Role of primary stability for successful osseointegration of dental implants: Factors of influence and evaluation

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Abstract: A secure implant primary (mechanical) stability is positively associated with a successful implant integration and long-term successful clinical outcome. Therefore, it is essential to assess the initial stability at different time-points to ensure a successful osseointegration. The present study critically reviews the factors that may play a role in achieving a successful initial stability in dental implants. Databases were searched from 1983 up to and including October 2013 using different combinations of various keywords. Bone quality and quantity, implant geometry, and surgical technique adopted may significantly influence primary stability and overall success rate of dental implants.

Keywords: dental implants, bone density, implant surface topography, osseointegration, primary stability, surgical technique

Introduction

Traditionally, endosseous implants are loaded once bone healing has occurred, which takes approximately 3 months in the mandible and 6 months in the maxilla [1, 2]. Today, modifications of this treatment protocol using immediate loading of implants are an eminent and acknowledged treatment strategy for the rehabilitation of missing teeth [3–5]. Histologic and histomorphometric evaluation of immediately loaded implants recovered from humans has also shown a high degree of bone-to-implant contact percentages [6, 7]. However, for any implant procedure, successful implant integration is a prerequisite criterion, which depends on a series of procedure-related and patient-dependent measures [8]. Successful osseointegration from the clinical standpoint is a measure of implant stability, which occurs after implant integration [9]. Two terms, such as the primary and the secondary implant stability, are related to implant therapy. Primary stability is associated with the mechanical engagement of an implant with the surrounding bone, whereas bone regeneration and remodeling phenomena determine the secondary (biological) stability to the implant [9, 10]. A secure primary stability is positively associated with a secondary stability [11]. Extent of implant stability may also depend on the situation of surrounding tissues [3, 12]. Bone quantity and quality, implant geometry, and surgical technique adopted are also among the predominant clinical factors that affect primary stability [13]. Therefore, it is essential to assess the implant stability at different time-points in order to ensure a successful osseointegration. In this context, the objective of the present review was to assess the factors that may play a role in achieving a successful primary stability in dental implants.

Materials and Methods

The National Library of Medicine, Washington DC (MEDLINE–PubMed) was searched for appropriate articles addressing the focused question. Databases were searched from 1983 up to and including October 2013 using the following terms in different combinations: “bone,” “dental,” “design,” “implant,” “immediate
loading,” “implant length,” implant diameter,” “maxilla,” “mandible,” “narrow implant,” “osseointegration,” “primary stability,” “surgical technique,” and “wide implant.”

The eligibility criteria were based on human and experimental studies, use of control group, articles published only in English language, and reference list of potentially related original and review studies. The second step was to hand-search the reference lists of original and review studies that were found to be relevant in the first step. After final selection of the papers, those that fulfilled the selection criteria were processed for data extraction. The structure of the present literature review was customized to mainly summarize the relevant information.

Pre-requisites for a successful primary stability

Primary stability is accomplished when the implant is placed in the bone in such a position that it is “well-seated.” This allows the implant to mechanically adapt to the host bone until secondary stability is achieved [13]. Impaired primary implant stability has been shown to jeopardize the osseointegration process [14]. The success of this adaptation, however, depends on several factors, including the density and dimension of the bone surrounding the implant, the implant design, and surgical technique used (Fig. 1).

Bone density and quality

The significance of bone density and its association with implant dentistry has existed for more than two decades. Several classifications regarding bone density have been recommended as shown in Fig. 2.

Bone quality is often referred to as the amount (and their topographic relationship) of cortical and cancellous bone in which the recipient site is drilled. A poor bone quantity and quality have been indicated as the main risk factors for implant failure as it may be associated with excessive bone resorption and impairment in the healing process compared with higher density bone [15–17]. Clinical studies have reported dental implants in the mandible to have higher survival rates compared to those in the maxilla, especially for the posterior maxilla [18, 19]. Bone quality has been considered as the basic cause of this difference. In the posterior maxilla, there is commonly thinner cortical bone combined with thicker trabecular bone compared to the mandible [20, 21]. Clinically, a poor degree of bone mineralization or limited bone resistance is observed in bones with poor densities, which are often referred to as “soft bones” [20, 22]. It has been shown that achieving optimum primary stability in soft bones is difficult and is also related to a higher implant failure rate for the implants placed in such bones [15, 23]. Turkylmaz et al. [24] reported the bone quality around the implant to be superior in the mandible compared to the maxilla. A clinical study [25] with 158 implant sites from 85 patients indicated a strong correlation between bone density and dental implant stability. Results by Miyamoto et al. [26] demonstrated that dental implant stability is positively associated with the thickness of cortical bone thickness. In contrast to the previous studies, additional studies in the posterior mandible showed high failure rates due to the poor bone quality as well as other additional factors [27, 28].

Computerized tomography (CT) has been regarded as the best radiographic method for analyzing the morphological and qualitative analysis of the residual bone [29–31]. It is also a valuable means for evaluating the relative distribution of cortical and cancellous bone [32]. However, the density of the surrounding bone seems to play an essential role in high occlusal forces, and therefore, the high bone-to-implant (BIC) percentages of a thin, “carpet”-like bone in contact with the implant surface seems to be not clinically significant compared to lower rate of BIC in a thick bone. Intraoperative surgical techniques, such as bone condensing, undersizing the osteotomy, improve the bone density and increase the primary (mechanical) stability. In contrast to that, loading effects on the peri-implant bone under delayed or immediate loading conditions influence the secondary (biological) stability increasing the percentage of the bone-to-implant (BIC) contacts [27, 33].
Implant design

Implant design refers to the three-dimensional structure of an implant with all the components and features that characterize it. It has been reported that the implant design is a vital parameter for attaining primary stability [34]. The texture of an implant’s surface can influence the bone–implant interface. Studies [6, 33, 35] have demonstrated a relationship between implant design and osseointegration. Implants of varying designs, placed in different bone qualities, reach various degrees of stability, which may determine their future clinical performance [36, 37]. Originally, implants were fabricated in a parallel design; however, they were not appropriate for most applications.

Tapered implants were later introduced to enhance aesthetics and assist implant placement between adjacent natural teeth [38]. The hypothesis behind using tapered implants was to provide a degree of compression of the cortical bone in an implant site with inadequate bone [39]. Cylindrical wide body implants increase the risk of labial bone perforation especially in thin alveolar ridges due to presence of buccal cavities, whereas the decrease in diameter of the tapered implants toward the apical region accommodates for the labial concavity [40]. However, according to Chong et al. [34], if bone quality and quantity are optimal, then they may compensate for implant design inadequacy.

Implant surface characteristics and diameter have also been shown to influence primary stability. Rough implant surfaces present a larger surface area and allow a firmer mechanical link to the surrounding tissues [11]. In vitro studies [41, 42] have shown that sandblasted implant surfaces promote peri-implant osteogenesis by enhancing the growth and metabolic activity of osteoblasts [41, 42]. Studies [6, 43, 44] have shown that surface topography and roughness positively influence the healing process by promoting favorable cellular responses and cell surface interactions. In poor bone quality sites, implants with an acid-etched surfaces can achieve a significantly higher bone-to-implant contact compared to implants with a machined surface [45]. Clinical studies have shown that implants with smaller diameters (less than 3.0 millimeters) provide sufficient primary stability in cases with a limited bone volume [46, 47].

It is accepted that all implants display some extent of bone loss after osseointegration and through time of function. It has been claimed that the introduction of microthreads or “retention grooves” at the neck of the implant may assist in reducing distributing stress and reducing the extent of bone loss following the implant installation [48]. In the reality, crestal bone preservation can be associated with the surgical technique and the presence of platform switching [49]. In addition, the progressive thread design seems to decrease the compression of the crestal bone preserving in that way the crestal bone loss [49].
Primary stability and osseointegration

Surgical technique

Besides the quantity and quality of bone and morphology of the implant, the surgical technique adopted also influences primary stability. Therefore, the undersized drilling technique was introduced to locally optimize bone density and subsequently improve primary stability. Numerous modifications in surgical technique have been described which might assist in enhancing primary stability of dental implants. Some studies [50, 51] recommend the use of a final drill diameter which is smaller than the diameter of the implant; however, Summers [52] recommended the technique of bone condensing, where, after using the pilot drill, the cancellous bone is pushed aside with “condensers” (osteotomes), thus, increasing the density of the surrounding bone, increasing in that way the initial implant stability.

It has been reported high survival rates with the immediate loading of dental implants, which are attributed to high primary stability [43, 53]. Some studies have also preferred insertion torque as a determinant of implant stability, and torque values of 32, 35, or 40 Ncm and higher have been chosen as thresholds for immediate loading [54, 55]. This threshold seems to be important due to the selection of implant–abutment connections, which have the need of this torque to engage the abutment to the implant body via the fixation screw based on the manufacturer guidelines. Also implants placed in a weak bone (poor bone quality) may be loaded immediately and demonstrate high survival rates when the final torque in the implant–abutment connection is lower, i.e., nearly 15–20 Ncm [13].

Methods of evaluation of the primary stability

Two methods are usually employed to measure the clinical stability of an implant, namely, the Periotest (PT) and resonance frequency analysis (RFA) measurement using Ossstell device. The PT gauges temporal contact of the tip of the instrument during repetitive percussions on the implant. PT values include a narrow range over the scale of the instrument and, thus, provide comparatively less sensitive information concerning implant stability [56]. It has been suggested that the measurement of the moment of force or torque (required for seating an implant in bone) can also be used to measure the primary stability of an implant [57].

The RFA device measures the resonance frequency of a transducer attached to the implant body, which is stimulated by different frequencies. According to a study by Sul et al. [58], RFA is a reliable indicator for identifying implant stability with assurance. This instrument has a graphic display panel showing the implant stability quotient (ISQ) values, which indicate the firmness at the implant–tissue interface [59]. ISQ values greater than 65 have been regarded as most favorable for implant stability, whereas ISQ values below 45 indicate a poor primary stability [60]. However, there is no justification for a routine clinical use of the PT and RFA techniques [61], as a disadvantage of the ISQ evaluation technique is that the value is dependent on the insertion of the magnet (transducer) to the implant. When the transducer is not well screwed on the implant body (without to use the final insertion torque), a low ISQ value has been evaluated. In addition, the ISQ value is possible to be performed only before the final abutment is connected and cannot be performed with the prosthetic restoration. Further modifications of this technique are needed in order to be able to evaluate the implant stability in a precise and clinical reliable way.

Effect of micromotions on primary stability

When the ends of a fractured long bone are reduced, then there should be absolutely no movement between the fragments to endorse fracture healing [62]. This happens because movements, even at the micrometer range, can induce a stress or strain that may hinder the formation of new cells in the gap. The same phenomenon is applied at the bone-to-implant interface [63]. The induction of micromotion during functional loading may primarily be responsible for failure of osseointegration and ultimately implant loss [64]. Micromotions above 50–100 micrometers may negatively influence osseointegration and bone remodelling by forming fibrous tissues and inducing bone resorption at the bone-to-implant interface [65–67]. Therefore, a high initial (mechanical) stability is essential for a successful osseointegration of dental implants. Studies [27, 33, 68] have reported that a well-controlled micromotion positively influenced bone formation; therefore, more advanced clinical conditions, like immediate functional loading of implants placed in healed ridges or also fresh extraction sockets, seem to improve the peri-implant bone density and improve the implant integration.

Conclusions

This literature review highlights the importance of achieving a successful primary stability for successful implant integration. Bone quality and quantity, implant geometry, and surgical technique adopted may significantly influence implant initial stability and overall success rate of dental implants.
References