Original article

Macroscopic and microscopic evaluation of a new implant design supporting immediately loaded full arch rehabilitation

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Summary

The purpose of this study is to evaluate macroscopic and microscopic appearance of a new implant design, with particular emphasis given to the type of prosthesis connection. Two dental implants of the same type (Torque Type®, WINSIX®, BioSAFin. S.r.l. - Ancona, Italy), with sandblasted and acid etched surfaces (Micro Rough Surface®), but differing from each other for the prosthesis connection system, were examined by scanning electron microscope (SEM) analysis at different magnifications: TTI implant, with a hexagonal internal connection, and TTX implant, with a hexagonal external connection. SEM analysis showed that the Torque Type® implant is characterized by a truncated cone shape with tapered tips. The implant body showed a double loop thread and double pitch with blunt tips. For both types of connection, the implant neck was 0.7 mm in height with a 3% taper. This implant design may be able to guarantee osteotomic properties at the time of insertion in a surgical site suitably prepared, a facilitated screwing, thanks to the thread pitch and to the broad and deep draining grooves, thereby ensuring a good primary stability. The different connection design appears defined and precise, in order to ensure a good interface between the fixture and the prosthetic components. Therefore, this design appears to be particularly suitable in cases where a good primary stability is necessary and a precise coupling between endosseous and prosthetic components, as it allows an easy insertion of the fixture even in conditions of reduced bone availability, and in cases of immediately loaded full-arch rehabilitations.

Key words: dental implant, Scanning Electron Microscope (SEM), implant connection.

Introduction

Osseointegrated implantology, thanks to many studies, is now considered a surgical discipline with proven effectiveness. Success in implant dentistry consists in getting a good rate of integration between implant and host bone, which defines a good osseointegration according to the principles initially introduced by Branemark and subsequently developed by numerous studies over the years (1-3).

The implant design is a key factor to achieve good primary stability. It should be designed to guarantee the establishment of a direct connection between bone tissue and implant surface during the early stages of the healing process, without the interposition of fibrous tissue, as well as to achieve an even distribution of the loads which, through the masticatory system, are transmitted to the peri-implant bone tissue whilst chewing (4,5).

There are two fundamental aspects of implant design: the macro-structure, characterized by the shape of the body, the characteristics of the neck and the apex, by the design, by the number and pitch of the thread, and the microstructure, characterized by the surface treatment. In addition, there is also the good accuracy of the prosthetic components (6-8).

It is known that differences in implant shapes induce significant changes in force distribution on the surrounding bone (9). The macroscopic geometric pattern of a dental implant can assume a cylindrical or conical form. For some years some companies have marketed the tapered form, with the aim of combining the advantages of both designs. A tapered implant creates the basis for an excellent primary stability by gradually allowing thin ridge expansion and determining the least stress possible at the interface with the surrounding bone (10,11).

The design of the implant neck, or crestal module, has undergone considerable evolution in recent years. The implant neck represents the transosseous area of the implant body where the highest concentration of mechanical stresses are evinced and where the transition between the hard tissue and soft tissue support occurs. Discriminating elements of the crestal module could be identified in the geometrical design and in the surface type. The possible geometric profiles of the implant neck are essentially three: straight walls, diverging walls and converging walls. Despite the diverging walls type seeming to be the best form, as it can provide a slightly higher primary stability after the implant insertion, from the clinical point of view the behavior of the bone before and after the load is not dissimilar between the three geometric figures. In fact, an aspect commonly observed at the level of the crestal module is the different bone level before and after the occlusal loading. Before loading, if the implant was positioned so that the prosthetic platform is at the level of the crestal bone, there will always be a clinical situation where the bone covers the entire implant neck. After application of the load there is invariably a vertical bone loss, the level of which is located in correspondence of the first thread. All this takes place independently from the geometrical shape and the level of the first thread.

The crestal module height was reduced over time by various manufacturers, until today, when the height of the smooth collar is reduced to less than 2 mm.

The morphology of the crestal module evolved in the same way - from a smooth surface to a treated surface with microthreads for increased stability of bone in the coronal zone, to favour aesthetics and peri-implant health (12).

The use of the smooth neck arises from the necessity to limit the plaque retention at the border zone between the implant, bone and soft tissue. The presence of micro retentions at the level of the crestal module is designed to adequately dissipate forces that are expressed at the cervical area of the bone-implant interface in the presence of occlusal stress, in all implant types, thus allowing to maintain the height of the bone spikes in accordance with the law of Wolff (13), a phenomenon that in the presence of a smooth neck does not happen.

As regards the design and the pitch of the threads, these must be designed to maximize the transmission of forces between the implant and surrounding bone tissue, and to correctly distributed stress arising between the bone interface and the implant (14). Their main role is to increase primary stability and extend the available surface of the implant for bone contact.

Among the various thread designs, the V-shaped threads and the broader square threads have been shown to generate less stress and to better distribute the loading forces compared to the thin threads and tapered apex threads (15). The phenomenon is best appreciated in the bone marrow, while no difference have been found in cortical bone.

Another important factor necessary to achieve success in implantology is represented by the surface properties of the material used (16). The micro-topography of the implant surface is able to affect the percentage of BIC (Bone-to-Implant Contact) and the cellular response of the host tissue (17). The treated surfaces stimulate osteoblast proliferation, as demonstrated by the increased expression of biological markers, which transposes into an increase of osteogenesis, thus assuming an important role regarding the long-term survival of the osseointegrated implants (18).

The titanium surface can be prepared with different techniques in order to obtain an optimal degree of roughness of the surface, as it has been shown that the wider the functional surface is in contact with the bone, the better the support for the prosthesis (19,20).

The rough implant surfaces determine a slightly better bone tissue response in quantitative terms of bone-implant contact percentage (21-23). The purpose of the surface treatment is to increase the contact area between the bone and the implant, thus improving the osseointegration. Even with only the threads, the resistance degree to tensile forces and compression is greater than smooth implants not threaded, and the presence of microretentions on the surface of the fixture allows to increase the tensile and torsion strength of the implant. In addition, some authors have demonstrated how macrophages, epithelial cells and osteoblasts, have a high tropism against rough surfaces (24,25).

In order to obtain a surface topography able to promote the process of osseointegration, various surface treatments have been tried out, such as sandblasting (26), acid etching (27), combined treatment of blasting and etching (28), surface coating with micro-granules of hydroxyapatite (29) or particles of titanium oxide (30), or electrochemical deposition (31). Recent researches highlighted how the micro-roughness obtained by blasting and acid etching is compatible with best clinical and histological results.

Several options also affect the types of connections between the endosseous fixture and implant prosthetic components.

External hexagonal connection was the first connection system used in implantology which was ideated by Branemark only as coupling mechanism to easily guide the stump insertion; its function was then expanded to become a real anti-rotation mechanism. The interface and the tightening screw are subject to very high masticatory loads, subjecting the screw to insidious lateral bending forces, tilting and elongation that may mobilize it (32).

Of the internal connections, the most widely used are internal hexagonal, internal octagonal, conical screw and Morse connections. The internal connections have shown an increased stability, better mechanical stability and resistance to lateral forces than external ones.

The aim of this study is to describe the macroscopic and microscopic appearance of a new implant design, with particular emphasis on the type of prosthesis connection.

Materials and Methods

In this study, the macroscopic and microscopic appearance of a new implant design was evaluated, with particular emphasis on the type of prosthetic connection. Two dental implants of the same type (Torque Type®, WINSIX®, BioSAFin S.r.l., Ancona, Italy), with sandblasted and acid etched surfaces (Micro Rough Surface®), but differing from each other for the prosthesis connection system, were examined by scanning electron microscope (SEM) analysis at different magnifications: TTI implant (Torque Type® Implant I), with a hexagonal internal connection, and TTX implant (Torque Type® Implant X), with a hexagonal external connection.

The macrostructure of the geometrical design of the different segments of the fixture, the characteristics of the prosthetic connection, and the microstructure of the implant surface were analyzed by Scanning Electron Microscope (Zeizz EVO-50, Cambridge, UK). Electron acceleration potential was kept between 15 and 25 kV, and the working distance kept between 9 and 12 mm, according to the different requirements and types of samples.

Results

At SEM analysis, both TTI and TTX implants were characterized by a truncated cone shape, with a tapered apex (Fig. 1).

Both implants showed a reduced crestal module represented by a smooth neck 0.7 mm height and 3% taper. The implant-prosthetic connection was characterized by a very deep lodging for the fixing screw, with a hexagonal form with a double parallel type connection (Fig. 2). The TTX implant includes a crestal module with a smooth surface, dominated by the external hexagonal connection module (Fig. 3). At SEM analysis, the neck surface seemed completely smooth and well polished; at 3000x magnification there were signs of lathing, typical of machined surfaces (Fig. 4).

With regard to the implant body, this was equipped with a double thread and double pitch. The thread pitch was 0.60 mm. The threads are "V" shaped with rounded tips and slopes inclined at approximately 45°.

The main thread has a step along its apical side which forms the smaller thread (Fig. 5). The depth of the main threads is 0.375 mm, as long as the depth of the secondary threads is 0.125 mm. The main thread width ranges from 0.07 mm at the top to 0.50 mm at the base, while

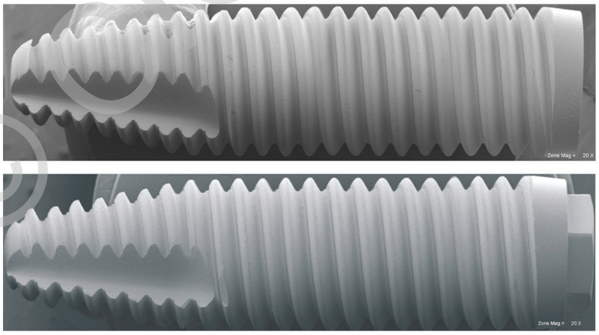

Figure 1 - SEM visualization of WINSIX® TT and TTX implants. It may be noticed the truncated shape of the fixture with tapered apex.

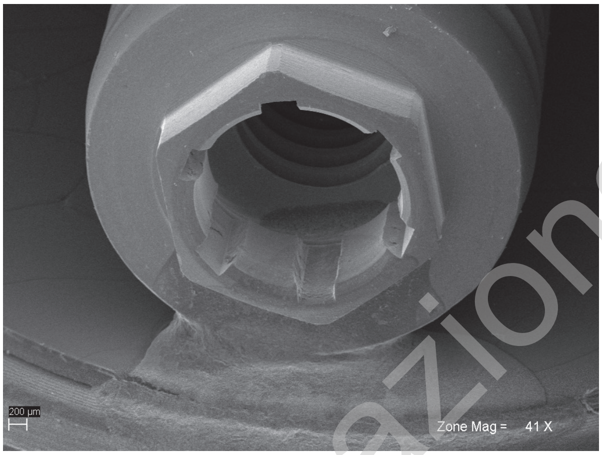

Figure 2 - SEM visualization of a TT implant-prosthetic connection with a deep lodging of hexagonal form and smooth crestal module.

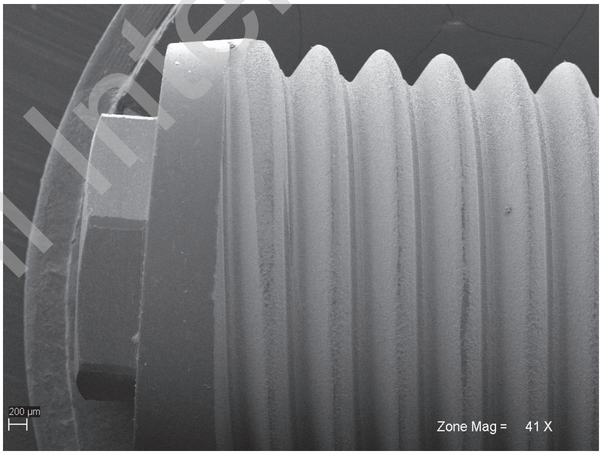

Figure 3 - SEM visualization of a TTX external implant-prosthetic connection constitute of smooth crestal module dominated by an hexagonal connection.

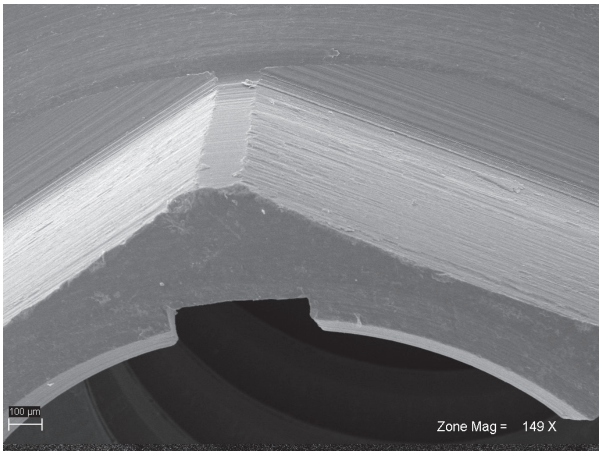

Figure 4 - SEM visualization of the machined neck surface (149x magnification).

the distance between each thread is 0.10 mm at the base and 0.53 mm at the peak. The implant shape is maintained constant along the entire implant body.

The apical portion shows a bevel apex, nearly flat, characterized by broad and deep drainage furrow, with increasing size apically (Fig. 6).

The surface of the implant body, defined by the manufacturer of Micro Rough Surface®, and realized by a subtraction process for etching and sandblasting, was regularly distributed along the surface (low magnification) (Fig. 7). In the apical portion, at 1980x magnification, it can be seen how the rough aspect of this surface recalls that typical of tooth enamel after acid etching. At higher magnification the surface appears to be characterized by small depressions and elevations of 2-4 µm (Fig. 8).

Discussion

In scientific literature it is widely reported that the macroscopic structure and the surface characteristics of dental implants play a decisive role in obtaining success in osseointegrated implantology (33). In particular, the geometrical design of the threads, their position and

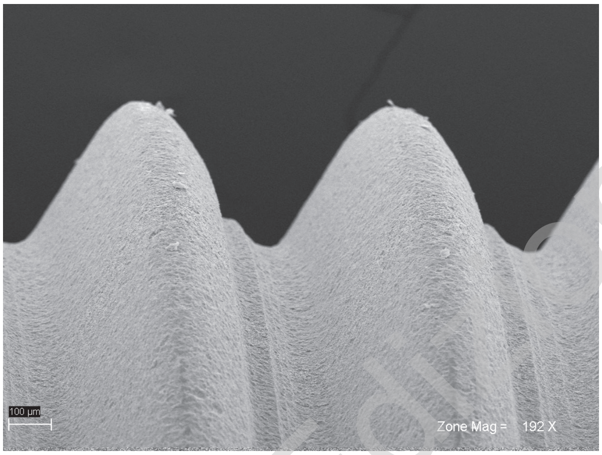

Figure 5 - SEM visualization of the continuous step that forms the smaller threads from the main threads (192x magnification).

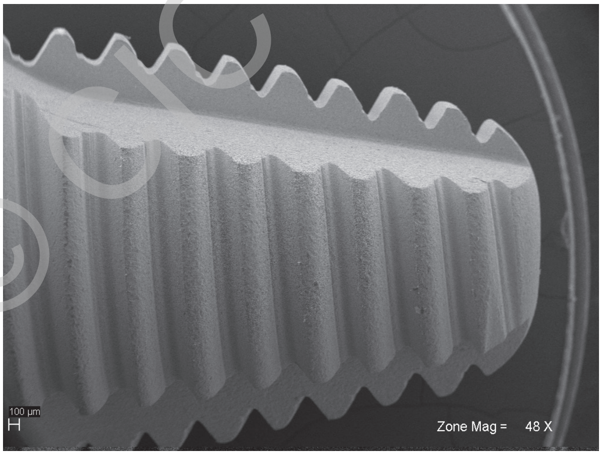

Figure 6 - SEM visualization of the bevel apex characterized by furrows drain.

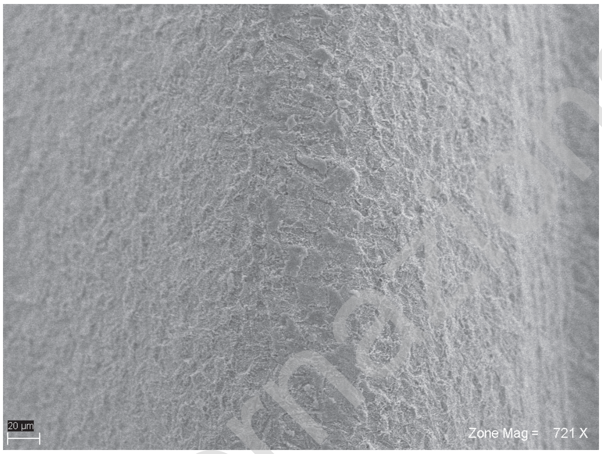

Figure 7 - SEM visualization of the Micro Rough Surface® regularly distribuited (721x magnification).

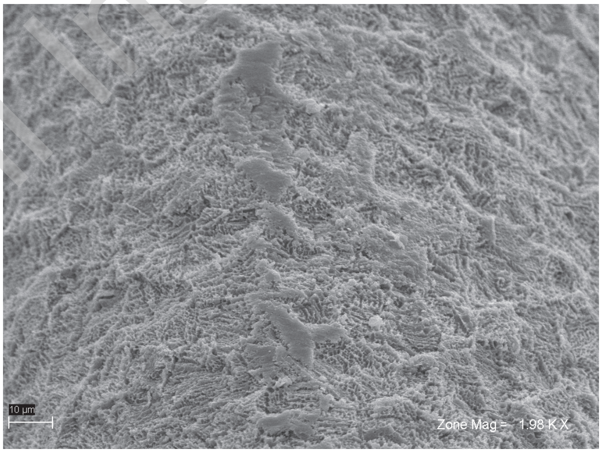

Figure 8A

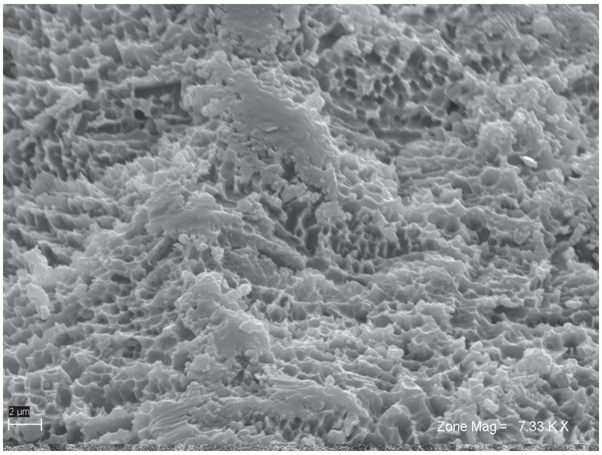

Figure 8B - SEM visualization of the Micro Rough Surface® at higher magnification (A:1980x; B: 7330x).

their pitch along the implant body determine a different response to functional loads and transmission of those forces to the surrounding bone tissue (34). The implant design plays an even more important role if surgical protocols providing immediate loading are adopted. It is known that in the initial stages following implant insertion, and especially after immediate loading, implant stability should be guaranteed by mechanical relationship between the fixture and the bone tissue rather than a biological bone integration. Therefore, the percentage of bone-implant contact and the friction that is obtained during the insertion play an important role in the mechanical behaviour of immediate loaded prosthetic implants.

The tapered shape of the implant fixtures TTI and TTX ensures a gradual expansion of the thin crests during the insertion phase of the fixture by determining the least possible stress to the surrounding bone. This factor is of fundamental importance in cases of reduced bone availability, where preserving cortical bone tissue is appropriate, as well as carrying out a three-dimensional expansion and compaction of the walls of the newly formed alveolar bone. The implant type analyzed showed a thread design that allows to release more force and give easy access to good primary stability. The thread geometry contributes to obtaining primary stability, responsible for the biomechanical behaviour of the bone-implant interface after the healing process (35).

The thread height is defined as the distance between the major and the minor diameter of the coil. A shallow thread depth, as well as those present in the Torque Type implants, favors insertion. In fact, although deeper threads ensure an increase of the surface and represent an advantage in areas of low density bone and high occlusal stress, on the other hand shallow threads allow an easy insertion in alveolar ridges with more dense bone without the need to perform tapping before the implant insertion (36).

In a study conducted by finite element analysis, it was demonstrated that the height of the thread more than its thickness is able to influence primary stability, and in particular threads with a height exceeding 0.44 mm is able to provide excellent biomechanical response when inserted into bone tissue of medium or low density with immediate loading (37).

In addition, these threads have an osteotomic effect, allowing to pack the peri-implant bone using a surgical technique that provides preparation of the implant site according to “press-fit” protocol. *In vitro* studies showed that in case of poor quality bone, such as in the posterior maxilla, implants with chamfer thread design produced lateral compressive forces which increased the bone-implant contact and consequently improved the primary stability (38). This factor is very important in case of immediate load technique of several implants, as in the case of rehabilitation providing the immediate solidification using bar techniques (Just on 4® and Just on 6®). Furthermore, as already demonstrated, under vertical load the presence of threads with bevel peak allows a reduction of divergent forces, thereby reducing the stress at the bone implant interface (39).

TTi and TTX implants also have a double loop thread, a principal and a secondary smaller one, due to the presence of a groove on the apical side of the main thread. An implant with double coil has an insertion speed twice as fast compared to an implant with a single coil. Some studies report that implants with a high number of loop threads and a reduced pitch possess a high percentage of BIC, due to increased surface area (40). Some studies showed how the ideal threads pitch to obtain a good primary stability, and an optimal distribution of the stress should be not more than 0.8 mm (41). A thread pitch less than this measurement was seen to positively influence the load distribution along the peri-implant bone walls, accompanied by a smaller crestal bone resorption (42).

The osteotomic effect at the implant site during the implant screwing phase is further achieved through the tapered apex and the self-tapping implant design with the cutting apical portion. Moreover, the presence of deep grooves at the apical level, constituting an anti-rotational system, is necessary for bone chip collection and clot discharge during the screwing phase (43).

With regard to the crestal module, the manufacturer’s choice to use a smooth neck reflects the concept to guarantee the minimum plaque retention, allowing to obtain an optimal integration with the bone tissue (44).

The constant size of the internal hexagon for the various implant diameters allows the use of few components, making the prosthetic steps and the eventual choice to adopt the Platform Switching technique easier.

The connection type through a long screw, ensures high connection stability, with considerable reduction of the stress between abutment and implant, and a greater contact surface which limits the microcirculation of biological fluids (45).

Another important factor analyzed was the implant surface, because the surface of the fixture is the only part to come into direct contact with the host tissue, influencing cellular and biochemical responses, acting also on the stability between bone and implant (46). SEM analysis allowed to assess the degree of roughness present on the implant body and on the apical portion, typical of a sandblasted and acid etched surface with signs of streaks, depressions and elevations highly variable in size and shape.

Recent clinical studies showed how an implant with a rough surface can be loaded before the traditional treatment protocols (47). Some studies showed that dental implants with low roughness values, as for the implant with machined surface, can promote the formation of fibrous tissue around the implant, reduce the percentage of bone-implant contact and show a lower resistance to the removal than implants with rough surfaces (48).

The implants with sandblasted and etched surfaces, for the presence of more regular micro-roughness produced by the etching treatment, seem to favor the bone healing process, also by the marked incidence of the increased cytokine production, such as osteogenic prostaglandin E2 (PGE_2), and transforming growth factor-beta (TGF-b1), with the latter less sensitive to surface roughness than in the case of PGE_2 (49). According to some authors, this treatment promotes osseointegration due to an increase in initial cell anchorage by osteoblasts (50). All in all, the results obtained prove that dental implants of a design that complies with the results of research regarding the macrostructural aspect and the microstructural surface topography, if used according to correct surgical and prosthetic protocols assure safe and predictable results.

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