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Review article

Primary stability of implant placement and loading related to dental implant materials and designs: A literature review

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Abstract A variety of implant placement and loading protocols are identified, ranging from immediate implant placement on the day of extraction to delayed placement for at least 6 months after complete healing. The method of assessment of implant placement and loading plays an important role in the implantation. The expected clinical outcomes depend largely on multiple factors, such as the macroscopic design of the implant, surgical technique, and the quality and quantity of local bone in contact with the implant, which would be described in detail. The purpose of this literature review was to explore the relationship between the factors influencing the implant placement stability and implant design. By understanding the original appearance of implant design and the stability requirements of implant placement, it is hoped that more research in the future can meet the needs of dentists and patients.

Introduction

Since their introduction in the 1960s, dental implants have become an important treatment plan option for the replacing missing natural teeth. Osseointegration is a prerequisite for successful dental implants. In the clinical application of osseointegration systems, Adell et al. suggested that the implant should avoid loading during osseointegration for a period of typically 3–4 months in the mandible and 6–8 months in the maxilla.[1] This means that the implant location should remain undisturbed for at least 3–8 months to allow for the wound to heal smoothly and to maintain osseointegration between the implant and the bone. This is due to the inevitable occlusal forces during mastication that produce micromotions of less than 0.1 mm at implant-bone interfaced, which are present in the early

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stages of immediate loading. The impact of such micromotion on the bone not only damages the bone tissue, but also induces the biomechanical effect that stimulate cellular signaling pathways to produce biological effects.[2] Furthermore, stresses around the bone-implant interface may induce fibrous tissue formation during wound healing rather than direct implant-bone contact, leading to failure of the clinical osseointegration process.[3,4]

The development of dental implantation must meet the increasing demands of patients for comfort, aesthetics and shorter treatment cycles. Advances in biomedical materials, improvements in implant macro-design,[5] implant micro-surface modification,[6] and concepts of biomechanical initial stabilization[7] will facilitate the successful clinical practice. Among the essential issues, the outcomes of implant loading depends on the primary implant stability, the surgical technique, the quality and quantity of the bone, and occlusal action, in addition to the implant design including material in itself and surface microstructure. Therefore, the purpose of this literature review was to explore the relationship between the influencing factors of implant placement stability and implant design, so as to further provide dentists with consideration of clinical implant needs.

Bone remodeling around implant after implant placement

When the implant is placed in the bone tissue, effective contact between the bone tissue and the implant surface is achieved through a series of bone remodeling processes.[8] The initial stability of the implant in the alveolar bone will be fixed by the mechanical locking characteristics of the implant itself. Osteocytes gradually induce secondary stability of the osseointegration with the implant over time through resorption of old bone and formation of new bone. In a study of implant placement in a rat maxillary model, Fujii et al. found that a thin layer of new bone was in contact with the implant surface on the fifth day, and also observed that bone loss exhibits cavitating osteocytes due to bone damage.[9] Two months after implant placement, the implant surface was covered by new bone with characteristics of cancellous bone. At the same time, the empty osteocyte lacuna remains. After three months, the original bone area has been replaced by newly formed bone containing intact bone cells.[10] Thus, in the process of bone remodeling around implant surface, the stability of the implant supported prosthesis under stress at different time points was formed by the different ratios of mechanical locking and new bone formation between the implant and bone interface.

Methods for the assessment of implant placement and loading

Generally, during the bone remodeling process around the implant, the surface treatment of the implant material and the mechanical stability of the implant design can be used to accelerate bone growth and maturation and increase primary stability. Therefore, the maximum implant-bone interface contact area can be obtained during the bone remodeling process. There are several clinical methods available for assessing implant stability: Insertion torque, Resonance frequency analysis and X-ray microtomography.

Insertion torque

Among the main parameters that determine loading stability, the most common index is the value of the torque at which the implant is inserted. However, the insertion torque (IT) may vary from study to study.[11–13] Grandi et al. used an insertion torque greater than 45 N cm to compare clinical outcomes after one year follow-up of a single implant loaded immediately after extraction using a definitive abutment and a provisional abutment.[12] In some studies, IT $\geq$ 35 N cm was the clinical loading criterion.[13] Others were based on IT $\geq$3 0 N cm in prospective clinical studies.[14] The torque value in most studies ranged from 30 to 45 N cm as the immediate loading threshold to ensure implant stability during osseointegration and to provide adequate strength for implant-abutment connection.

Resonance frequency analysis

Resonance frequency analysis (RFA) combined with insertion torque is another important evaluation metric for immediate/early loading. In 1998, Meredith et al. introduced RFA as a non-invasive and objective quantitative clinical technique to establish valuable information for monitoring implant success and osseointegration. RFA is measured as an Implant Stability Quotient (ISQ) on a scale of 1–100, with relatively stable implants having relatively high ISQ values (>60).[14] Margossian et al. compared the 2-year success rate of immediate and conventional delayed loading of partial mandibular implants.[13] When the baseline for success was IT $\geq$ 30 N cm and ISQ $\geq$ 60, they found that the 2-year success rate was 93.3% in the immediate provisionalization with occlusal loading group and 100% in no occlusal loading group and delayed loading group. In addition, IT $\geq$ 25 N cm and ISQ $\geq$ 60 were proposed by Degidi et al.[15]; IT $\geq$ 20 N cm and ISQ $\geq$60 by Fung et al. were also evaluation criteria for immediate load.[16]

X-ray microtomography

Histomorphometric data of implant-bone contact (BIC) are direct evidence for evaluating implant osseointegration. Under the microscope observation, Zagury et al. found that a high degree of bone contact along the implant threads provided anchoring of the implant.[17] Greater BIC is generally believed to result in better implant stability.[18] However, histomorphometry is a destructive method and limits the analysis of sections along the long axis of the implant. Sennerby et al. tested a new X-ray microtomography technique for non-invasive assessment of the structure of peri-osseous implants.[19] In addition, Park et al. analyzed specimens by 3D microtomography and compared them with traditional histomorphology.[20] A correlation coefficient of 0.855 was found, which means that the two data sources are statistically significantly correlated, whereby the 3D technique successfully provides non-invasive three-dimensional imaging for osseointegration assessment.

Factors affecting primary stability

Primary stability of the implant has been identified as a positive factor for clinical outcome and successful osseointegration.[21] However, the primary stability is affected by many factors, including macroscopic implant design and surgical technique as well as the quality and quantity of local bone in contact with the implant.[22]

Implant shape

Regarding the macroscopic design, it is mainly the shape of the implant that is positively correlated with the load on the bone site and its biomechanical stress distribution.[23] In addition, in the development of mechanical locking of implants, the geometry of implants is mostly considered to play a key role in providing initial stability.[24] The shape of dental implants can generally be divided into three categories: subperiosteal implants, transosteal implants, and endosseous implants. Among them, the endo-osseous implant has various shapes such as blade shape, needle shape, cylindrical shape, disc shape, steppe shape and conical shape.

Subperiosteal implant

A subperiosteal implant is an implant that is placed directly over the bone and then fixed with locking screws, rather than drilling the implant into the bone, as described in Fig. 1.[25] This type of implant design is most commonly used to cover large areas of edentulous and severely atrophied areas. The advantage of subperiosteal implants is that they can be directly supported by a large area of atrophic mandibllar cortical bone. Traditional subperiosteal implants are technically complex and pose unpredictable risks due to difficult positioning and high complication rates.[26,27] A case of chronically infected fistula in a subperiosteal implant made of cobalt-chromium alloy was described by Markiewicz et al., which such a large area and rigidity made its removal and reconstruction relatively difficult.[27] Linkow et al. also reported a lower clinical success rate due to lower precision of early impression-taking materials and complex casting techniques in the laboratory, combined with inadequate framework design and complicated surgical procedures.[26] Kuo et al. observed five removable partial dentures supported by cobalt-chromium alloy subperiosteal implants and found common complications of lower lip numbness and exposure of metal framework, although the stability of the mandibular dentures was improved the after 1—2 years.[28] With the advent of digital dentistry,[29] methods and materials such as cone beam computed tomography (CBCT),[30] intraoral scanners,[31] 3D printers[32] have emerged. For example, Cohen et al. developed a 3D additive manufacturing (AM) sintered Ti—6Al—4V alloy and a subperiosteal implant structure treated with grid sandblasting and acid etching, and combined with the patient's computerized tomography (CT) data. As a result, the precise fit between the traditional subperiosteal implant shape and the patient's bone contour was improved, creating a high-quality environment for bone cell migration and attachment.[33] In addition, the use of locking screws further strengthened the stability of the implant during surgery. The placement of subperiosteal implants re-interprets its procedure in the context of new technologies and makes the treatment a highly predictable and safer surgical procedures, especially for complex jawbone atrophy that an effective and safe treatment option for those of the elderly posterior mandibular edentulous patients.[33,34] Therefore, for patients with bone atrophy who do not require extensive bone replacement surgery, it is a practical and quick to provide primary stability of the implant and immediate loading of the prosthetic occlusion through the direct contact between the implant and the cortical bone and the fixation of the locking screw for possible surgical tightening.

Transosteal implant

The American Dental Association (ADA) describes the transosteal implant as a *trans*-osseous biocompatible device whose threaded post penetrates the superior and inferior cortical bone plates of the mandibular symphysis and exists through the oral mucosa to provide support and attachment for the prosthesis.[35] These implants usually consist of long screws that go through the bone, making an incision under the chin that penetrates the entire jawbone and emerges at the bottom of the chin and holds the top and bottom pressure plates in place. The top studs are then attached to the prosthesis as described in Fig. 2. Standard *trans*-osseous implants are available in a variety of sizes and shapes to meet the needs of the patient, including implants for single teeth, multiple teeth, and complete denture support, which can provide good primary stability of the prosthesis. Because it is composed of a base plate locked at the bottom of the jawbone and several screws long enough to penetrate the jawbone and pass out of the oral cavity to fix the lower edge of the bone and carry the upper edge of the denture restoration. This implant

Figure 1 Subperiosteal implant.

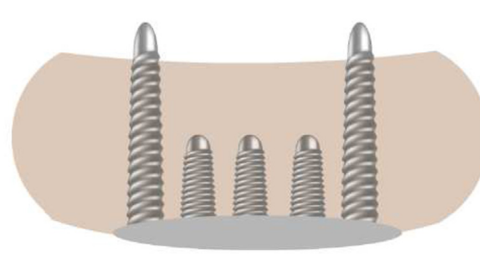

Figure 2 Transosteal implant.

structure is more suitable for the mandibular structure with regular bone blocks.[36,37] But this type of implant is no longer routinely used in current dental practice. The reason is that the complicated operation can only be used on the lower jaw and the shape is not easy to conform to the skeletal morphology of all patients.[36,37]

Endosseous implant

An endosseous implant is an implant prepared directly in the jawbone and inserted into the cavity and locked in the corresponding cavity, as shown in Fig. 3. The shape of the endosseous implant can be blade-like or root-like.

Blade form implant: It is composed of wide, flat, knife-like slices embedded in the bone, and is suitable for bone areas with sufficient height but narrow width. By increasing the contact friction area between the implant and the bone, the stability of the implant is increased. Although blade implants have been used clinically for immediate loading, the most common complication of endosseous blade implants is the growth of fibrous tissue on the implant surface.[38] However, Stefano et al. histologically assessed the peri-implant tissue of immediately loaded blade implants removed after a 20-year loading period due to abutment fracture. It was found that there was tight, cortical, mature bone and well-formed bone at the interface of the implant. Bone-implant contact was 51% $\pm$ 6%.[39] Carlo et al. used the distal endosseous extension (EDE) surgical technique to create a slot on the supralateral side of the bony ridge into which a blade-like implant was inserted and pushed back so that the implant was embedded under the untouched tissue and retains the cortical bone over it.[40] As a result, there was less bone crest tissue damage during implantation and the immediate stability of the implant can be achieved. In addition, the planar contact of the blade-like implant with the bone was more resistant to lateral loading forces of varying intensities and directions. The 5-year success rate of 97.7% thus allowed the use of this technique with asymmetric blade-like implants, recommended for edentulous reconstruction of narrow vertebrae located in posterior D3-D4 type mandibles. Menchini-Fabris et al. used a retrospective case series of 40 patients to study the clinical outcomes of blade implants for the treatment of moderately atrophic posterior maxillae with residual heights between 4 mm and 8 mm.[41] In the absence of extensive reconstructive surgery and transplantation, the 12-month cumulative survival rate was 97.5%. Thus, blade implants have been proposed since Linkow in 1968 to overcome implant limitations in atrophic ridges with reduced horizontal width. In 2014, the U.S. Food and Drug Administration (FDA) also reclassified blade implants from Class III (high-risk devices) to Class II (special controls), a fact that suggests that blade implants can be successfully used with the revised surgical techniques, which may pave the way and concepts for the introduction of new blade-type implant shapes into clinical applications.[42]

Figure 3 Endosseous implant.

Root form implant: The basic shape is to imitate the natural tooth root, which can be generally divided into two categories, the cylindrical implant with a cylindrical main body and the conical implant with a tapered shape. The macro-geometry of the implant is thought to play a key role in maintaining stability due to the development of mechanical locking. In 2015, Kan et al. studied 171 implants from 112 implant patients with immediate implantation and immediate loading in the aesthetic area of the anterior teeth, and examined conical and cylindrical implant body designs according to the criteria of Dellinges and Tebrock relationship with primary stability.[43] Their results showed that the instability probability of tapered implants was only 1.1%, significantly lower than that of cylindrical implants (20.5%) and concluded that tapered implants had a greater distribution of compressive force on the bone surrounding the implant socket compared to cylindrical implants. Such a design aids in the compaction of bone in the implant socket during implant placement, which in turn results in increased insertion torque and implant stability.[44,45] Siegele et al. also studied the stress distribution in the bone surrounding the implant with different implant shapes (cylindrical, conical, stepped, screw, hollow-cylindrical) by means of finite element analysis (FEA).[46] They found that different implant shapes had significantly different stress distributions in the bone. In particular, conical or stepped implants had significantly higher stresses than smooth-shaped implants. It can be seen that the inverted triangular shape of the conical bone implant allows the implant to pass through the hole-prepared bone more easily when it is placed, and its compressive force in the bone is better distributed, and the initial stability obtained by immediate placement better than cylindrical bone implants. However, conical or stepped implants with curvature introduce significantly higher stress peaks at the implant-bone interface than cylindrical implants.

Implant thread

Many implants incorporate thread cutting geometry into the macrogeometry. Through the effective thread design, not only the surface area is increased, but also the pressure is effectively distributed on the surrounding bone and the lateral thread and the vertical bone have a clamping effect to improve the primary stability of the implant.[47] Thread geometry includes pitch, depth, and shape; all of these variables have different effects on the stress distribution of the peri-implant bone. In a 2D FEA study by Desai et al., implants with more microthreads (i.e. smaller pitches) were found to have better fretting and stress at the bone-implant interface when immediate loading.[48] Ma et al. used a 3D FEA to study the effect of implant pitch on the primary stability of the immediately loaded implant and found that with the increase of the pitch, the resistance to vertical force also decreased.[49] The narrow and shallow threads are easily self-cutting way locked in dense bone for stability.

Wide and deep threads appear to have a significant impact on implant stability, especially in cancellous bone.[50] Furthermore, many implants are manufactured not only using thread cutting geometry in the macrogeometry to self-tapping, but also bringing in a shallower second cutting surface to achieve higher stability without increasing compressive stress of the bone.[51]

Stability is the ability of the implant to withstand axial, lateral and rotational loads. Not only the thread pitch and thread depth are the factors that determine the stability of the implant, but also the thread shape and face angle are one of the factors of the implant stability. According to Mich's classification, there are roughly four types of thread shapes currently used in dentistry: square thread, V-shape thread, buttress thread and reverse buttress thread.[52] Ramkumar's study concluded that the stepped thread has good primary stability compared to the V-shaped thread. Implants with buttress threads are more resistant to extraction forces than V-threads.[53] Steigenga et al. reported that implants with a square thread design had significantly higher BIC and greater reverse torque compared to V-shaped and reverse buttress thread designs.[54] Calì et al. confirmed by using FEA that the model with square threads and 6° inclination gave the best results, reducing displacement and equivalent stress peaks in the immediate postoperative loading.[55] From a biomechanical point of view, the most favorable thread design for immediate implantation and loading is a square thread pitch of 1.6 mm.[56] For V-threads, implant spacing of more than 0.8 mm produces the most favorable stress distribution.[57] Thread widths between 0.18 mm and 0.30 mm, thread depths between 0.34 mm and 0.50 mm, and thread tip face angles of less than 30° reduce stress distribution at the bone-implant interface, resulting in better load distribution.[58,59]

Implant material

In addition to the design of the implant shape, the implant material is also one of the factors affecting the primary stability of the immediate implantation. From a chemical point of view, dental implants can be made of metal, ceramic or polymer. Titanium metal and its alloys are currently the most widely used implant materials in dentistry, not only supported by numerous scientific evidences, but also clinically observed with good long-term survival rate.[60] Although titanium and titanium metal have a higher modulus of elasticity than bone, they are closer to bone than any other implant material. Thus, a more favorable stress distribution is produced at the bone-implant interface to protect the bone tissue. In addition, due to the excellent physical properties of titanium, various implant geometries and sharp thread shapes and face angles can be faithfully constructed to achieve the primary stability of immediate placement and loading of the implant.[61] Nevertheless, the surface properties of titanium need to be modified to improve the surface roughness of the implant and the chemotaxis of osteoblasts to achieve faster osseointegration. In turn, it can compensate for the interfacial gap where the primary mechanical stability of the implant is continuously reduced due to the activation of osteoclasts. For example, sand-blasted and acid-etched (SLA), which is most commonly used at present, is one of the surface treatment techniques to provide a medium-roughness ($1\ \mu m < Ra < 2\ \mu m$) implant surface. It can shorten the osseointegrated healing rate to 6 weeks, which provides immediate implant placement and a large clinical loading-bearing space.[62]

Although the success rate of titanium implants is as high as 90%, however, clinical studies by Olmedo and Egusa showed a possible association between surface corrosion of titanium and the risk of host hypersensitivity and peri-implantitis.[63,64] Unlike the aesthetic factors and allergic reactions of titanium, zirconia implants are increasingly used in clinical practice. Zirconia has less bacterial adhesion to the surface than titanium. However, the main disadvantage of zirconia implants is low temperature degradation (aging), which leads to reduced mechanical properties (strength and toughness).[65] In addition, zirconia is more brittle and more prone to cracking than titanium, so that implant geometries used in titanium cannot be transferred directly to zirconia. The sharp edges common in titanium implants should also be avoided in zirconia implant design.[66] On the other hand, Arlucea et al. found in an in vitro study of the primary stability of zirconia and titanium implants that under static compressive loading of crowns, zirconia implants achieved higher average IT and RFA values than titanium implants.[67] They also found a strong correlation between ISQ and micromotion measurements for titanium implants and a weak correlation for zirconia implants, which were associated with a doubling of the modulus of elasticity between the two. Although the zirconia implant has a higher average IT and RFA, it has unstable micromotion characteristics that may affect future osseointegration. Therefore, there should be more basic and long-term clinical studies on zirconia implants to apply the protocol for immediate placement and loading.

The development of implants based on polyetheretherketone (PEEK) may be valuable metal-free implant alternative to traditional titanium implants. However, Schwitalla's research showed that PEEK implants in their current form cannot adequately withstand the insertion torque required to achieve immediate loading for primary stability. It is necessary to develop new manufacturing processes.[68]

Bone quantity and quality for surgical drilling protocol

Glauser et al. evaluated the success rates of implants immediately placed and loaded in different regions of the jaw, which showed a success rate of only 66% in the posterior region of the upper jaw, whereas 91% survived in other regions of the lower jaw.[69] Chaushu et al. compared the clinical success rates of immediate placement versus immediate loading of single-tooth implants in freshly extracted versus healed sites, with two-year survival rates of 82.4% and 100%, respectively.[70] The authors concluded that, in this patient population, the immediate loading risk of placing a single-tooth implant at a fresh extraction site was approximately 20%. The success rate of osseointegration in the implant-receiving area depends on an adequate blood supply to the bone and minimal movement to provide more bone-graft contact. Bone mass is proportional to the elastic modulus of the bone. Higher bone density results in a higher modulus of elasticity, resulting in a larger area in contact with the implant. The elastic modulus of compact cortical bone (13.7 GPa) is about ten-fold that of cancellous bone (1.37 GPa).[71] In addition, developing woven bone is more prone to overloading. Immediate placement of the implant in this area may result in reduced primary stability and does not allow micromotion of the implant prior to osseointegration. Ibrahim et al. assessed the effect of four different types of bone defects (three-walled, one-walled, circumferential, and non-defective) on the primary stability of the implant.[72] The results showed that the implant stability values decreased in all bone defect types as the defect size increased, but the loss of stability was most pronounced in circular defects. In addition, implant stability was significantly reduced when 50% of the implant area was not embedded in bone. Therefore, scholars suggest that improved biomechanical bone conditions and more cortical bone involvement are beneficial to the initial stability of immediate loading.[73]

Multiple in vivo studies have revealed that peri-implant bone regeneration and remodeling can be significantly enhanced by small-scale drilling protocols that may result in higher primary implant stability as well as BIC during healing.[74] However, to some extent, uncontrolled IT increases during surgical drilling and implantation will lead to bone resorption at the implant margin due to stress concentrations caused by excessive bone compression.[75] On the other hand, the concept of bone drilling, namely bone densification implant osteotomy, has also been proposed to improve the local quality of low-density ridges, thereby facilitating the primary stability of the implant. Lahens et al.[76] and Mello-Machado et al.[77] studied the effect of bone densification on the initial stability and early osseointegration of implants in low-density bone in animal experiments. As a result, BIC was significantly higher with the bone densification technique compared to conventional drilling, regardless of the macroscopic geometry of the implant. Through a systematic search, Padhye et al. found that insertion torque, BIC and BAF (bone area fraction occupancy) were increased in the bone densification group compared with the conventional drilling group.[78] Therefore, the bone densification technique running counterclockwise at the osteotomy site can lead to enlargement of the osteotomy site and increase the bone density near the osteotomy to increase the BIC area (BIC) and the primary stability of the implant. Furthermore, in low-density bone, endosseous implants can exhibit higher insertion torque when placed at the site of bone densification, without barriers to osseointegration compared with standard subtractive drilling methods.

In recent years, Chen et al. have used one-drill osteotomy to create stepped implant preparation holes with the over-drilling area and under-drilling area matched to the tapered implant fixture.[79] In the under-drilling area, the shaved autogenous bone debris is forced to move toward the over-drilling area space to form frictional stability, and the self-tapping stability obtained by cooperating with the self-tapping thread system in the over-drilling hole forms the step-locking claimed by the author. Not only can excessive bone compression be avoided but also excellent primary stability can be obtained.

Discussion

Clinical options for implant placement and loading as defined by ITI consensus meetings in 2003, 2008 and 2013 and Esposito et al. in a 2013 Cochrane systematic review article.[80,81] Depending on the needs of the patient and their bone condition, the timing of implant placement and loading varies from immediate placement on the day of extraction to delayed placement at least 6 months after the bone has fully healed. Researchers have developed various schedules and protocols for various implant placement and loading. Javed et al. studied the factors related to implant stability and osseointegration. In conclusion, it emphasized that bone quality and quantity, implant geometry and surgeon's surgical technique may significantly affect the primary stability and the success rate of implant osseointegration.[21] Therefore, the expected clinical results of implant placement time and loading protocol were also highly dependent on the operator's experience and many objective factors: the macroscopic design of the implant, the surgical technique, and the quality and quantity of the local bone. Fujii et al. pointed out that when the implant was implanted, the interface between the implant and the bone will produce mechanical locking and fixation, and the formation and maturation of the osteocytes over time lead to the secondary stability of remodeling.[9] Therefore, the success rate of immediate implant placement has a considerable correlation with the mechanical locking capability of the implant itself.

In order to match the residual alveolar bone ridge, even if the implant shape design is not similar to the tooth shape, the new design can achieve the primary stability required for the immediate placement and loading through a special inter-locking system and self-tapping thread design for operator's choice. For example, Mangano et al. used personalized 3D-printed subperiosteal titanium implants with locking screws to restore the atrophic posterior jaw of elderly patients.[34] Cohen et al. adopted the AM technology to sinter the subperiosteal implant structure of Ti–6Al–4V alloy to match the morphology of the patient's residual ridge, and increased the contact area by closely fitting the cortical bone and lateral fixation screws.[33] Grids were then sandblasted and acid etched to improve the contact area and enhanced bone cell migration and growth, resulting in improved BIC and primary stability. Carlo et al. improved the design of the traditional blade implant, made a slot on the upper side of the bone crest, inserted the blade implant into it and pushed it back, so that the soft and hard tissues behind the implant abutment would not be damaged and the stability of blade implant could be improved.[40] Its clinical outcome can reach 97.7% success rate. Menchini-Fabris et al. treated patients with moderate atrophy of the maxillary posterior region with a two-stage newly manufactured extension implant.[41] Positive clinical results were achieved when the implant was embedded in bone for 3 months to achieve sufficient osseointegration and then the abutment was connected for loading without extensive reconstruction surgery. In a study by Lan et al., cylindrical bone implants were used for the biomechanical analysis.[56] It turned out that the most favorable thread design for square thread implant stability and bone stress distribution under loading was 1.6 mm pitch. For V-shaped threads, an implant thread distance of more than 0.8 mm was considered by Kong et al. to be the most favorable stress distribution,[57] while Lan et al. considered 1.2 mm to be the optimal pitch of.[56] Not only that, but Abuhussein et al. suggested that narrow and shallow threads were easier to lock into bone in a self-tapping manner for stability.[50] Moreover, both wide and deep threads seemed to have a significant effect on implant stability in cancellous bone. It is well-known that through the surface modification of the implant, a faster rate of osseointegration can be obtained. Hanawa said that by surface modification such as sandblasting and acid etching or titanium plasma spraying (TPS) on the implant surface, a more suitable surface roughness and faster osseointegration can be obtained.[82] In addition, hydroxyapatite (HA) and titanium dioxide (TiO_2) coatings prepared by plasma spraying and electrochemical techniques as well as surface alkalization were also effective in improving hard tissue compatibility.

Over the years, the materials used to manufacture subperiosteal implants have shifted from chromium-cobalt-molybdenum to titanium and its alloys,[83] and carbon coatings[84] to more biocompatible HA coatings[85] to reach the purpose of osteointegration. Moreover, sandblasting and acid etching to improve the surface roughness of the implant and the widespread application of CBCT to favor the consistency of the implant and bone morphology have greatly improved the survival rate of implants.[83] However, many of the observed complications such as postoperative infection, strut dehiscence, bone resorption, and fibrous cysts are still occasionally reported.[86] Early subperiosteal implants involved a two-stage surgical procedure to complete the implant placement, the first stage involving the impression of the bone surface required for implant fabrication. With the introduction of CBCT to provide parameters for the manufacture of subperiosteal implants, the second stage became the only operation required to place subperiosteal implants, simply exposing the bone, adjusting the position and fit of the implant, then lock it with fixation screws.[34] However, this implantation process has some disadvantages, and the positioning of the implant itself is a very complicated process.

Endosseous implants address some of the limitations of subperiosteal implants.[86] However, standard endosseous implants offer only a limited selection of standard diameters, lengths, and thread parameters.[46] In addition, prior to implant placement, drilling the bone to prepare the hole for the implant must be performed. Lack of consistency between implant design and bone remodeling will result in reduced stability and formation and accumulation of fibrous tissue.[38] No need to drill bone is one of the advantages of subperiosteal implants, which increases implant stability by placing the implant above the available healthy cortical bone according to the cortical bone geometry. In this case, a relatively small area is sufficient for good anchorage. In addition, it has the advantage of retaining the natural cortical bone and improving the stress distribution in the cortical bone after loading of the implant prosthesis.[33] The use of metallic materials in both subperiosteal and endosseous implants is primarily due to their plasticity allowing the implant to easily conform to the shape of the bone and the desired design of the implant. However, aesthetic problems caused by metal exposure are usually associated with the application of metallic materials, in addition to possible problems caused by allergic reactions and bacterial adhesion. Therefore, zirconia implants are an important alternative to dental implants due to their biocompatibility, lower bacterial adhesion, high mechanical strength, and aesthetic color.[87,88] However, a potential disadvantage of zirconia implants is that the material degrades at low temperatures, slowly changing shape and losing durability when exposed to low temperatures for prolonged periods of time. Furthermore, another disadvantage of zirconia is its brittleness, which limits their effectiveness in load-bearing bone, which may vary depending on the implant location and various factors affecting extrinsic occlusal forces, so much research is still needed.[65,66] On the other hand, how to densify the osteotomy site of the prepared hole by endosseous implants, select more cortical bone implantation area, and retain more natural bone implantation cavity area are all adjuncts to improve the success of immediate implant placement. Today, optimizing the surgical process and shortening the healing time is a common expectation of dentists and patients. By understanding the original appearance of implant design, it is hoped that more research in the future can meet the needs of doctors and patients.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

References

1. Adell R, Lekholm U, Rockler B, Bra°nemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. *Int J Oral Surg* 1981;10:387—416.
2. Gao SS, Zhang YR, Zhu ZL, Yu HY. Micromotions and combined damages at the dental implant/bone interface. *Int J Oral Sci* 2012;4:182—8.
3. Bra°nemark PI. Osseointegration and its experimental background. *J Prosthet Dent* 1983;50:399—410.
4. Akagawa Y, Hashimoto M, Kondo N, Satomi K, Takata T, Tsuru H. Initial bone—implant interfaces of submergible and supramergible endosseous single-crystal sapphire implants. *J Prosthet Dent* 1986;55:96—100.
5. Buser DA, Schroeder A, Sutter F, Lang NP. The new concept of ITI hollow- cylinder and hollow-screw implants: Part 2. Clinical aspects, indications, and early clinical results. *Int J Oral Maxillofac Implants* 1988;3:173—81.
6. Piattelli A, Paolantonio M, Corigliano M, Scarano A. Immediate loading of titanium plasma-sprayed screw-shaped implants in man: a clinical and histological report of two cases. *J Periodontol* 1997;68:591—7.
7. Salama H, Rose LF, Salama M, Betts NJ. Immediate loading of bilaterally splinted titanium root-form implants in fixed

prosthodontics — a technique reexamined: two case reports. *Int J Periodontics Restor Dent* 1995;15:344—61.
8. Albrektsson T, Branemark PI, Hansson HA, Lindström J. Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. *Acta Orthop Scand* 1981;52:155—70.
9. Fujii N, Kusakari H, Maeda T. A histological study on tissue responses to titanium implantation in rat maxilla: the process of epithelial regeneration and bone reaction. *J Periodontol* 1998;69:485—95.
10. Mello ASDS, Santos PLD, Marquesi A, Queiroz TP, Margonar R, Faloni APDS. Some aspects of bone remodeling around dental implants. *Rev Clin Periodoncia Implantol Rehabil Oral* 2018;11:49—53.
11. Gallucci GO, Benic GI, Eckert SE, et al. Consensus statements and clinical recommendations for implant loading protocols. *Int J Oral Maxillofac Implants* 2014;29:287—90.
12. Shibly O, Patel N, Albandar JM, Kutkut A. Bone regeneration around implants in periodontally compromised patients: a randomized clinical trial of the effect of immediate implant with immediate loading. *J Periodontol* 2010;81:1743—51.
13. Margossian P, Mariani P, Stephan G, Margerit J, Jorgensen C. Immediate loading of mandibular dental implants in partially edentulous patients: a prospective randomized comparative study. *Int J Periodontics Restor Dent* 2012;32:e51—8.
14. Meredith N. Assessment of implant stability as a prognostic determinant. *Int J Prosthodont* 1999;11:491—501.
15. Degidi M, Daprile G, Piattelli A. Implants inserted with low insertion torque values for intraoral welded full-arch prosthesis: 1-year follow-up. *Clin Implant Dent Relat Res* 2012;14:e39—45.
16. Fung K, Marzola R, Scotti R, Tadinada A, Schincaglia GP. A 36-month randomized controlled split-mouth trial comparing immediately loaded titanium oxide-anodized and machined implants supporting fixed partial dentures in the posterior mandible. *Int J Oral Maxillofac Implants* 2011;26:631—8.
17. Zagury R, Harari ND, Conz MB, Soares GDA, Jr GMV. Histomorphometric analyses of bone interface with titanium-aluminum-vanadium and hydroxyapatite-coated implants by biomimetic process. *Implant Dent* 2007;16:290—6.
18. Scarano A, Degidi M, Iezzi G, Petrone G, Piattelli A. Correlation between implant stability quotient and bone-implant contact: a retrospective histological and histomorphometrical study of seven titanium implants retrieved from humans. *Clin Implant Dent Relat Res* 2006;8:218—22.
19. Sennerby L, Wennerberg A, Pasop F. A new microtomographic technique for non-invasive evaluation of the bone structure around implants. *Clin Oral Implants Res* 2001;12:91—4.
20. Park YS, Yi KY, Lee IS, Jung YC. Correlation between microtomography and histomorphometry for assessment of implant osseointegration. *Clin Oral Implants Res* 2005;16:156—60.
21. Javed F, Ahmed HB, Crespi R, Romanos GE. Role of primary stability for successful osseointegration of dental implants: factors of influence and evaluation. *Interv Med Appl Sci* 2013;5:162—7.
22. Prasant MC, Thukral R, Kumar S, Sadrani SM, Baxi H, Shah A. Assessment of various risk factors for success of delayed and immediate loaded dental implants: a retrospective analysis. *J Contemp Dent Pract* 2016;17:853—6.
23. Baggi L, Cappelloni I, Girolamo MD, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. *J Prosthet Dent* 2008;100:422—31.
24. Misch CE. *Dental Implant Prosthetcis*, second ed. 2015pp29.
25. Linkow LI. Use of a tripodal mandibular subperiosteal implant with ramus hinges for facial asymmetry. *J Oral Implantol* 2000;26:120—3.
26. Linkow LI, Ghalili R. Critical design errors in maxillary subperiosteal implants. *J Oral Implantol* 1998;24:198—205.
27. Markiewicz MR, Nishiyama K, Yago K, et al. Draining orocutaneous fistula associated with a failing subperiosteal implant: report of a case. *J Oral Implantol* 2007;33:347—52.
28. Kuo YS, Hong CY, Kok SH, Lin FH. Mandibular subperiosteal implant denture. *China J Oral Maxillofac Surg* 1990;1:1—8.
29. Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. *BMC Oral Health* 2017;17:124.
30. Jacobs R, Salmon B, Codari M, Hassan B, Bornstein MM. Cone beam computed tomography in implant dentistry: recommendations for clinical use. *BMC Oral Health* 2018;18:88.
31. Mangano FG, Hauschild U, Veronesi G, et al. Trueness and precision of 5 intraoral scanners in the impressions of single and multiple implants: a comparative in vitro study. *BMC Oral Health* 2019;19:101.
32. Zarone F, Di Mauro MI, Ausiello P, Ruggiero G, Sorrentino R. Current status on lithium disilicate and zirconia: a narrative review. *BMC Oral Health* 2019;19:134.
33. Cohen DJ, Cheng A, Kahn A, et al. Novel Osteogenic Ti-6Al-4V Device for restoration of dental function in patients with large bone deficiencies: design, development and implementation. *Sci Rep* 2016;6:20493.
34. Mangano C, Bianchi A, Mangano FG, et al. Custom-made 3D printed subperiosteal titanium implants for the prosthetic restoration of the atrophic posterior mandible of elderly patients: a case series. *3D Print Med* 2020;6:1.
35. American Dental Association. *Current dental terminology*. Chicago: Illinois, 2021.
36. Sher JH, Cranin AN, Rabkin MF, Silverbrand HF, Satler NM. The transosteal implant. *J Oral Implantol* 1979;8:611—6.
37. Unger JW, Burns DR, Hoffmann RM. The Transosteal implant in the prosthodontic reconstruction of the edentulous mandible. *Compendium* 1989;10:624—7.
38. James RA. Peri-implant considerations. *Dent Clin North Am* 1980;24:415—20.
39. Stefano DD, Iezzi G, Scarano A, Perrotti V, Piattelli A. Immediately loaded blade implant retrieved from a after a 20-year loading period: a histologic and histomorphometric case report. *J Oral Implantol* 2006;32:171—6.
40. Carlo LD, Pasqualini M, Shulman M, et al. Endosseous distal extension (EDE) blade implant technique useful to provide stable pillars in the ipotrophic lower posterior sector: 22 years statistical survey. *Int J Immunopathol Pharmacol* 2019;33:2058738419838092.
41. Menchini-Fabris GB, Marconcini S, Giammarinaro E, et al. Extension implants in the atrophic posterior maxilla: 1-year results of a retrospective case-series. *J Dent Sci* 2020;15:9—13.
42. Linkow LI. The blade vent—a new dimension in endosseous implantology. *Dent Concepts* 1968;11:3—12.
43. Kan JY, Roe P, Rungcharassaeng K. Effects of implant morphology on rotational stability during immediate implant placement in the esthetic zone. *Int J Oral Maxillofac Implants* 2015;30:667—70.
44. O'Sullivan D, Sennerby L, Meredith N. Influence of implant taper on the primary and secondary stability of osseointegrated titanium implants. *Clin Oral Implants Res* 2004;15:474—80.
45. Chong L, Khocht A, Suzuki JB, Gaughan J. Effect of implant design on initial stability of tapered implants. *J Oral Implantol* 2009;35:130—5.

46. Siegele D, Soltesz U. Numerical investigations of the influence of implant shape on stress distribution in the jaw bone. *Int J Oral Maxillofac Implants* 1989;4:333—40.
47. Sennerby L, Pagliani L, Petersson A, Verrocchi D, Volpe S, Andersson P. Two different implant designs and impact of related drilling protocols on primary stability in different bone densities: an in vitro comparison study. *Int J Oral Maxillofac Implants* 2015;30:564—8.
48. Desai SR, Singh R, Karthikeyan I. 2D FEA of evaluation of micromovements and stresses at bone-implant interface in immediately loaded tapered implants in the posterior maxilla. *J Indian Soc Periodontol* 2013;17:637—43.
49. Ma P, Liu HC, Li DH, Lin S, Shi Z, Peng QJ. Influence of helix angle and density on primary stability of immediately loaded dental implants: three-dimensional finite element analysis. *Zhonghua Kou Qiang Yi Xue Za Zhi* 2007;42:618—21.
50. Abuhussein H, Pagni G, Rebaudi A, Wang HL. The effect of thread pattern upon implant osseointegration. *Clin Oral Implants Res* 2010;21:129—36.
51. Yamaguchi Y, Shiota M, Fujii M, Shimogishi M, Munakata M. Effects of implant thread design on primary stability-a comparison between single- and double-threaded implants in an artificial bone model. *Int J Implant Dent* 2020;6:42.
52. Misch CE. *Contemporary Implant Dentistry*, third ed. Elsiver publication, 2008.
53. Ramkumar K, Sripriya S, Meenakshi A, Sabarigirinathan C, Thulasingam C. Comparison of primary stability in craniofacial implant with V-shape and buttress thread design in goat skull using resonance frequency analysis. *Indian J Dent Res* 2020;31: 403—7.
54. Steigenga J, Al-Shammari K, Misch C, Nociti Jr FH, Wang HL. Effects of implant thread geometry on percentage of osseointegration and resistance to reverse torque in the tibia of rabbits. *J Periodontol* 2004;75:1233—41.
55. Calì M, Zanetti EM, Oliveri SM, et al. Influence of thread shape and inclination on the biomechanical behaviour of plateau implant systems. *Dent Mater* 2018;34:460—9.
56. Lan TH, Du JK, Pan CY, Lee HE, Chung WH. Biomechanical analysis of alveolar bone stress around implants with different thread designs and pitches in the mandibular molar area. *Clin Oral Invest* 2012;16:363—9.
57. Kong L, Liu BL, Hu KJ, et al. Optimized thread pitch design and stress analysis of the cylinder screwed dental implant. *Hua Xi Kou Qiang Yi Xue Za Zhi* 2006;24:509—12.
58. Ao J, Li T, Liu Y, et al. Optimal design of thread height and width on an immediately loaded cylinder implant: a finite element analysis. *Comput Biol Med* 2010;40:681—6.
59. Kong L, Hu K, Li D, et al. Evaluation of the cylinder implant thread height and width: a 3-dimensional finite element analysis. *Int J Oral Maxillofac Implants* 2008;23:65—74.
60. Nicholson JW. Titanium alloys for dental implants: a review. *Prosthesis* 2020;2:11.
61. Bidez MW, Misch CF. Force transfer in implant dentistry: basic concepts and principles. *J Oral Implantol* 1992;18:264—74.
62. Bornstein MM, Lussi A, Schmid B, et al. Early loading of non-submerged titanium implants with a sandblasted and acid-etched (SLA) surface: 3-year results of a prospective study in partially edentulous patients. *Int J Oral Maxillofac Implants* 2003;18:659—66.
63. Olmedo DG, Paparella ML, Brandizzi D, Cabrini RL. Reactive lesions of peri-implant mucosa associated with titanium dental implants: a report of 2 cases. *Int J Oral Maxillofac Surg* 2010; 39:503—7.
64. Egusa H, Ko N, Shimazu T, Yatani H. Suspected association of an allergic reaction with titanium dental implants: a clinical report. *J Prosthet Dent* 2008;100:344—7.
65. Pereira G, Silvestri T, Camargo R, et al. Mechanical behavior of a Y-TZP ceramic for monolithic restorations: effect of grinding and low-temperature aging. *Mater Sci Eng C Mater Bio Appl* 2016;63:70—7.
66. Bankoglu Güngör M, Aydın C, Yılmaz H, Gül EB. An overview of zirconia dental implants: basic properties and clinical application of three cases. *J Oral Implantol* 2014;40:485—94.
67. Arlucea N, Brizuela-Velasco A, Dieguez-Pereira M, et al. Zirconia vs. Titanium dental implants: primary stability in-vitro analysis. *Materials* 2021;14:7886.
68. Schwitalla AD, Zimmermann T, Spintig T, et al. Maximum insertion torque of a novel implant-abutment-interface design for PEEK dental implants. *J Mech Behav Biomed Mater* 2018;77: 85—9.
69. Glauser R, Rée A, Lundgren A, Gottlow J, Hämmerle CH, Schärer P. Immediate occlusal loading of Branemark implants applied in various jaw bone regions: a prospective 1-year clinical study. *Clin Implant Dent Relat Res* 2001;4:204—13.
70. Chaushu G, Beals DW, Larsen PE. Immediate loading of single tooth implants: immediate vs non-immediate implantation. A clinical report. *Int J Oral Maxillofac Implants* 2001;5:267—72.
71. Huang YC, Ding SJ, Yuan C, Yan M. Biomechanical analysis of rigid and non-rigid connection with implant abutment designs for tooth-implant supported prosthesis: a finite element analysis. *J Dent Sci* 2022;17:490—9.
72. Ibrahim A, Heitzer M, Bock A, et al. Relationship between implant geometry and primary stability in different bony defects and variant bone densities: an in vitro study. *Materials* 2020;13:4349.
73. Yim HJ, Lim HC, Hong JY, et al. Primary stability of implants with peri-implant bone defects of various widths: an in vitro investigation. *J Periodontal Implant Sci* 2019;49:39—46.
74. Huang HM, Chee TJ, Lew WZ, Feng SW. Modified surgical drilling protocols influence osseointegration performance and predict value of implant stability parameters during implant healing process. *Clin Oral Invest* 2020;24:3445—55.
75. Duyck J, Corpas L, Vermeiren S, et al. Histological, histomorphometrical, and radiological evaluation of an experimental implant design with a high insertion torque. *Clin Oral Implants Res* 2010;21:877—84.
76. Lahens B, Neiva R, Tovar N, et al. Biomechanical and histologic basis of osseodensification drilling for endosteal implant placement in low density bone. An experimental study in sheep. *J Mech Behav Biomed Mater* 2016;63:56—65.
77. Mello-Machado RC, Sartoretto SC, Granjeiro JM, et al. Osseodensification enables bone healing chambers with improved low-density bone site primary stability: an in vivo study. *Sci Rep* 2021;11:15436.
78. Padhye NM, Padhye AM, Bhatavadekar NB. Osseodensification - A systematic review and qualitative analysis of published literature. *J Oral Biol Craniofac Res* 2020;10:375—80.
79. Chen L, Chen N, Chen A, et al. A one-drill system for predictable osteotomy and immediate implant placement. *EC Dent Sci* 2023;22:114—28.
80. Hammerle CH, Chen ST, Jr TGW. Consensus statements and recommended clinical procedures regarding the placement of implants in extraction sockets. *Int J Oral Maxillofac Implants* 2004;19:26—8.
81. Esposito M, Grusovin MG, Maghaireh H, Worthington HV. Interventions for replacing missing teeth: different times for loading dental implants. *Cochrane Database Syst Rev* 2013;28: CD003878.
82. Hanawa T. Titanium-tissue interface reaction and its control with surface treatment. *Front Bioeng Biotechnol* 2019;7:170.
83. Gellrich NC, Zimmerer RM, Spalthoff S, et al. A customised digitally engineered solution for fixed dental rehabilitation in

severe bone deficiency: a new innovative line extension in implant dentistry. *J Cranio-Maxillofacial Surg* 2017;45:1632—8.
84. Leake D, Reed O, Bokros J, Armitage J, Haubold A. Carbon-coated subperiosteal dental implants for fixed and movable prostheses. *J Prosthet Dent* 1979;42:327—34.
85. Kay JF, Golec TS, Riley RL. Hydroxyapatite-coated subperiosteal dental implants: design rationale and clinical experience. *J Prosthet Dent* 1987;58:339—43.
86. Dantas TA, Vaz PCS, Silva FS. Subperiosteal dental implants: past or future? a critical review on clinical trials/case reports and future directions. *J Oral Dent Health Res* 2022;4:1—12.
87. Ding SJ, Chu YH, Wang DY. Enhanced properties of novel zirconia-based osteo-implant systems. *Appl Mater Today* 2017;9:622—32.
88. Dantas TA, Pinto P, Vaz PCS, Silva FS. Design and optimization of zirconia functional surfaces for dental implants applications. *Ceram Int* 2020;46:16328—36.