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Bone stability around dental implants: Treatment related factors

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ABSTRACT

The bone bed around dental implants is influenced by implant and augmentation materials, as well as the insertion technique used. The primary influencing factors include the dental implant design, augmentation technique, treatment protocol, and surgical procedure. In addition to these treatment-related factors, in the literature, local and systemic factors have been found to be related to the bone stability around implants.

Bone is a dynamic organ that optimises itself depending on the loading condition above it. Bone achieves this optimisation through the remodelling process. Several studies have confirmed the importance of the implant design and direction of the applied force on the implant system. Equally dispersed strains and stresses in the physiological range should be achieved to ensure the success of an implant treatment.

If a patient wishes to accelerate the treatment time, different protocols can be chosen. However, each one must consider the amount and quality of the available local bone. Immediate implantation is only successful if the primary stability of the implant can be provided from residual bone in the socket after tooth extraction. Immediate loading demands high primary stability and, sometimes, the distribution of mastication forces by splinting or even by inserting additional implants to ensure their success.

Augmentation materials with various properties have been developed in recent years. In particular, resorption time and stableness affect the usefulness in different situations. Hence, treatment protocols can optimise the time for simultaneous implant placements or optimise the follow-up time for implant placement.

Contents

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1. Introduction

Dental implants are an increasingly reliable treatment alternative for dental rehabilitation, which has been used for different implant types and treatment concepts (Balshi et al., 2013; Buser et al., 1997; Duttenhoefer et al., 2013; Esposito et al., 1998a; Gunne et al., 1999). It is essential to understand the reaction of the bone around dental implants under different conditions in the oral cavity to improve the long-term survival rates of the implants (den Hartog et al., 2008; Schwartz-Arad et al., 2005).

The presupposition for implant success is the growth of bone directly to the implant surface (the so-called osseointegration), which is histologically defined as the direct contact of bone and implant, clinically asymptomatic rigid fixation and direct load transfer into the bone, without a soft tissue intermediate layer," (Bahat and Sullivan, 2010; Brånemark, 1983; Mai et al., 2012; Piatelli et al., 2011; Rahimi et al., 2009). Histologically, the bone healing process and factors providing osseointegration and can be measured by increasing bone implant contact (BIC) (Dominiak et al., 2012; Götz et al., 2012).

Implant healing and osseointegration have three stages of stability: primary, secondary, and tertiary. Primary stability is measured directly after implant placement and depends on the implant design, bone density and chosen implant placement preparation method (Javed et al., 2013). Bone condensing (e.g., with an ultrasonic device) can improve the primary stability and resulting BIC values (Blaszczyszyn et al., 2012; Sağirkaya et al., 2013). Secondary stability results from healed matured bone in direct contact with the implant surface. According to the biological healing stages, a stability gap is found between the stage of primary and secondary stability. Thus, one aim is to improve the implant surfaces to accelerate bone implant contact during the healing period and to minimise the stability gap (Botzenhart et al., 2014). Furthermore, implants should not be loaded in this stage to avoid the risk of early implant failure (Esposito et al., 2009). Final tertiary stability, the functional adaption of the surrounding bone to the implant under loading (Hasan et al., 2014), is based on primary and secondary stability and is de facto responsible for long-term implant success.

Hence, bone stability around dental implants depends on factors that may or may not be directly influenced by the implantologist, such as local bone quality and bone metabolism, in addition to systemic factors, such as age, systematic chronic diseases and lifestyle (e.g., smoking habits). However, treatment-related factors, such as augmentation material, implant design (macro and micro), surgical procedures and loading protocols, are also involved. The aim of this review was to provide a short overview about the current state of knowledge regarding those treatment-related factors.

2. Implant and abutment design

To ensure long-term bone stability around dental implants, the load transfer during biting through the implant body into the surrounding bone must be considered. The resulting energy should not be too low or too high, but it should stimulate permanent vital reorganisation. Bone remodelling in general can be defined as a process in which bone gradually alters its morphology in an attempt to adapt to any new external load. There are two opposite bone remodelling scenarios: resorption and deposition; the former can occur due to certain decreases in the magnitude of the mechanical load, and the latter can be caused by a certain increase in mechanical load (Doblaré and García, 2002). Bone density can vary in different locations, ages, genders and health statuses in the range of 1.7–2.0 g/cm^3 for cortical bone and 0.2–1.0 g/cm^3 for cancellous bone (O'Mahony et al., 2000). Phenomenologically, the process of bone remodelling is strongly influenced by the mechanical loading conditions. Bone disuse would lead to resorption, while placing bone under certain mechanical loads can yield deposition until a new equilibrium is achieved. Currently, mathematical models are used to simulate this bone adaptive behaviour, primarily using the finite element method (FEM) as a simulation tool (Bagge, 2000; Doblaré and García, 2001). Most of these models have been used to predict density distributions in the femur. Until now, few studies have tried to explain the remodelling process around dental implants (Chou et al., 2008; Li et al., 2007; Vander Sloten et al., 2007). A quadratic method to account for the overload effect of dental implant induced bone remodelling was introduced by Li et al. (2007), as overloading is one of the main causes of implant loosening (Hasan et al., 2012; Isidor, 1996).

One approach to minimise crestal bone loss is the implant macro design and grooves or fine threads in the implant neck, which are believed to stabilise the implant and transfer masticatory forces without any stress peaks to the surrounding bone bed. With the resulting consistent physiological pressure, the healing process and remodelling of bone tissue around the implant can be supported (Gedrange et al., 2008; Hartwig et al., 1995; Rahimi et al., 2009). Another approach is to position the implant–abutment interface relative to the bone crest at the time of implant placement to alter the horizontal relationship between the implant diameter and the attached abutment diameter; this process is commonly termed 'platform switching'. According to some histological studies (Ericsson et al., 1995; Mombelli et al., 1987), hypothetically, platform switching may increase the distance between the abutment inflammatory cell infiltrate and the alveolar crest, thus decreasing the bone-resorptive effect. A 5-year clinical study (Wennstrom et al., 2005) that reported data from an implant with abutment diameter showed a mean marginal bone loss of 0.06 mm in the first year of function. It was concluded that the bone loss in the first year, as well as annually thereafter, was smaller compared to other studies reporting a mean bone loss of ~1.5–2.0 mm. Such results suggest the potential usefulness of implants and abutments with non-matching diameters.

Each implant/abutment design introduces varying stresses to the implant–bone interface during clinical function. There is a growing belief that implant failure might be caused by disequilibrium of forces acting on the oral implants (Esposito et al., 1998a; Papavasiliou et al., 1996; Petrie and Williams, 2005; Stegaroiu et al., 1998a; Stegaroiu et al., 1998b; Williams et al., 1990; Zhiyong et al., 2004). Although an adaptive remodelling response is observed around dental implants, the biomechanical aspects of these processes remain uncertain (Hoshaw et al., 1994). A first essential step towards obtaining insight into the forces that are transferred to the bone (and, therefore, affect it) is to qualify and quantify the stresses and strains generated in the bone surrounding endosseous implants. The finite element method (FEM), for example, can be used for this process. Furthermore, FE analyses can provide detailed qualitative and quantitative data at any location using a mathematical model.

In many clinical instances, and due to the morphology of the bone in the premaxilla, implants have to be placed in angulated positions, thereby complicating the restoration with conventional (0°) abutments. To solve such cases, preangulated abutments have been introduced by implant companies as a prosthetic option. Angled abutments are required in many clinical cases due to the morphology of the bone to ensure adequate positioning of the final restoration.

Abutment angulation is one of the numerous biomechanical variables involved in implant dentistry that need scientific evaluation. In a study of immediately loaded fixed partial prosthesis (FPP), equally good treatment outcomes were observed when immediate loading of the implants occurred under appropriate clinical conditions (Gapski et al., 2003). Success in such cases is dependent

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upon controlling micro-movement at the bone/implant interface during implant loading and the biomechanical response of the bone in terms of stresses and strains with immediately loaded partial or complete prostheses. This process can be achieved when numerous implants attain adequate primary stability at the time of placement, are subject to rigid inter-implant splinting, and occlusal forces are appropriately controlled during the osseointegration period (Gapski et al., 2003; Szmukler-Moncler et al., 1998; Szmulkler-Monkler et al., 2000).

Hasan et al. (2011a, 2011b) observed minor differences in implant displacements, stress and strain distributions of the straight and 20° angled abutments, with a considerable decrease in implant displacements and bone loading in osseointegrated cases. A fixed partial prosthesis (FPP) supported by two implants cannot be recommended for immediate loading. A noticeable reduction in the determined biomechanical bone loading was observed when more implants were used to support an immediately loaded prosthesis. These studies recommended the insertion of additional implants for immediately loaded prostheses. In another study by Hasan et al. (2011c), the influence of abutment design on the amount of bone resorption around implants used to support FPP was investigated for up to 1-year in immediately loading and osseointegrated cases. The authors observed significant differences ($P < 0.005$) in the probing depths between the immediately loaded implants and the osseointegrated implants with angled abutments and between the osseointegrated implants with straight abutments and the angled osseointegrated implants six and twelve months from abutment placement. However, they observed no significant differences between the immediately loaded and osseointegrated implants with straight abutments or between the immediately loaded implants with straight and angled abutments. The aforementioned studies emphasise the influence of abutment design and the associated implantation protocol on crestal bone resorption around dental implants.

3. Occlusal loading

Sanz-Sánchez et al. (2014) reviewed the type of loading used in implant restoration in different studies (Esposito et al., 2013; Shibly et al., 2012). They concluded that in single tooth and short span bridges, occlusal forces may directly impact the implant and, thus, patients may be more susceptible to implant failure. Moreover, they stated that "the outcome of immediately loaded implants in comparison to conventionally loaded implants in regards to the type of loading (occlusal versus non-occlusal contacts) provided at the time of restoration delivery (within one week after implant placement), the occlusal pattern resulted in a slight greater risk of implant failure (risk ratio = 1.9 vs. 1.4) and smaller change in implant stability quotients values (WMD = 0.625 vs. 1.187) than the non-occlusal pattern," (Sanz-Sánchez et al., 2014). In this review, no definitive conclusion could be established in terms of the most effective loading method (Cannizzaro et al., 2010; Margossian et al., 2012; Sanz-Sánchez et al., 2014; Vogl et al., 2013).

Pellicer-Chover et al. (2014) investigated the relationship between occlusal loading and peri-implant clinical parameters (probing depth, bleeding on probing, gingival retraction, width of keratinised mucosa, and crevicular fluid volume) in patients with implant-supported complete fixed prostheses in both arches. They concluded that the maxillary implant closest to the point of highest occlusal loading presented significantly higher volumes of crevicular fluid compared to the maxillary implant with the least loading that was furthest from the study implant.

In animal studies (Miyata et al., 1997, 2002; Isidor, 1998), overloading has been generated using a fixed prosthetic set-up supported by splinted implants, resulting in lateral rather than axial overloading. Other studies (Heitz-Mayfield et al., 2004; Kozlovsky et al., 2007) have observed that excessive occlusal loading was created in the antagonist arch using one-piece crowns (Pellicer-Chover et al., 2014).

4. Surgical protocol

The surgical process certainly influences the long-term stability and success of implants. Careful diagnoses, as well as the choice of adequate treatment methods and materials, are essential. One approach to reduce the amount of bone resorption after tooth extraction is through socket preservation. An alternative method for socket preservation is immediate implantation after tooth extraction, although it has been shown that immediate implantation cannot restrict bone resorption and must be limited to cases with sufficient residual bone that are free from acute inflammation. However, socket preservation is still a reliable treatment for suitable cases (Alharbi et al., 2014; Engelhardt et al., 2014), and good clinical outcomes can be achieved, particularly in combination with small augmentations (Heinemann et al., 2013).

Different loading protocols are available for dental implants. In general, implants can be loaded immediately, loaded early or delayed. The time at which an implant is loaded can affect the treatment outcome. Esposito et al. (2013) investigated the efficacy of immediate (within 1 week), early (between 1 week and 2 months), and conventional (after 2 months) loading of osseointegrated implants, as well as immediate occlusal versus non-occlusal loading during the bone healing phase. The authors concluded, "It is possible to successfully load dental implants immediately or early after their placement in selected patients, though not all clinicians may achieve optimal results. It is unclear whether it is beneficial to avoid occlusal contacts during the osseointegration phase. Trends suggest that immediately loaded implants fail more often than those conventionally loaded, but less commonly than those loaded early." Additionally, the aforementioned study recommended a high degree of primary implant stability to ensure a successful immediate/early loading procedure.

Primary stability is considered to play a fundamental role in obtaining successful osseointegration. Friberg et al. (1991) reported an implant failure rate of 32% for implants that demonstrated inadequate initial stability. Initial stability can be significantly decreased in low density bone by increasing the risk of failure (Schnitman et al., 1990). Although bone density and quantity are local factors and cannot be controlled, implant design and surgical technique may be adapted to the specific bone situations to improve initial implant stability (Friberg et al., 2002). A scientifically established method for evaluating primary stability is to measure the insertion torque as an invasive, single-use technique. The maximum insertion torque is necessary to screw the implant into the prepared bone cavity. In general, the measured values are between 5 N cm and 50 N cm. At present, it is unknown how much torque is necessary to achieve sufficient primary stability for individual implant systems. Current opinions suggest that a minimum of 30 N cm should be used. The insertion torque increases as the bone density increases (Piattelli et al., 1998). Studies have demonstrated a clear correlation between implant insertion torque or thread cutting torque and bone mineral density, which can be determined using micro-radiography (Kirsch and Ackermann, 1989) or with the help of dental quantitative computed tomography (DQCT, Glauser et al., 2001). Major factors, such as the implant length, diameter, surface texture and thread configuration, must be considered for initial stability. A number of in vivo studies have demonstrated that increased surface topography, which results in increased surface area, leads to increased bone-to-implant contact shortly after the implant placement (Buser et al., 1991; Heinemann et al., 2009a,b;

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Leucht et al., 2007), which maybe essential, particularly in combination with shortening the implant structure (Botzenhart et al., 2014; Hasan et al., 2013).

However, increased bone-to-implant contact, gained only by increasing machined surface roughness, may not always increase the biomechanical interaction with the bone. Each implant system tolerates micromotion differently. For implants with roughened surfaces, tolerance ranges from 50 μm to 150 μm (Vaillancourt et al., 1995). Machined surfaces can withstand approximately 100 μm of micro movement (Thakur, 1997). Controlling the amount of occlusal loading and ensuring primary stability of the immediately loaded implants are critical to achieving osseointegration. It has been suggested that splinting implants through a rigid connector (either a permanent or provisional prosthesis) could assist in the distribution of the functional load (Esposito et al., 2008). Normal occlusal loads during the healing phase could be essential for implant success. In a study by Glauser and co-workers, it was found that more failures occurred among the bruxism group (Glauser et al., 2001). It could be proven that additional splinted implants can improve their stability even with poor bone quality (e.g., maxillary bone), and clinical studies under similar conditions have demonstrated good results for implants with adequate primary stability following splinting by the denture (Hasan et al., 2011a,b; Heinemann et al., 2010).

5. Augmentation materials

The available bone volume for implant placement is insufficient in most cases. Therefore, bone augmentation techniques are common in implantology. Former autogenous bone is generally accepted as the “gold standard” for these procedures. It provides vital cells and optimum biocompatibility for the patient. Surgical techniques should respect adequate handling of harvesting and augmentation, for example overheating of the transplanted material (Heinemann et al., 2012a,b). The main disadvantage of autogenous bone is a second surgery and, therefore, additional risk of additional postoperative pain and wound healing complications. To avoid a second surgery, bone substitutes are suggested. In general, augmentation materials are divided as follows: autologic (autogenous), allogenic (homologenous), xenogenic (heterologous) and alloplastic (synthetic) bone (substitute). Today, it has been proven that that there is a need for different materials and techniques, depending on the indication and intended resorption period, to guarantee the stability and reorganisation of the augmented area (Canullo et al., 2013; Götz et al., 2008; Heinemann et al., 2012a,b; Nevins et al., 2013).

To provide vital cells, particulate bone from the operation area and the patient’s blood should be mixed into the substitute. One of the most common augmentation procedures is sinus lifting in the lateral maxilla. Many bone substitutes have been shown to be reliable, even without additional autogenic bone (Canullo et al., 2012; Heinemann et al., 2009a,b; Nevins et al., 2013; Ramírez-Fernández et al., 2013). To improve the condition for the implant placement, early augmentation directly after tooth extraction has been recommended, and different bone substitutes have been investigated in this context.

Early extraction socket healing is expected to decrease the alveolar ridge by 2 mm to 4 mm horizontally and 1 mm vertically. This change is time dependent. By the end of the first year postextraction, nearly 6 mm of buccal loss can be expected (Fernandes et al., 2011; Iasella et al., 2003; Lekovic et al., 1997, 1998). Adequate volumes of alveolar bone are necessary to provide favourable aesthetics and successful long-term outcomes for dental implants. Therefore, to preserve the original ridge dimensions following tooth extraction and to promote bone regeneration of the residual alveolar socket, various bone grafts and substitutes used with or without barriers for guided tissue regeneration (GTR) have been suggested (Barone et al., 2008; Feuille et al., 2003; Froum et al., 2002; Iasella et al., 2003; Serino et al., 2003). Among these grafting materials, bovine bone mineral xenografts were able to promote bone regeneration and preserve the pre-extraction alveolar ridge dimensions when grafted in immediate extraction sockets, particularly when combined with collagen (Araújo and Lindhe, 2009; Artzi et al., 2000; Carmagnola et al., 2003). The use of xenografts, particularly bovine bone, has increased in ridge preservation, as well as other bone augmentation procedures. Two important benefits of xenograft bone are the reduction of the disadvantages associated with autografts, as well as their unlimited availability. Some studies have found that bovine bone grafted sites demonstrated a good outcome, indicating that this material might be a good bone substitute for bone augmentation before implant installation (Artzi and Nemcovsky, 1998; Artzi et al., 2000; Hammerle et al., 1998). However, the downsides of using bovine bone include its slowly resorbability and healing with fibrous encapsulation (Artzi et al., 2000, 2001; Carmagnola et al., 2003), which leads to long or even no remodelling in the central part of the augmented socket. This result may have significant disadvantages, for example when tooth movement in the augmented region is followed (Gedrange et al., 2010).

As an alternative to socket preservation, collagen materials have shown proangiogenic qualities (Twardowski et al., 2007) and accelerate the growth, proliferation and maturation of endothelial cells (Breithaupt-Faloppa et al., 2006), thereby encouraging estimated physiological bone regeneration. A mixture of both, xenogenic or synthetic granules and collagen mesh could be optimum for stabilisation following early reorganisation in the patient’s bone (Heinemann et al., 2012a,b). An essential thought is that early and multiple vascularisation should be used because it functions as a highway for nutrition transport in the new tissue and prevents resorption (Canullo et al., 2013; Götz et al., 2012). However, many questions remain to be answered. In degradation and reorganisation of augmented materials, the results are still inconclusive. In addition to different measurements of embedded granules, various stages of progress have been observed early (after some healing time), sometimes in the same patient. Therefore, classifications of different reorganisation stages and histomorphometric measurements have been established (Götz et al., 2008; Canullo et al., 2013).

6. Conclusions

The bone stability around dental implants and the success of dental implants depends on the following factors.

1. Treatment-related factors that can be influenced by the implantologist (e.g., the implant design), including the macro and micro design. A small diameter and short implants are good possible options for treating patients with limited bone volume.
2. Small diameter implants can be loaded immediately. However, controlling the amount of occlusal loading and ensuring primary stability of the immediately loaded implants are essential. Immediate loading is contraindicated for short implants.
3. The effect of abutment design on the long-term success of implants is directly related to the loading protocol.
4. Treatment protocols should be adequately chosen, according to the clinical indication and bone quality. In particular, when immediate loading is indicated, the basic guidelines must be considered for success.
5. The augmentation material, when necessary, must be properly chosen for the situation and indication of each individual case.

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6. The properties of a growing number of various materials allow for safe bone regeneration and stability in different situations. Hence, by carefully choosing the material and developing a good treatment protocol, implantologists can ensure long-term bone stability around implants.

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