.

9.2 Tooth Morphology

9.2.1 Adult Incisors

Human incisors have thin, blade-like crowns which are adapted for the cutting and shearing of food . There are two incisors per quadrant, four per arch. The first incisor, the central incisor, is next to the midline. The second incisor, the lateral incisor, is distal to it. Maxillary incisors by definition arise in the premaxilla (which is merged into the maxilla in humans); mandibular incisors are the teeth that articulate

with them.

9.2.1.1 Maxillary Central Incisor. It is the most prominent tooth in the mouth. It has a nearly straight incisal edge and a gracefully curved cervical line. The mesial presents a straight outline; the distal aspect is more rounded. Mamelons are present on freshly erupted, unworn central incisors. The lingual aspect presents a distinctive lingual fossa that is bordered by mesial and distal marginal ridges, the incisal edge, and the prominent cingulum at the gingival. Mesial and distal aspects present a distinctive triangular outline. This is true for all of the incisors. The incisal ridge of the crown is aligned on the long axis of the tooth along with the apex of the tooth. The crown is roughly triangular in outline; the incisal edge is nearly a straight line, though slightly crescent shaped. The mesial contact point is just about at the incisal, owing to the very sharp mesial incisal angle. The distal contact point is located at the junction of the incisal third and the middle third. Viewed from the labial, the distal incisal angle is more rounded that the mesial. In many specimens, a cross-section mid-root reveals a right triangle outline. The hypotenuse is toward the mesial. The maxillary central incisor usually develops normally. Variations include a short crown or, on occasion, and unusually long crown. This tooth is rarely absent. The Hutchinson incisor is a malformation due to congenital syphilis in utero. An important non-metric variation of the upper incisors is the shovel shaped incisor trait. It presents with large, robust marginal ridges and a deep lingual fossa. This feature is significant in Chinese, Eskimo-Aleuts, and North American Indians. It is an important clue to population movements, especially those peoples who moved into the Americas from Siberia since the end of the Ice Age.

9.2.1.2 Maxillary Lateral Incisor. The maxillary lateral incisor resembles the central incisor, but is narrower mesio-distally. The mesial outline resembles the adjacent central incisor; the distal outline and particularly the distal incisal angle is more rounded than the mesial incisal angle (which resembles that of the adjacent central incisor. The distal incisal angle resembling the mesial of the adjacent canine. On the

lingual surface, the marginal ridges are usually prominent and terminate into a prominent cingulum. There is often a deep pit where the marginal ridges converge gingivally. A developmental groove often extends across the distal of the cingulum onto the root continuing for part or all of its length. In proximal view, the maxillary lateral incisor resembles the central except that the root appears longer about 1/2 times longer than the crown. A line through the long axis of the tooth bisects the crown. In incisal view, this tooth can resemble either the central or the canine to varying degrees. The tooth is narrower mesiodistally than the upper central incisor; however, it is nearly as thick labiolingually. The mesial contact is at the junction of the incisal third and the middle third. The distal contact is located at the center of the middle third of the distal surface. The distoincisal angle is more rounded than the mesial incisal angle. The tip of the root may incline distally, but this is not a consistent finding. This tooth is quite variable. Often the tooth is narrow, conical, and peg-shaped. It is absent either singly or bilaterally in 1-2 percent of individuals. Only the lower second premolar is more frequently missing. The lingual pit when present can be very deep and is prone to early caries in many individuals.

9.2.1.3 Mandibular Central Incisor. The mandibular central incisor is the smallest tooth in the dental arch. It is a long, narrow, symmetrical tooth. The incisal edge is straight. Mesial and distal outlines descend apically from the sharp mesial and distal incisal angles. The lingual surface has no definite marginal ridges. The surface is concave and the cingulum is minimal in size. Both mesial land distal surfaces present a triangular outline. The incisal edge is at right angles to a line passing labiolingually through the tooth reflecting its bilateral symmetry. The symmetry of this tooth makes a judgement on right and left unreliable. This tooth is consistent in development and is rarely absent. The upper incisor region is a common site for supernumerary teeth which may occasionally occur in the midline; such a variant is called a mesodens.

9.2.1.4 Mandibular Lateral Incisor. This tooth resembles the central incisor, but is somewhat larger in most proportions. It is a more rounded tooth; this is espe-

cially evident in the distal incisal angle in unworn specimens. There is a lack of the bilateral symmetry seen in the central. Except for the lack of symmetry, this tooth resembles the central. Like the central, the crown presents a triangular outline. When viewed critically, the rotation of the incisal edge can be seen. The incisal edge 'twisted' from the 90 degree angle with a line passing labiolingually through the tooth. Two significant features assist in identification, even in a worn tooth. The incisal edge is 'twisted' relative to a line passing from the labial to the lingual anticipating the curvature of the dental arch. Also, the cingulum will be shifted toward the side from whence the tooth has come.

9.2.2 Adults Canines

Human canines are the longest and most stable of teeth in the dental arch. Only one tooth of this class is present in each quadrant. In traditional dental literature, canines are considered the cornerstones of the dental arch. They are the only teeth in the dentition with a single cusp. They are especially anchored as prehensile teeth in the group from whence they get their name, the Carnivora. Maxillary canines by definition are the teeth in the maxilla distal, but closest to the incisors. Mandibular canines are those lower teeth that articulate with the mesial aspect of the upper canine.

9.2.2.1 Maxillary Permanent Canine. The canine is approximately 1 mm narrower than the central incisor. Its mesial aspect resembles the adjacent lateral incisor; the distal aspect anticipates the first premolar proximal to it. The canine is slightly darker and more yellow in the color than the incisor teeth. The labial surface is smooth, with a well developed middle lobe extending the full length of the crown cervically from the cusp tip. The distal cusp ridge is longer than the mesial cusp ridge. Distinct mesial and distal marginal ridges, a well-developed cingulum, and the cusp ridges form the boundaries of the lingual surface. The prominent lingual ridge extends from the cusp tip to the cingulum, dividing the lingual surface into mesial and distal fossae. The mesial and distal aspects present a triangular outline. They resemble the incisors, but

are more robust especially in the cingulum region. The asymmetry of this tooth is readily apparent from this aspect. It usually thicker labiolingually than it is mesiodistally. The tip of the cusp is displaced labially and mesial to the central long axis of this tooth. The distal surface is fuller and more convex than the mesial surface. The mesial contact point is at the junction of the incisal and middle third. Distally, the contact is situated more cervically. It is at the middle of the middle third. Each of the major features of this tooth is 'variations on a theme.' In some persons, a cusp-like tubercle is found on the cingulum. Lingual pits occur only infrequently. On occasion, the root is unusually long or unusually short.

9.2.2.2 Mandibular Permanent Canine. The mandibular canine is noticeably narrower mesidistally than the upper, but the root may be as long as that of the upper canine. In an individual person, the lower canine is often shorter than that of the upper canine. The mandibular canine is wider mesiodistally than either lower incisor. A distinctive feature is the nearly straight outline of the mesial aspect of the crown and root. When the tooth is unworn, the mesial cusp ridge appears as a sort of 'shoulder' on the tooth. The mesial cusp ridge is much shorter than the distal cusp ridge. The marginal ridges and cingulum are less prominent than those of the maxillary canine. The lingual surface is smooth and regular. The lingual ridge, if present, is usually rather subtle in its expression. The mesial and distal aspects present a triangular outline. The cingulum as noted is less well developed. When the crown and root are viewed from the proximal, this tooth uniquely presents a crescent like profile similar to a cashew nut. The mesiodistal dimension is clearly less than the labiolingual dimension. The mesial and distal 'halves' of the tooth are more identical than the upper canine from this perspective. You will recall that the cusp tip of the maxillary canine is facial to a ling through the long axis. In the mandibular canine, the unworn incisal edge is on the line through the long axis of this tooth. One variation of this tooth has captured the attention of board examiners. It is this: On occasion, the root is bifurcated near its tip. The double root may, or may not be accompanied by deep depressions in the root.

9.2.3 Adult Premolars

The premolar teeth are transitional teeth located between the canine and molar teeth. There are two premolars per quadrant and are identified as first and second premolars. They have at least two cusps. There is always one large buccal cusp, especially so in the mandibular first premolar. The lower second premolar may, at times present with two lingual cusps. Premolar teeth by definition are permanent teeth distal to the canines preceded by deciduous molars. In primitive mammals there are four premolars per quadrant. The most mesial two have been lost in New World monkeys, apes, and humans. Paleontologists refer to human premolars as Pm3 and Pm4.

9.2.3.1 Maxillary First Premolar. The buccal surface is quite rounded and this tooth resembles the maxillary canine. The buccal cusp is long; from that cusp tip, the prominent buccal ridge descends to the cervical line of the tooth. The lingual cusp is smaller and the tip of that cusp is shifted toward the mesial. The lingual surface is rounded in all aspects. The mesial aspect of this tooth has a distinctive concavity in the cervical third that extends onto the root. It is called variously the mesial developmental depression, mesial concavity, or the canine fossa, a misleading description since it is on the premolar. The distal aspect of the maxillary first permanent molar also has a developmental depression. The mesial marginal developmental groove is a distinctive feature of this tooth. There are two well-defined cusps buccal and lingual. The larger cusp is the buccal; its cusp tip is located midway mesiodistally. The lingual cusp tip is shifted mesially.The occlusal outline presents a hexagonal appearance. On the mesial marginal ridge is a distinctive feature, the mesial marginal developmental groove. The distal contact area is located more buccal than is the mesial contact area. Two distinctive traits help is distinguishing right and left. The mesial developmental depression and the mesially displaced lingual cups tips are consistent clues for determining right and left. When well defined, the mesial marginal ridge is also a clue to right and left. About 80 percent of upper premolars have two roots; the next most common variant is a single root. Most upper first premolars of people in our society have two roots;

however, a single root is found in about 20 percent of teeth. Three rooted premolars are found occasionally.

9.2.3.2 Maxillary Second Premolar. This tooth closely resembles the maxillary first premolar but is a less defined copy of its companion to the mesial. The buccal cusp is shorter, less pointed, and more rounded than the first. Again, this tooth resembles the first. The lingual cusp, however, is more nearly as large as the buccal cusp. Mesial and distal surfaces are rounded. The mesial developmental depression and mesial marginal ridge are not present on the second premolar. The crown outline is rounded, ovoid, and is less clearly defined than is the first. When viewed from the facial, the distal contact area is located more cervically than is the mesial contact area. The one consistent clue to right and left is the lingual cusp tip which is shifted mesially. The maxillary second premolar has a single root. The occlusal anatomy is more variable in the second than in the first. There is wide variability is root size, curvature, and form.

9.2.3.3 Mandibular First Premolar. The outline is very nearly symmetrical bilaterally, displaying a large, pointed buccal cusp. From it descends a large, well developed buccal ridge. This tooth has the smallest and most ill-defined lingual cusp of any of the premolars. A distinctive feature is the mesiolingual developmental groove. (Remember the mesial marginal developmental groove in the upper first premolar? That one is mesial. The one on the lower is toward the lingual.) The large buccal cusp tip is centered over the root tip, about at the long axis of this tooth. The very large buccal cusp and much reduced lingual cusp are very evident. You should keep in mind that the mesial marginal ridge is more cervical than the distal contact ridge; each anticipates the shape of their respective adjacent teeth. The occlusal outline is diamond-shaped. (Review of premolar occlusal outlines: the upper first is hexagonal, the upper second is ovoid, the lower first is diamond, and the lower second is square.) The large buccal cusp dominates the occlusal surface. Marginal ridges are well developed and the mesiolingual developmental groove is consistently present. There are

mesial and distal fossae with pits, affectionately known as 'snake eyes' when they are restored. When viewed from the facial, each contact area/height of curvature is at about the same height. The larger distal occlusal fossa and mesial lingual marginal developmental groove are consistent clues to right and left. The distal surface has a longer radius of curvature than does the mesial surface. There is a single root. Grooved and/or bifurcated roots do sometimes occur. This is a variable tooth in both crown and root. It may, in some persons, more nearly resemble the lower second premolar.

9.2.3.4 Mandibular Second Premolar. From this aspect, the tooth somewhat resembles the first, but the buccal cusp is less pronounced. The tooth is larger than the first. Two significant variations are seen in this view. The most common is the three-cusp form which has two lingual cusps. The mesial of those is the larger of the two. The other form is the two-cusp for with a single lingual cusp. In that variant, the lingual cusp tip is shifted to the mesial. The buccal cusp is shorter than the first. The lingual cusp (or cusps) are much better developed than the first and give the lingual a full, well-developed profile. The two or three cusp versions become clearly evident. In the three-cusp version, the developmental grooves present a distinctive 'Y' shape and have a central pit. In the two cusp version, a single developmental groove crosses the transverse ridge from mesial to distal. (Review: the lower second premolar is larger than the first, while the upper first premolar is just slightly larger than the upper second.) From the facial, the mesial contact is more occlusal than the distal contact. Why? The distal marginal ridge is lower than the mesial marginal ridge. In the two cusp version, the lingual cusp tip is shifted mesially. In the three cusp version, the larger of the two lingual cusps is to the mesial. The mandibular second premolar has a single root that is usually larger than that of the first premolar. There may be one or two lingual cusps. This tooth is sometimes missing; only the third molars and upper lateral incisors are missing more frequently than this tooth.

9.2.4 Adult Molars

The permanent molars occupy the most posterior portion of the dental arch. They have the largest occlusal surfaces of any of the teeth and have from three to five major cusps. Lower permanent molars always have two lingual cusps; upper permanent molars always have two buccal cusps. Lower molars have two roots; upper molars have three roots. Molar teeth by definition are cheek teeth that are not preceded by primary teeth. Permanent molars are accessional teeth without primary predecessors. In contrast to the molars, permanent incisors, canines, and premolars are succedaneous (successional teeth). Primitive mammals had three molars per quadrant. Humans and most primates retain that number. In humans, these teeth are important in chewing and maintaining the vertical dimension.

9.2.4.1 Maxillary First Permanent Molar. The mesiobuccal and distobuccal cusps dominate the facial outline. They are separated by the buccal developmental groove. All three roots are visible. The buccal roots present a 'plier handle' appearance with the large lingual root centered between them. Two cusps of unequal size dominate the occlusal profile. The cusps are separated by the lingual developmental groove which is continuous with the distolingual (or distal oblique) groove. The larger mesiolingual cusp often displays the Carabelli trait. It is a variable feature. It appears most often as a cusp of variable size, but is occasionally expressed merely as a pit. In mesial perspective the mesiolingual cusp, mesial marginal ridge, and mesiobuccal cusp comprise the occlusal outline. When present, the Carabelli trait is seen in this view. In its distal aspect, the two distal cusps are clearly seen; however, the distal marginal ridge is somewhat shorter than the mesial one. A small concavity on the distal surface that continues onto the distobuccal root is occasionally described. The tooth outline is somewhat rhomboidal with four distinct cusps. The cusp order according to size is: mesiolingual, mesiobuccal, distobuccal, and distolingual. The tips of the mesiolingual, mesiobuccal, and distobuccal cusps form the trigon, reflecting the evolutionary origins of the maxillary molar. The distolingual cusp is called the talon (heel) and is a more recent acquisition in evolutionary history. A frequent feature of maxillary molars

is the Carabelli trait located on the mesiolingual cusp. The mesial contact is above, but close to, the mesial marginal ridge. It is somewhat buccal to the center of the crown mesiodistally. The distal contact is similarly above the distal marginal ridge but is centered buccolingually. The large mesiolingual cusp, single large lingual (palatal) root, and Carabelli trait make distinguishing right and left easy. There are three roots, two buccal and one lingual. The lingual root is the longest and is often described as 'banana shaped.' The mesiobuccal root is not as long; the distobuccal is the smallest of the three. Observe that the sequence of diminishing root size corresponds to the sequence of diminishing cusp size described above. Deviation from the accepted normal is infrequent. The Carabelli trait is a variable feature. It is of special interest to the dental anthropologist in tracing human evolutionary history.

9.2.4.2 Maxillary Second Permanent Molar. The crown is shorter occluso-cervically and narrower mesiodistally when compared to the first molar. The distobuccal cusp is visibly smaller than the mesiobuccal cusp. The two buccal roots are more nearly parallel. The roots are more parallel; the apex of the mesial root is on line with the buccal developmental groove. Mesial and distal roots tend to be about the same length. The distolingual cusp is smaller than the mesiolingual cusp. The Carabelli trait is absent. The crown is shorter than the first molar and the palatal root has less diverence. The roots tend to remain within the crown profile. The distolingual cusp is smaller on the second than on the first molar. When it is much reduced in size, the crown outline is described as 'heart-shaped.' The Carabelli trait is usually absent. The order of cusp size, largest to smallest, is the same as the first but is more exaggerated: mesiolingual, mesiobuccal, distobuccal, and distolingual. Both mesial and distal contacts tend to be centered buccolingually below the marginal ridges. Since the molars become shorter, moving from first to this molar, the contacts tend to appear more toward the center of the proximal surfaces. The large mesiolingual cusp, small distolingual cusp, and the three roots make distinguishing right and left easy. There are three roots, two buccal and one lingual. The roots are less divergent than the first with their apices usually falling within the crown profile. The buccal roots tend to incline to the distal. The distolingual cusp is the most variable feature of this tooth.

When it is large, the occlusal is somewhat rhomboidal; when reduced in size the crown is described as triangual or 'heart-shaped.' At times, the root may be fused.

9.2.4.3 Maxillary Third Permanent Molar. Maxillary and mandibular third molars show more developmental variation that any of the other permanent teeth. They are the teeth most often congenitally missing. The crown is usually shorter in both axial and mesiodistal dimensions. Two buccal roots are present, but in most cases they are fused. The mesial buccal cusp is larger than the distal buccal cusp. In most thirds, there is just one large lingual cusp. In some cases there is a poorly developed distolingual cusp and a lingual groove. The lingual root is often fused to the buccal cusps. The outline of the crown is rounded; it is often described as bulbous in dental literature. Technically, the mesial surface is the only 'proximal' surface. The distal surface does not contact another tooth. The crown of this tooth is the smallest of the maxillary molars. The first molar is the largest in the series. The outline of the occlusal surface can be described as heart-shaped. The mesial lingual cusp is the largest, the mesial buccal is second in size, and the distal buccal cusp is the smallest. This tooth is rounded and variable in shape. The distal surface has no contact with any other tooth. Although this tooth is a variable and anomalous tooth, right and left is fairly easy to determine. The mesiobuccal cusp is much larger than the distobuccal cusp. This helps in the determination of right and left. There are three roots, two buccal and one lingual; however, they are usually fused into one functional root. They are the most variable teeth in the dentition. Impaction occurs frequently. Some resemble the adjacent second molar; others may have many cusps, small 'cusplets', and many grooves.

9.2.4.4 Mandibular First Permanent Molar. The lower first permanent molar has the widest mesiodistal diameter of all of the molar teeth. Three cusps cusps separated by developmental grooves make on the occlusal outline seen in this view. Moving from mesial to distal, these features form the occlusal outline as follows: mesiobuccal cusp, mesiobuccal developmental groove, distobuccal cusp, distobuccal developmental

groove, and the distal cusp. The mesiobuccal cusp is usually the widest of the cusps. The mesiobuccal cusp is generally considered the largest of the five cusps. The distal cusp is smaller than any of the buccal cusps and it contributes little to the buccal surface. The two roots of this tooth are clearly seen. The distal root is usually less curved than the mesial root. Three cusps make up the occlusal profile in this view: the mesiolingual, the distolingual, and the distal cusp which is somewhat lower in profile. The mesiobuccal cusp is usually the widest and highest of the three. A short lingual developmental groove separates the two lingual cusps. The distinctive height of curvature seen in the cervical third of the buccal surface is called the cervical ridge. The mesial surface may be flat or concave in its cervical third . It is highly convex in its middle and occlusal thirds. The occlusal profile is marked by the mesiobuccal cusp, mesiolingual cusp, and the mesial marginal ridge that connects them. The mesial root is the broadest buccolingually of any of the lower molar roots. The distal surface of the crown is narrower buccolingually than the mesial surface. Three cusps are seen from the distal aspect: the distobuccal cusp, the distal cusp, and the distolingual cusp. This tooth presents a pentagonal 'home plate' occlusal outline that is distinctive for this tooth. There are five cusps. Of them, the mesiobuccal cusp is the largest; the distal cusp is the smallest. The two buccal grooves and the single lingual groove form the "Y5" patern distinctive for this tooth. The five cusp and "Y5" pattern is important in dental anthropology. The mesial contact is centered buccolingually just below the marginal ridge. The distal contact is centered over the distal root, but is buccal to the center point of the distal marginal ridge. The cervical ridge on the buccal aspect, the two buccal cusps located to the buccal along with the distal cusp provide identification of the buccal aspect. The distal cusp is the smallest and is displaced along the occlusal aspect. These features make possible identification of right and left. Lower molars have mesial and distal roots. In the first, molar, the mesial root is the largest. It has a distal curvature. The distal root has little curvature and projects distally. Most lower first molars have five cusps. Occasionally the distal cusp is missing. More rarely, in large molars, the distal cusp is joined by a sixth cusp, the 'cusp six' or tuberculum sextum. Two mesial roots are seen on occasion; this Sinodont feature is occasionally seen clinically, particularly in persons of North American Indian heritage.

9.2.4.5 Mandibular Second Permanent Molar. When compared to the first molar, the second molar crown is shorter both mesiodistally and from the cervix to the occlusal surface. The two well-developed buccal cusps form the occlusal outline. There is no distal cusp as on the first molar. A buccal developmental groove appears between the buccal cusps and passes midway down the buccal surface toward the cervix. The crown is shorter than that of the first molar. The occlusal outline is formed by the mesiolingual and distolingal cusps. The mesial profile resembles that of the first molar. The distal profile is formed by the distobuccal cusp, distal marginal ridge, and the distolingual cusp. Unlike the first molar, there is no distal fifth cusp. There are four well developed cusps with developmental grooves that meet at a right angle to form the distinctive "+4" pattern characteristic of this tooth. When moving distally from first to third molar, the proximal surfaces become progressively more rounded. The net effect is to displace the contact area cervically and away from the crest of the marginal ridges. When viewed occlusally, there is a distinctive prominence of enamel at the mesiobuccal a feature shared with first deciduous molars. Examined from the mesial or distal, the lingual surface has its height of curvature midway between the occlusal and the cervical line. On the buccal surface, the height of curvature is at the gingival third near the cervical line. There are two roots which are often shorter than those of the first. When compared to first molar roots, those of the second tend to be more parallel and to have a more distal inclination. Morphologically this is a stable tooth. Five cusp versions are seen on occasion, however root variability is greater than in the first molar.

9.2.4.6 Mandibular Third Permanent Molar. The crown is often short and has a rounded outline. Similarly, the crown is short and the crown is bulbous. Mesially and distally, this tooth resembles the first and second molars. The crown of the third molar, however, is shorter than either of the other molars. Technically, only the mesial surface is a 'proximal' surface. Four or five cusps may be present. This surface can be a good copy of the first or second molar, or poorly developed with many accessory grooves. The occlusal outline is often ovoid and the occlusal surface is constricted. Occasionally, the surface has so many grooves that it is described as crenulated a

condition seen in the great apes. The rounded mesial surface has its contact area more cervical than any other lower molar. There is no tooth distal to the third molar. In the five cusp version the buccal side of the tooth is easily identified. This can be confirmed by comparison with the lingual and buccal surface contours. In four cusp versions the mesial cusps are usually more developed than the distal cusps, contributing to this tooth's ovoid occlusal profile. The two roots are usually short, often curved distally, and poorly developed. This is an extremely variable tooth and on occasion it is missing. While the most common anomaly of upper third molars is that they are undersized, lower third molars can be undersized or oversized. Lower third molars fail to erupt in many people.

10. COMPARISON OF TOOTH MORPHOLOGY WITH IMPLANTS

In previous chapter we have deeply made the analysis of the tooth anatomy and morphology. Since with dental implants we are aiming to replace the missing function of the teeth and missing esthetic of the teeth; we have to compare the anatomical structures and find the most appropriate modeling for the implant design. Previous implants designs such as supperiostal implants and blade implants were far from the anatomical tooth structure and they were mainly designed as the anchorage material in the bone or under the preiosteum to support the suprastructures. With the developments and new design modern dental implants looks like the root of the teeth. They are mainly conical or cylindrical, and all have different surface characteristics, but all resemble a root. In previous chapter we have studied the different tooth anatomies and we have clearly seen that only incisors and canines have one root. Eventhough we use implants in the posterior region to replace premolar or molar teeth, which has two or three roots we still use implants in the shape of one root. Posterior teeth are functioning as grinding whereas anterior teeth functions in cutting. So this emphasizes the need for a gradual support in the posterior region to heavy occlusal loads.

Implants are placed in jaw bones where previously tooth was extracted or not developed congenitally. So the bone structure to receive the implant fixture is narrow coronally and wider apically. We can carefully follow the morphology and structure of bone in maxilla and mandible to adopt the design process accordingly.

11. PROTOTYPING THE DESIGN

A prototype is an original type, form, or instance of something serving as a typical example, basis, or standard for other things of the same category. The word derives from the Greek prototypon "primitive form", neutral prototypos "original primitive", from protos "first" and typos "impression" [92].

In many fields like biomedical researches, there is great uncertainty as to whether a new design will actually do what is desired. New designs often have unexpected problems. A prototype is often used as part of the product design process to allow designers the ability to explore design alternatives, test theories and confirm performance prior to starting production of a new product. It is used to tailor the prototype according to the specific unknowns still present in the intended design. For example, some prototypes are used to confirm and verify in a proposed design whereas other prototypes will attempt to verify the performance or suitability of a specific design approach.

In general, series of prototypes will be designed, constructed and tested as the final design emerges and is prepared for production. With rare exceptions, multiple iterations of prototypes are used to progressively refine the design. A common strategy is to design, test, evaluate and then modify the design based on analysis of the prototype. In many product development organizations, prototyping specialists are employed - individuals with specialized skills and training in general fabrication techniques that can help bridge between theoretical designs and the fabrication of prototypes.

11.1 Basic prototype categories

There is no general agreement on what constitutes a "prototype" and the word is often used interchangeably with the word "model" which can cause confusion. In general, âprototypesâ fall into four basic categories.

11.1.1 Proof-of-Principle Prototype

Also called a breadboard. This type of prototype is used to test some aspect of the intended design without attempting to exactly simulate the visual appearance, choice of materials or intended manufacturing process. Such prototypes can be used to âproveâ out a potential design approach such as range of motion, mechanics, sensors, architecture, etc. These types of models are often used to identify which design options will not work, or where further development and testing is necessary.

11.1.2 Form Study Prototype

This type of prototype will allow designers to explore the basic size, look and feel of a product without simulating the actual function or exact visual appearance of the product. They can help assess ergonomic factors and provide insight into visual aspects of the product's final form. Form Study Prototypes are often hand-carved or machined models from easily sculpted, inexpensive materials (e.g., urethane foam), without representing the intended color, finish, or texture. Due to the materials used, these models are intended for internal decision making and are generally not durable enough or suitable for use by representative users or consumers.

11.1.3 Visual Prototype

This group will capture the intended design aesthetic and simulate the appearance, color and surface textures of the intended product but will not actually embody the function(s) of the final product. These models will be suitable for use in market research, executive reviews and approval, packaging mock-ups, and photo shoots for sales literature.

11.1.4 Functional Prototype

Also called a working prototype will, to the greatest extent practical, attempt to simulate the final design, aesthetics, materials and functionality of the intended design. The functional prototype may be reduced in size (scaled down) in order to reduce costs. The construction of a fully working full-scale prototype and the ultimate test of concept is the engineers' final check for design flaws and allow last-minute improvements to be made before larger production runs are ordered.

11.2 Characteristics and Limitations of Prototypes

Engineers and prototyping specialists seek to understand the limitations of prototypes to exactly simulate the characteristics of their intended design. It is important to realize that by their very definition, prototypes will represent some compromise from the final production design. Due to differences in materials, processes and design fidelity, it is possible that a prototype may fail to perform acceptably whereas the production design may have been sound. A counter-intuitive idea is that prototypes may actually perform acceptably whereas the production design may be flawed since prototyping materials and processes may occasionally outperform their production counterparts. It is possible to use prototype testing to reduce the risk that a design may not perform acceptably, however prototypes generally cannot eliminate all risk. There are pragmatic and practical limitations to the ability of a prototype to match the intended final performance of the product and some allowances and engineering judgement are often required before moving forward with a production design.

Building the full design is often expensive and can be time-consuming, especially when repeated several times building the full design, figuring out what the problems are and how to solve them, then building another full design. As an alternative, "rapid-prototyping" or "rapid application development" techniques are used for the initial prototypes, which implement part, but not all, of the complete design. This allows designers to rapidly and inexpensively test the parts of the design that are most likely

to have problems, solve those problems, and then build the full design. With the recent advances in computer modeling it is becoming practical to eliminate the creation of a physical prototype (except possibly at greatly reduced scales for promotional purposes), instead modeling all aspects of the final product as a computer model.

The most common use of the word prototype is a functional, although experimental, version of a material or machine (e.g., automobiles, domestic appliances, consumer electronics) whose designers would like to have built by mass production means, as opposed to a mockup, which is an inert representation of a machine's appearance, often made of some non-durable substance. A researcher can build a prototype (and make additions and modifications) much quicker with these techniques however, it is much faster and usually cheaper to mass produce custom printed circuit boards than these other kinds of prototype boards. For further more clarification on the subject of what a prototype is we can look at these comparisons since every project has different stages as to what or where they are in development.

11.3 Advantages and Disadvantages of Prototyping

11.3.1 Advantages of prototyping

May provide the proof of concept necessary to attract funding. Early visibility of the prototype gives an idea of what the final system looks like. Encourages active participation among users and producer. Enables a higher output for user. Cost effective (development costs reduced). Increases system development speed. Assists to identify any problems with the efficacy of earlier design and coding. To refine the potential risks associated with the delivery of the system. Various aspects can be tested and quicker feedback can be got from the user. Helps to deliver the product in quality easily. User interaction available in during development cycle of prototype.

11.3.2 Disadvantages of prototyping

Producer might produce a system inadequate for overall organization needs. User can get too involved whereas the program cannot be to a high standard. Structure of system can be damaged since many changes could be made. Producer might get too attached to it (might cause legal involvement). Not suitable for large applications. Can cause loss in consumer interest and subsequent cancellation.

12. PRODUCTION OF PROTOTYPE

The model development was first started with the search of appropriate software to be used to design the model. With the consultations and the search carried through the solid material designing software or surface designing softwares were found relatively appropriate to carry the study. First of all courses on Alibre Design software was taken from MTM Computer Ltd to develop personal knowledge and capabilities to use designing software. Personal development courses were taken to be able to better understand the limits of designing. Furthermore due to the limited time allocated for this research, instead of using the limited time for learning the use of software applications support was taken from Mr. Hrant Arzumanyan for applying the developed ideas to the computer aided designed model at Rhino Software. The starting point of the design was to mimic the classical implant model of conic structure.

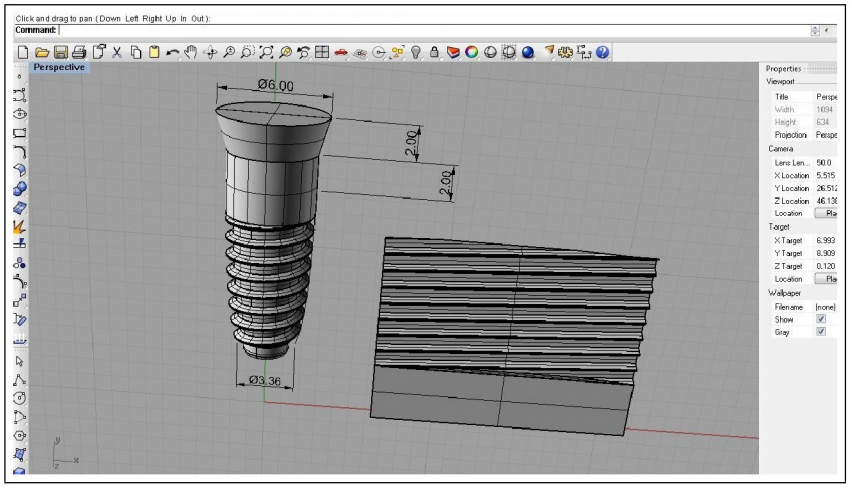

Figure 12.1 Model developments in 3D designing software.

Then development of the apical portions to increase the stability was realized. The preliminary designs were not sophisticated and not found to be logical in terms of clinical application and also production of such a model was very complicated, thus would not be a model proposed rather than a research subject. As we have studied very carefully the tooth structure and morphology in previous chapters, especially

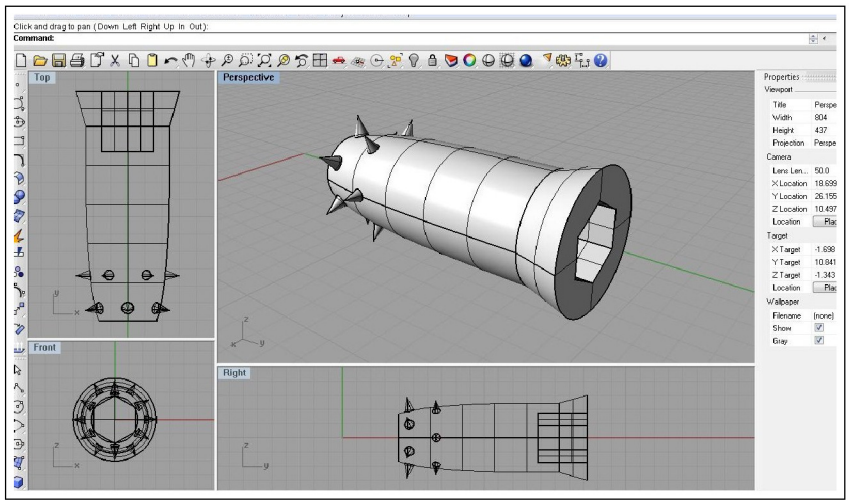

Figure 12.2 Model developments in 3D Designing software.

in posterior regions where bone quality is not good, the shape of premolar or molar tooth would be a very good model to develop. The molar teeth has two or three roots depending on the region of the jaw bone, but both with having a furcation and separate roots has more stability in bone rather than one rooted teeth. That is why we have studied the possibility of a mechanism to mimic the tooth structure.

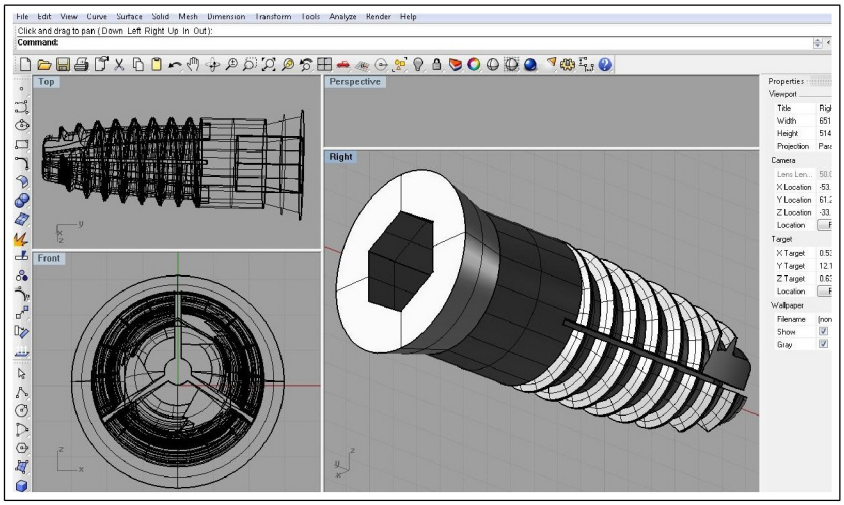

Figure 12.3 Model developments in 3D Designing software.

The conical implant design is cut to three portions in the apical part of the material to be separated to mimic the three rooted structure of the molar teeth. It is easier to shape a titanium implant exactly as tooth with three roots. But the difficulty is the implant site preparation for such a model. Because the bone structure

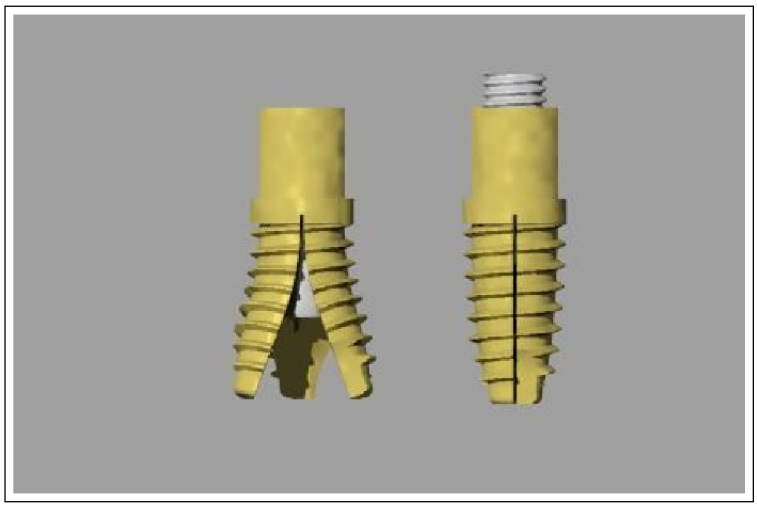

Figure 12.4 Drawing of developed model apical arms open and apical arms close.

is very narrow mostly and to open a big insertion hole will cause complications on the osseointegration. The ideal but also the difficult aspect is to design such a model that will enter the prepared bone site in a conical shape and then change its shape to a three rooted teeth structure.

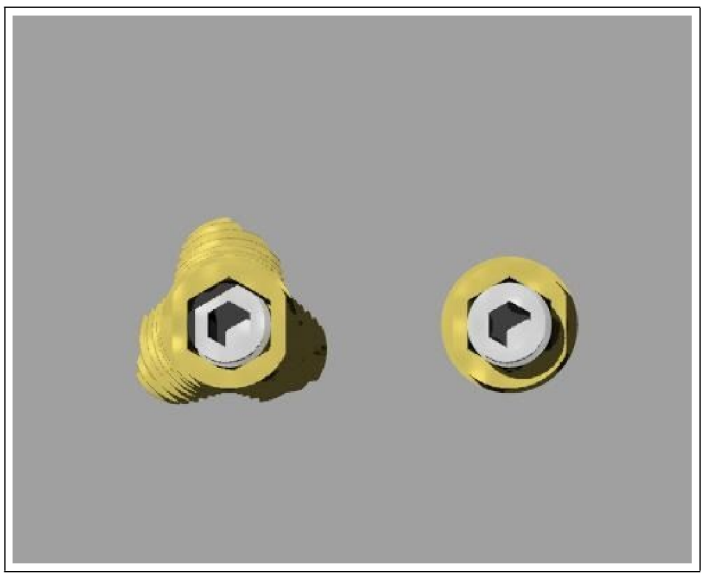

Figure 12.5 Drawing of developed model apical arms open and apical arms close (Occlusal view).

That is why design was developed in the apical portion with three cuts, which will enable the move of the apical portions externally. This movement will reshape the implant inside the bone in a three rooted form which we believe will increase the primary stability of the dental implant.

This was studied in different manners to find the most appropriate approach to find the method to expand the apical root portions of the implant design. Itâs possible to tap some sizes of pins to open the apical arms, but this would be an irreversible action where we have no control.

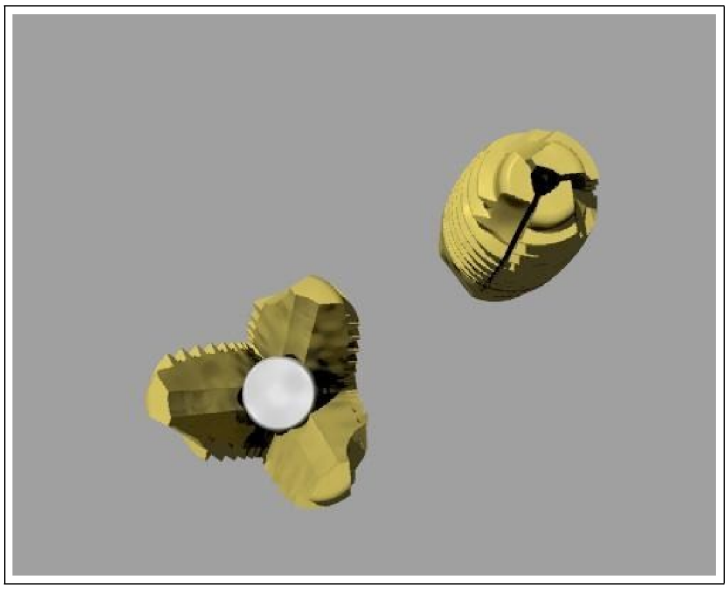

Figure 12.6 Drawing of developed model apical arms open and close(Apical view).

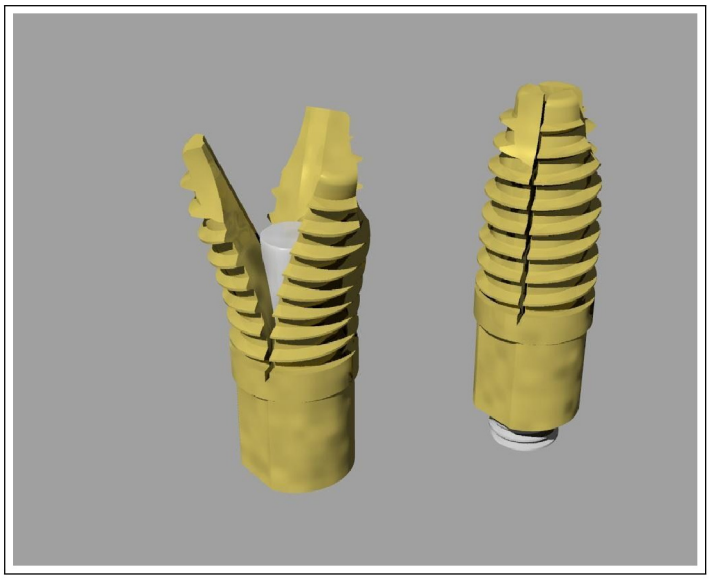

Figure 12.7 Drawing of developed model apical arms open and close(Lateral view).

But afterwards we have developed the design with transvertical passing screw to open the apical arms. This gave us the choice of controlling the degree of opening at the apical arms to form the rooted teeth structure and also in case of any complication

to remove back the screw to easily remove from the applied bone.

The design is then worked in detail in Rhino Ceros software to precisely adaptation of the pieces and also prepared for casting processes.

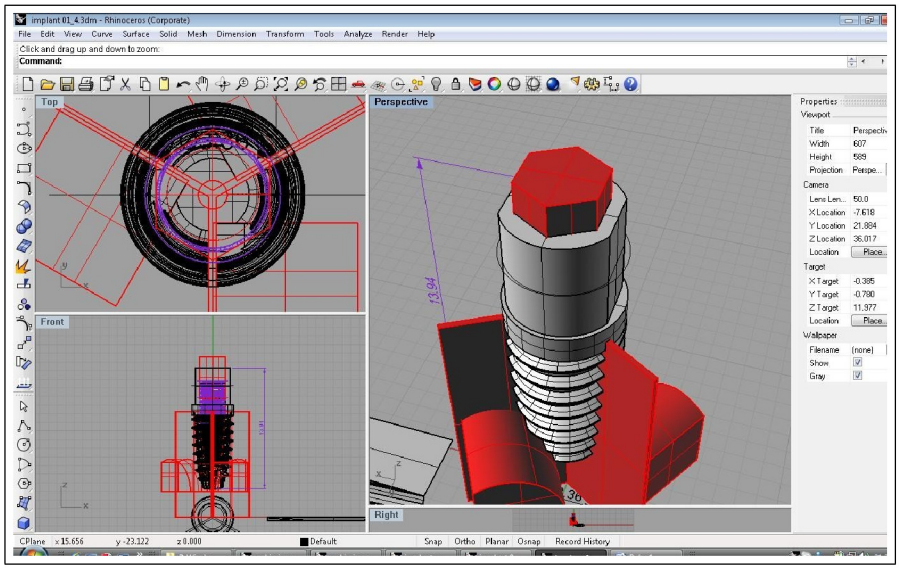

Figure 12.8 Model apical portions sectioning the extension pieces.

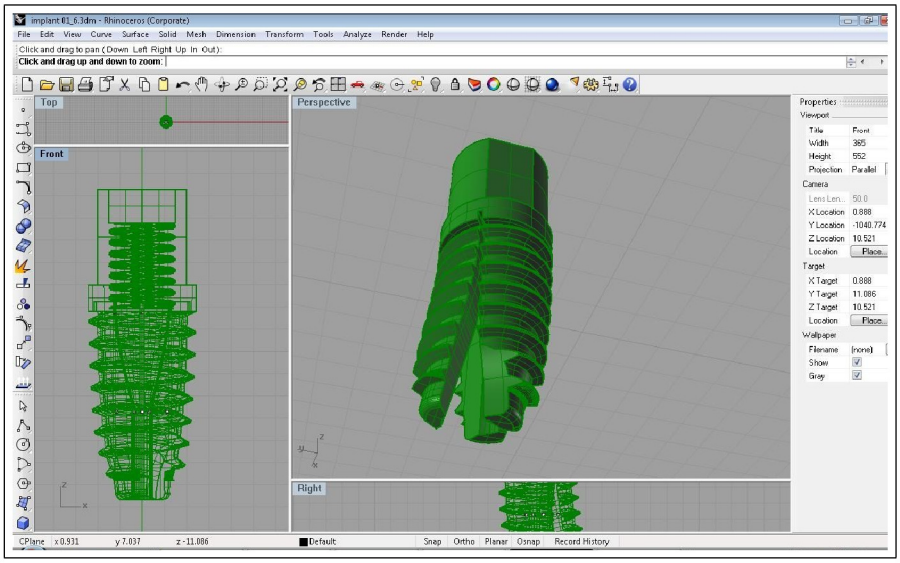

Figure 12.9 Model apical portions controlling of the extension pieces.

Plastic prohtotypes were produced with the aim to produce the model. The plastic models were taken from specially developed prototyping machines thus we had very succesfull prototypes of the developed dental implant design.

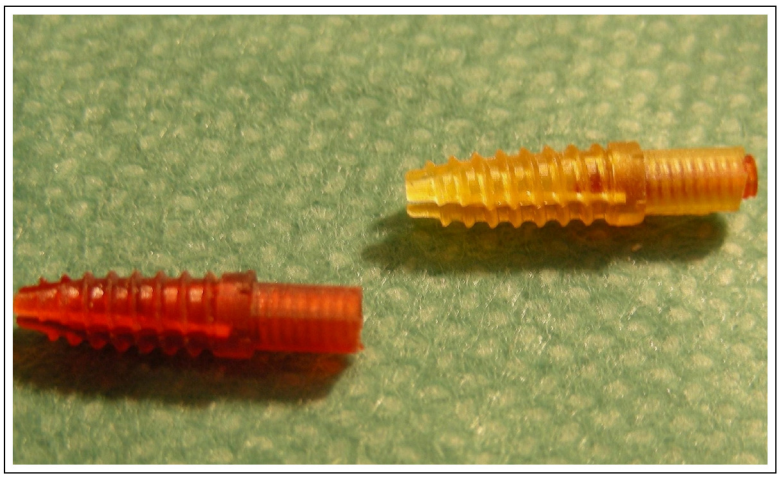

Figure 12.10 Model developed in final specification at software is transferred to prototype produced.

These prototypes were then casted in dental metal production owens but the casting was not succesfull when the product was carried in casting to titanium.

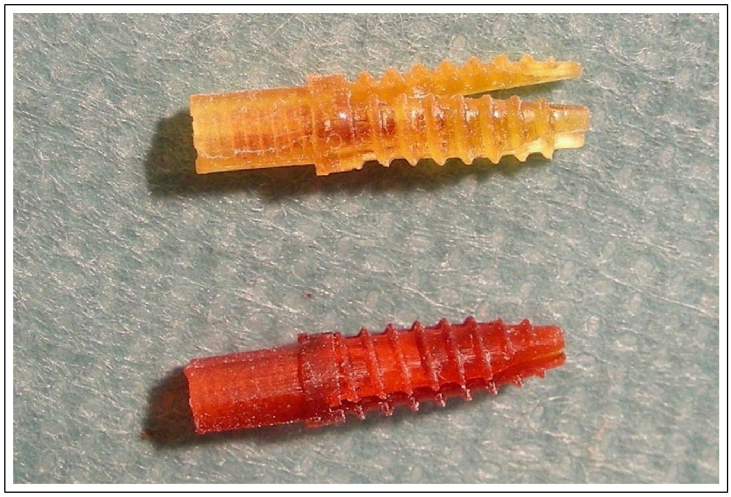

Figure 12.11 Model developed in final specification at software transfered to prototype is tested to function (opening) in apical arms.

The design developed for this research has surface and structure which is really complicated to produce replicas by casting. Then we have decided to step further to pass to the milling machines to produce our developed implant design.

Industrial zones in Istanbul was visited many times to find production facilities for medical sensitive products such as implants. During our visits to industrial zones, we have realised that not all types of milling devices are capable to produce products such

as implant which need high precision. We have communicated with the distributors of the international companies selling CNC-milling devices.

We were able to find an orthopedic implant production company who accepted to help the research project. The technical drawings of the developed implant design was prepared to fullfill the demands of the company to produce these implants.

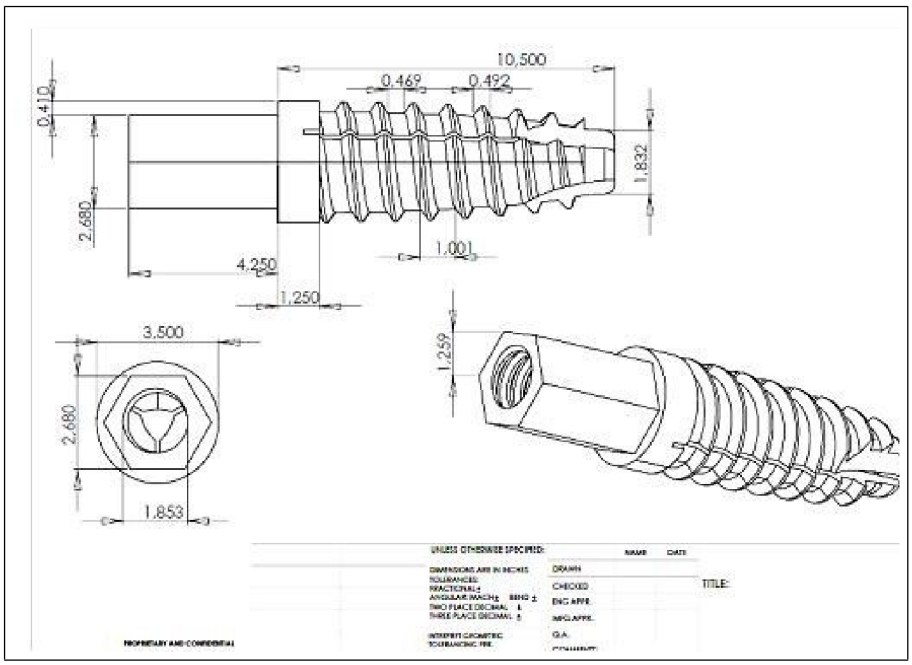

Figure 12.12 Technical drawing of the model developed in final specification for CNC milling.

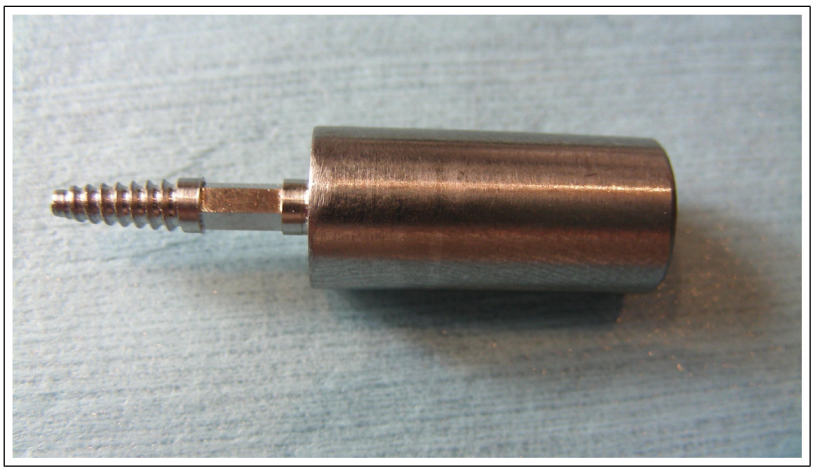

Figure 12.13 Processing of titanium bar at CMC milling machine.

The developed implant design samples were produced from Grade 4 Titanium. The titanium bars were treated in milling machines to adapt to the design, and then

cleaned for testing. For this research also control implants were produced, totaly in exact shape but without the apical arms which are supposed to be opened inside the bone after insertion.

Figure 12.14 Manufactured control implant (left) and developed implant design (right).

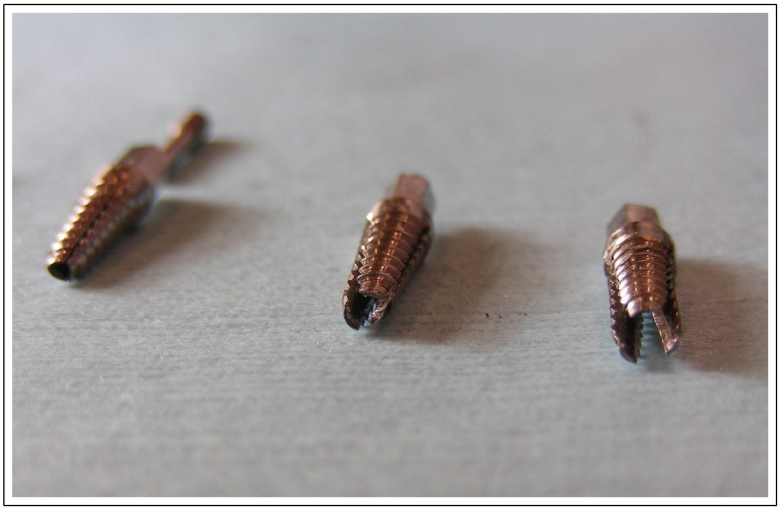

Figure 12.15 Manufactured implant design, apical arms of the implant are opened.

13. PRIMARY STABILITY TESTS IN BOVINE SPINAL BONE

Developed implant design was fabricated from Grade 4 type titanium. It has been suggested that implants should also be evaluated for possible rotational movements. Recently, it was, e.g., proposed to apply a reverse-torque test, with forces not exceeding 10Ncm, to every single implant at abutment connection to discover mobile implants [48]. With this procedure, an incidence of 4.7 percent of early failures was reported. In the report by Sullivan [48], an increase of the reverse-torque test to 20 Ncm was shown to reduce the number of late failures.

In the research of this procedure, in our study three different media is selected as similar structural properties. Implants produced were tested in bovine iliac bone, bovine spinal bone and polymer block. All media was first prepared an implant hole with a 2mm drill.

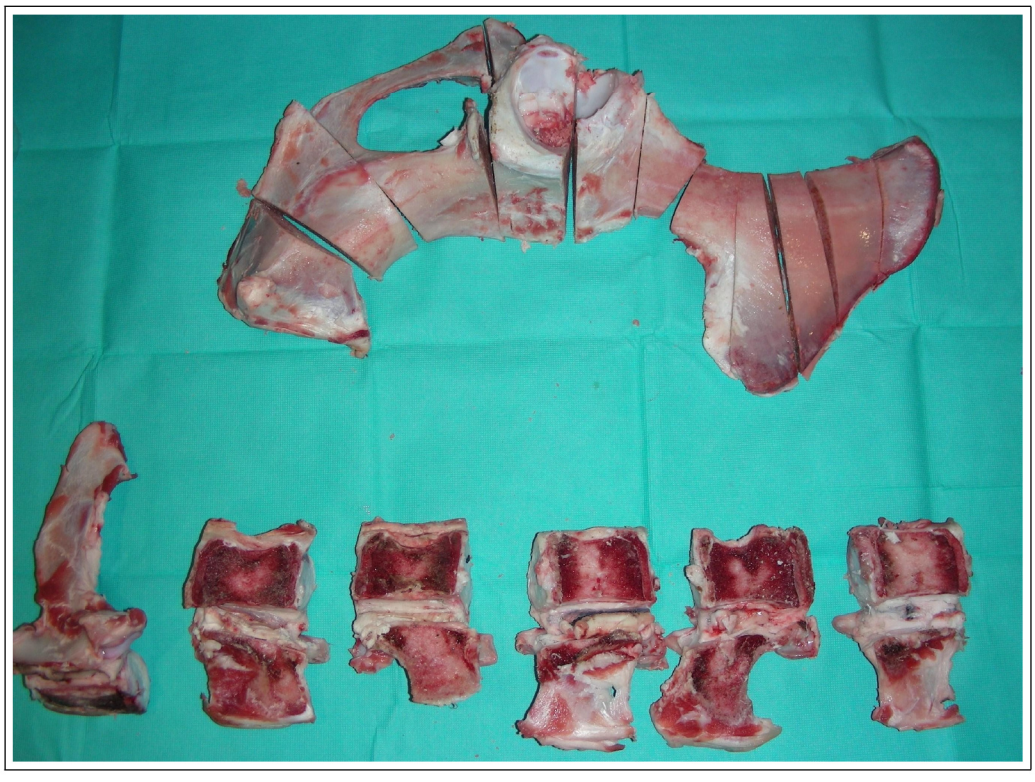

Figure 13.1 Bovine iliac and spinal bone pieces cut into segments for bone testing.

Then implants were inserted with torque controlled medical device WH Co. ImplaMED. All insertion torques were recorded. Then starting from 5 Ncm implants were applied removal torque to test the initial stability.

Each implant in all samples and in three different media was applied with digital torque control in sequences of 5 Ncm, 10Ncm, 15Ncm, 20 Ncm, 25Ncm, 30Nm, 35Ncm, 40Ncm, 45Ncm and 50Ncm.

All data collected is shown below on tables representing the specific media and sample. The sample withstands the removal torque is market with â+â until the torque value where the implant started to move out from the bone socket.

13.1 Bovine Spinal Bone Tests

Four implant application sites are prepared with 2.0mm drill. The drilling speed is fixed with 800 rpm using WH Implamed device.

Each site is cleaned for excess bone particles after the drilling is finished. Drilling is applied by the same surgeon, at the same condition and the same day. After holes are prepared in the bone, implants both the control implant and the developed design are inserted in their prepared sockets the simultaneously recording the insertion torque values.

Insertion torque values are recorded by digital torque meter of the WH Implamed Device, and the torque values are increased step by step until the implants reaches to its final position. Then the implants are applied removal torques again with gradually applied forces.The removal torque values are gradually increased from 5 Ncm to 50 Ncm with 5Ncm intervals.

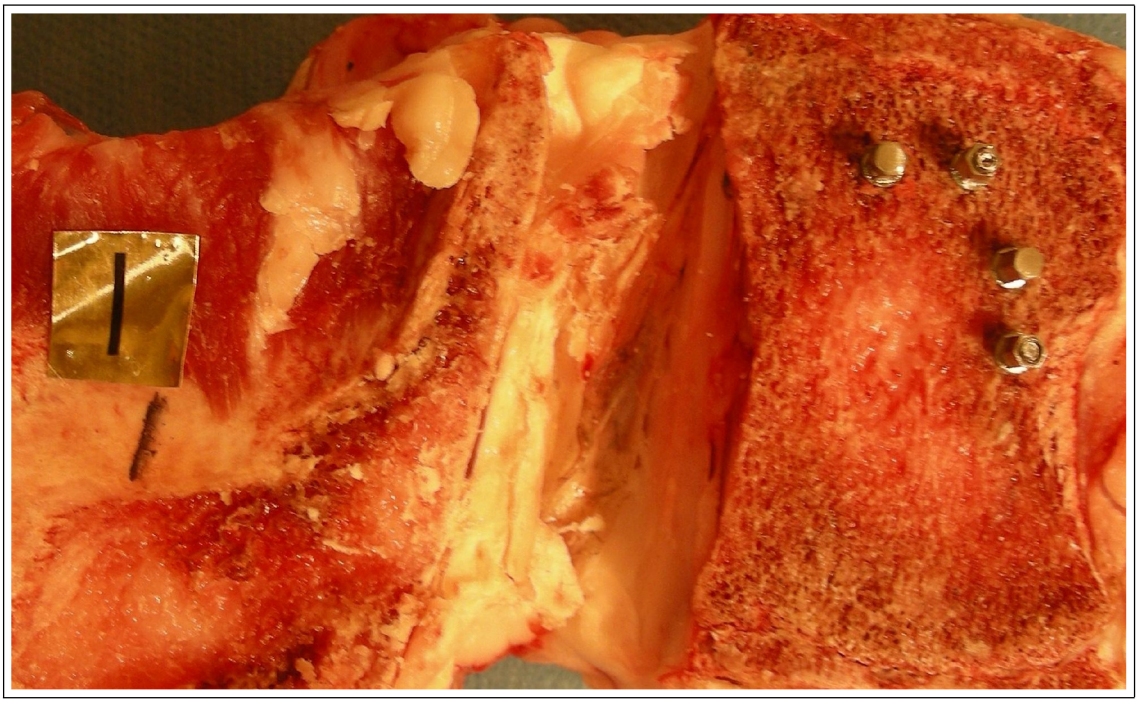

Figure 13.2 Bovine spinal bone sample 1, implants are placed by torque control.

Table 13.1
Bovine spinal bone test sample 1 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	1	2	3	4
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	+	+	+
30 Ncm	+	+	+	+
35 Ncm	+	+	+	+
40 Ncm	+	+	+	+
45 Ncm	+	-	+	-
50 Ncm	+	-	+	-
Removal Torque Ncm	50	40	50	40
Insertion Torque Ncm	50	30	50	30
Resistance gained Ncm	0	+10	0	+10
Resistance Gained %	0	+33	0	+33

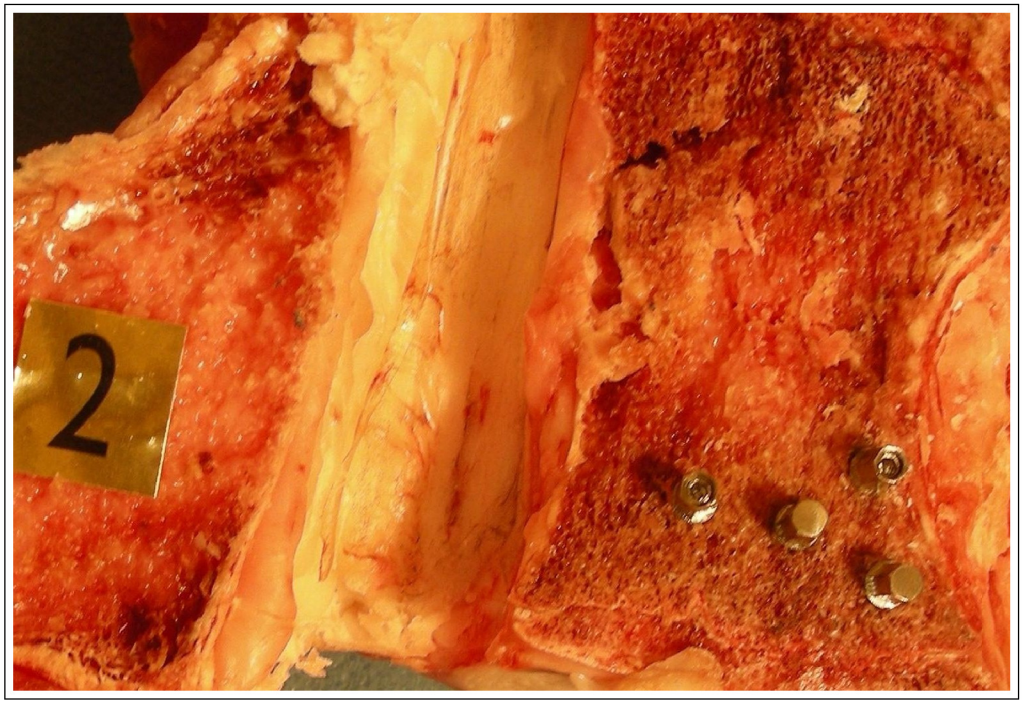

Figure 13.3 Bovine spinal bone sample 2, implants are placed by torque control.

Table 13.2
Bovine spinal bone test sample 2 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	2	1	4	3
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	+	+	+
30 Ncm	+	+	+	+
35 Ncm	+	+	+	+
40 Ncm	+	-	+	+
45 Ncm	+	-	+	-
50 Ncm	-	-	-	-
Removal Torque Ncm	45	35	45	40
Insertion Torque Ncm	45	25	45	30
Resistance gained Ncm	0	+10	0	+10
Resistance Gained %	0	+40	0	+33

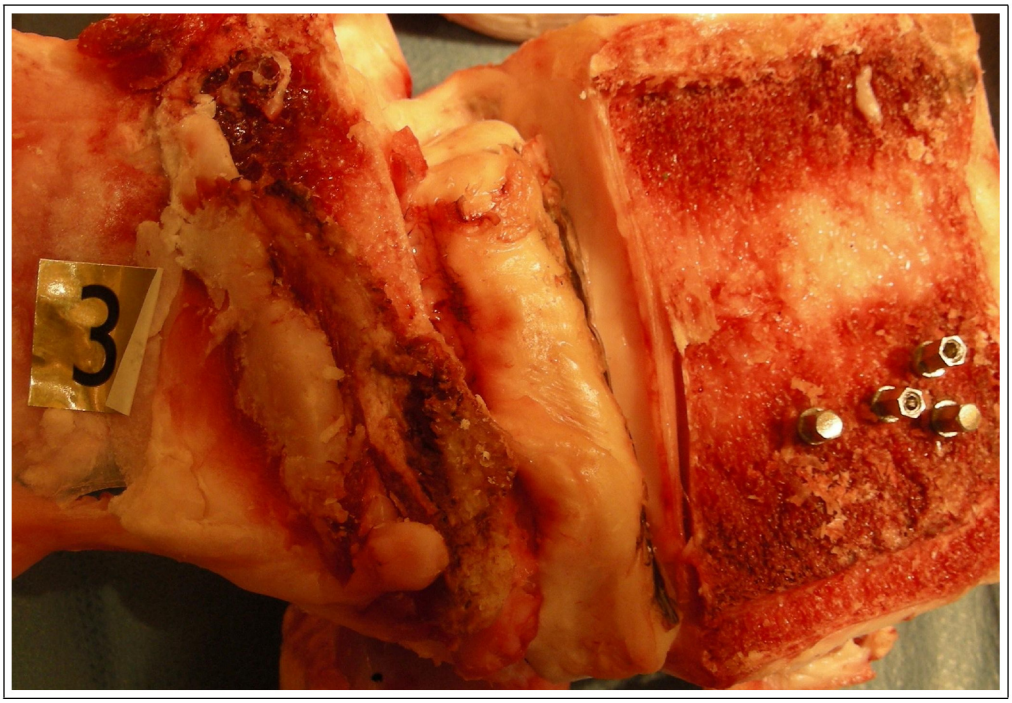

Figure 13.4 Bovine spinal bone sample 3, implants are placed by torque control.

Table 13.3
Bovine spinal bone test sample 3 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	1	2	4	3
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	+	+	+
30 Ncm	+	+	+	+
35 Ncm	+	+	+	+
40 Ncm	+	+	+	+
45 Ncm	+	-	+	+
50 Ncm	-	-	-	-
Removal Torque Ncm	45	40	45	45
Insertion Torque Ncm	45	30	45	35
Resistance gained Ncm	0	+10	0	+10
Resistance Gained %	0	+33	0	+28

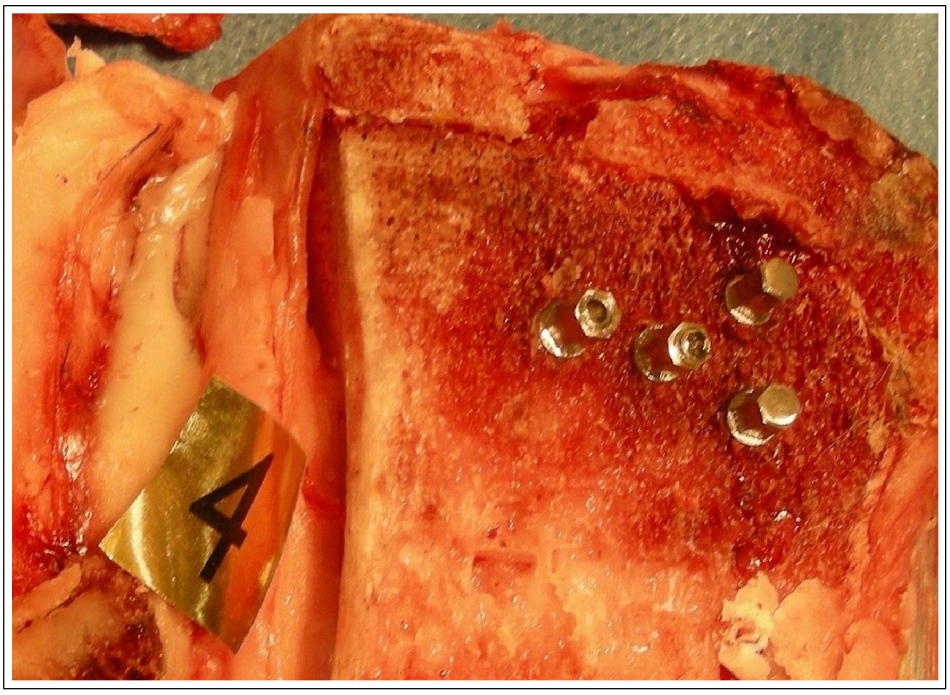

Figure 13.5 Bovine spinal bone sample 4, implants are placed by torque control.

Table 13.4
Bovine spinal bone test sample 4 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	3	1	4	2
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	+	+	+
30 Ncm	+	+	+	+
35 Ncm	+	+	+	+
40 Ncm	+	-	+	+
45 Ncm	+	-	+	-
50 Ncm	-	-	-	-
Removal Torque Ncm	45	40	45	40
Insertion Torque Ncm	40	30	40	25
Resistance gained Ncm	+5	+10	+5	+15
Resistance Gained %	+12	+33	+12	+60

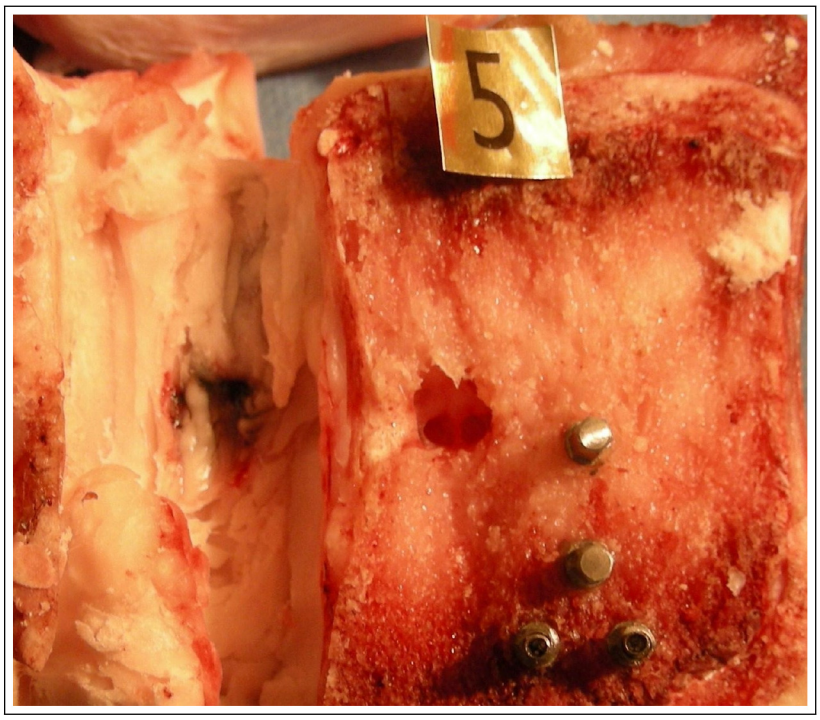

Figure 13.6 Bovine spinal bone sample 5, implants are placed by torque control.

Table 13.5
Bovine spinal bone test sample 5 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	1	2	3	4
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	+	+	+
30 Ncm	+	+	+	+
35 Ncm	+	+	+	+
40 Ncm	-	+	+	+
45 Ncm	-	-	+	-
50 Ncm	-	-	-	-
Removal Torque Ncm	35	40	45	40
Insertion Torque Ncm	40	25	35	30
Resistance gained Ncm	-5	+15	+10	+10
Resistance Gained %	-12	+60	+28	+33

14. PRIMARY STABILITY TESTS IN BOVINE ILIAC BONE

Implants produced were tested iliac bone. All media was first prepared an implant hole with a 2mm drill. Then implants were inserted with torque controlled medical device WH Co. ImplaMED. All insertion torques were recorded. Then starting from 5 Ncm implants were applied removal torque to test the initial stability.

Each implant in all samples and in three different media was applied with digital torque control in sequences of 5 Ncm, 10Ncm, 15Ncm, 20 Ncm, 25Ncm, 30Nm, 35Ncm, 40Ncm, 45Ncm and 50Ncm.

All data collected is shown below on tables representing the specific media and sample. The sample withstands the removal torque is market with â+â until the torque value where the implant started to move out from the bone socket.

14.1 Bovine Iliac Bone Tests

Four implant application sites are prepared with 2.0mm drill. The drilling speed is fixed with 800 rpm using WH Implamed device. Each site is cleaned for excess bone particles after the drilling is finished. Drilling is applied by the same surgeon, at the same condition and the same day. After holes are prepared in the bone, implants both the control implant and the developed design are inserted in their prepared sockets the simultaneously recording the insertion torque values.

Insertion torque values are recorded by digital torque meter of the WH Implamed Device, and the torque values are increased step by step until the implants reaches to its final position. Then the implants are applied removal torques again with gradually applied forces.The removal torque values are gradually increased from 5 Ncm to 50 Ncm with 5Ncm intervals.

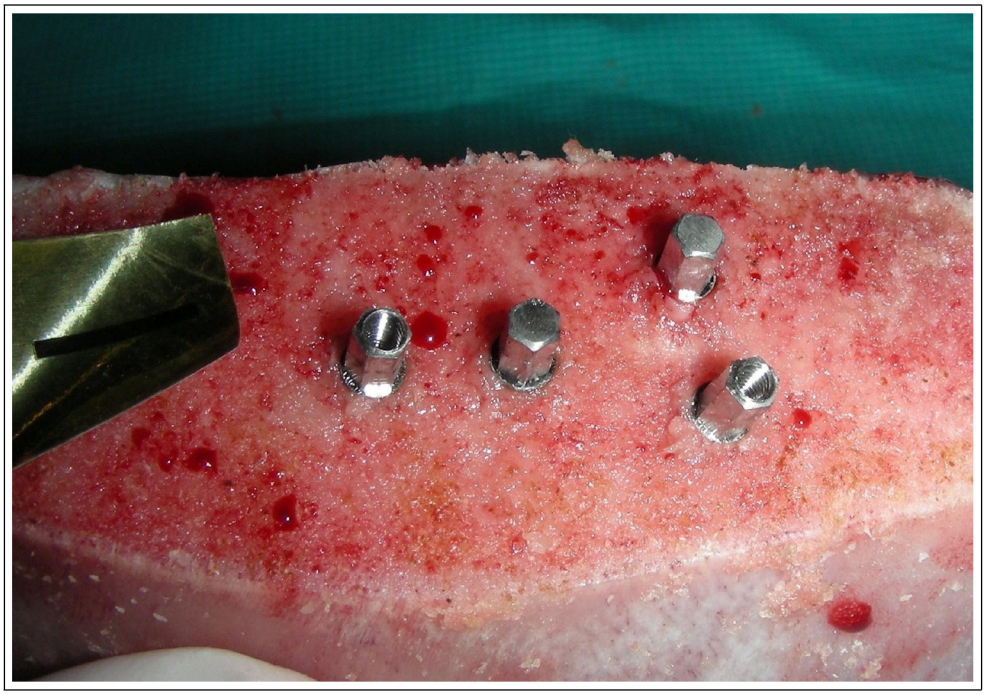

Figure 14.1 Bovine iliac bone sample 1, implants are placed by torque control.

Table 14.1
Bovine iliac bone test sample 1 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	2	1	3	4
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	+	-	-
30 Ncm	+	-	-	-
35 Ncm	-	-	-	-
40 Ncm	-	-	-	-
45 Ncm	-	-	-	-
50 Ncm	-	-	-	-
Removal Torque Ncm	30	25	45	40
Insertion Torque Ncm	25	15	35	30
Resistance gained Ncm	+5	+10	-5	+5
Resistance Gained %	+20	+66	-20	+33

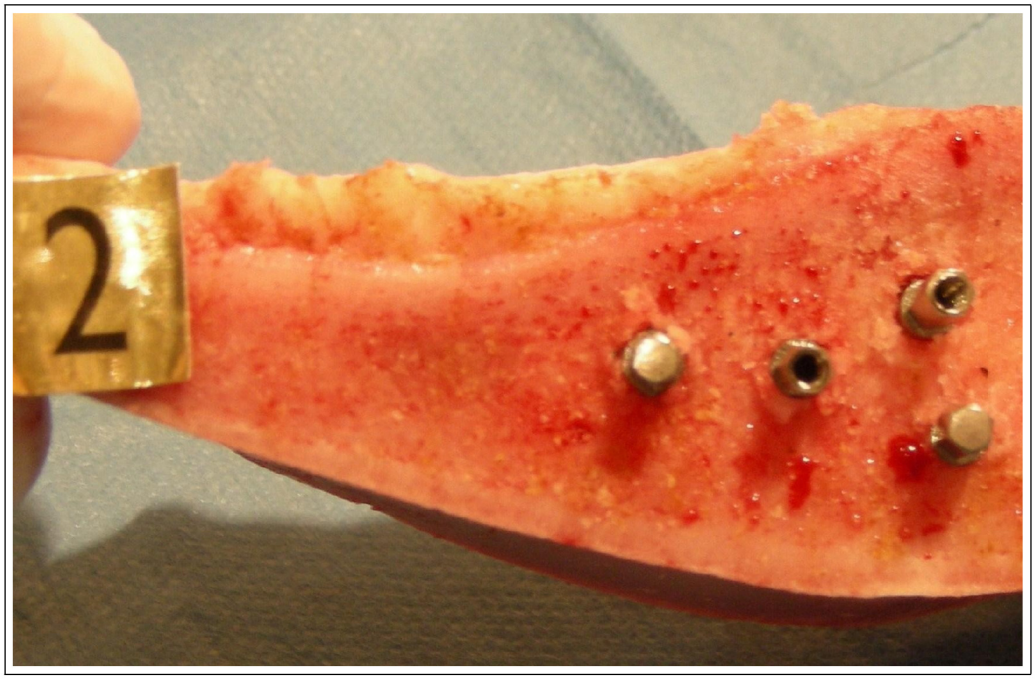

Figure 14.2 Bovine iliac bone sample 2, implants are placed by torque control.

Table 14.2
Bovine iliac bone test sample 1 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	1	2	4	3
5 Ncm	+	+	+	+
10 Ncm	+	+	+	-
15 Ncm	+	+	-	-
20 Ncm	+	-	-	-
25 Ncm	-	-	-	-
30 Ncm	-	-	-	-
35 Ncm	-	-	-	-
40 Ncm	-	-	-	-
45 Ncm	-	-	-	-
50 Ncm	-	-	-	-
Removal Torque Ncm	20	15	10	5
Insertion Torque Ncm	20	10	15	5
Resistance gained Ncm	0	+5	-5	0
Resistance Gained %	0	+50	-33	0

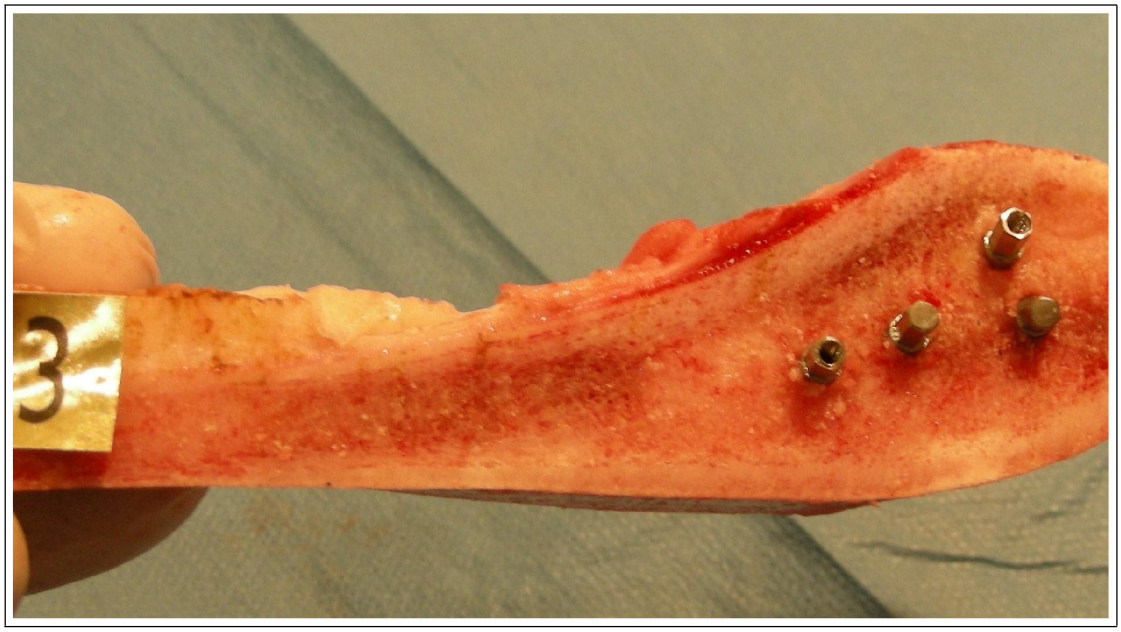

Figure 14.3 Bovine iliac bone sample 3, implants are placed by torque control.

Table 14.3
Bovine iliac bone test sample 3 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	2	1	4	3
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	-	-
25 Ncm	+	-	-	-
30 Ncm	-	-	-	-
35 Ncm	-	-	-	-
40 Ncm	-	-	-	-
45 Ncm	-	-	-	-
50 Ncm	-	-	-	-
Removal Torque Ncm	25	20	15	15
Insertion Torque Ncm	25	15	15	10
Resistance gained Ncm	0	+5	0	+5
Resistance Gained %	0	+33	0	+50

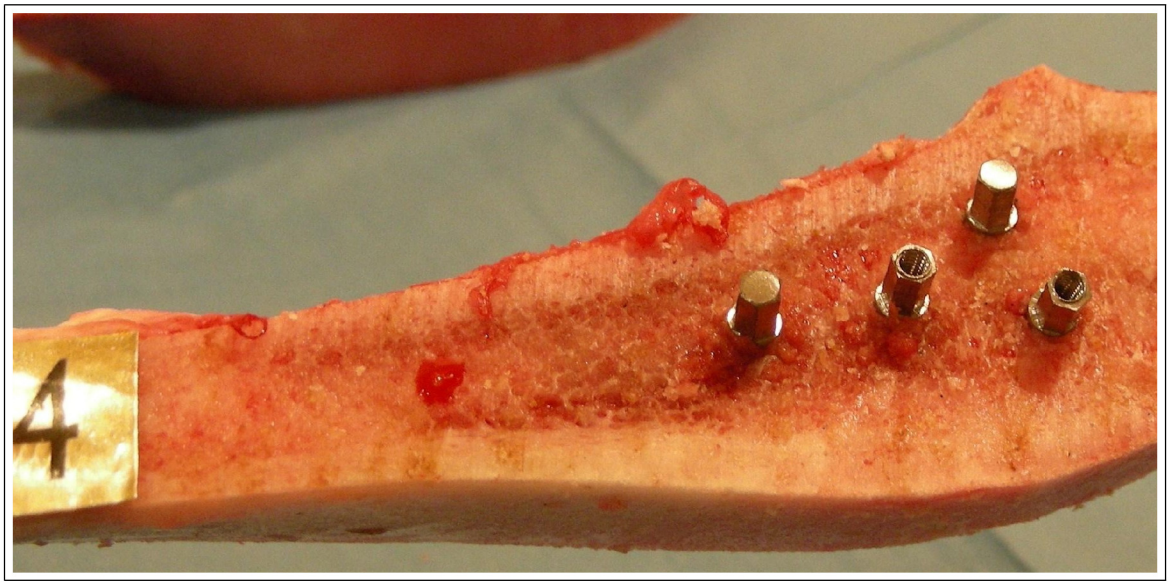

Figure 14.4 Bovine iliac bone sample 4, implants are placed by torque control.

Table 14.4
Bovine iliac bone test sample 4 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	1	2	3	4
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	+	+	+
30 Ncm	+	+	+	+
35 Ncm	+	-	+	-
40 Ncm	-	-	-	-
45 Ncm	-	-	-	-
50 Ncm	-	-	-	-
Removal Torque Ncm	35	30	35	30
Insertion Torque Ncm	35	20	30	20
Resistance gained Ncm	0	+10	+5	+10
Resistance Gained %	0	+50	+16	+50

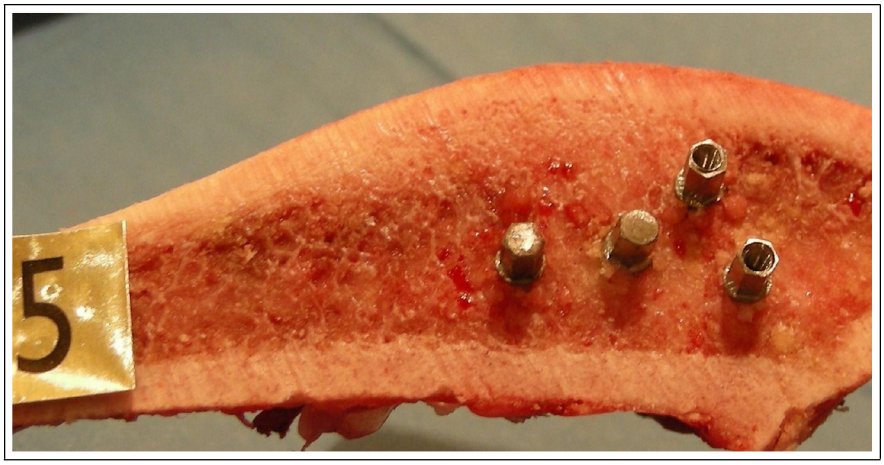

Figure 14.5 Bovine iliac bone sample 5, implants are placed by torque control.

Table 14.5
Bovine iliac bone test sample 5 findings.

	Control Implant	Designed Implant	Control Implant	Designed Implant
Position	1	3	2	4
5 Ncm	+	+	+	+
10 Ncm	+	+	+	+
15 Ncm	+	+	+	+
20 Ncm	+	+	+	+
25 Ncm	+	-	+	+
30 Ncm	+	-	+	+
35 Ncm	-	-	+	-
40 Ncm	-	-	-	-
45 Ncm	-	-	-	-
50 Ncm	-	-	-	-
Removal Torque Ncm	30	20	35	30
Insertion Torque Ncm	35	20	30	20
Resistance gained Ncm	-5	0	+5	+10
Resistance Gained %	-14	0	+14	+50

15. PRIMARY STABILITY TESTS IN POLYMER BLOCK

Implants produced were tested polymer blocks. All media was first prepared an implant hole with a 2mm drill. Then implants were inserted with torque controlled medical device WH Co. ImplaMED. All insertion torques were recorded. Then starting from 5 Ncm implants were applied removal torque to test the initial stability.

Each implant in all samples and in three different media was applied with digital torque control in sequences of 5 Ncm, 10Ncm, 15Ncm, 20 Ncm, 25Ncm, 30Nm, 35Ncm, 40Ncm, 45Ncm and 50Ncm.

All data collected is shown below on tables representing the specific media and sample. The sample withstands the removal torque is marked with (+) until the torque value where the implant started to move out from the polymer socket.

15.1 Polymer Block Tests

Two implant application sites are prepared with 2.0mm drill. The drilling speed is fixed with 800 rpm using WH Implamed device. Each site is cleaned for excess bone particles after the drilling is finished. Drilling is applied by the same surgeon, at the same condition and the same day. After holes are prepared in the polymer block, implants both the control implant and the developed design are inserted in their prepared sockets the simultaneously recording the insertion torque values.

Insertion torque values are recorded by digital torque meter of the WH Implamed Device, and the torque values are increased step by step until the implants reaches to its final position. Then the implants are applied removal torques again with gradually applied forces.The removal torque values are gradually increased from 5 Ncm to 50 Ncm with 5Ncm intervals.

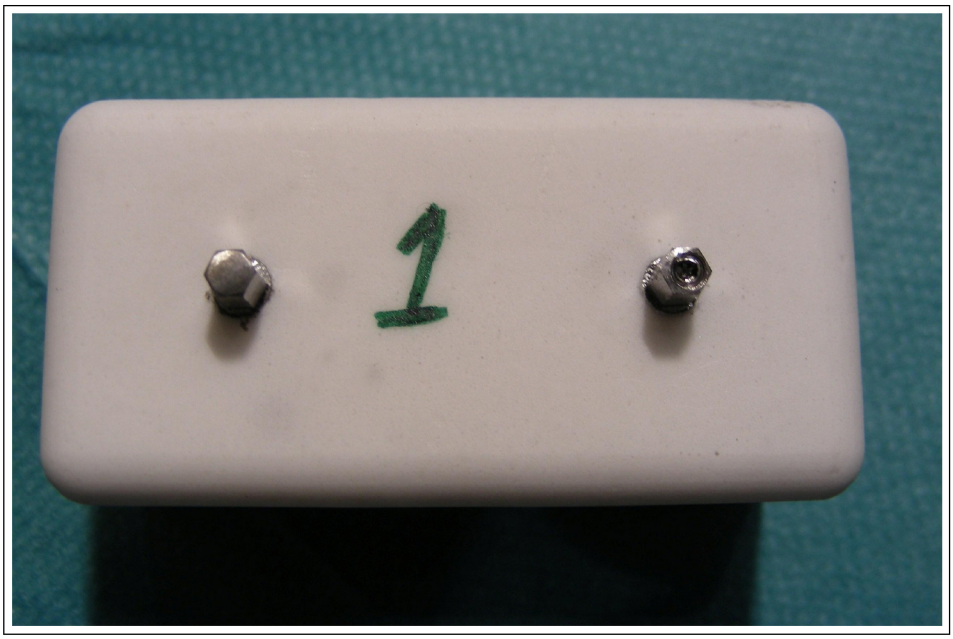

Figure 15.1 Polymer block sample 1, implants are placed by torque control.

Table 15.1
Polymer block test sample 1 findings.

	Control Implant	Designed Implant
Position	1	2
5 Ncm	+	+
10 Ncm	+	+
15 Ncm	+	+
20 Ncm	-	+
25 Ncm	-	+
30 Ncm	-	-
35 Ncm	-	-
40 Ncm	-	-
45 Ncm	-	-
50 Ncm	-	-
Removal Torque Ncm	15	25
Insertion Torque Ncm	20	15
Resistance gained Ncm	-5	+10
Resistance Gained %	-25	+66

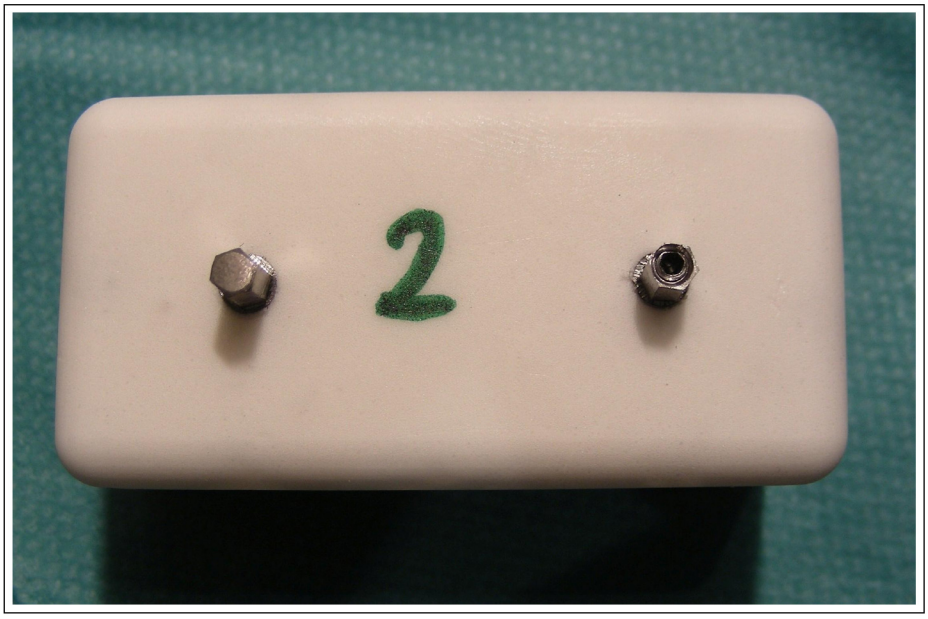

Figure 15.2 Polymer block sample 2, implants are placed by torque control.

Table 15.2
Polymer block test sample 2 findings.

	Control Implant	Designed Implant
Position	1	2
5 Ncm	+	+
10 Ncm	+	+
15 Ncm	-	+
20 Ncm	-	+
25 Ncm	-	-
30 Ncm	-	-
35 Ncm	-	-
40 Ncm	-	-
45 Ncm	-	-
50 Ncm	-	-
Removal Torque Ncm	10	20
Insertion Torque Ncm	15	15
Resistance gained Ncm	-5	+5
Resistance Gained %	-33	+33

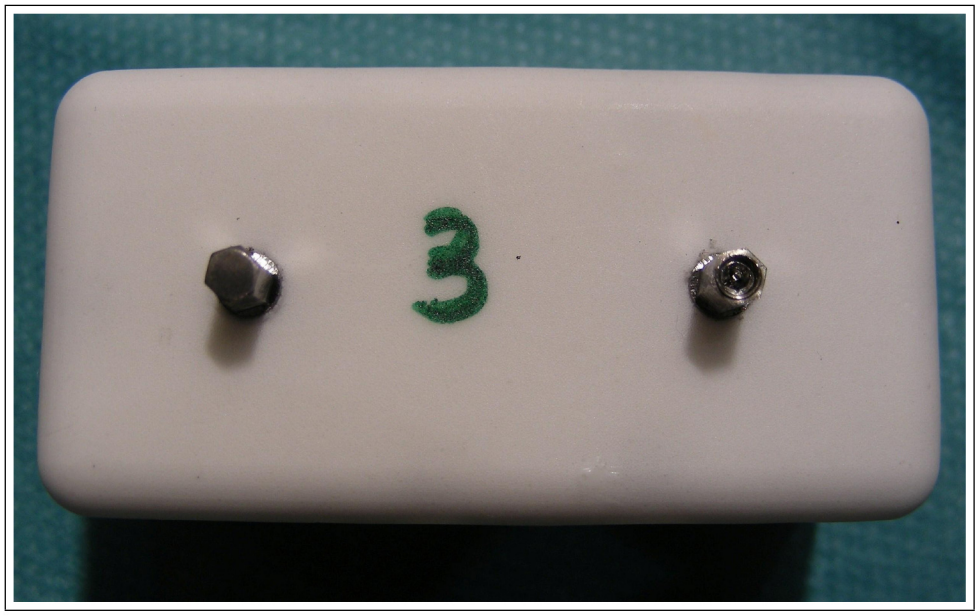

Figure 15.3 Polymer block sample 3, implants are placed by torque control.

Table 15.3
Polymer block test sample 3 findings.

	Control Implant	Designed Implant
Position	1	2
5 Ncm	+	+
10 Ncm	+	+
15 Ncm	+	+
20 Ncm	-	+
25 Ncm	-	+
30 Ncm	-	+
35 Ncm	-	-
40 Ncm	-	-
45 Ncm	-	-
50 Ncm	-	-
Removal Torque Ncm	15	30
Insertion Torque Ncm	20	20
Resistance gained Ncm	-5	+10
Resistance Gained %	-25	+50

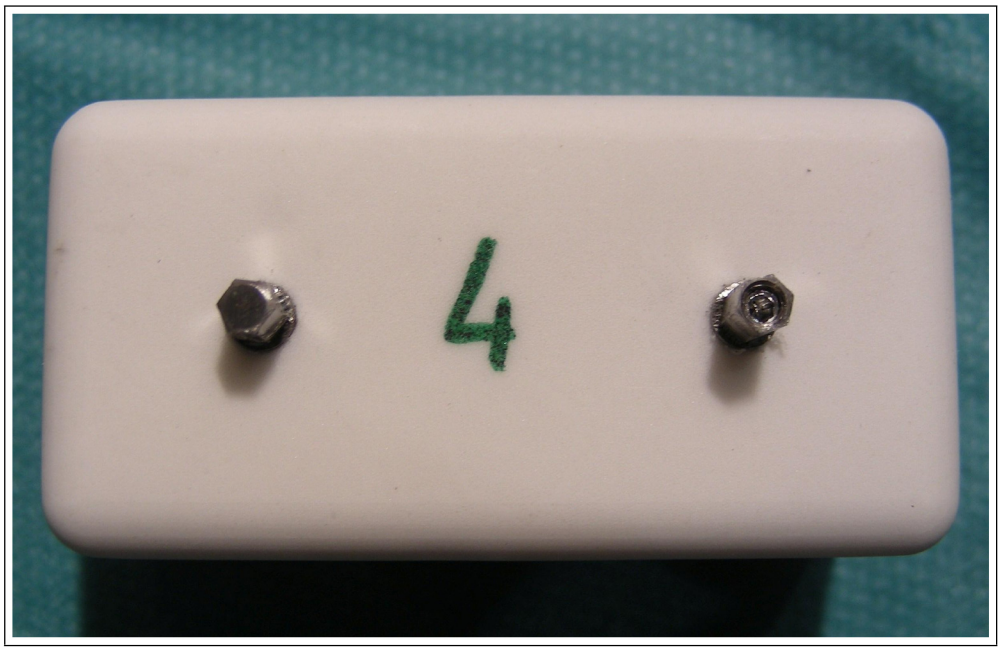

Figure 15.4 Polymer block sample 4, implants are placed by torque control.

Table 15.4
Polymer block test sample 4 findings.

	Control Implant	Designed Implant
Position	1	2
5 Ncm	+	+
10 Ncm	+	+
15 Ncm	+	+
20 Ncm	+	+
25 Ncm	-	+
30 Ncm	-	+
35 Ncm	-	-
40 Ncm	-	-
45 Ncm	-	-
50 Ncm	-	-
Removal Torque Ncm	20	30
Insertion Torque Ncm	25	20
Resistance gained Ncm	-5	+10
Resistance Gained %	-20	+50

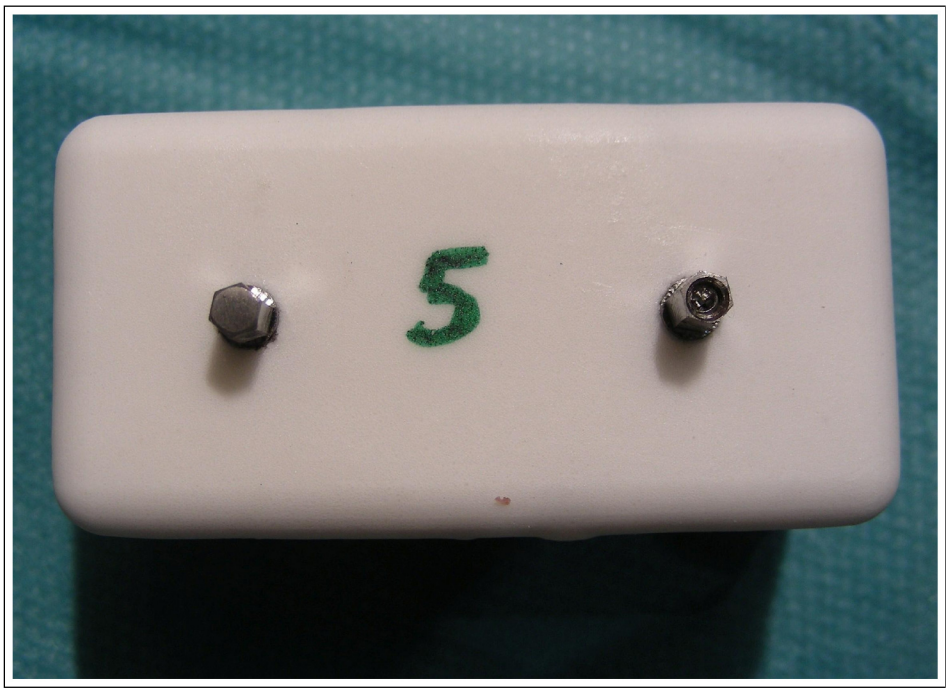

Figure 15.5 Polymer block sample 5, implants are placed by torque control.

Table 15.5
Polymer block test sample 5 findings.

	Control Implant	Designed Implant
Position	1	2
5 Ncm	+	+
10 Ncm	+	+
15 Ncm	+	+
20 Ncm	-	+
25 Ncm	-	-
30 Ncm	-	-
35 Ncm	-	-
40 Ncm	-	-
45 Ncm	-	-
50 Ncm	-	-
Removal Torque Ncm	15	20
Insertion Torque Ncm	20	15
Resistance gained Ncm	-5	+5
Resistance Gained %	-25	+33

16. DISCUSSION

Earlier studies reported different success rate percentages in different regions of the jawbone: 97, 99, 89, and 71 in 673 implants [93]; 100, 94, 92, and 74 in 137 implants; 94, 95, 88, and 87 in 2359 implants [94], in anterior mandible, posterior mandible, anterior maxilla and posterior maxilla, respectively.

In the Seong [94] study, cAD-composite apparent density was lower in the posterior maxilla than in any other region. For Elastic Modulus (EM) and Hardness (H), posterior bone was superior to anterior bone. These findings suggest that the amount of cortical bone and trabecular bone per unit volume available for implant is more important for implant success, than stiffness of the cortical bone or trabeculae in contact with an implant.

Elastic modulus represents the ratio of applied stress to change in shape of an elastic body. The higher the boneâs elastic modulus, the more stress is needed to induce a unit deformation. Elastic modulus measured by nano-indentation can be slightly different from elastic modulus measured by conventional three-point bending or compression testing. The nano-indentation technique allows measurement of the intrinsic material property of bone, which is independent of the specimen size, while the elastic properties measured by 3-point bending or compression testing are affected by the size and shape of the sample, which might reflect a mixture of structural and material properties.

Nano-indentation also has several limitations. Bushby [95] performed nano-indentation on 11 rectangular (5 - 2 - 25 mm) cortical specimens from horse metacarpal bone to see the effects of dehydration and polymethyl methacrylate embedding of the bone sample. They reported that the modulus increased from 11.2 to 12.5 to 19.5 GPa, for wet, dehydrated in ethanol, and embedded conditions, respectively. This might explain why nano-indentation elastic modulus is, in general, higher than elastic

modulus measured with mechanical tests. When the bone surface was rough due to poor polishing or when the specimen surface was slanted against the indenter, errors might have occurred, but those are not common or inherent problems. Bushby [95] found that indenting with higher loads increased the volume of material contributing to the elastic modulus measurement and reduced surface effects on the measured modulus value.

The Seong [94] study found that elastic modulus differed significantly between maxilla (14.9 GPa) and mandible (18.3 GPa). Also, posterior jawbone (17.5 GPa) had significantly higher elastic modulus than anterior jawbone (15.7 GPa), perhaps because of adaptation to higher chewing force in the posterior part of the jawbone. The elastic modulus of cortical bone (17.7 GPa) and trabecular bone (15.4 GPa) (averaging together maxillas and mandibles) also differed significantly.

This result agrees with previous findings that cortical bone elastic modulus is higher than trabecular bone elastic modulus. Wolffâs assumption that compact bone is simply more dense cancellous bone, so cortical and trabecular bones should have approximately the same elastic properties might not be accurate, based on the current and above mentioned studies.

Few previous studies have measured apparent density of jawbones. Oâmahony [96] reported a mean hydrated apparent density of 0.55 g/cm3 from an edentulous mandibular trabecular bone from a 74-year-old female. Misch [97] presented a mean apparent density with bone marrow in situ of 1.18 g/cm3 from 9 human mandibular trabecular bones. Schwartzdabney and Dechow [98] reported a density of 1.85â2.0 g/cm3 from 10 dentate human mandibular cortical bones. The Seong [94] studyâs composite (cortical plus trabecular) apparent density, averaging 1.18 g/ cm3 in the mandible and 0.67 g/cm3 in the maxilla, is well situated among these previous estimates. Elastic modulus and hardness were calculated from the identical indentation on the same bone sample, so their high association was expected. The composite apparent density indicates the amount (quantity) of cortical and trabecular bone per unit volume, while lamella level elastic modulus measured by nano-indentation represents

the intrinsic mechanical properties of the bone tissue, so they can be independent each other and their moderate correlation can be explained.

The relation between elastic modulus and apparent density has been extensively studied. Trabecular bone elastic modulus from compression tests was found to be proportional to the cube of the apparent density and strength proportional to the square of the apparent density. Both Youngâs modulus and strength were found to be proportional to the square of apparent density [99]. Mandibular trabecular bone showed a linear relationship between density and elastic modulus and a cubic relationship between density and strength. In that study, elastic modulus and composite apparent density showed reasonable agreement with a linear relationship ($r = 0.52$), and similar agreement with a cubic relationship, between elastic modulus and composite apparent density 3 ($r = 0.51$). Since the present study used the nano-indentation method to measure elastic modulus, not the compression test, and composite apparent density was measured from specimens containing both cortical and trabecular bone, a different relationship might be expected.

Age-related bone loss has been associated with a decrease in bone density and mineral content in cortical and trabecular bone. Atkinson and Woodhead [100] measured the bone density of mandibular cortical bone from 43 subjects (aged 44â84 years) and found that cortical bone became less dense and had more porosity with increasing age, while tooth loss did not induce a significant density change but rather a reduction of alveolar bone crest height.

Owing to the edentulism and high average age (83.3 years) of the subjects in the current study, it is reasonable to expect the lower level of composite apparent density measurements found. One finding in the current study that might be related to aging is that fatty degeneration was often found in the posterior maxillary alveolar ridge, with its cortical bone surface relatively hard. Schnitzler and Mesquita [101] measured fatty degeneration on iliac crest bones in 98 subjects. They found that the extent of fatty degeneration increased with age and concluded that fatty degeneration, which may have occupied space vacated by bone loss, was an aging phenomenon.

Wang and Puram [102] defined toughness as a quantitative measure of bone quality in terms of its susceptibility to fracture. A few earlier studies [103] showed that fracture toughness of cortical bone depends on bone density. Wang [104] studied the relationship of fracture toughness to other physical bone properties in femurs from 18 baboons. They found that fracture toughness of bone decreased as age increased and only micro-hardness changed significantly (increased) while other parameters, such as bone mineral density, elastic modulus, yield strength and porosity did not. The clinically observed low implant success rates in the posterior maxilla might be due to the fact that the posterior maxilla has the lowest composite apparent density and relatively high hardness, which might indicate low fracture toughness. This could lead to relatively easy fractures of bone during surgical drilling and implant insertion, and resultant low implant stability and success. The current study did not provide quantitative evidence of the extent of fatty degeneration or fracture toughness, but it suggests that aging and its effects on fatty degeneration and fracture toughness, in at least the posterior maxilla, should be further studied, and that implant surgery on the posterior maxilla in elderly patients should be planned cautiously.

The suggested implant design aims to increase the primary stability of the material just after application in the prepared bone site. The production of the design was made under the materials and CNC milling machines commercially used by medical device production companies. Through the market analysis and informations gathered from the industry, there are specially fabricated CNC milling machines that are working with high precision to produce dental implants or angled pieces for dental implants. But these kinds of CNC machines are specially owned and used by companies who are programming the CNC machines for weeks and they do not accept to break their production cycle to produce test materials for research purposes. One of the main difficulties during preparation of the samples to be tested was to find production facilities to produce the developed implant design.

In previous chapter we have given in detail the results of the tests made in all different media with each having five samples. The results when gathered together gives promising results. When only the bovine spinal bone samples are evaluated inside the

group there is an average of 38.6 percent gain of retention for removal torques with the developed implant design when the apical arms are open, whereas in the control group of implant with non-opening apical standard shape the gain in retention for removal torques is 0.4 percent. The second media was chosen as bovine iliac bone, and when the samples are evaluated the results in this group shows an average of 38.2 percent gain of retention for removal torques with the developed implant design when the apical arms are open. The results from the polymer group are more promising for the same type of implant where we have found 46.4 percent of gain to retention for removal torques with the developed implant design.

The designed implants were tested in different medias to compare the behavior of the proposed implant design in different types of bones. The results of this research are promising, and thats worthwile to study to develop this design in a more precise production facility and researches to be carried in vivo to be clinically prove the efficacy of the developed model.

Table 16.1
Results of the digital recordings from the developed implant design.

	Insertion Torque(Ncm)	Removal Torque(Ncm)	Gain(Ncm)	Gain %
Bovine spinal bone sample 1 (a)	30	40	10	33
Bovine spinal bone sample 1 (b)	30	40	10	33
Bovine spinal bone sample 2 (a)	25	35	10	40
Bovine spinal bone sample 2 (b)	30	40	10	33
Bovine spinal bone sample 3 (a)	30	40	10	33
Bovine spinal bone sample 3 (b)	35	45	10	28
Bovine spinal bone sample 4 (a)	30	40	10	33
Bovine spinal bone sample 4 (b)	25	40	15	60
Bovine spinal bone sample 5 (a)	25	40	15	60
Bovine spinal bone sample 5 (b)	30	40	10	33
Bovine iliac bone sample 1 (a)	15	25	10	66
Bovine iliac bone sample 1 (b)	15	20	5	33
Bovine iliac bone sample 2 (a)	10	15	5	50
Bovine iliac bone sample 2 (b)	5	5	0	0
Bovine iliac bone sample 3 (a)	15	20	5	33
Bovine iliac bone sample 3 (b)	10	15	5	50
Bovine iliac bone sample 4 (a)	20	30	10	50
Bovine iliac bone sample 4 (b)	20	30	10	50
Bovine iliac bone sample 5 (a)	20	20	0	0
Bovine iliac bone sample 5 (b)	20	30	10	50
Polymer block sample 1	15	25	10	66
Polymer block sample 2	15	20	5	33
Polymer block sample 3	20	30	10	50
Polymer block sample 4	20	30	10	50
Polymer block sample 5	15	20	5	33

Table 16.2
Results of the digital recordings from the control implant design.

	Insertion Torque(Ncm)	Removal Torque(Ncm)	Gain(Ncm)	Gain %
Bovine spinal bone sample 1 (a)	50	50	0	0
Bovine spinal bone sample 1 (b)	50	50	0	0
Bovine spinal bone sample 2 (a)	45	45	0	0
Bovine spinal bone sample 2 (b)	45	45	0	0
Bovine spinal bone sample 3 (a)	45	45	0	0
Bovine spinal bone sample 3 (b)	45	45	0	0
Bovine spinal bone sample 4 (a)	40	45	5	12
Bovine spinal bone sample 4 (b)	40	45	5	12
Bovine spinal bone sample 5 (a)	40	35	-5	-12
Bovine spinal bone sample 5 (b)	35	45	10	28
Bovine iliac bone sample 1 (a)	25	30	5	20
Bovine iliac bone sample 1 (b)	25	20	-5	-20
Bovine iliac bone sample 2 (a)	20	20	0	0
Bovine iliac bone sample 2 (b)	15	10	-5	-33
Bovine iliac bone sample 3 (a)	25	25	0	0
Bovine iliac bone sample 3 (b)	15	15	0	0
Bovine iliac bone sample 4 (a)	35	35	0	0
Bovine iliac bone sample 4 (b)	30	35	5	16
Bovine iliac bone sample 5 (a)	35	30	-5	-14
Bovine iliac bone sample 5 (b)	30	35	5	14
Polymer block sample 1	20	15	-5	-25
Polymer block sample 2	15	10	-5	-33
Polymer block sample 3	20	15	-5	-25
Polymer block sample 4	25	20	-5	-20
Polymer block sample 5	20	15	-5	-25

17. CONCLUSION

In the last decade, dozens of implant systems have been marketed, some of which have undergone longitudinal trials with the results published in refereed journals, while others have been subjected to more limited testing. The development of new systems has been accelerated in last years and implants became a treatment modality in modern dentistry.

Eventhough there are many types of implants available in the medical applications, some developments are required regarding the need of improving the success of surgical interventions. The research implemented to use titanium which is well documented to provide all necessary mechanical and bio-compatibility requirements. This research focused to propose a new implant design, not conical or cylindrical designs which are actual designs applied, but a new design which will resemble the tooth anatomy as with roots, thus increase the primary stability and open new indications to implant applications.

The clinically observed low implant success rates in the posterior maxilla might be due to the fact that the posterior maxilla has the lowest composite apparent density and relatively high H, which might indicate low fracture toughness. This could lead to relatively easy fractures of bone during surgical drilling and implant insertion, and resultant low implant stability and success. The suggested implant design aims to increase the primary stability by the apical arms which extend inside the bone after inserted in the surgically prepared hole. When the apical arms of the developed design are opened with the activating screw, the shape of the conical implant transforms into a three rooted molar teeth. The research was originally projected to develop a design and prototype the proposed design. Furthermore stability tests in means of anti-rotational resistance were applied to the samples of the developed implant design.

The results of this study indicates promising future perspectives and possible higher success rates, especially in poor bone quality situations. In different bone structures and polymer material, designed implant with apical arms has shown relatively average gain of 38.6 percent in bovine spinal bone samples, 38.2 percent in bovine iliac bone samples and in polymer block 46.4 percent gain in retention to removal torques; thus positive future directions to make further researches on the material production and also testings of such a new dental implant design including in vivo clinical controlled studies will be beneficial for better understanding the behavior of the developed implant design under different conditions.

REFERENCES

1. Arnaudow, M., and U. Garlischs, "Endo-osseous implantation method of artificial tooth roots," *Zahnartl Welt*, Vol. 10, no. 81, pp. 313–318, 1972.

2. Perry, S., *Mehrere Falle von Implantationen*, Korr Zahnheilk, 2nd ed., 1988.

3. Branemark, P.-L., and R. Adell, "Intra-osseous anchorage of dental prostheses, experimental studies," *Scand J Plast Reconstr Surg*, Vol. 3, pp. 81–90, 1969.

4. Branemark, P.-L., and R. Adell, "0sseointegrated implants in the treatment of the edentulous jaw. experience from a 10 year period," *Scand J Plast Reconstr Surg*, Vol. 11, pp. 16–20, 1977.

5. Branemark, P.-L., R. Adell, T. Albrektsson, U. Lekholm, J. Lindstrom, and B. Rockier, "An experimental and clinical study of osseointegrated implants penetrating the nasal cavity and maxillary sinuses," *Int J Oral MaxillofacSurg*, Vol. 13, pp. 497–500, 1984.

6. Branemark, P.-L., G. Zarb, and T. Albrektsson, *Tissue Integrated Prostheses. Osseointegration in Clinical Dentistry*, Quintessence Publishing, 1985.

7. Adell, R., U. Lekholm, P.-L. Branemark, and B. Rockier, "15-year study of osseointegrated implants in the treatment of the edentulous jaw," *Int J Oral Surg*, Vol. 10, pp. 387–416, 1981.

8. Smithloff, M., and M.-E. Fritz, "The use of blade implants in a selected population of partially edentulous adults; a five-year report," *Int J Oral Surg*, Vol. 47, pp. 19–24, 1976.

9. Cranin, A., M. Rabkin, and L. Garfinkel, "A statistical evaluation of 952 endosteal implants in humans," *J American Dent Assoc*, Vol. 94, pp. 315–320, 1977.

10. Pohler, O., "Swiss screw: concept and experimental work," *Oral Implantol*, Vol. 12, pp. 338–349, 1986.

11. Ledermann, P., "Sechs jahrige klinische erfahrungen mit dem titan plasma beschichteten iti-schrauben implantat in der regio," *Schwelz Mschr Zahnhellk*, Vol. 93, pp. 1070–1089, 1983.

12. Cranin, N., M. Klein, and A. Simons, *Atlas of oral implantology*, Thieme, 1993.

13. Lekholm, U., and G. Zarb, *Patient selection and preperation/tissue integrated prosthesis*, Quintessenz, 1985.

14. Misch, C., "Int journal of oral implantology," *Schwelz Mschr Zahnhellk*, Vol. 6, pp. 23–28, 1990.

15. Truhlar, R., H. Morris, S. Ochi, and S. Winkler, "Second stage failures related to bone quality in patients receiving dental implants," *Implant Dent*, Vol. 3, pp. 252–255, 1994.

16. Truhlar, R., S. Farish, L. Scheitler, and H. Morris, "Bone quality and implant design related outcomes through stage ii surgical uncovering," *J Oral Maxillofac Surg*, Vol. 55, pp. 46–54, 1997.

17. Atwood, D., "Bone loss of edentoulous alveolar ridges," *J Oral Maxillofac Surg*, Vol. 50, pp. 10–14, 1979.

18. Fallschussel, T., *Zahnartzliche Implantologie*, Quintessenz, 1986.

19. Misch, C., and K. Judy, "Classification of partially edentoulous arches for implant dentistry," *Int Joun Oral Implantology*, Vol. 4, pp. 7–10, 1987.

20. Albrektsson, T., P.-L. Branemark, and H.-A. Hansson, "Classification of partially edentoulous arches for implant dentistry," *Ada Orthop Scand*, Vol. 52, pp. 155–170, 1981.

21. Zarb, G., and T. Albrektsson, "Osseointegration: a requiem for the periodontal ligament," *Int J Periodont Rest Dent*, Vol. 2, pp. 88–91, 1991.

22. Branenark, P.-L., *A biomechanical study of osseo-integration. In-vivo measurements in rat, rabbit, dog and man.* PhD thesis, Goteborg University, Goteborg, Sweden, 1996.

23. Meyer, A., R. Baier, and J. Natiella, "Investigation of tissue/implant interactions during the first two hours of implantation," *Journal of Oral Implantology*, Vol. 14, pp. 363–379, 1988.

24. Pearson, B., R. Klebe, B. Boyan, and D. Moskowicz, "Comments on the clinical application of fibronectin in dentistry," *Journal of Dental Research*, Vol. 67, pp. 515–517, 1988.

25. Lang, N., D. Karring, and J. Lindhe, *3rd European Workshop on Periodontology*, Quintessenz, 1999.

26. Brunette, D.-M., "Spreading and orientation of epithelial cells on grooved substrata," *Experimental Cell Research*, Vol. 167, pp. 203–217, 1993.

27. Windeler, A.-S., L.-F. Bonewald, A.-G. Khare, and B.-D. Boyan, "The influence of sputtered bone substitutes on cell growth and phenotypic expression," *The Bone-Biomaterial interface*, Vol. 13, pp. 205–213, 1991.

28. Martin, J.-Y., Z. Schwartz, and T. Hummert, "Effect of titanium surface roughness on proliferation, differentiation, and protein synthesis of human osteoblast-like cells," *The Bone-Biomaterial interface*, Vol. 29, pp. 389–401, 2004.

29. Buser, D., R. Schenk, S. Steinemann, and S. Fiorellini, "Influence of surface characteristics on bone integration of titanium implants," *Journal of Biomedical Materials Research*, Vol. 25, pp. 889–902, 2001.

30. Gotfredsen, K., A. Wennerberg, C. Johansson, and S. Skovgaard, "Anchorage of ti02-blasted,ha-coated, and machined implants," *Journal of Biomedical Materials Research*, Vol. 29, pp. 1223–1231, 2004.

31. Albrektsson, T., and G. Zarb, "Current interpretations of the osseointegrated response: clinical significance," *Int J Prosthodont*, Vol. 6, pp. 95–105, 1993.

32. Albrektsson, T., and F. Isidor, *1st European Workshop on Periodontology*, Quintessenz, 1994.

33. Steenberghe, D., "Outcomes and their measurement in clinical trials of endosseous oral implants," *Annals of periodontology*, Vol. 2, pp. 291–298, 1997.

34. Lekholm, U., D. Steenberghe, and I. Herrmann, "Osseointegrated implants in the treatment of partially edentulous jaws," *Int J Oral Maxillofac Implants*, Vol. 9, pp. 627–635, 1994.

35. Esposito, M., P. Thomsen, J. Molne, and C. Gretzer, "Iminunohistochemistry of soft tissues surrounding late failures of branemark implants," *Clin Oral Implants Res*, Vol. 8, pp. 352–366, 1997.

36. Berglundh, T., and J. Lindhe, "The topography of the vascular systems in the periodontal ligament and peri-implant tissues," *Journal of Clinical Perio*, Vol. 21, pp. 189–193, 1994.

37. Lang, N., A. Mombelli, M. Tonetti, U. Bragger, and C. Hammerle, "Clinical trials on therapies for peri-implant infections," *Ann Periodontol*, Vol. 2, pp. 343–356, 1997.

38. Listgarten, M., "Clinical trials of endosseous implants: issues in analysis and interpretation," *Ann Periodontol*, Vol. 2, pp. 299–313, 1997.

39. Egelberg, J., "The blood vessels of the dento gingival junction," *Journal of Periodontal Research*, Vol. 1, pp. 163–179, 1966.

40. Lang, N., A. Wetzel, H. Stich, and R. Caffesse, "Histologic probe penetration in healthy and inflamed peri-implant tissue," *Clin Oral Implants Res*, Vol. 5, pp. 191–201, 1994.

41. Salcetti, J., J. Moriarty, L. Cooper, and F. Smith, "The clinical, microbial, and host response characteristics of the failing implant," *Int J Oral Maxillofac Implants*, Vol. 12, pp. 32–42, 1997.

42. Esposito, M., J. Hirsch, U. Lekholm, and P. Thomsen, "Biological factors contributing to failures of osseointegrated oral implants," *Eur J Oral Sci*, Vol. 1, pp. 527–551, 1998.

43. Ericsson, I., and J. Lindhe, "Probing depth at implants and teeth," *Joun Clinical Periodontology*, Vol. 20, pp. 623–627, 1993.

44. Buser, D., H. Weber, and N. Lang, "Tissue integration of non-submerged implants," *Clinical Oral Impl; Research*, Vol. 1, pp. 33–40, 1990.

45. Buser, D., H. Weber, and U. Bragger, "Tissue integration of one stage iti implants," *Inter Jour of Oral and Maxf Implant*, Vol. 6, pp. 405–412, 1992.

46. Wetzel, A., H. Stich, and R. Caffesse, "Histologic probe penetration in healthy and inflamed peri-implant tissues," *Clin Oral Implants Res*, Vol. 5, no. 4, pp. 191–201, 1994.

47. Misch, C., *Contemporary Implant Dentistry*, Mosby, 1983.

48. Sullivan, D., R. Sherwood, and T. Collins, "The reverse-torque test: A clinical report," *Int Jour of Oral Maxillofac Implants*, Vol. 2, pp. 179–185, 1996.

49. Grondahl, K., and U. Lekholm, "The predictive value of radio-graphic diagnosis of implant instability," *Int Jour of Oral Maxillofac Implants*, Vol. 12, pp. 59–64, 1997.

50. Goaz, P., and S. White, *Oral Radiology, principles and interpretrations*, Mosby, 1982.

51. Albrektsson, T., G. Zarb, P. Wortington, and A. Eriksson, "The long-term efficacy of currently used dental implants," *Int Jour of Oral Maxillofac Implants*, Vol. 1, pp. 11–25, 1997.

52. Smith, D., and G. Zarb, "Criteria for success of osseointegrated endosseous implants," *J Prosthet Dent*, Vol. 62, pp. 567–572, 1989.

53. Haas, R., W. Haimbock, G. Mailath, and G. Watzek, "The relationship of smoking on peri-implant tissue: a retrospective study," *J Prosthet Dent*, Vol. 76, pp. 592–596, 1996.

54. Singh, G., R. O'neal, W. Brennan, S. Strong, J. Horner, and T. V. Dyke, "Surgical treatment of induced peri-implantitis in the micro pig: clinical and histological analysis," *J Periodontol*, Vol. 64, no. 10, pp. 984–989, 1993.

55. Tonetti, M., "Surgical treatment of induced peri-implantitis in the micro pig: clinical and histological analysis," *Periodontol 2000*, Vol. 17, pp. 55–62, 1998.

56. Ichikawa, T., K. Hirota, H. Kanitani, Y. Miyake, and N. Matsumoto, "In vitro adherence of stretococcus constellatus to dense ha and titanium," *Journal of Oral Rehabilitation*, Vol. 25, pp. 125–127, 1998.

57. Hirsch, J., U. Lekholm, and P. Thomsen, "Biological factors contributing to failures of osseointegrated oral implants," *Eur J Oral Sci*, Vol. 3, pp. 721–764, 1998.

58. Spiekermann, H., *Color Atlas of Dental Medicine;Implantology*, Thieme, 1995.

59. Uhthoff, H., and J.-P. Germain, "The reversal of tissue differentiation around screws," *Clin Orthop*, Vol. 123, pp. 248–252, 1977.

60. Matsuo, M., T. Nakamura, Y. Kishi, and K. Takahashi, "Micro vascular changes after placement of titanium implants," *J Periodontology*, Vol. 70, pp. 1330–1338, 1999.

61. Quirynen, M., I. Naert, and D. Steenberghe, "Fixture design and overload influence marginal bone loss and fixture success in the branemark system," *Clin Oral Implants Res*, Vol. 3, pp. 104–111, 1992.

62. Isidor, F., "Loss of osseointegration caused by occlusal load of oral implants. a clinical and radiographic study in monkeys," *Clin Oral Implants Res*, Vol. 7, pp. 143–152, 1996.

63. Sanz, M., J. Alandez, P. Lazaro, M. Quirynen, and D. Steenberghe, "Histo-pathologic characteristics of peri-implant soft tissues in branemark implants with 2 distinct clinical and radiological patterns," *Clin Oral Implants Res*, Vol. 2, pp. 128–134, 1991.

64. Frost, H., "Wolff's law and bone's structural adaptations to mechanical usage: an overview for clinicians.," *Angle Orthodontist*, Vol. 64, pp. 175–188, 1994.

65. Rangert, B., T. Jemt, and L. Jorneus, "Forces and moments on branemark implants," *Int Jour of Oral and Maxfac Implants*, Vol. 4, pp. 241–247, 1989.

66. Zarb, C., and A. Schmitt, "The longitudinal clinical effectiveness of' osseointegrated dental implants," *J Prosthetic Dent*, Vol. 64, pp. 185–194, 1990.

67. Hansson, B., R. Adell, U. Breine, and J. Lindstrom, *Osseointegrated implants in the treatment of the edentulous jaw*, Almqvist Wiksell, 1977.

68. Cordioli, G., and Z. Majzoub, "Heat generation during implant site preparation: an in vitro study," *Int J Oral Maxillofac Implants*, Vol. 12, pp. 186–193, 1997.

69. Tolman, D., and R. Lanev, "Tissue-integrated prosthesis complications," *Int J Oral Maxillofac Implants*, Vol. 7, pp. 477–484, 1992.

70. Rangert, B., P. Krogh, and B. Langer, "Bending overload and implant fracture," *Int J Oral Maxillofac Implants*, Vol. 10, pp. 326–334, 1995.

71. Glantz, P., and K. Nilner, "Biomechanical aspects of prosthetic implant-borne reconstructions," *Periodontology 2000*, Vol. 17, pp. 119–124, 1998.

72. Lungren, D., and L. Laurell, "Biomechanical aspects of fixed bridge work," *Periodontology 2000*, Vol. 14, pp. 23–40, 1994.

73. Hammerle, C., D. Wagner, U. Bragger, A. Lussi, and N. Lang, "Threshold of tactile sensivity percieved with dental endossous implants and natural teeth," *Clin Oral Implant Research*, Vol. 6, pp. 83–90, 1995.

74. Falk, H., "On occlusal forces in dentitions with implant supported fixed cantilever bridges," *Swedish Dental Journal*, Vol. 69, pp. 1–40, 1990.

75. Naert, I., M. Quirynen, and D. Steenberghe, "A study of 589 consequitive implants supporting complete fixed prosthesis," *Journal of Prosthetic Dentistry*, Vol. 68, pp. 949–956, 1992.

76. Laurell, L., and D. Lungren, "Periodontal ligament areas and occlusal forces in dentitions restores with cross arch bilateral and abutment bridges," *Jour of Clinical Periodontology*, Vol. 12, pp. 850–860, 1985.

77. Lindh, T., J. Gunne, and S. Danielsson, "Rigid connections between natural teeth and implants," *Int Journ Of Oral and Maxf Implants*, Vol. 12, pp. 674–678, 1997.

78. Richter, E., "In vivo vertical forces on implants," *Int Journ Of Oral and Maxf Implants*, Vol. 10, pp. 99–108, 1995.

79. Misch, C., and Y. Ismail, "Finite element stress analysis of tooth to implant fixed partial denture designs," *Journal of Prosthodontics*, Vol. 2, pp. 83–87, 1993.

80. Olsson, M., J. Gunne, P. Astrand, and K. Borg, "Bridges supported by free standing implants versus bridges supported by tooth and implant," *Clin Oral Implant Research*, Vol. 6, pp. 114–121, 1995.

81. Gunne, J., P. Galntz, and A. Svensson, "Vertical load distribution on a teeth unit prosthesis supported by natural tooth and a single branemark implant," *Clin Oral Implant Research*, Vol. 6, pp. 40–46, 1995.

82. Langer, B., and B. Rangert, *Biomechanical interactions between implants and teeth*, Nevins Mellonig, 1988.

83. Rieger, F., K. Fareed, R. Adams, and W. Tanquist, "Bone stress distribution for three endosseus implants," *Journal of Prosthetic Dentistry*, Vol. 61, pp. 223–228, 1989.

84. Frenh, A., C. Bowles, P. Parham, and C. Cobb, "Comparison of peri-implant stresses transmitted by four commercially available osseointegrated implants," *Int J. of Periodontics Restorative Dentistry*, Vol. 9, pp. 221–230, 1989.

85. Steenberghe, D., U. Lekholm, and C. Bolender, "Applicability of osseointegrated oral implants in the rehabilitation of partial edentulism," *Int Jur. Of Oral and Max. Implants*, Vol. 5, pp. 272–281, 1990.

86. Bass, S., and R. Triplett, "The effects of preoperative resorption and jaw anatomy in implant success," *Clin Oral Implant Research*, Vol. 2, pp. 193–198, 1991.

87. Sennerby, L., L. Thomsen, and L. Ericson, "A morphometric and biomechanic comparison of titanium implants," *Int Journ. Of Oral and Max Implants*, Vol. 7, pp. 62–71, 1992.

88. Tummers, M., and I. Thesleff, "Root or crown: A developmental choice orchestrated by the differential regulation of the epithelial stem cell," *Development*, Vol. 6, pp. 1049–1057, 2003.

89. Hunt, A., "A description of the molar teeth and investing tissues of normal guinea pigs," *J. Dent. Res*, Vol. 38, no. 2, pp. 216–231, 1959.

90. Http://en.wikipedia.org/wiki/tooth.

91. Http://www.forensicdentistryonline.org/morphology.htm.

92. Dictionary, E. http://www.etymonline.com.

93. Drago, C., "Rates of osseointegration of dental implants with regard to anatomical location," *J Prosthod*, Vol. 1, pp. 29–31, 1992.

94. Seong, W., U. Kim, J. Swift, J. Heo, and S. Hodges, "Elastic properties and apparent density of human edentulous maxilla and mandible," *Int. J. Oral Maxillofac. Sur*, Vol. 38, pp. 1088–1093, 2009.

95. Bushby, A., V. Ferguson, and A. Boyde, "Nano-indentation of bone: Comparison of specimens tested in liquid and embedded in polyethylmethacrylate," *J Mater Res*, Vol. 19, pp. 249–259, 2004.

96. Mahony, A., J. Williams, J. Katz, and P. Spencer, "Anisotropic elastic properties of cancellous bone from a human edentulous mandible," *Clin Oral Impl Res*, Vol. 11, pp. 415–421, 2000.

97. Misch, C., Q. Zhimin, and M. Bidez, "Mechanical properties of trabecular bone in the human mandible: implications for dental implant treatment planning and surgical placement," *J Oral Maxillofac Surg*, Vol. 57, pp. 700–706, 1999.

98. Dabney, C., and P. Dechow, "Variations in cortical material properties throughout the human dentate mandible," *Am J Phys Anthropol*, Vol. 120, pp. 252–277, 2003.

99. Rice, J., S. Cowin, and J. Bowman, "On the dependence of the elasticity and strength of cancellous bone on apparent density," *J Biomechanics*, Vol. 21, pp. 155–168, 1988.

100. Atkinson, P., and C. Woodhead, "Changes in human mandibular structure with age," *Archs Oral Biol*, Vol. 13, pp. 1453–1463, 1968.

101. Schnitzler, C., and J. Mesquita, "Bone marrow composition and bone microarchitecture and turnover in blacks and whites," *J Bone Miner Res*, Vol. 13, pp. 1300–1307, 1998.

102. Wang, D., and S. Puram, "The toughness of cortical bone and its relationship with age," *Ann Biomed Eng*, Vol. 32, pp. 123–135, 2004.

103. Wright, T., and W. Hayes, "Fracture mechanics parameters for compact bone â effects of density and specimen thickness," *J Biomech*, Vol. 7, pp. 419–430, 1977.

104. Wang, D., N. Masilamani, J. Mabrey, M. Alder, and C. Agrawal, "Changes in the fracture toughness of bone may not be reflected in its mineral density, porosity,and tensile properties," *J Bone*, Vol. 23, pp. 67–72, 1998.