MACROSCOPIC AND MICROSCOPIC DENTAL IMPLANT DESIGN: A REVIEW OF THE LITERATURE

By

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“For my mother, father, love of my life, family and friends who have guided me and molded me every step of the way.”

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BIC	Bone-to-Implant contact
FEA	Finite element analysis
HA	Hydroxyapatite
Ti	Titanium
TPS	Titanium plasma-sprayed

Abstract of Thesis Presented to the Graduate School
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Macroscopic and Microscopic implant design features can have an effect on an implant's success or failure. Knowing design features such as body, thread shape, surface coatings, and surface topography are key to a clinician's implant selection. The purpose of this review is to analyze the research literature to determine important aspects of a dental implants macroscopic and microscopic design.

A literature search was conducted using MEDLINE to identify studies using simulated laboratory models, animal, and human studies related to this topic. The following keywords were used: macroscopic, microscopic, implant geometry, thread design, surface, coatings, and the results were correlated. Most significant studies were selected based on study design (i.e. prospective double-blinded, cross-sectional, case reports), sample size, and statistical analyzes. 1,049 studies were identified in the preliminary search with 7 studies meeting the inclusion criteria of FEA studies with compressive stress (MPa) of cortical bone measured at the implant crest.

The results demonstrated the role macroscopic and microscopic design features may play on implant stability both initially and long-term success. Cylindrical form

implants with no thread or a thick squared thread were found to have the lowest compressive forces found at the bone crest. While implants with a tapered form and v-threads were found to have the highest compressive forces at the bone crest. Cylindrical implants were found to have less compressive force at the bone crest vs tapered form implants. Endosseous tapered and screw shaped dental implants are currently preferred due to their threads engaging in the bony walls which allows for good primary stability and the threads increasing the surface area in contact with bone. Thread pitch should be minimal (increased amount of threads) in order for best resistance to vertical loading. Additionally, increased thread lead and therefore thread helix angle has been found to reduce resistance to vertical forces. Shallow thread depth is indicated for dense bone to avoid the need for a bone tap, while deeper thread depth is indicated for better primary stability in weak bone. An increase in the thread face angle will result in an increase in shearing forces. Forces are distributed through compression best in the square and buttress thread shapes. With regard to microscopic features, titanium is considered the material of choice due to its inert processes and it does not inhibit osteoblast growth. Titanium alloys are used to improve the strength characteristics. For surface morphology, a roughened surface results in an increased BIC and a decrease in the shear forces observed.

Macroscopic and microscopic design features of dental implants play a role in initial and long term stability following placement. Due to force distribution through these design features and the variations seen in bone quality and quantity, there may not be a perfect implant design which would suit all needs and indications. Rather than the current trends with implant companies unifying their implant products surgically, based on the principles outlined, implant design principles could necessitate multiple macroscopic implant designs with more unified prosthetic platform.

CHAPTER 1
INTRODUCTION

Since developing in the 1960s the modern dental implant has become a significant treatment option in the replacement of lost natural teeth. The dental implant industry has recently seen great growth in the number of manufacturers and different designs available. Currently a variety of implant lengths, surfaces, body designs, platform connections, thread forms, and body designs are available.

In addition to proprietary features and retaining profitability, these variations in implant designs available can aid in osseointegration. The overall implant shape, spacing and profile of the threads can have an effect on achieving success (Siegele and Soltesz, 1989, Djavanmard et al., 1996). Additionally the implant surface can be another critical factor in achieving osseointegration and implant success (Albrektsson et al., 1981a).

In the current practice dental implants are accepted as a standard of care with long term success rates as high as 97% in studies after 10 years of implant function (Fugazzotto, 2005).

Despite the high success rate of implants, it is important to be mindful of the implant design factor proposed by Albrektsson, which may influence the success or failure of an implant. Implant design can be broken down into two categories: macroscopic and microscopic. Macroscopic design features include body design and thread geometry. Microscopic design includes implant materials, surface morphology, and surface coatings.

The aim of this paper was to analyze how implant design features may maximize the success seen in implant placement and additionally minimize the complications observed. This review is aimed at assessing different macro and microstructure design of implants and will present a review of the literature that focuses on the influence macro and microstructure may have on implant osseointegration.

CHAPTER 2
BACKGROUND

Historically, attempts at implanting materials to replace lost or broken down dentition were made dating as early back as the ancient Egyptians. Attempts were made using a variety of materials including gold and seashells, which were hammered directly into the osseous crest (Driskell, 1987). Within the past few centuries these attempts have been revisited using additional types of materials and methods. These attempts very often ended with failure of the implant due to the lack of stable integration with supporting tissues of the periodontium(Ring, 1995a, Ring, 1995b). The phenomena, which occurred was typically an interposed layer of soft tissue between the implanted device and bone, regardless of the material being used for implantation. This fibrous encapsulation of the implanted material typically led to the implants becoming mobile, infected and mobile ultimately necessitating failure and subsequent removal.

Modern dental implant history is typically credited with the use of titanium as the material of choice. The discovery of bone to titanium integration is typically accredited to a discovery made by Dr. Branemark in the 1950s. Dr. Branemark was a professor of anatomy and studying blood circulation within the tibia of rabbits. In order to view the circulation, Dr. Branemark was using a device made of titanium implanted into the bone. Upon trying to remove the device, he discovered there was a very tight union between the bone and implanted titanium device. This union was later described as "osseointegration" and was the beginning of predictable dental implant success in 1965 (Branemark et al., 1969).

The term "osseointegration" had been shown to be effective in a achieving an intimate bone to implanted device interface. Additional clinical studies were performed which proved that commercial grade titanium could be implanted and restored with a dental prosthesis for long term 15-year success (Albrektsson et al., 1981b). Since the early beginnings of modern dental implant use, millions of dental implants have been predictably placed in patients.

Predictable dental implants have changed the clinician's mindset and are offered to patients with hopeless or missing teeth on daily basis. Uses of dental implants are currently one of the most successful procedures a clinician can perform. In a study performed by Haas et al. with 76 implants using the traditional Branemark design only 2 implants (2.63%) were removed due to failure over the course of the 6 year follow up (Haas et al., 1995). Additionally in a retrospective study of 607 implants placed in sites where bone regeneration was performed, success rates exceeded 97%. The study also stratified the success between maxillary and mandibular sites. Success of 97.2% was observed in maxillary sites and 97.4% in mandibular with implants up to 133 months in function (Fugazzotto, 2005). While the use of dental implants has proven to be very successful, the number of failures is still a limitation of implant therapy and remains a concern to clinicians throughout the world.

Two different theories have been purposed as being integral to the achievement and maintenance of osseointegration. These two hypotheses are the biological and the biomechanical. The biological hypothesis focuses on the effect of bacterial plaque and host response patterns on implant survival. The biomechanical hypothesis emphasizes occlusal overload on the supporting bone and the effect of compressive, tensile, and shear forces.

Attempts to identify factors influencing success have been made throughout the evolution of the dental implant sciences. Dating back to 1981, Albrektsson reported several factors, which may play a role in observed results. These included: surgical techniques, host bed, implant design, implant surface, material biocompatibility and different loading conditions (Albrektsson et al., 1981b). These identified factors can influence the interface between bone and the implant material, therefore the success. An understanding of these factors and applying principles, which may help to limit them, could decrease failures observed by the clinician. Additional decreases in implant failures could lead to advancements in placement of less predictable situations such as immediate implant placement with immediate loading, placement in smokers and diabetics, and placement in less than ideal bone quality.

CHAPTER 3
MATERIALS AND METHODS

A literature search was conducted using MEDLINE to identify studies using simulated laboratory models, animal, and human studies related to this topic. The following keywords were used: macroscopic, microscopic, implant geometry, thread design, surface, coatings, and the results were correlated. Most significant studies were selected based on study design (i.e. prospective double-blinded, cross-sectional, case reports), sample size, and statistical analyzes. 1,049 studies were identified in the preliminary search with 7 studies meeting the inclusion criteria of FEA studies with compressive stress (MPa) of cortical bone measured at the implant crest.

CHAPTER 4
RESULTS

Macroscopic Features: Body Design

Since the discovery of osseointegration between titanium and bone for the use of dental implantation, a wide variety of implant configurations have been used. The most popular of which include endosseous (bladelike, pins, cylindrical, disk-like, screw shaped, and tapered with screw shaped), subperiosteal frame-like and transmandibular implants.

Endosseous blade implants (Fig 4-1) were originally designed in the 1960s and were tapped into a straight osteotomy created by a high-speed surgical handpiece. Once the implant was tapped into place and sutured there were single or multiple posts, which remained protruding through the periodontium in preparation for restoration with a fixed prosthesis. The prosthesis was typically restored through cementation after several weeks of healing (Linkow, 1969). The most common complication observed with the endosseous blade implants was a fibrous soft tissue downgrowth along the implant surface also known as “fibrous encapsulation”. This complication was commonly the direct result of overheating and subsequent necrosis of the bone in contact with the implant during preparation of the osteotomy (James, 1980). Additional complications occurred in the event of bacterial infection with resulting destruction of the resulting bone. Implant removal often resulted in loss of ample bone loss due to the difficulty in removing an implant with such an elongated design.

Many studies reported a 5-year success rate of less than 50% with massive destruction of surrounding bone. Removal of such implants although nonfunctional and mobile usually necessitated additional bone removal due to the design being retentive in nature (Cranin et al., 1977, Smithloff and Fritz, 1976).

Endosseous pin implants were placed in a divergent manner in usually using 2 or 3 implants per restoration. At the point where the pins converged upon each other cement was typically used to connect the implants together. Once connected, these implants could be restored as single teeth or in the case of edentulous regions as fixed partial prostheses. As observed in endosseous blade implants, overheating through drilling lead to the same types of fibrous encapsulation. However, unlike in the case of blade implants, pins were easier to remove once the cement connection was eliminated and did not lead to boney destruction to the same extent as with blade implants.

Disk implants although not as popular as the previously mentioned body designs, were placed through a lateral pin into the alveolus with a disk on top. The lateral placement of the implant into the alveolus allowed for significant resistance to vertical forces but success suffered from fibrous encapsulation as well (Scortecci, 1999).

Transmandibular implants were primarily developed for the prosthetic reconstruction of the edentulated mandible with a residual crest height of 10mm or less. Placement of transmandibular implants was achieved through an extraoral access incision and subsequent fixation transorally. The procedure involved for the placement of transmandibular implants required general anesthesia and due to the high complication rates it has become uncommonly used (Small, 1975, Small et al., 1974, Small and Misiek, 1986).

Subperiosteal implants were designed mainly for removable overdenture use and minimal fixed prostheses. The subperiosteal implant is designed by a lab following an intra-surgical impression taken of the residual ridge. Once the framework was placed within the mouth, typical healing resulted in the same fibrous encapsulation seen with the endosseous blade implants. Upon remodeling of the bone to adapt to this encapsulation often resulted in failure due to the framework's poor adaptation to the bone. Success rates reported for subperiosteal implants were typically poor at around 50% approximately 5 to 10 years following loading. Complications were also high with exposure and inflammation being common issues observed (Obwegeser, 1959, Albrektsson and Sennerby, 1991).

Endosseous cylindrical implants were originally designed by an organization known as the International Team for Implantology (ITI) beginning in 1974. The initial design was a hollow-cylinder which was thought to improve the surface area for increased bone-to-implant contact. The implant being hollow along with the addition of holes along the body was thought to additionally be favorable for the fixation of the implant allowing for bone growth to occur in and around the implant surface (Schroeder et al., 1976). This design was phased out with the ITI system after survival rates were found to be higher for the non-hollow counterpart (Albrektsson, 2003).

Similar to the hollow ITI implant, Niznick developed an implant with the Core-Vent system (Niznick, 1982). It was thought that additional surface area would allow for better bone ingrown and fixation of the implant. Although the Core-Vent system is used currently, survival for hollow cylinder implants were less than ideal and are rarely seen available in the present implant market.

When discussing development of the endosseous cylindrical implant, it is important to mention the implant system known as the IMZ implant with a built in internal mobile shock absorber which had hopes to mimic natural aspects of a natural tooth; mainly the periodontal ligament. The IMZ implant was used to splint fixed partial bridges to natural teeth (Kirsch, 1983). This implant system was proven to have good short-term results but was a poor performer over long periods of time. In a study by Haas, 1,920 IMZ implants were analyzed for success up to 100 months. The study reported as low as 37.9% success in the maxillary sites (Haas et al., 1996).

Although endosseous cylindrical implants have shown greater success than the blade, pin and disk-like implants; the surface in contact with the bone under load is subject to heavy shearing forces and as a result rely heavily on the implant surface or microscopic characteristics of the implant.

Shortly after the development and use of the endosseous cylindrical implants a thread or screw shape was added to the body of the cylinder. Currently the most commonly used implant design available, the addition of a thread pattern allowed for implants to engage surrounding bone and achieve excellent initial stability following placement. Addition of a thread to the body design also allowed for an increase in potential bone-to-implant contact potential without compromising survival, as was the case with hollow and vented implants.

Initially, threaded cylindrical endosseous implants were parallel walled and have been shown to be successful over long periods of time. However, more recent designs have begun to incorporate a tapered wall form. Advantages of the tapered form implant include: less space in apical region allowing for placement in narrow spaces or in narrow regions with labial or lingual concavities, better stability for immediate placement, and better distribution of compressive forces.

When compared to a parallel walled implant, the tapered implant has been shown in FEA to have 17.9% less force in the trabecular region of the implant (Geng et al., 2004b, Geng et al., 2004a). This was also observed for press-fit situations using FEA comparing a cylindrical and stepped cylindrical design in stress distribution through the surrounding bone. Using single-tooth implants, the results suggested the stresses were more evenly distributed in the tapered form rather than the strictly cylindrical(Holmgren et al., 1998). This is contrasted by the findings by Siegele and Soltesz who compared a variety of implant shapes using a bonding mechanism between implant and bone and contact only to look at forces. Their results showed that different implant shapes lead to a variety of stress distributions within the bone and found implants with curvature such as the conical or stepped design introduced significantly higher stresses than the cylindrical or cylindrical with a thread pattern (Siegele and Soltesz, 1989).

For the present investigation, FEA studies selected looking at compressive forces at the crest found cylindrical form implants with no thread or a thick squared thread were found to have the lowest compressive forces found at the bone crest. While implants with a tapered form and v-threads were found to have the highest compressive forces at the bone crest. Cylindrical implants were found to have less compressive force at the bone crest vs tapered form implants (Table 4-1).

Macroscopic Features: Thread Geometry

Thread geometry includes thread pitch, depth and configuration or shape; which can all play a role in the stress distribution of an implant to the surrounding bone. This distribution can be observed at primary placement, healing and during the loading phase of the implant. Clinicians must choose a macro design, which will aid in the long-term support and success of an implant (Geng et al., 2004a).

An understanding of the forces an implant might endure is essential to the concepts of implant thread geometry. Favorable and unfavorable force distribution is key to design and selection of an implant based on the macroscopic features it may have. Misch identified three main types of load an implant may endure at the interface between the implant surface and bone. These three forces are compressive, tensile and shear (Figure 4-2). Compressive forces have been shown to be the most favorable when discussing bone possibly due in part to a concept developed by Wolff in 1892. Wolff observed a direct relationship with increasing mechanical loading and reactive bone formation. In the presence of stress bone formation is seen while a decrease in stress or function is observed to have the opposite effect with loss of bone density(Wolff, 1892). Tensile and shear forces are thought to be unfavorable due to an observed weakening of the bone. Efforts are therefore, focused on increasing compressive forces and minimizing the tensile and shearing forces which may weaken the bone to implant interface. As previously mentioned, efforts to attain this have been made through tapering of the implant body and adjusting the thread design (Holmgren et al., 1998, Misch, 2008, Lemons, 1993).

Thread pitch (Fig 4-3) refers to the distance from the center of the thread to the center of the next thread, measured parallel to the axis of the screw(Jones, 1964) The thread pitch is often known as being inversely related to the number of threads in the unit area and can be calculated by dividing the unit length by the number of threads(Misch, 2008). If implant length is the same, a smaller pitch means there are a greater amount of threads. In a study by Roberts, implant were placed into rabbit femurs and continuously loaded over the course of 8 weeks. Implants with more threads (i.e. smaller pitch) were found to have a higher percentage of BIC. The study also found bone formation perpendicular to the loaded threads (Roberts et al., 1984). Another study using FEA looked at implant pitch as it related to resistance to vertical forces and found with increasing thread pitch, the resistance to vertical forces was weakened. (Ma et al., 2007)

Often confused with implant pitch is a feature know as the lead (Fig 4-3). The lead is the distance from the center of the thread to the center of the same thread after one turn. Practically speaking this could be the distance the implant would advance if it was advanced one turn (Abuhussein et al., 2010). If the implant has a single thread then the pitch equals the lead. However, this is not always the case, some implants are made to have a double or triple thread design in which two or three threads run parallel to each other (Fig 4-4). The reasoning behind this is to maintain the increased number of threads along the implant surface, which will help to maintain a high level of resistance to vertical forces and maintain a high level of BIC at the same time as allowing for increased speed of implant insertion. Although this concept allows the linear pitch to remain the same, the thread helix angle increase found in double and triple threaded implants has been shown to have a decreased resistance to vertical forces (Ma et al., 2007, Roberts et al., 1984).

Thread depth (Fig 4-3) has been defined as the distance from the tip of the thread to the body of the implant or the distance between the major and minor diameters of the thread. Thread width (Fig 4-3) is the distance in the same axial plane between the coronal most and the apical most part, at the tip of a single thread. The role thread depth plays are proposed to occur on insertion and BIC of the implant. A shallow thread will be easier to insert into dense bone without having to use a drill to tap the site prior to insertion. A deep thread will allow for much greater primary stability specifically for situations such as soft bone or immediate implant sites (Abuhussein et al., 2010, Misch, 2008).

The face angle (Fig 4-3) is the angle between the face of a thread and a plane perpendicular to the long axis of the implant. Studies have shown altering the face angle can have an effect on the forces at the bone to implant interface. A relatively small face angle will tend to increase tensile and compressive type forces, while increasing the face angle has been shown to result in an increase of shearing type forces along the implant to bone interface. This concept has been observed to occur regardless of the thread shape within their respective groupings (Bumgardner et al., 2000).

Thread shape (Fig 4-5) describes the geometry of the implant thread and is a function of differing values with regards to all the terminology describing thread design. Thread pitch, depth, width, lead, and face angle all play a role in the resulting overall geometric shape of a thread. There are currently five major thread shapes used in dentistry today with minor variations across the entire dental implant market. These five shapes include; V-shape, square, buttress, reverse buttress and spiral. One could assume applying the principles previously outlined, that these shapes all distribute the favorable and unfavorable stresses in different ways. As was also discussed, compressive forces are thought to be the most favorable with an ongoing goal to minimize tensile and shearing forces.

According to Misch, V-shaped threads typically have a face angle of 30 degrees in implant dentistry which tends to introduce greater shearing forces to the interface than in the case of the reverse buttress which typically has a face angle of 15 degrees or the square thread which does not posses a face angle of any noteworthiness and therefore the smallest amount of shearing forces amongst the group. The axial forces transmitted in the V-shaped and reverse buttress thread form are mainly an interplay of compressive, tensile, and shearing (Misch, 2008). These shearing forces have been found to ultimately result in greater defect formation (Hansson and Werke, 2003). The ideal thread shape with respect to transmission of compressive forces generated at the interface has been shown to be the square and buttress threads (Barbier and Schepers, 1997). Forces transmitted to the implant to bone interface are different depending on whether or not the implant is loaded. Research has shown regardless of thread shape, bone is evenly distributed on the coronal and apical portions of the implant thread prior to loading. However, when the implant was loaded, the majority of the stresses were seen at the tip and along the apical aspect of the thread (Kohn, 1992, Bolind et al., 2005, Duyck et al., 2001)

Microscopic Features: Implant Materials

While implant macrostructure plays a role in the surgical stability and force distribution, it is important to remember the impact implant microdesign has on achieving osseointegration. When considering features essential to implant osseointegration, biocompatibility has been shown to play a key role. Selection of ideal materials for dental implants can enhance this osseointegration (Steigenga et al., 2003, Davies, 1998).

In an article by Steinemann, corrosion and cellular reactions were compared amongst a variety of materials. These included Co, Cu, Ni, Valadium, Iron, Gold and Titanium. Ti was found to be fully inert with regards to tissue interactions. Fibroblasts in contact with Ti, niobium, zirconium, and tantalum can proliferate but not in proximity with molybdenum, copper, or vanadium. In an experiment with osteoblasts cultured on pure metal discs, growth inhibition was absent for Ti and Zirconium, relatively weak for tin and aluminum, and strong or total for zinc, iron, copper, molybdenum, vanadium, nickel, silver, niobium, and tantalum. This suggests a unique capacity of Ti and Zi for osseointegration ("a direct structural and functional connection between ordered, living bone, and the surface of a load carrying implant'). Additionally, pure Ti has limited mechanical strength, which necessitates the use of Ti alloys which does not interfere with the osseointegration capabilities making it one of the materials of choice (Steinemann, 1998).

Microscopic Features: Surface Morphology

The surface morphology of implants differs between companies and has been shown to play a role in achieving osseointegration. When discussing the history and development of implant surface morphology, it is important to point out that modification of the traditionally machined implant surfaces were made in an attempt to improve the BIC by increasing the surface area available (Fig 4-6). This is advantageous because an increased BIC would subsequently lead to a decrease in shear strength (Hansson and Norton, 1999). This has been shown to be an effective concept, in a meta-analysis by Stach, implants with a roughed surface morphology were found to achieve a higher degree of osseointegration and faster than their machined surface counterparts (Stach and Kohles, 2003).

Surface roughness of implants can be produced through either an additive or subtractive process (Fig 4-7). The additive processes include: titanium plasma-sprayed (TPS) surfaces, Hydroxyapatite (HA) and calcium phosphate coatings, ion deposition, and oxidation. Subtractive processes used include: electropolishing, mechanical polishing, blasting, etching, and laser microtexturing (Aljateeli and Wang, 2013).

Table 4-1. D1 Cortical Bone Stresses (Mpa) at Crest of Implant. Data from (Baggi et al., 2008, Fazel et al., 2009, Desai et al., 2012, Cruz et al., 2006, Chowdhary et al., 2013, Geng et al., 2004a, Geng et al., 2004b)

Implant Design	D1 Cortical Bone Stresses (Mpa) at Crest of Implant					Mean
Cylindrical no thread	50	25	60	7	12	30.8
Cylindrical v-thread		60	80	13	220	93.25
Tapered v-thread	61	60	216	65	210	122.4
Cylindrical thin-thread	62	165	80	8	65	76
Cylindrical square thin thread	59		30	144		77.6
Cylindrical square thick thread	100		33	15		49.33

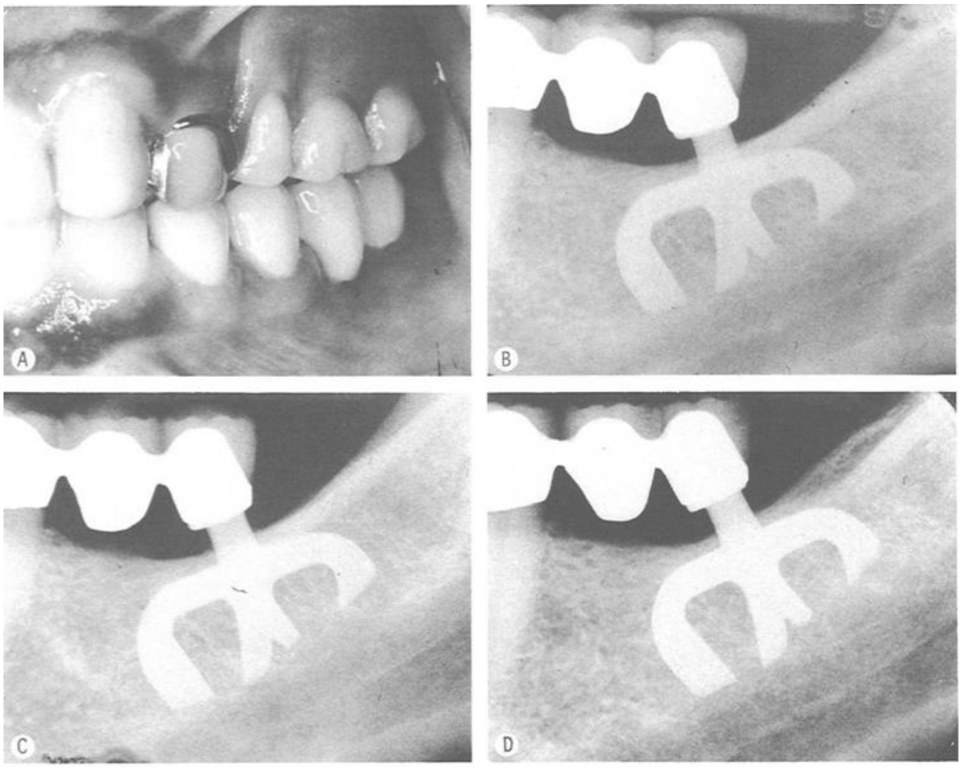

Figure 4-1. Blade form implants. Adapted without permission from (Smithloff and Fritz, 1976). A clinical photograph and radiographs from insertion in 1970 through follow-up in 1985.

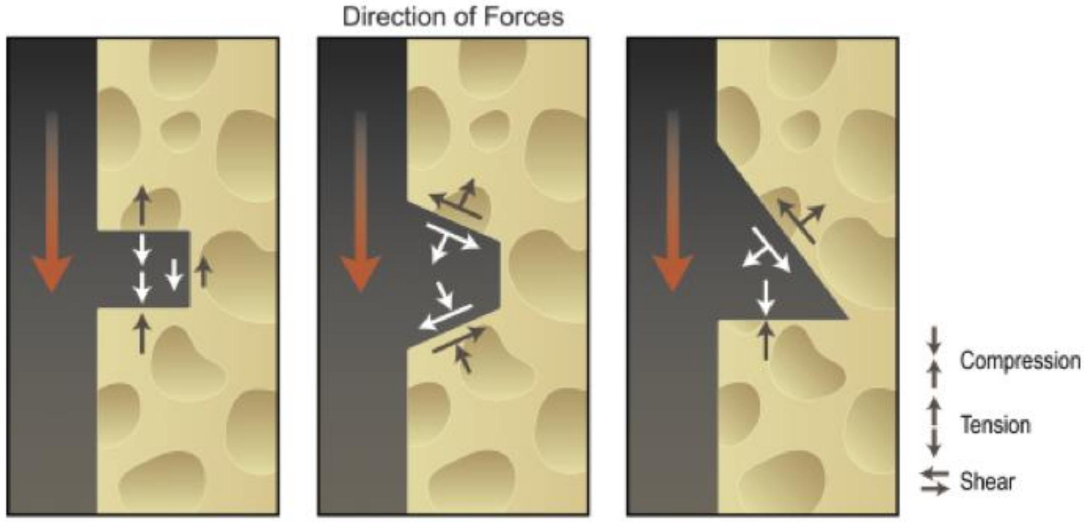

Figure 4-2. Implant force types. Adapted without permission from (Abuhussein et al., 2010)

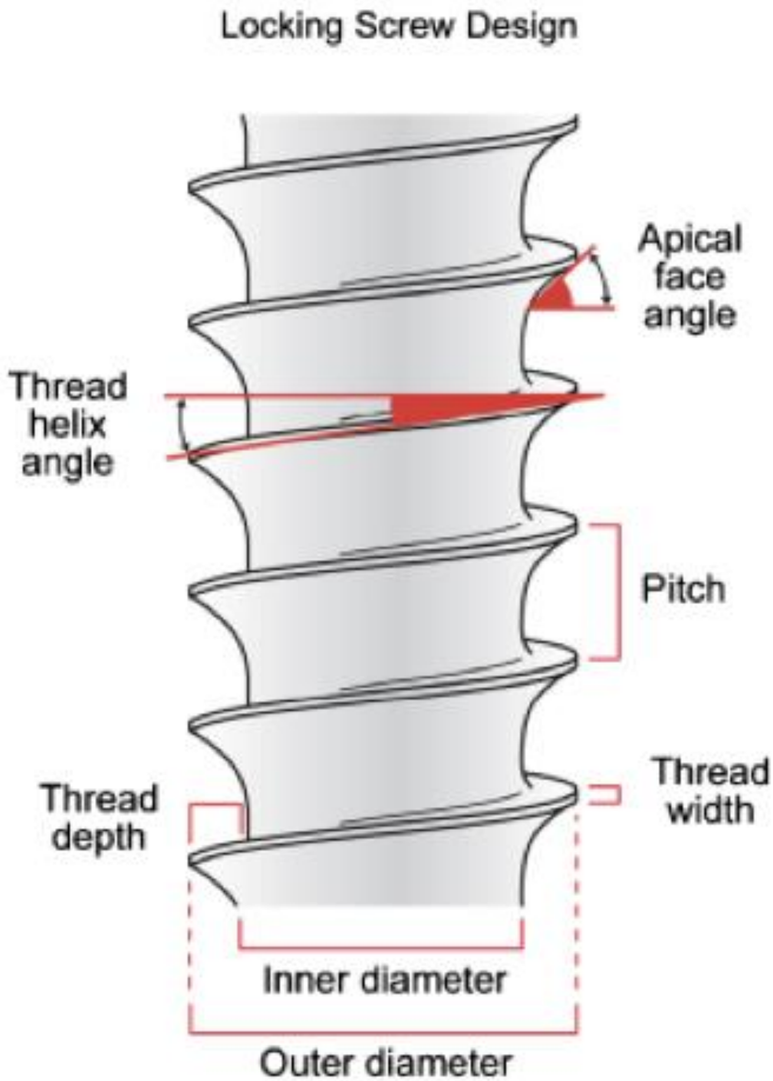

Figure 4-3. Thread diagram. Adapted without permission from (Abuhussein et al., 2010)

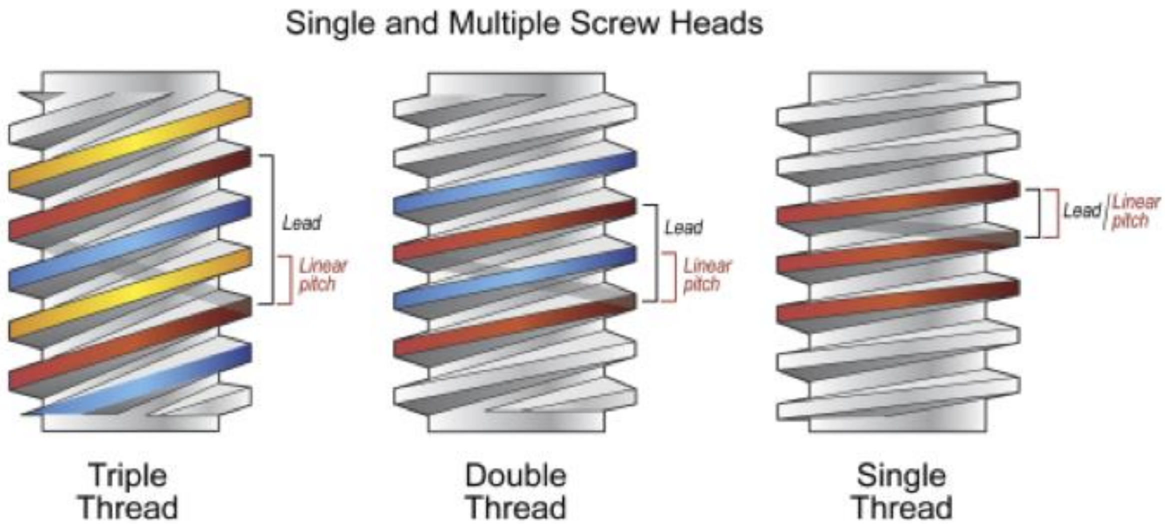

Figure 4-4. Implant thread lead. Adapted without permission from (Abuhussein et al., 2010)

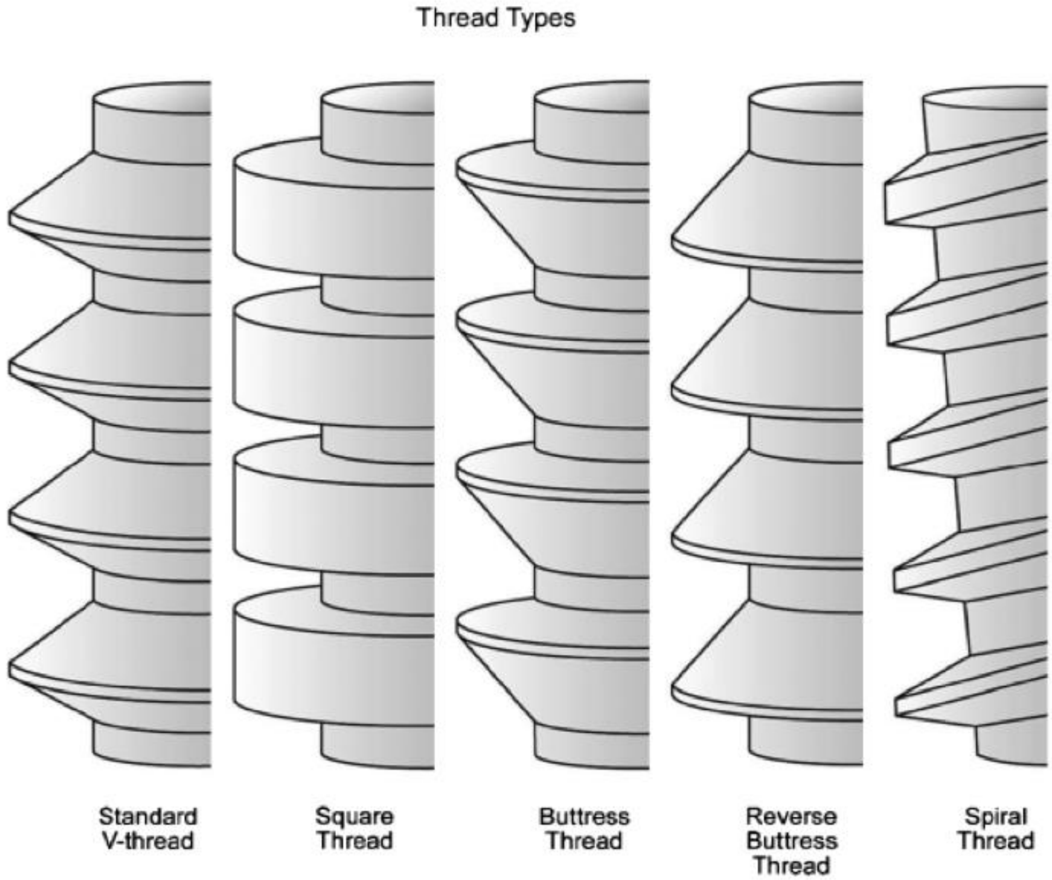

Figure 4-5. Implant thread types. Adapted without permission from (Abuhussein et al., 2010)

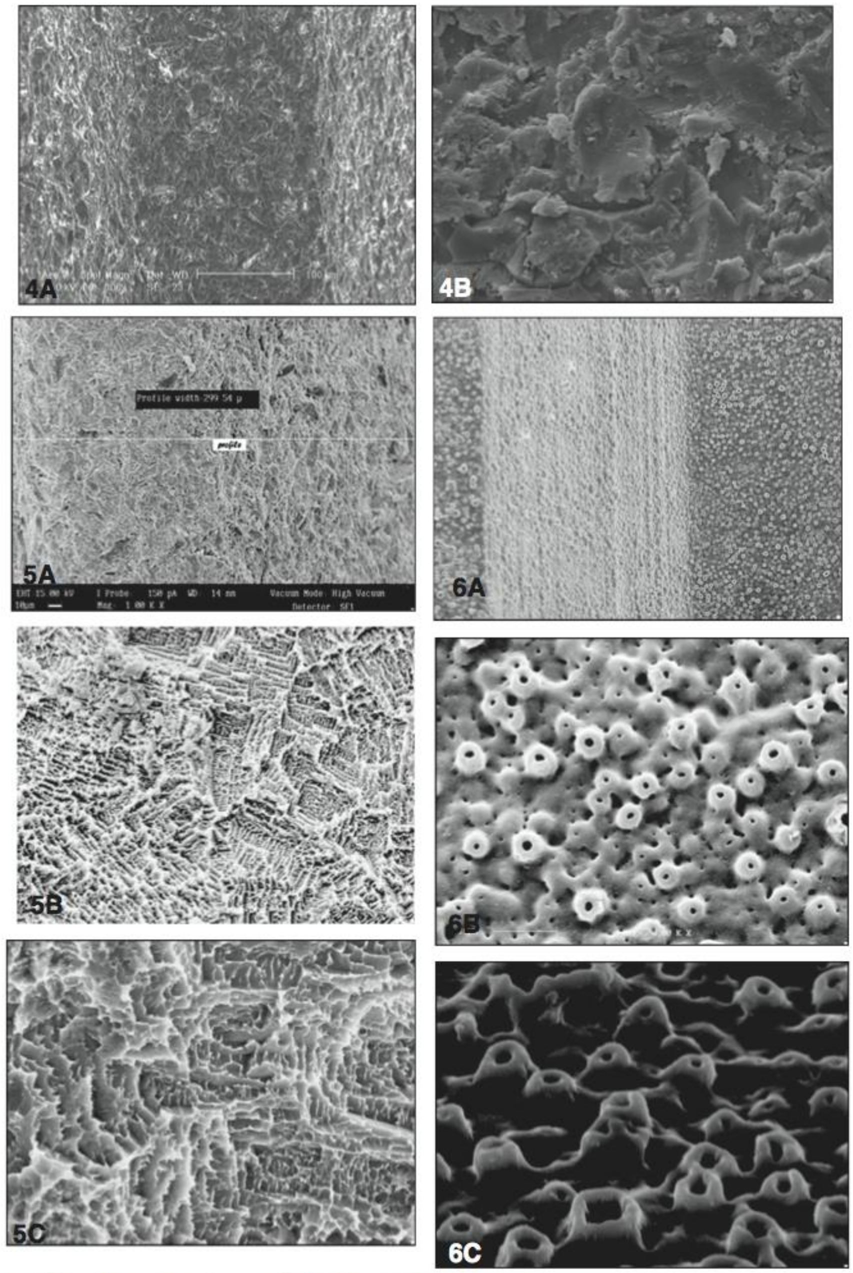

Fig. 4. Sandblasted surface at SEM. Deep valleys alternated to elevated sharp crests make up a surface with irregular distributed porosity. (*A*: 300× magnification; *B*: 5000× magnification).
Fig. 5. SEM analysis of the SLA (sandblasted, large grit acid-etched) surface; the sandblasted and acid-etched treatment leave a microrough surface morphology with cavities of prominent edges and a evenly distributed porosity. (*A*: 1000×; *B*: 5000×; *C*: 10,000×).
Fig. 6. SEM analysis of the FCC implant covering. FCC implant surface showed a more regular microrough morphology compared with Sab and SLA implant surfaces. Porosity with a typical morphology due to the electrochemical treatment can be detected (*A*: 1000×; *B*: 5000×; *C*: 12,000×).

Figure 4-6. Implant surface types.   Adapted without permission from (Tete et al., 2008)

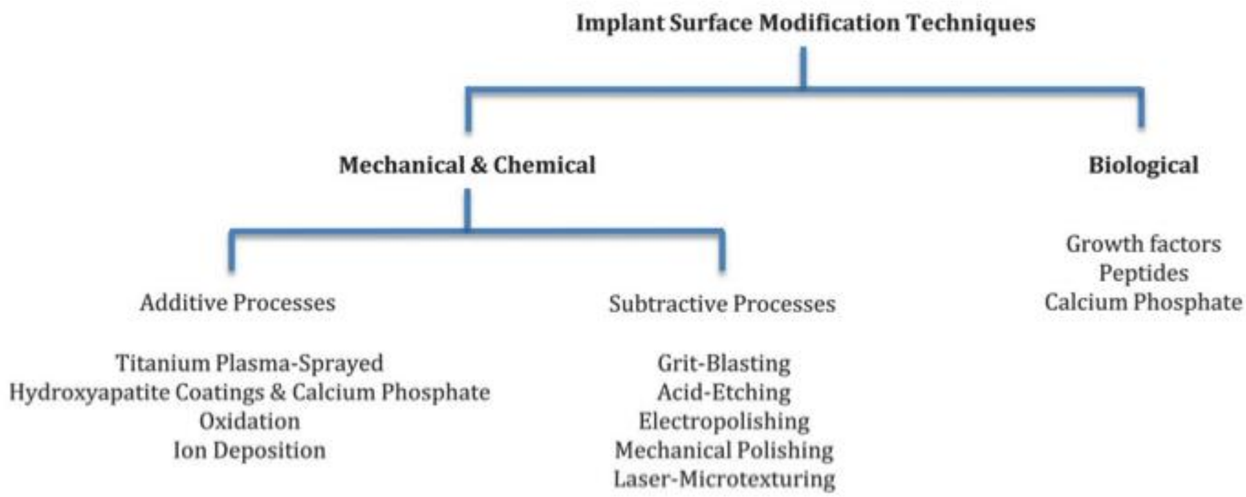

Figure 4-7.Implant surface treatment. Adapted without permission from (Aljateeli and Wang, 2013)

CHAPTER 5
DISCUSSION

Macroscopic and microscopic implant design features have been shown to play a role in implant stability and survival of implants. This role was identified as crucial by Albrektsson in 1981 where he proposed implant design, implant surface, and material biocompatibility all affected implant success (Albrektsson et al., 1981b). While there are certainly other factors involved in an implant's success one should not ignore the "biomechanical hypothesis" which implicates occlusal overload and other forces on bone as one of the factors playing a role in achieving osseointegration.

Many implant body designs have been used in an attempt to find the ideal design that will decrease or even eliminate implant failures. Some designs such as the endosseous blade, pin, disk-like, and the subperiosteal implants; were all subject to failure due to an observed fibrous encapsulation and post-operative infections due to periodontal abscess-like formation or exposure of the substructure. Rather than accepting these designs as failures and only looking to new developments; it is important to look at their macroscopic and microscopic design features questioning what might have lead to their demise or success.

FEA studies selected looking at compressive forces at the crest found cylindrical form implants with no thread or a thick squared thread were found to have the lowest compressive forces found at the bone crest. While implants with a tapered form and v-threads were found to have the highest compressive forces at the bone crest. Cylindrical implants were found to have less compressive force at the bone crest vs. tapered form implants.

Likewise, it is important to consider the current trends in implant design and ask if their macroscopic and microscopic elements are enhancing or hindering their success. Often times changes in design can be delayed or resisted due to the cost involved in making the switch. For macroscopic changes to implant design this cost can be appreciated in the fabrication of the implant, the instrumentation required to place a different implant, restorative instrumentation required if the implant-abutment connection is altered, marketing, training of employees, surgeons and staff. While this list is not all-inclusive, there is a clear investment, which needs to be made anytime an implant company considers altering its macroscopic design features. This is also certainly true for changes to the microscopic features of an implant; however, the list is not quite as long or involve near the same cost as in the case of macroscopic alterations. This could provide some explanation for why implant companies have chosen to develop and invest heavily in implant materials, surface morphology, and surface coatings; rather than in changes to the macroscopic design, which may involve a greater investment and put the company at risk.

Whatever the costs involved may be, the literature has shown the clear role macroscopic and microscopic design has on the success of an implant in the short and long term. These design features are important to keep in mind when a surgeon is faced with the decision of which implant to place. Applying principles of the design features outlined should allow for the development of faster, more reliable integration of dental implants with higher success rates over time.

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