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Increasing the Stability of Dental Implants: the Concept of Osseodensification

SUMMARY

One of the most important factors that affect osseointegration is the primary stability of the implant. Dental implants inserted at the posterior region of the maxilla exhibit the lowest success rates as the low density bone in this area often jeopardize rigid fixation of the implant. Many surgical techniques have been developed to increase the primary stability of an implant placed in low density bone, such as bicortical fixation of the implant, undersized preparation of the implant bed and bone condensation by the use of osteotomes. A new promising technique, named osseodensification, has been recently developed that creates an autograft layer of condensed bone at the periphery of the implant bed by the aid of specially designed burs rotating in a clockwise and anti-clockwise direction. The purpose of this review is to emphasize that implant primary stability is strongly influenced by the surgical technique, to quote and briefly analyse the various surgical procedures laying weight to osseodensification procedure.

Key words: Osseodensification, Implant Stability, Bone Condensation, Insertion Torque, Bone Density, Bone Compression

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Introduction

Osseointegration of dental implants may be affected by a variety of factors. As early as 1981 Albrektsson et al[1] demonstrated the six major parameters of osseointegration, mainly: the implant material, the implant surface, the implant design, the condition of the bone at the host bed, the surgical technique and the loading conditions. However, as research revealed more on the role of these factors, it is more useful to categorize them by their determinants:

1. implant related factors: the biocompatibility of the material[2,3], the topography[4,5], composition[6-8] and coating[9-11] of the surface, the shape and design of the implant[12-14] and the length and diameter[15,16] of the fixture,
2. host bed factors: the bone volume[17,18], density[19-21] and vascularity[22-24].
3. surgical factors: achieving primary stability[25-27], mechanical trauma, thermal trauma or infection[28-32],
4. biomechanical factors: loading conditions[33-35],
5. patient related factors: systemic disease[29,30,36-38], systemic medication[39-43], radiotherapy[44,45] and parafunctional habits[46,47].

Primary stability of the implant is, however, of utmost importance as it is related to the parameters of all five categories. It is, actually, influenced by the shape and design of the implant[48,49], the quality and quantity of the bone[26,50], the surgical technique and skills of the surgeon[51-53], whilst its maintenance is depended on the loading conditions, the presence of parafunctional habits[46,47] and the healing capacity of the host[54,55].

Furthermore, primary stability is reported to be a prerequisite for the establishment of osseointegration, that is, the secondary stability of the implant[26,56]. Once a treatment plan has been made the achievement of adequate primary stability during implant installation is a matter of the surgical technique and the experience of the surgeon.

Many techniques are reported to increase the primary stability of dental implants. The purpose of this paper is to quote these techniques, their scientific background and present a recently developed technique based on the concept of osseodensification[57].

Materials and methods

Criteria for Considering Studies for this Review

The inclusion criteria comprised clinical studies conducted in patients, systematic meta-analyses and experimental studies that evaluated the association between implant primary and secondary stability and/or micro-movement, resonance frequency analysis, insertion and removal torque value, surgical technique, implant characteristics and percentage of bone-to-implant contact.

Search Method for Identification of Studies

For the identification of the studies to be considered in this review, combinations of the following keywords were used: "dental implants", "implant stability", "primary stability", "secondary stability", "implant stability quotient", "ISQ", "resonance frequency analysis", "RFA", "osteotome technique", "undersized drilling", "surgical technique", "implant micro-movement," "insertion torque value", " ITV", "removal torque value", "RTV", osseodensification" and "osseointegration".

Searched Databases

A search of health science database MEDLINE-PubMed was performed, including papers published until March 2017. After final selection of the papers, those that fulfilled the selection criteria were processed for extraction of information. The present literature review was customized to summarize the relevant data.

What is implant stability

It is stated that micromotion of the implant more than 50 to 100 μm during healing period may impair the process of osseointegration and lead to fibrous integration of the implant, that is, implant failure[58]. Therefore, an implant is considered to be "stable" when its micromovement is less than this threshold.

Implant primary stability is positively related to the insertion torque exercised[26]. According to Norton[59] torque of only 25 Ncm would seem more than sufficient to yield a favorable clinical outcome. However, if the implant is scheduled to be immediately loaded then an insertion torque of at least 32 Ncm is to be considered[60], which should be increased to 45Ncm in sites of low quality bone[61].

Implant primary stability is affected by the density of the host bone[26]. This means that in cases of low quality bone, like the posterior maxilla, it is potentially difficult to achieve high insertion torque and adequate primary stability. In these cases implants are more vulnerable to failure especially if immediate loading is exercised.

Primary and secondary stability

Primary stability is the mechanical anchorage of a post or a screw – in this case a biocompatible implant – as it is wedged in a properly prepared hole in a matrix – in this case the host bed in the living bone. Primarily this contact between the two materials has only mechanical connection characteristics and not biological. However, bone is a living tissue and, due to surgical trauma, a periphery of about 1mm around the implant body is devitalized, resorbed and remodeled[62-64]. This biologic procedure will, consequently loosen the bone-to-implant mechanical contact decreasing, thus, implant's primary mechanical stability. Fortunately, as bone forms around the implant body, according to the phenomenon of osseointegration, the implant's connection to new bone is increasing. Therefore, a biologic stability of the implant is achieved, the so-called secondary stability, leading to an osseointegrated implant.

During osseointegration process primary mechanical stability is not totally eliminated as new bone is formed and secondary stability has time to increase up to full osseointegration status. However, theoretically, the implant is more vulnerable to micromovement and susceptible to fibrous integration during a short time period that primary stability reaches its lowest point while secondary stability has not yet been fully established (for a graphic attribution of these phenomena see Raghavendra et al.[65]). The time sequence of these phenomena is not yet fully understood and this time period has not yet been determined.

How implant stability is measured

Implant stability may be evaluated either by measuring histologically the bone-to-implant contact percentage or by recording the reverse torque value during implant removal. Both methods are well documented[66,67], however they are destructive methods with no clinical value.

Clinically the implant stability may be assessed either by recording the insertion torque value or by the use of the resonance frequency analysis.

Insertion torque measurement is a well established method however, it may assess only primary stability during implant placement[25,68]. Resonance frequency analysis may be used at any time point during implant's life. Nevertheless, resonance frequency analysis is not a direct measurement of implant stability as it only records the rigidness of the matrix that the instrument's probe is connected to. Furthermore, its values were never directly related to implant actual micro-motion[69]. Implant micromotion is the only direct method of assessing implant stability although, for the moment, no instrument has been developed to measure implant micromotion intra-orally. However, the efficacy of the method has been reported in experimental studies[25,70].

How primary stability affects secondary stability

Implant insertion torque determines its primary micromovement and, therefore, its primary stability[25].

Furthermore it has been reported that insertion torque is directly related to the initial bone-to-implant contact percentage at the time of implant placement[25,71].

It is also reported that insertion torque value is related to the removal torque value of an implant after 2 or 4 weeks of osseointegration period[72,73]. This is a very important result as it shows that secondary stability of an implant, that is the establishment of osseointegration, is affected, among other factors, by its primary stability. Nevertheless, as has been previously mentioned, topographical features of the implant and surgical implant placement technique may modulate such correlation. B u t how the clinician during implant installation may increase the primary stability of an implant?

Increasing the primary stability of an implant

Dental implants inserted at the posterior region of the maxilla exhibit the lowest success rates[20,21] mainly due to the thin cortical plate and the low density trabecular bone by which this region is characterized. Additionally, trabecular bone has only a minor influence on the implant stability compared to the marginal compact bone[74,75].

During the past decades many surgical techniques have been developed to increase the primary stability of an implant placed in low density bone. Originally it was suggested that the stage of bone tapping should be omitted, especially in cases of low density bone[76].

Another method that was proposed is to increase implant primary stability by achieving bi-cortical fixation[74]. It has been reported that bicortical anchorage significantly increases primary implant stability[77,78]. On the contrary, Ivanoff et al.[79], in a retrospective study, record 3 times higher fracture rate in bicortical implants than monocortical ones. According to the authors, possible explanation for this could be increased stress and bending forces as a result of prosthetic misfit or high occlusal tables.

A widely used method to surgically increase implant primary stability is the underpreparation for the implant bed. This is usually achieved by using as a last drill one or more sizes smaller that the implant diameter. The efficacy of the method has been recorded in many animal[80,81] and clinical studies[82,83]. It is mentioned, however, that, in the presence of poor-bone quality, a 10% undersized implant bed preparation is sufficient to improve the primary stability of the implant; additional decrease does not seem to enhance primary stability values[84]. A drawback to the method might be the elimination of the dimensions of the healing chamber between pristine bone and implant body that could decrease the speed of woven bone filling and thus, the establishment of the secondary biologic fixation. A variation of the method of underpreparation is the stepped osteotomy of the implant bed. Studies on this method report significantly greater implant stability in terms of insertion torque than the conventional osteotomy in soft bone[85,86].

The rationale beyond bone condensation at the periphery of implant bed is to insert the implant in a matrix of higher density. The use of osteotomes for bone condensation of low-density bone was firstly described by Summers[87]. The technique involves the use of implant-shaped tapered tools of increasing diameter with the aid of which bone, instead of being removed from the implant bed, is compressed inwards. It is reported that this process increases the density of peri-implant bone[88,89,90]. Although it is assumed that bone is condensed apically and laterally, Blanco et al.[89] report that the increase bone density is mainly detected at the periapical area while laterally - at the periphery - there was no increase in bone density. Furthermore, it is not clear if this increased density improves implant's primary stability as well. Many studies confirm that the compaction of trabeculae is an effective method to increase primary stability of an implant[91,92]. According to them the bone-condensing technique can be recommended as an alternate surgical approach for implant site preparation in reduced bone density to achieve greater implant stability. However, other studies[93,94] report that the increased peri-implant density gained by the osteotome technique does not ensure greater bone-to-implant contact and does not improve implant primary stability. The explanation given is that trabecular fractures that accompany the bone condensation procedure trigger a prolonged period of healing and bone resorption preventing implants to achieve superior secondary stability. On the other hand, Stavropoulos et al.[95] reported good primary stability of implants placed with bone condensation technique, despite the minor cracks detected in the coronal portion of the alveolar ridge. It is emphasized[96] that bone condensation technique should be performed in low density bone, while in denser bone this technique may exhibit a negative effect as it may impair the biomechanical environment of the bone-implant interface due to the osteocyte damage and extensive microfarctures. Nevins et al.[97] compared low, moderate and high condensation of the walls of the implant bed. The scenario intended to induce moderate degree of compression provided the best overall results. Recently a new technique of preparation the implant bed has been developed based on an osseodensification drilling concept[57].

The osseodensification implant site preparation

Traditional drilling as a method of osteotomy preparation for implant placement is considered to be a subtractive procedure that cuts and removes bone tissue from the implant site. Conventional drills facilitate this removal, while special drills with a retentive design (deep grooves) have been manufactured, that enables storage of displaced bone chips between the drill flutes for potential retrieval and regenerative use[98,99]. However, primary stability of the implant is greatly affected as bone is removed from the implantation bed[100]. Osseodensifying burs have been designed to work in a non-subtractive manner. They have many lands with negative rake angle which work in a non-cutting mode. Nevertheless, they have a cutting chisel edge and a tapered shank so, as they enter deeper into the bone, they expand the osteotomy, smoothly compacting bone in the periphery. They work in order to forward bone chips and debris inwards the implant bed rather than removing it from the implant bed[101]. They can be used in a non-cutting counter-clockwise direction to smoothly condense bone or in a cutting clockwise direction. The implant bed preparation begins with a much smaller hole than conventional drilling due to recovery of elastic strain. The purpose is to create a condensed autograft zone along the periphery and at the apex of the implant. Inventors claim that the compaction of bone is performed by a controlled deformation which occurs through viscoelastic and plastic mechanisms provided that the load is kept beneath the strength of the bone. In their study this new osseodensification method increased the inserition torque of implants to approximately 49 Ncm in low density bone compared to the standard drilling technique placed implants that reached approximately 25 Ncm. When the ossodensified osteotomy remained empty its diameter was reduced by approximately 91%, which, according to the authors was to the viscoelastic nature of deformation[99]. The residual strains of viscoelasticity create compressive forces against the implant surface, as a spring-back effect, increasing the bone-to-implant contact and primary stability[102,103].

The efficacy of this new surgical technique to enhance bone density, ridge width and implant secondary stability was evaluated by Trisi et al.[104] in a recent study. The researchers inserted 20 implants in the iliac crest of 2 sheep. On the left sides they used the conventional drilling protocol (control group) while on the right sides they inserted the implants by using the osseodensification method (test group). Biomechanical and histological analyses were performed after 2 months. Authors report a significant increase of the ridge width and bone volume percentage of approximately 30% in the test group compared to the control group. Additionally, better removal torque values and micromotion under lateral forces were recorded for the test group. The increase of bone density in the test group was particularly evident in the most coronal implant region where bone trabeculae were thickened because of incorporation of autogenous bone fragments during the healing process. It was concluded that the osseodensification procedure is able to increase the bone volume around implants inserted in low density bone which may lead to enhanced implant stability.

Lopez et al.[105] assessed the biomechanical and histological effects of osseodensification surgical instrumentation in a spine model animal study. They inserted fixation devices in the vertebral bodies of the spine of 12 sheep. The sheep cervical spine model was selected due to its low density bone configuration. The left-sided vertebral body devices were implanted using regular surgical drilling while the right-sided devices were implanted using osseodensification drilling. Six of the twelve sheep were sacrificed at three weeks post-surgery, and the remaining six were sacrificed after six weeks. Structural competence of hardware was measured using biomechanical testing of pullout strength, while the quality and degree of new bone formation and remodeling was assessed via histomorphometry. Statistical evaluation showed significantly higher levels of insertion torque for the osseodensification group (approximately 65 N cm) relative to the regular drilling group (approximately 35 N cm) group. Pullout strength demonstrated osseodensification drilling to provide superior anchoring when compared to the control group collapsed over time with statistical significance. Authors concluded that, despite the limitation that no load was incurred on the implanted devices, this technique can potentially improve the safety and success rates of bony drilling at all sites of low bone density and limited bone volume.

The effect of osseodensification method on the initial stability and early osseointegration of endosteal implants with conical or parallel wall design was examined by Lahens et al.[106]. The study was executed in the ilium of 5 sheep. A total of 30 implants were placed, 15 conical and 15 parallel, according to three insertion protocols: (i) regular drilling, (ii) clockwise osseodensification drilling and (iii) counterclockwise osseodensification drilling. In this way 6 subgroups were formed. Six weeks after surgery the animals were sacrificed. Insertion torque, as a function of implant type and drilling technique, revealed higher values for osseodensification relative to regular drilling, regardless of implant macrogeometry. A significantly higher bone-to-implant contact for both osseodensification techniques was observed compared to regular drilling. There was no statistical difference in bone-to-implant contact as a function of implant type, or in bone-area-fraction occupancy as a function of drilling technique, but there were higher levels of bone-area-fraction occupancy for parallel than conic implants. Authors concluded that regardless of implant design, the osseodensification drilling procedure improved primary stability and bone-to-implant contact due to the densification of autologous bone debris at the bone walls.

Achieving high primary implant stability is of utmost importance for the establishment of osseointegration. Based on the recognition that neither insertion torque nor bone-implant contact is an accurate measure of implant stability it is obvious that few studies report actual measurement of primary implant stability immediately after condensation. Many techniques have been developed to increase primary stability of implants. Based on this short literature review osseodensification is a new promising procedure for enhancing bone density around implants and increase primary stability. Further, experimental as well as clinical studies are needed to clarify the biological reaction of peri-implant bone to this method and its influence on actual implant micromotion.

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