Chapter

Characteristics of Implant Systems That Can Accelerate and Improve the Osseointegration Process

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Abstract

The research and development of new implant models modifying the micro and macro design has increased significantly in the last decades. With the advancement of knowledge about the biological behavior of these materials when implanted in living tissue, a great search for morphological changes at macrogeometric, microgeometric and even nanogeometric levels was started, to accelerate the process of osseointegration of implants, reducing the time for the rehabilitation treatment. This chapter will seek to demonstrate, through scientific evidence, the potential effect of the morphological characteristics of implants on osseointegration. Modifications in the surface treatment of implants will be discussed to improve the osseointegration process in terms of quality and time reduction, changes in the surgical technique used for the osteotomy of the implant installation site, and macrogeometric changes in the shape of the implant body.

Keywords: implant design, implant microgeometry, implant macrogeometry, rapid osseointegration, titanium implants

1. Introduction

Dental implants have become a predictable and safe form of treatment for the replacement of missing teeth. Surely, implants have revolutionized dentistry practice in worldwide, enabling the rehabilitation of patients who have lost single teeth to patients with loss of all teeth. Thus, various types of treatments made possible by improving the quality of life and patient satisfaction. Among these treatments that had the greatest representation, we can mention: the cases of totally edentulous people, who could receive implants to improve the fixation of removable dentures or even receive fixed dentures; patients with partial losses with a lack of posterior pillars (teeth) who had to wear removable dentures and could receive fixed dentures; and patients who had unit losses where it was possible to rehabilitate them without wearing out natural healthy teeth.

Since its diffusion by Branemark in the 60s [1, 2], dental implants have been the object of many studies and, consequently, have undergone several changes. However, the base material for its manufacture, titanium, continues to be used due to its excellent biological and mechanical characteristics. Surgical techniques have also undergone several advances and modifications. Initially, a waiting time for the beginning of the rehabilitation procedures of 6 months was recommended, with implants installed in the bone tissue and covered by mucosa during this waiting period for osseointegration. With the advancement of knowledge, it was proposed that for implants installed in the mandible, the waiting time could be less than in the maxilla, due to the difference in density between the two anatomical sectors. However, Gehrke and Tavares da Silva Neto [3], showed in a clinical study that the evolution of osseointegration is the same in the 2 types of bone (maxilla and mandible) and that the implants could be loaded in both arches with the same waiting time, as long as these sites who received implants were in adequate condition. On the other hand, new techniques aiming to speed up the treatment time and provide greater comfort to patients, such as post-extraction implants (immediate), immediate loading on the implants, implants with simultaneous bone regeneration, among others, were proposals and studied and, currently, are widely used.

Different changes at nano-, micro- and macro-structural levels have been researched and proposed with the aim of improving and/or accelerating the processes involved in the osseointegration of dental implants. Such possibilities became possible with the evolution of scientific knowledge about the events involved in the healing process of peri-implant tissues after implant insertion. In this sense, several types of surface treatment have been proposed in order to promote a physical–chemical stimulation capable of accelerating the initial phases of bone neoformation on the implant [4, 5]. Among the main methods used to produce surface roughness of implants are the addition processes (e.g., titanium plasma spray, hydroxyapatite coating) and subtraction processes (e.g., acid etching, microparticle blasting, laser). Among all of them, the most used procedure currently by most of the world industry is the subtraction methods, as they have shown good results and are less costly. On the other hand, the addition of ions (e.g., Calcium, Magnesium, hydroxyapatite) on these surfaces at nano- and/or micrometric levels has shown good results for the osseointegration.

Initially, the implants had a cylindrical macrogeometry, being later proposed implants with macrogeometry with conical designs. Tapered shaped implants had advantages over cylindrical ones, especially regarding the surgical process, where they were shown to generate less trauma to the bone tissue resulting from the drilling process used for this type of implant. In addition to this change in the body of the implant body, changes in the shape of the turns, which were initially triangular and with little depth, received other shapes, such as trapezoidal, square, and with greater depth and distance in the thread pitch. Also, changes in the cervical portion of the implants, which are in contact with the cortical bone, have been proposed. Among these changes, we can mention the presence of smooth (polished) surfaces, treated (rough) surfaces and the presence of micro-turns. Regarding the prosthetic connections, the implants had several alterations, being proposed different models of fittings, always with the intention of improving the stability of the rehabilitation in the long term. **Figure 1** shows different types of implants and designs proposed in recent decades.

More recently, with scientific evidence that the installation of implants with less compression of the bone tissue could benefit and accelerate the osseointegration process, new macrogeometric models of implants were proposed. In this sense, it was shown that the presence of free spaces of bone tissue or the presence of uncompressed fragments can facilitate the cellular work of phagocytosis and bone matrix neoformation, as shown schematically in the **Figure 2**. This type of condition, creating a space

Figure 1.
Available dental implants with different design and connections. (courtesy of Implacil De Bortoli company, Brazil).

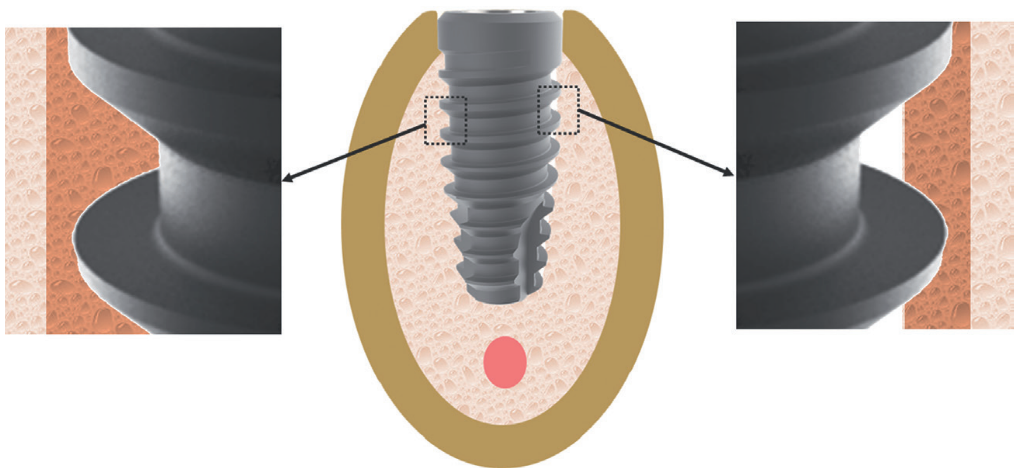

Figure 2.
Schematic image depicting the installation of an implant in a conventional technique (left) causing bone compression over an extensive area, and the implant insertion with spaces between the bone and the implant (right) decreasing bone compression area.

between the bone tissue and the implant, is achieved through a modification in the surgical technique, that is, in the relationship between the diameter of the last reamer used and the diameter of the implant to be inserted into the bone. Thus, in this chapter we will describe and discuss some advances resulting from these changes in the structure of dental implants during the last decades.

2. Characteristics of implants, proposed changes and results obtained

2.1 Surface treatments

The first dental implants were developed without any type of surface treatment, they were carried out by a machining process, which resulted in implants with a smooth surface. For a long time, this implant was conceived as the gold standard. Experimental studies comparing smooth and rough surfaces demonstrate a better biological response to the latter. With the evolution of implantology, changes in implant surfaces began to be carried out in order to improve osseointegration [6].

The processes of changes in the surface of implants can be carried out by the addition method, when some type of material is added to the layer by means of plasma spray coating, or subtraction, when part of this surface layer is removed by physical and/or chemical processes, such as abrasion by blasting or acid etching [7]. The texturing of the implant surface can influence the osseointegration process both in cell differentiation, after implant placement, and in the amount of calcified bone matrix [7, 8]. Thakral et al. [9], reported that texturing techniques in dental implants can influence the establishment of osseointegration, both for cell differentiation, after implant insertion, and for calcified bone matrix. Also, according to Wennerberg and Albrektsson [10], the treated surfaces result in greater bone/implant contact (BIC), compared to smooth implants. Thus, implants with textured surfaces are indicated for sites with a lower BIC at the end of surgery. On the other hand, Att et al. [11], state that bone is indistinctly deposited on porous or smooth surfaces. Therefore, porosity would not be a necessary condition for bone apposition to occur.

Regarding the initial stability of the implants, the surface treatment of the implants does not change the initial stability values of the implants, as shown in studies comparing the insertion torque and stability analysis by resonance frequency using implants with the same design with and without surface treatment [12, 13].

2.1.1 Machined surfaces (smooth)

Machined implants with an untreated surface are considered to have a smooth surface. Machined implants with an untreated surface are considered to have a smooth surface. However, they have small grooves that allow the bone mineralization process towards the implant, but they do not have an osteoinductive surface. This type of surface is considered anisotropic, which is responsible for promoting the cell adhesion process and the production of the protein matrix. The machined implant has a surface roughness between 0.5 μm and 1 μm. This smooth surface is formed a surficial microgroove, resulting from the machining process, produced by the passage of the cutting tool. This type of surface does not receive chemical or mechanical treatment, presenting only the micromorphology of the machining process [9]. **Figure 3** shows representative images of a smooth surface at different magnifications.

2.1.2 Surfaces textured by the plasma spray process

Plasma spray is the type of plasma spray treatment that has been most used, which is elaborated with the ionized flame of a gas heated between 10000°C and 30000°C,

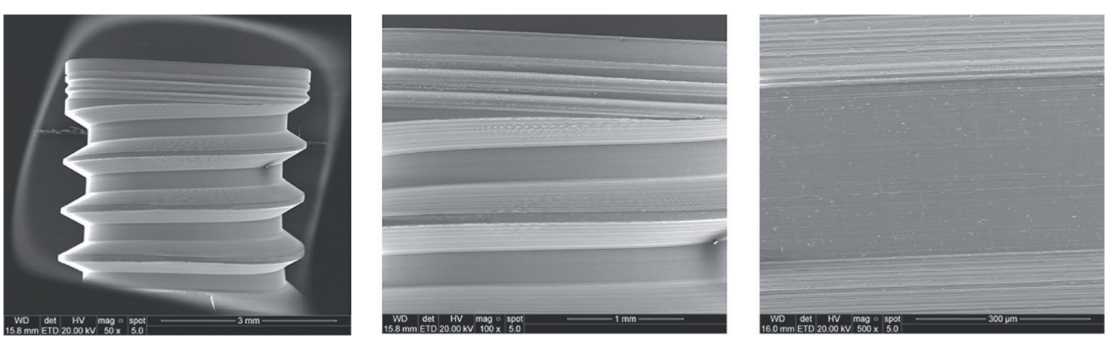

Figure 3.
Representative SEM images with different magnifications of the surface micro grooves resulting from the machining process, produced by the passage of the cutting tool.

and the particles are launched at high speed against the implant body. Upon contact, these particles cool and solidify. Plasma spray is used to apply and incorporate Ti (titanium) and HA (hydroxyapatite) onto the implant surface [14].

Titanium plasma spray is formed by coating the implant with ionized gases by thermal spraying with titanium plasma spray. In this method, the ionized flame of a gas is launched against the implant wall at an elevated temperature between 10000°C and 30000°C. With this change, there is an acceleration of blood absorption, due to the effect on the wettability of this surface, there is an increase in the surface contact area, promoting better osseointegration [14, 15]. The titanium particle is fused on the surface, forming a ~ 50 μm thick layer, with the resulting coating being between 10 μm and 40 μm, increasing the surface of the implant. Herrero-Climent et al. [16], carried out a comparative study between plasma spray titanium (TPS) and titanium oxide blasted surfaces, demonstrating that the TPS surface presented a unique pattern of bone matrix formation when compared to the titanium oxide blasted surface.

Meanwhile, the treatment for coating with apatite nucleation occurs through three stages: alkaline treatment, thermal treatment, and immersion in a synthetic solution equivalent to blood plasma. This layer is obtained by spraying the plasma spray of hydroxyapatite onto the implant surface [15]. Roughness depends on the size of the particles, their adhesion, the speed and distance at which they were launched against the implant [14]. According to De Groot et al. [17], hydroxyapatite plasma spray implants have already been studied and considered to have a high potential for osseointegration. Other authors showed that titanium implants coated with plasma spray of hydroxyapatite had greater amounts of bone at the bone/implant interface when compared to implants with smooth surface [18, 19].

2.1.3 Laser surface treatment

In this type of surface treatment, the implant's surface is modified by irradiation by means of laser beams, producing erosions and a rough surface. It is considered a clean treatment as it does not interact with any external material during the surface modification process, in which the laser beam acts as a physical means in the treatment of this surface [15]. Studies have shown that this method can stimulate adequate osseointegration to implants [20, 21]. In addition, laser treatment has the advantage that oriented, regular micro-grooves with different depths can be created at defined points on the surface [14]. Roughness sizes depend on the pulse intensity of the emitting source [9]. This type of surface has been extensively studied by Ricci et al. [22], showing that micro sulci can modulate cell organization and, consequently, positively influence the osseointegration process.

2.1.4 Surface blasting by micro particles

This type of treatment for the implant surface is blasting with microparticles of some abrasive material (e.g., aluminum oxide or titanium oxide), which promotes irregular surface depressions. Ideally, there should be no adhesion of particles to the implant (residues), which should be removed during the cleaning and decontamination processes. Obviously, the roughness caused depends on the size of the microparticles used, the time and pressure used in the process [9, 14, 15, 21]. In **Figure 4** it is possible to observe the result of the treatment of a surface using only the sandblasting with aluminum oxide particles. However, the roughness produced has sharp edges and several non-uniform irregularities, which can make contact and cell organization difficult and, consequently, have an opposite effect to what is expected for an adequate osseointegration. Currently, this type of isolated treatment is little used by the industry.

Moreover, SEM (scanning electron microscopy) analysis of implants subjected to microparticle blasting, in this case aluminum oxide (Al_2O_3), show residues from the manufacturing process that can contaminate the implant surface (**Figure 5**), which would be harmful to osseointegration, as they would compete with calcium for bone formation. On the other hand, the use of titanium oxide in place of alumina can be an alternative to avoid these undesirable effects on the implant surface [23–25].

In this sense, Gehrke and Collaborators, comparing implants blasted with aluminum oxide and titanium oxide, demonstrated that the residual particles from blasting can interfere in the osseointegration process in these places where they are present [23]. Moreover, in other studies using in vitro and in vivo tests, were demonstrated an excellent biologic response of the surfaces treated by sandblasting with microparticles of titanium oxide [24], with minimal risk of contamination by the residual debris from the blasting procedure [25].

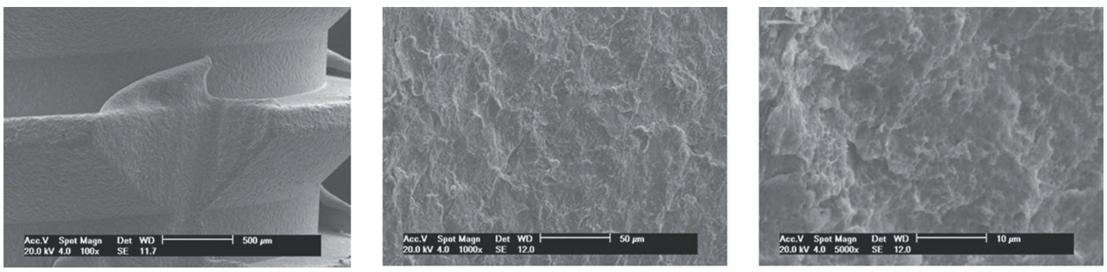

Figure 4.
SEM images of a surface treated by sandblasting with aluminum oxide, where we can observe in higher magnifications the presence of sharp edges and other deformations resulting from this surface treatment process.

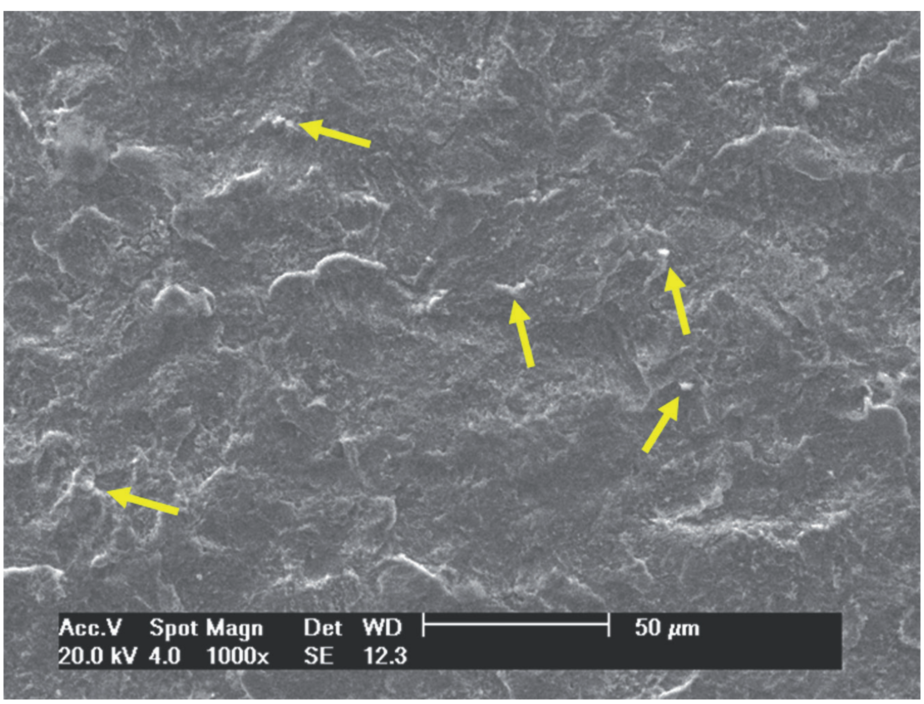

Figure 5.
SEM image showing some locations, among several in the same sample, with the presence of residual microparticles on a blast-treated surface. This surface continued to show the presence of residues even after the washing and decontamination process.

2.1.5 Surface blast treatment followed by acid etching

As described above, the sandblasting process, which can be done by different particles (e.g., aluminum oxide or titanium oxide) and different sizes (150–500 μm), creates deep, amorphous roughness and can leave sharp edges sharp on the surface of the implants. Therefore, acid etching was used after the blasting process, leaving a much more regular surface, and eliminating (rounding) the peaks left by the first process. This union between the 2 types of treatment was called and patented as SLA surface (Sandblasted, large grit, acid-etched implant surface) by the Straumann Company. For the treatment of SLA Straumann surface implants, blasting with coarse-grained aluminum oxide (250–500 μm) is initially performed, producing macro-roughness in the implant, followed by an acid etching (HCl/H2SO4), which is responsible for the microroughness on this surface [6]. However, this treatment model is used by several companies, with variation both in the blasting process and in the acid etching process.

In this sense, comparing 2 different models of implant surface blasting with aluminum oxide and titanium oxide and subsequent etching by different acids in scanning microscopy images, we can observe that the texture of the surfaces has a different morphology between them, as shown in images in **Figure 6.**

To accelerate and improve the osseointegration process of this type of SLA surface, the processing means were modified, being made under nitrogen atmosphere and later stored in isotonic NaCl (sodium chloride), this surface being called SLActive. Thus, these implants could provide a more active osseointegration process than other implants [26] and, consequently, could be loaded with a reduced waiting time. In this new technique, the surface is hydroxylated, and this chemical change improves the surface structures, which are ideal for protein adsorption and to promote immediate implant intent into bone tissue. The SLActive surface was developed to optimize implant stability in less time and reduce treatment risks in the early stages [27]. Rupp et al. [27], demonstrated that the SLActive and SLA surfaces did not show apparent differences when both had the same topography, however, statistically significant differences were observed within two or four weeks of BIC repair (bone/implant contact). This demonstrates that the changes were not a consequence of the topography, but that they were probably due to changes in the chemical structures made on the surface. Oates et al. [28] demonstrated that accelerated bone formation can influence

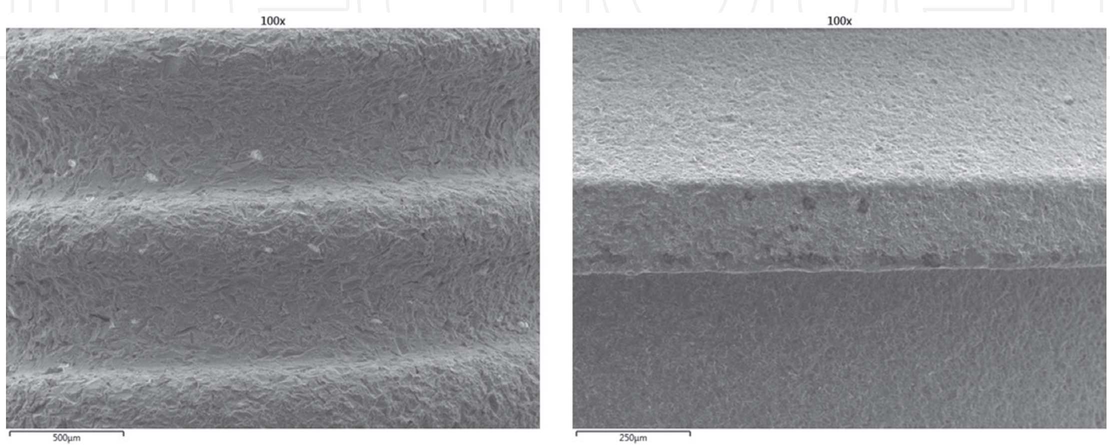

Figure 6.
Images obtained by SEM at 100x magnification, showing 2 different models of implant surface sandblasting: (a) with aluminum oxide and (b) with titanium oxide. Both received further conditioning by different acids. We can observe that the surface texture has a different morphology between them.

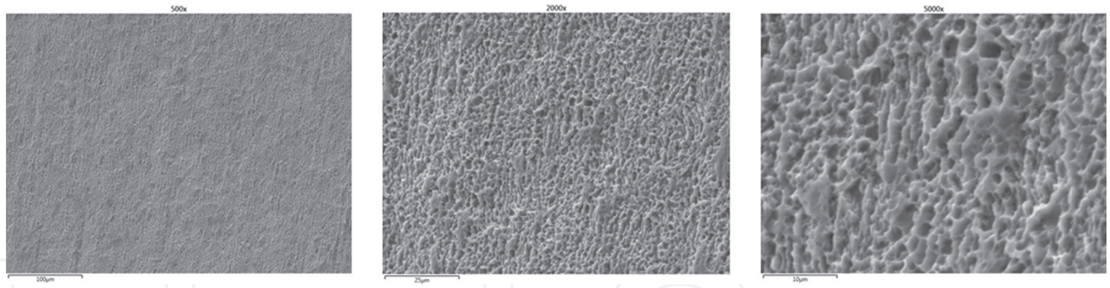

Figure 7.
SEM images at different magnifications of an acid-etched implant surface.

implant stability. Also, in that same study, the authors observed that the transition time from primary stability to secondary stability was two weeks for SLActive surface and four weeks for SLA.

2.1.6 Acid conditioning treatment

The surface treatment by conditioning through acids is made by immersing the implant in an acidic substance, which causes erosion on this surface. Acid concentration, time and temperature are determining factors of the surface microstructure. On the smooth surface, the most used process is the double acid attack, carried out with sulfuric acid and hydrochloride [29]. This surface treatment process provides a very uniform morphology, however, with less depth of ripple compared to SLA-type surfaces. An advantage of this type of treatment is that it supposedly does not leave residues of contaminants in your process. In **Figure 7** we can see an implant surface treated by acid etching.

2.1.7 Anodized surfaces

In the case of nanotextured surfaces, treated with anodizing, they receive an extra layer of titanium dioxide. Thus, these surfaces are obtained using the implant as an anode, activating ions, and applying an electrical potential, which generates charge and ion transfer reactions. Controlled, the electric field will guide the oxidation process that takes place on the implant and results in an increase in the thickness of the titanium oxide (TiO_2) layer. With the increase of this titanium oxide layer and the addition of other elements, such as phosphate (PO_4), there is a potentialization of osseointegration [9].

Corrosion resistance and biocompatibility are related to the presence of a non-reactive oxide layer, which prevents the formation of fibrous tissue around the implant and creates a direct contact with the bone tissue [21, 27]. Implants with this surface treatment are less dependent on chemical composition, as the resulting process is defined by a complementary increase in bone-implant contact [30]. This type of surface treatment has become well known in the implantology field for being used in implants from the Nobel Biocare company (Sweden). **Figure 8** shows images obtained by SEM of the surface of an anodized implant.

2.1.8 Biomimetic surfaces

Abe et al. [31], presented a procedure that allowed to cover the implant surface with a uniform layer of HA similar to the biological layer, up to 15 μm thick, called the biomimetic method. This type of surface treatment consists of the heterogeneous

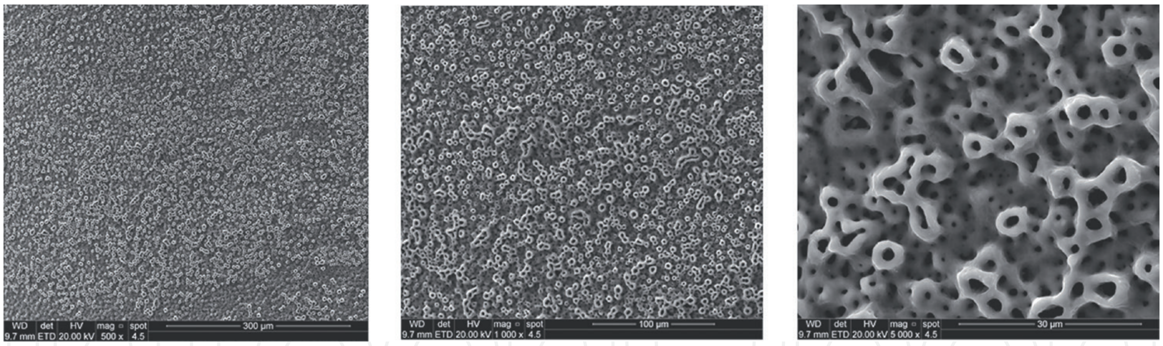

Figure 8.
SEM images with different magnifications of an implant surface treated by the anodized method.

precipitation of calcium phosphate under physiological conditions of temperature and pH on the dental implant, using a solution of ions similar to blood plasma with a view to deposition of the apatite layer. Once the molecules are integrated into the material structure, they are gradually released, thus being able to increase bone conductivity and enhance bone formation around the implant [32]. Currently, calcium phosphate is one of the main biomaterials for bone tissue replacement and regeneration, as its main characteristics are similar to the mineral phase of bone tissue, excellent biocompatibility, bioactivity, absence of toxicity, degradation rates variables and osteoconductivity [32]. Another advantage of this surface treatment is that biologically active molecules, such as osteogenic agents, can be precipitated as inorganic components to form a matrix with both osteoinductive (growth factors) and osteoconductive (calcium phosphate layer) properties [21, 27]. **Figure 9** shows SEM images of an implant surface treated by the biomimetic method.

Studies on this type of surface have shown greater contact between bone and implant on surfaces with biomimetic calcium phosphate coatings than on untreated surfaces [21]. Huang et al. [33], investigated the effects of chemical and nanotopographic modifications in the initial stages of osseointegration, and the results showed a greater removal torque and greater bone apposition for implants with chemical nanotopographic modifications. Recently, we presented in a study of adhesion, cell growth and in vitro mineralization using a surface with deposition of hydroxyapatite nanoparticles showed a superior result to the control group [23]. Furthermore, our group studied the deposition of calcium–magnesium on the surface of implants, where an acceleration and improvement in the osseointegration of implants inserted in rabbit tibiae was observed histomorphometrically, compared to implants with surface treated by blasting with titanium oxide and conditioning acid.

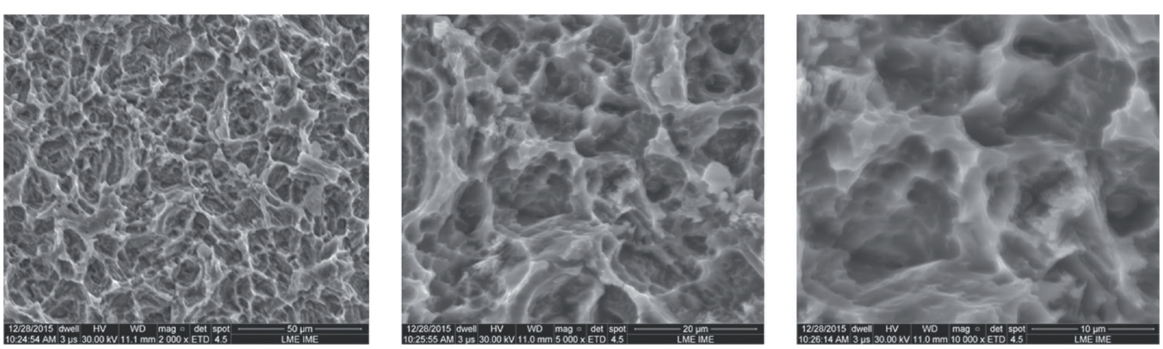

Figure 9.
SEM images at different magnifications showing an implant surface treated by the biomimetic method.

In conclusion, we can say that the main results of surface treatments with the aim of improving osseointegration were to accelerate the osseointegration time, allowing the anticipated loading of implants. On the other hand, osseointegration occurs on the surfaces of dental implants, regardless of whether these are treated or not. Surface treatments improve the result of osseointegration, especially in the initial stages, benefiting a bone apposition with qualitative and quantitative density. Despite the results presented, the dental literature is not unanimous as to the best type of surface treatment.

2.2 Implant body shape

Bone density and quality, surgical technique and implant body geometry are factors to be considered to obtain a shorter period of osseointegration, thus enabling a reduction in treatment time [34]. The relationship between these factors will determine the initial stability of the implant, defined as the absence of movement after its surgical insertion [35–38]. According to some studies [34, 39, 40], the success of implants is dependent on the initial stability achieved, as this is a prerequisite for bone cell differentiation and osseointegration [41]. The shape of the implant has been one of the most contested variables among engineers and researchers, as it can directly influence the biomechanics of the implant inserted into bone tissue [42].

Regarding the implant body shapes most frequently found on the world market, we have cylindrical, semi-tapered and tapered implants, as shown schematically in **Figure 10**. Currently, most implant manufacturing companies use the last two implant designs mentioned above (semi-tapered or tapered). Initially, tapered implant designs were introduced in implant dentistry with the main advantage of producing better initial stability compared to cylindrical implants. Later, several studies were developed and published comparing the tapered with the cylindrical implant designs [43–45]. Recently, new discoveries about the advantages of these designs were observed, such as and, mainly, the lesser surgical trauma during the drilling procedures and insertion of these implants in the bone tissue [46].

Other authors have shown that the use of implants with a conical design can increase stability in low-density bone, since results demonstrated greater contact osteogenesis with this type of design [45]. However, the difference in this stability between implants with different designs has not been sufficiently investigated, with

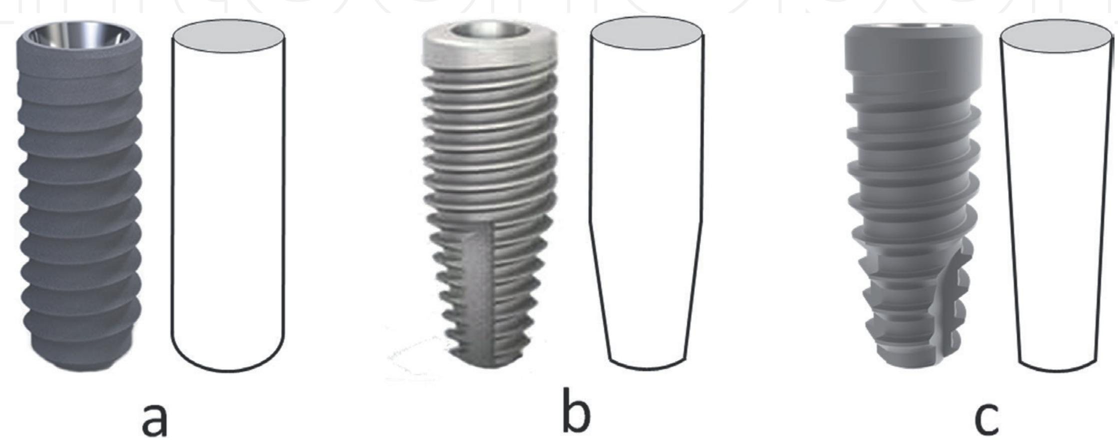

Figure 10.
Representative images of 3 implant designs: (a) cylindrical implant, (b) semi-tapered implant and (c) tapered implant.

disagreements about the fact that the tapered implant shows higher values of initial stability when compared to the cylindrical implant [47] or not cylindrical [48].

For years, companies have sought to commercialize the tapered shape in order to combine the advantages of the two designs, considering that a tapered implant creates a basis for adequate primary stability, by allowing the gradual expansion of thin bone crests and determining a minimum of possible stress at the interface with the surrounding bone [49]. In addition, tapered implants can be used in different clinical situations, being installed with less damage to the bone bed, but their installation in the lower arch has not been widespread, as it is strongly recommended for areas with low density bone or bone beds after dental extractions [50].

2.3 Shape of the implant threads

During the last decades, different implant macrogeometries have been proposed and marketed, with variation in different points, such as body design, cervical and apical design, threads design, among others. As for the thread design, these can be found with square, V-shaped, trapezoidal and inverted trapezoidal shapes [45]. **Figure 11** demonstrates different implant coil designs presented and marketed by different implant companies.

For some authors, implants with narrow pattern threads increase the surface area, leading to a more favorable stress distribution, and achieving higher primary stability values [51, 52]. In addition, stresses are more sensitive to thread pitch in cancellous bone than in cortical bone [53]. However, considering that the ideal implant should provide a balance between compression and traction forces, minimizing the generation of shear force, the square shape was designed to reduce such force at the bone-interface. Implant and increase the stability of the implant [53]. Thread depth, thickness, angle, end and helical angle are some of the various geometric patterns that determine the functional surface of the thread and affect the distribution of biomechanical loads on implants [7].

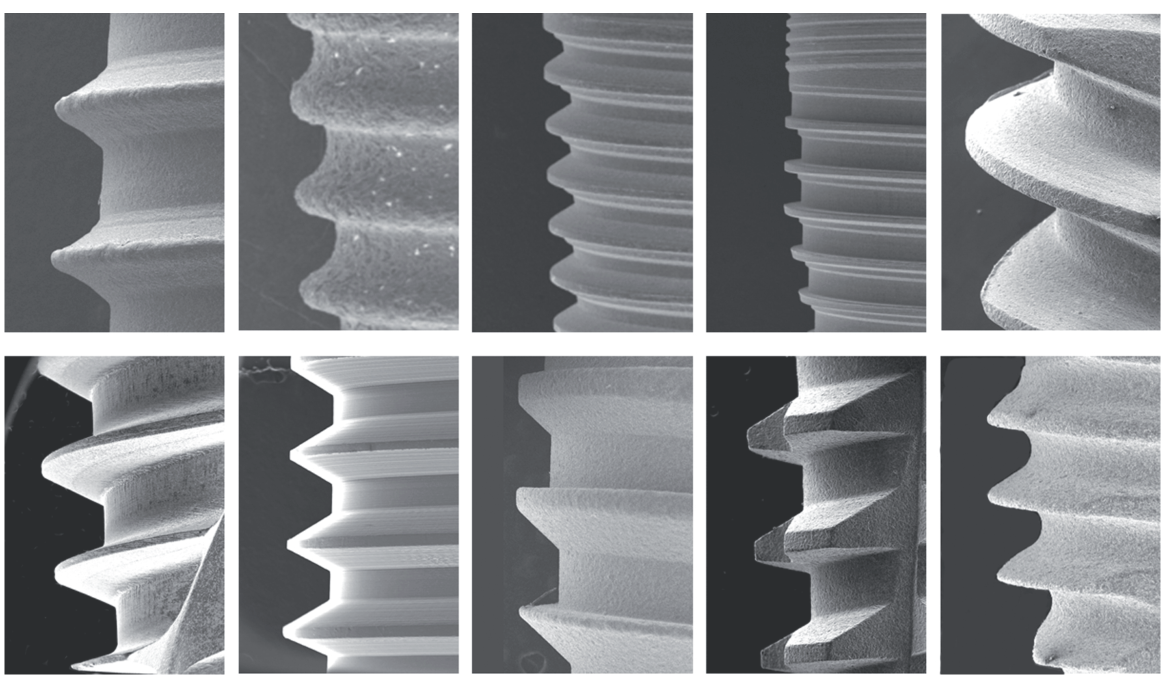

Figure 11.
Images of different designs of implant threads produced and marketed.

Transforming shear forces into resistance forces at the bone interface is the proposal to incorporate threads into the body of implants [54, 55]. This is why most implants are currently threaded, as non-threaded implants essentially result in shear forces at the bone-implant interface [26, 56–58]. Kohn et al. [59], demonstrated that the tension is more concentrated in the area of contact between the bone and the crest of the thread and that this tension decreases from the crest to its most basal portion. It has been proposed that threads, due to their shapes, would generate heterogeneous stress fields within the "physiological overload zone", thus promoting new bone formation [60], which would justify the formation of bone in intimate contact with the crest of the threads. However, it should be noted that the threads have different shapes, therefore different distributions of forces and biological responses, which will be discussed below.

The functional surface area per unit of implant length can be modified by varying 3 parameters of the thread geometry: pitch, shape and depth [61]. The shape of the thread is a very important feature of its general geometry. The shape of the thread can change the direction of occlusal loading of the prosthesis to different directions in the bone. Under axial loads, a triangular thread is comparable to a trapezoidal thread when the face angles are similar, which are usually 30 degrees [62]. It has been suggested that a square thread design reduces the shear force component, transferring the axial force that falls on the prosthesis to the implant body in a more axial fashion, favoring bone compression [63]. This would be particularly important for the bone crest region, where, according to Lum [64], most occlusal forces are distributed. Therefore, implant design considerations that reduce the development of shear forces at the bone-implant interface can improve long-term success, particularly in low-density bones [65]. The original Bränemark implant, introduced in 1965, had triangular threads, to be installed in place with threaded osteotomy16. The initial design has been modified over the years to allow for a simpler and more efficient installation, as well as a better distribution of loads. Albrektsson et al. [66], recommend that the top of the threads be rounded to relieve stress concentration.

The thread pitch is defined as the number of threads per unit of length in the same axial plane and on the same side of the axis of the implant body [61]. The smaller the pitch, the greater the number of threads in the implant body, and therefore the greater surface area. So, if the magnitude of force is increased or bone density is reduced, the thread pitch can be reduced to increase the functional surface area, thus improving the stress distribution. Ease of surgical insertion is also associated with the number of threads. The smaller the number of threads, the easier the implant insertion. In denser bones, however, a smaller number of threads is more favorable, since the hard bone offers greater resistance during insertion of a threaded implant [61]. Another important factor to be discussed is the difference between the final milling dimension proposed by the manufacturer and the implant body. Usually, the dimension of the last reamer used for the osteotomy corresponds to the diameter of the implant body. Thus, the deeper the turns, the greater this difference will be, causing a greater insertion of the implant (threads) into the bone tissue. **Figure 12** schematically shows the difference between the cutter and the implant in two different thread models.

Other concept is the "double-thread" and "triple-thread" implants has been recently introduced [63]. These implants have been associated with faster threading in the surgical alveolus and with an increase in primary stability, as they require a higher insertion torque, and are indicated for cases of low density bone [67]. However, the number of threads, their depth and the total surface area are exactly the same regardless of the number of threads, whether single, double or triple.

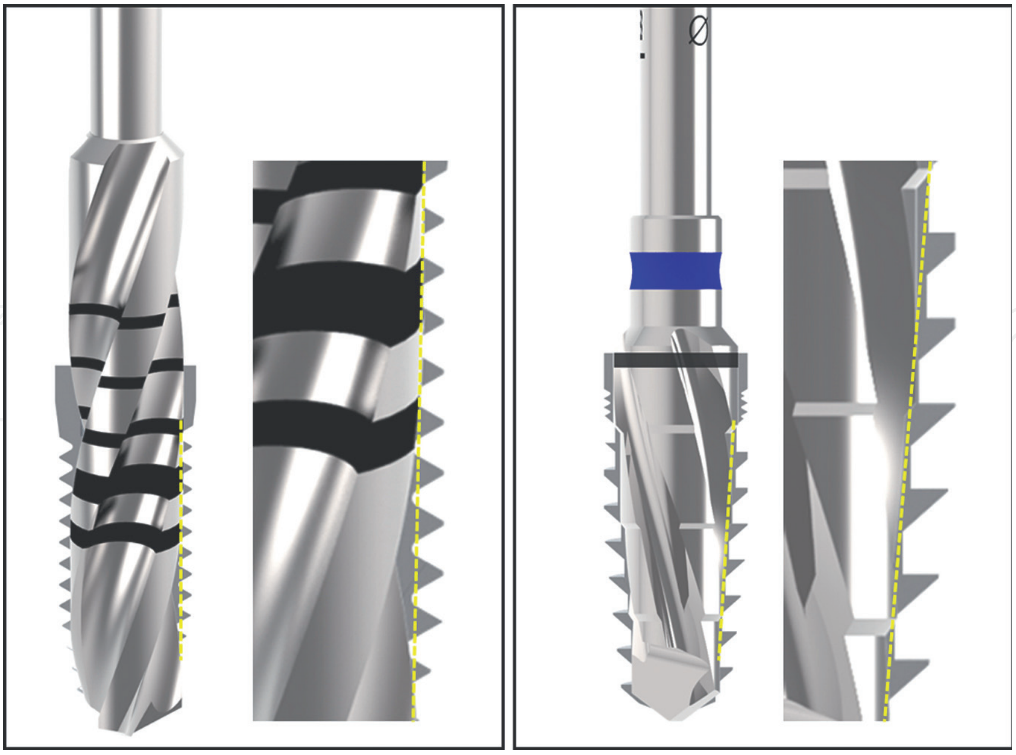

Figure 12.
Schematic images of the difference between the final reamer used for the osteotomy of each implant model and the thread depth that would be introduced into the bone tissue.

Instead of using a single instrument to make a 0.6 mm thread for each turn on the device, 2 or 3 instruments make 2 or 3 turns at the same time. These 2 or 3 devices are independent, starting 180° apart from each other and are also 0.6 mm threaded apart. In other words, a single thread contours the implant body 0.6 mm apart and the double thread 1.2 mm apart, on the same surface area. This technique allows installation of the implant in half the time [63].

The triangular thread shape has a 10 times greater shear over the bone than a square thread and is similar to the trapezoidal thread [61]. Square threads have an optimized surface area, which is great for transmitting intrusive and compressive loads, resulting in less bone tension. Trapezoidal threads are optimized to resist tensile loads [68]. Implants with reverse trapezoidal threads have fewer and shallower threads [63].

Another advance in the shape of threads has been the introduction of round shapes, which are said to induce osseocompression [63]. A round-shaped design has shown, in histological observations in animals, the formation of lamellar bone by osseocompression [69]. This allows the bone to be shaped and compacted circumferentially.

Thread depth refers to the distance between the largest and smallest diameter of the thread. Traditional implants offer a uniform thread depth, however this can be varied along the length of the implant in order to provide a functional surface area in the most intense stress regions (such as the alveolar bone crest region) [61]. Regarding the quality and percentage of osseointegration, Steigenga et al. [70], analyzed the effect of 3 types of threads (triangular, square and trapezoidal) through histomorphometric and reverse torque analyses. They found a significantly higher reverse feel and percentage of bone-to-implant contact for implants with square threads. No significant difference was found between the tests for implants with triangular and trapezoidal threads, corroborating the results of other studies with different methodologies [61, 62, 70]. It should be considered that the different shapes of the threads cause different distributions of forces and biological responses [56, 57, 59, 60, 62, 71, 72].

2.4 New implant macrogeometries

Modifications in the morphology and roughness of the implant surface were initially attempted not only to accelerate the host's response to the implant, but also to increase the level of mechanical locking between the bone and the implant surface, thus improving initial stability and subsequent dissipation loads during the functional requirements of the system [72]. Numerous studies based on histological tests have shown that surface texturing, created by different processes, leads to greater contact between bone and implant compared to the machined surface [6, 10, 73], which is a desirable answer to improve the overall biomechanics of the system, as show in the Section 2.1 of the present chapter. However, recently, new implant designs have been developed that seek, mainly, to accelerate and improve the quality of osseointegration through the concept of decreasing bone tissue compression during implant installation.

In most implant systems, osteotomy is recommended using the last drill with a diameter slightly smaller than the diameter of the implant, so that it can be inserted with a high degree of torque. Obviously, the more undersized the site that will receive the implant, the greater the insertion torque. However, studies have shown that high levels of torque can cause high compression of bone tissue, which can lead to extensive bone remodeling over time [74]. Several other studies have shown that, depending on the implant insertion torque and the physiological tolerance limit, microfractures or compression osteonecrosis may occur [75–77].

In this sense, it was recently proposed in some studies that approximating the osteotomy diameter with the diameter of the implant that will be implanted can facilitate and improve osseointegration [77, 78]. This fact was demonstrated in other animal studies, in which implants that were installed with high torque had a certain amount of necrotic bone inside the threads of the implants, while in samples where a perforation with a diameter closer to the diameter of the implant, greater new bone formation [78]. In this case, the free space created within the implant threads, resulting from the diameter-drill-implant relationship, was called healing chambers (**Figure 13**).

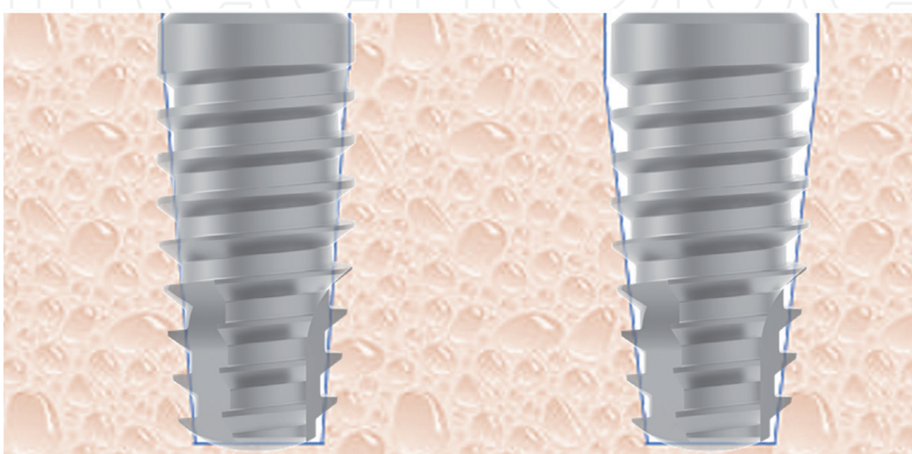

Figure 13.
Schematic images of the relationship between the osteotomy (blue lines) and the implant diameter inserted. In the left image the regular osteotomy and in the right image the oversized osteotomy generating the healing chambers.

In order to reduce the compression during insertion of the implant into bone tissue, two new implant models were recently launched on the world market, the BLX Straumann model (Basel, Switzerland) and the Maestro Implacil De Bortoli model (São Paulo, Brazil), that are presented in the **Figure 14**.

The first model (BLX Straumann implant) has technical recommendations to avoid bone compression, that during the execution of movements for insertion, whenever the torque of 35 N is reached, the professional must perform anti-rotational turns movements (removal torque) and then go back to inserting, repeating this movement whenever necessary. Thus, with a torque value below 35 N, bone tissue compression would be low, facilitating the osseointegration process. While in the second model described (Maestro Implacil implant), healing chambers were created in the implant body, which consist of small circular cavities 0.2 mm deep by 0.5 mm in diameter, as shown in **Figure 15**. With the presence of these healing chambers, bone tissue decompression occurs automatically during its insertion, not

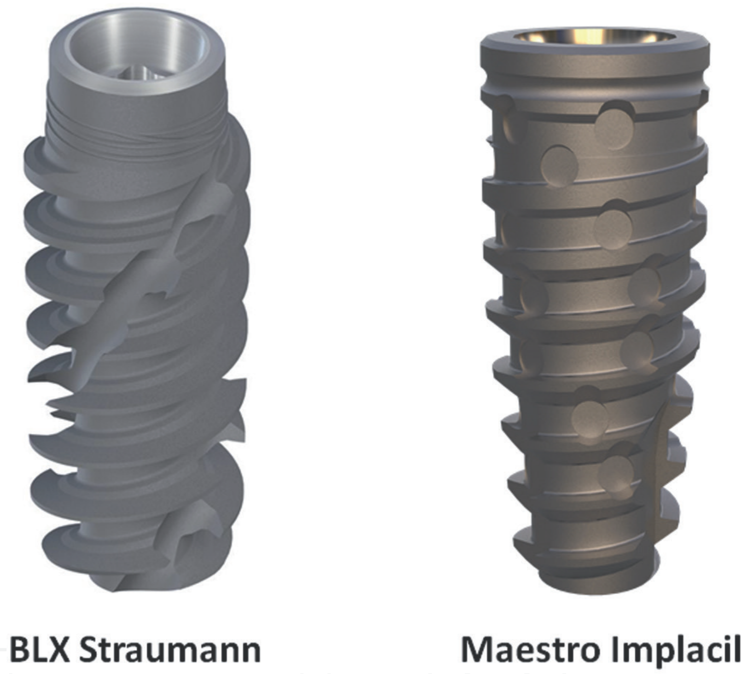

Figure 14.
Image of both implant models recently launched on the world market that were developed to reduce bone compression during the insertion process.

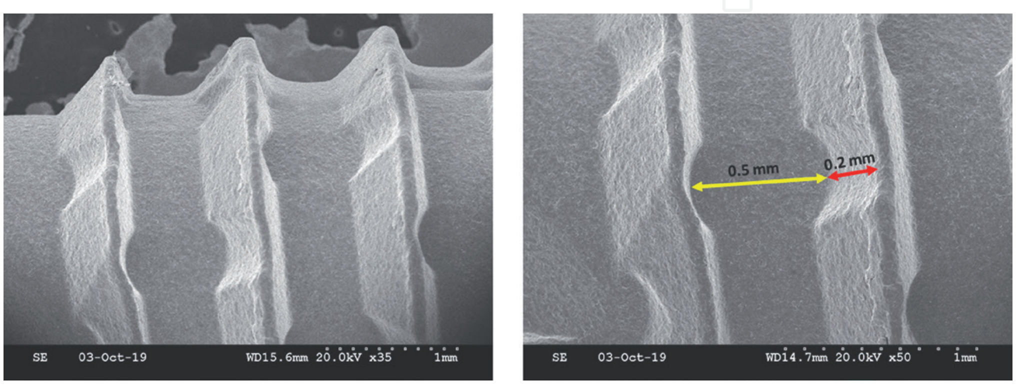

Figure 15.
SEM image of the healing chambers that were created in the implant body, which consist of small circular cavities 0.2 mm deep by 0.5 mm in diameter.

requiring any additional maneuvers. As reported in our studies of this new implant macrogeometries, this implant model has a reduced insertion torque compared to the model that does not feature healing chambers but did not show lower initial stability values measured by resonance frequency [12, 79–81].

3. Conclusions

Within the exposed in this chapter, we can conclude that there is no implant with ideal characteristics, whether from a nano-, micro- or macrogeometric point of view. However, great advances in the knowledge of biological processes involving implant osseointegration have been discovered in recent years, which allowed a better understanding of these events. Undoubtedly, the new macrogeometric designs, based on the biological concept of minimizing surgical trauma, brought important advances in terms of accelerating the osseointegration process and, mainly, being able to benefit patients with systemic and/or local weaknesses that could negatively interfere in the process of implant osseointegration.

Conflict of interest

The authors declare no conflict of interest.

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