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Review Article

Effects of Bone Types on Bone Remodeling of a Dental Implant: A Review of the Literature

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Abstract

The bone quantity and quality, indicating density and strength of bone are the important factors in dental implant treatment. Bone quality frequently dictates the overall treatment plan of a patient due to changes in compatible surgical approach, appropriate wound healing time, and preferred pattern of occlusal forces on the final restoration. Furthermore, bone augmentation before implant placement in the area where the bone architecture is inadequate can affect the loading protocol. An article search was proceeded using the PubMed database with keywords "type of bone," "bone density," "bone quality," "loading time," and "bone remodeling". Fifty-three original articles meeting the inclusion criteria were analyzed. This literature review compiles basic knowledge on the effect of quality of bone to loading time of dental implant, effects of bone density to dental implant treatment success, bone classification, factors affecting bone density in individual, definition of each loading protocol, and effects of various types of bone to remodeling process of peri-implant bone.

Keywords: bone density, bone quality, peri-implant bone, type of bone

Introduction

Dental implants have been used in dentistry since 1960.(1) Implants have garnered a high success rate of 7-year at a rate of 95% and 90% in the maxilla and mandible, respectively.(2) One of the most important factors that affect the success of dental implants is bone quantity and quality. This is determined by the strength and architecture of the external and internal structures of the bone.(3) Bone quality is an important consideration in dental implant treatment planning, as it affects the final implant design, surgical plan, wound healing time, and pattern of occlusal loading on the final restoration.(4,5)

The complete osseointegration of dental implants requires not only appropriate bone quality in terms of height, width, and appropriate shape, but also proper bone density.(6) According to the study by Zarb and Schmitt, bone quality and quantity are important factors in predicting dental implant treatment outcomes.(7) A classification system was developed in order to standardize assessment of bone quality for patients. Bone quality can be classified into 4 types which will be discussed later in this literature review. This classification system has been used by multiple studies evaluating implant success and failure rates as they relate to multiple factors. These factors include stress distribution in the early stage of bone-implant contact area between cortical bone or trabecular bone with dental implant, which resulted in primary implant stability in terms of healing time and stress distribution to the peri-implant bone. Therefore, the number of dental implants or dental implant with more surface area needed to be considered in order to be consistent with the occurring stress.

Another important factor to consider is bone augmentation prior to implant placement. Bone augmentation is used when dental implants are to be placed in areas with inadequate bone architecture, or in areas with insufficient alveolar bone height. Augmented sites usually exhibit different elasticity compared to original bone will result in different stress distribution on the surface and bone remodeling.(8) Additionally, complete osseointegration is correlated to peri-implant bone remodeling with different bone types, as it affects wound healing time after implant placement and subsequently impacts decision in selecting appropriate loading protocol.

The Aim of this review is to evaluate the effect of bone quality of the surgical site on loading time. The effect of bone density on dental implant treatment success. The effect of bone classification, factors affecting bone density in individual, definition of each loading protocol, and relationship of various bone types on remodeling process of dental implant in order to enhance better understanding and further implementation accordingly.

An literature search was conducted using the PubMed database with keywords "type of bone," "bone density," "bone quality," "loading time," and "bone remodeling". The search yielded 53 articles. The inclusion criteria was; 1) Articles in Thai or English concerning peri-implant bone remodeling or loading time for dental implant. 2) Articles in Thai or English evaluating the success rate of dental implant treatment in relation to bone quality or bone type. The exclusion criteria included; 1) all non-Thai or non-English articles. 2) Articles which are not related to bone quality or bone type or dental implant remodeling. 3) Articles which do not mention bone quality and loading time for dental implant. 53 articles were selected and reviewed accordingly.

Definition

Definition of loading protocol

Loading protocols can be classified into 3 categories; Immediate loading, early loading, and conventional loading. Immediate loading defined as implant restoration in function within 1 week after implant placement. Early loading is defined as implant restoration in function within 1 week to 2 months after implant placement. Conventional loading is when the implant defined as implant restoration in function after least 2 months after implant placement.(9)

Definition of bone quality

Bone quality or bone density refers to the internal structure of the bone. The classification is based on the mechanical properties of the bone including density and modulus of elasticity.(6) The bone structure consists of cortical bone, which affects dental implant stability, and trabecular bone, which affects blood supply.(3,10) Bone quality is determined by various factors such as bone turnover, microarchitecture, as well as the amount and distribution of mineralization.(11) A classification by Zarb and Schmitt classifies bone structure according to bone quality and quantity as they relate to dental implant treatment success.(7)

Classifications of bone in dental implant

Classification of bone by Zarb and Schmitt

According to the study by Zarb and Schmitt in 1995, the bone quality is classified into 4 types as a standard guideline for patient classification prior to dental implantation as follows.(7)

D1: Jaw bone consisting of homogenous cortical bone

D2: 2-mm outer cortical bone surrounding inner high-density trabecular bone

D3: 1-mm outer cortical bone surrounding inner high-density trabecular bone

D4: 1-mm outer cortical bone surrounding inner low-density trabecular bone

A study of Jaffin and Berman in 1991 identified a 3% failure rate of dental implant in D1, D2, and D3 bone. The failure rate increases even further to 10% in D4 bone.(12) Furthermore, it was shown that stress distribution primarily occurs during the primary contact area of bone and dental implant, mostly on cortical bone.(3) Thus high-density bone has better resistance for dental implant movement during wound healing, and also provides better stress distribution. In cases with reduced bone quality it is recommended that the number of dental implants should be increased, or that dental implants with more surface area should be used.(3,13-15)

Lekholm and Zarb classification

The study of Lekholm and Zarb in 1985 classified bone into 4 types according to the anterior part of the jaw (Figure 1).[16]

A study by Schnitman found a 10% difference between bone type II and type III in terms of dental implant survival and decreasing survival rate of 22% in low density bone.[17-19] Similarly, John *et al.* also found only a 3% failure rate Type III bone and up to 28% failure rate in type IV bone, and that the resorption rate of alveolar bone also depended on the bone density.[20-27]

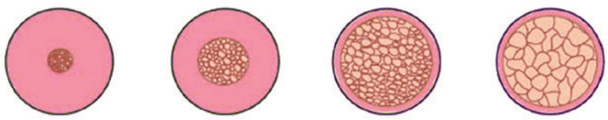

Figure 1: Four types of bone. (A) Type I cortical bone. (B) Type II a thick layer of cortical bone surrounding a core of dense trabecular bone. (C) Type III a thin layer of cortical bone surrounding a core of dense trabecular bone. (D) Type IV a thin layer of cortical bone surrounding a core of low density trabecular bone. (modified from Lekholm and Zarb, 1985)[16]

Misch classification

Misch classified 4 bone types according to bone density in edentulous ridge of maxilla and mandible as D1, D2, D3, and D4.[3,10]

D1: Mainly comprised of cortical bone

D2: Thick dense to porous outer cortical bone and coarse inner trabecular bone

D3: Thin porous outer cortical bone and fine trabecular bone

D4: Scarce cortical bone on the alveolar bone crest and mostly comprised of trabecular bone

Low density bone, incomplete mineralization, trabecular bone with many spaces or immature bone can be classified as D5 bone type. The bone density assessment could be predicted via tactile sense during surgery, bone position in jaw, and x-ray.

D2 bone type is mostly found in mandible, while D3 bone type is mostly found in maxilla (65% in anterior maxilla). D4 bone type is mostly found in maxilla (40% in posterior maxilla).[3] The bone density that is appropriate for implant placement is D1 or D2.

Table 1: Percentage of different bone density (bone type) in different jaw area

Type	Anterior maxilla	Posterior maxilla	Anterior mandible	Posterior mandible
D1	0	0	6	3
D2	25	10	66	50
D3	65	50	25	46
D4	10	40	3	1

Furthermore with bone D1 and D2, the loading force can be applied immediately after implant placement for patient with ridge atrophy. The success rate of dental implants is correlated to dental implant primary stability, remaining bone structure, dental implant design, surgical strategies, wound healing time, and loading protocol on restoration. The structure of the bone can be described in terms of quality or density.

Effect of bone density towards success of dental implant

The following factors have been shown to affect the treatment plan in order to achieve successful implant treatment.

1. Different bone strength
2. Elastic modulus of the bone
3. Percentage of contact between bone surface and dental implant
4. Stress and strain distribution to the bone

Increasing the implant surface area can decrease the stress on the bone-implant contact area, and also enable the application of reduced-diameter dental implant.[16, 26, 28-31] Every 0.5 mm increase of the dental implant diameter will help increase 10-15% surface area. The highest stress distribution is found at the alveolar crest when cylindrical shaped dental implant is used. Bone augmentation prior to implant placement is an applicable technique for implant placement in area with inadequate bone structure such as posterior maxilla or mandible with inadequate height of alveolar bone or maxillary sinus pneumatization which requires a surgery to increase bone height for better implant stability. According to the study of Chou *et al.* in 2012 founded that bone augmentation with low elastic modulus bone grafting material resulted in reduced stress on the surface and increased bone remodeling rate. Therefore, grafted bone with low hardness can prevent bone resorption after implant placement.[32]

Osseointegration is related to bone remodeling as a wound healing process after implant placement. The higher bone remodeling rate, resulting in the faster osseointegration process. The bone remodeling can be accelerated via different methods such as loading protocol by adapting to the force interacting to the bone on apposition or resorption.[17,18] The same principle could also be applied in bone remodeling acceleration by providing loading during wound healing in early loading or immediate loading. A previous study found that the latter enhances more bone remodeling, resulting in more density of the bone surrounding the dental implant.[20-22]

Bone quality

Success rate of dental implants in different areas of the jaw depends on various factors, including quantity and quality of bone, jaw trauma history, distance between important anatomical structures such as maxillary sinus or inferior alveolar nerve, the need for additional bone augmentation and other surgery, quantity of blood supply, and wound healing rate.[33]

Bone quality also depends on area of the jaw planned for implant placement.[30,34] The area with the highest bone density is anterior mandible, while posterior maxilla has the lowest bone density. Adell *et al*. identified that the success rate of implant placed in anterior mandible was 10% higher than posterior maxilla.[35] Similarly, Schnitman *et al* identified that the success rate of implant placed in posterior maxilla was lower than in anterior mandible. The high failure rate was also found in posterior maxilla due to lowest bone density. Furthermore, 78% of failure rate was found with the implant placed in the area with low bone density.[36]

Friberg *et al.* found that 66% of implants failed when placed in a resorbed maxillary arch, in conjunction with cancellous bone.[30] According to Jaffin and Berman 5-year follow up study, a failure rate of 44% was found for implant placed in poor bone quality of the maxilla, 55% failure rate in low density bone, and only 3% failure rate in medium density bone.[12]

Hermann *et al.* found that implant failure depended particularly on patient's bone quality, especially with low quality bone which resulted in more failure rate when compared to other factors such as area of the jaw where the implant was placed.[37] This is consistent with the study of Smedberg *et al.* in which 36% failure rate was found in lowest bone quantity, and dental implant survival rate was relative to bone density rather than the area where the implant was placed.[38]

The study by He *et al.* on the effect of bone density towards survival rate of dental implants and factors affecting failure of dental implants in different bone density found that the failure rate of dental implant in low quality bone occurred more with patient aged over 50 years old or the implant was placed in posterior maxilla. Risk factors for people with low bone density include elderly patients, smoking, non-threaded implant, and immediate loading protocol, while diabetes is a risk factor for those with high bone density.[39]

Bone strength and bone density

Bone strength and density affect the stress distribution during implant placement due to the load transferred from restoration to the implant and subsequently to the bone which can result in implant failure.[40,41]

A study by Misch *et al.* evaluated the mechanical properties of trabecular bone in the mandible. Bone classified as D2 had more than 47-68% of compressive strength when compared to D3 bone.[42] Since bone has more elasticity than Titanium, the difference between the two materials may create microstrain conditions of pathologic overload and cause implant failure.[41] Furthermore, D4 bone is more likely to cause implant mobility and implant failure when compared to other bone types.[43]

The minimum bone height for implant placement for early loading is 7 mm for D1 bone, 9 mm for D2 bone, and 12 mm for D3 bone, using V-shaped thread on Titanium surface.[44] Dental implants being placed in low density bone should be designed with more depth and thread frequency than that of high density bone. Moreover, surface treatment of dental implant to increase proportion of bone to implant contact for low density bone can also help increase survival rate of dental implant.[42]

Bone density does not affect only the resistance of implant movement during the primary phase of osseointegration, but also helps with stress distribution from the implant to the surrounding bone. Therefore, the increasing failure rate might result from low bone quality.[43]

Bone density in relation to stress distribution

Alveolar bone resorption and implant failure during primary phase of osseointegration after loading results from excessive stress on bone surface and dental implant.[45] Different bone densities also affect stress distribution. D1 bone exhibits the maximum stress around the neck of implant. At the same loading force D2 bone exhibits a slightly greater crestal stress, additionally the intensity of the stress was shown to extend farther apically along the implant body. D4 bone exhibits the greatest crestal stress that is farthest apically along the implant body.[3]

Factors affecting bone density

Bone density or bone quality can change in accordance with various factors such as hormone, vitamin intakes, and mechanical properties of the bone. According to Wolff, the bone remodeling is directly proportional to the forces applied.[18] Every time the function of bone is modified, a definitive change occurs in the internal architecture of the bone. Furthermore, Hermann *et al.* found a relationship between implant failure and bone quality.[37] This was especially noticeable in poor bone quality. MacMillan and Parfitt reported that maxilla and mandible have different biomechanical properties.[46,47] Mandible, is designed as an independent force absorption unit. Thus, with remaining teeth, the outer cortical bone is denser and thicker and the trabecular bone is denser and coarser. In contrast, maxilla is designed as a force distribution unit because maxilla has a thin cortical bone and fine trabecular bone, and the bone density is reduced after tooth loss.[3,13-15,32,48]

Different types of bone and loading time

Effect of loading time towards survival rate of dental implant is still a subject of controversy.[48-50] Some studies found that less loading time or immediate loading and taper-shaped implant led to treatment successful. Scharer *et al.* found higher survival rate of dental implants placed with immediate loading in low density bone.[51] Cosyn *et al.* reported 93% survival rate of dental implant during 4 years using early loading, and 99.2% survival rate using conventional loading.[52] The study of Eliasson *et al.* also showed similar results; early loading resulted in higher failure rate.[53] According to an article of Jing He *et al.* the survival rate of dental implants placed with immediate loading was 90.48% which was less than those placed using the conventional loading protocol.[39] It was also found that the risk of failure rate from immediate loading was 6.8 time higher than conventional loading, as a result of poor osseointegration. Therefore, caution is advised when placing implants in low density bone and it is recommended to select the appropriate size of dental implant relative to the bone and extending the loading time to allow for better osseointegration.

Effect of bone grafting towards bone remodeling

Bone grafting prior to implant placement is an appropriate technique for area with inadequate bone architecture. Areas usually requiring bone augmentation include the posterior maxilla or mandible which exhibit insufficient height of alveolar bone, and the maxillary sinus which exhibits pneumatization. According to a study by Chou *et al*. on the differences in elastic modulus of bone.[32] It was found that the elastic modulus of autologous grafted bone ranged from 2 GPa to 13.7 GPa, the more elastic modulus or hardness of the bone, the less stress will occur on the surface, resulting in slower remodeling rate. Therefore, the use of low hardness bone grafting material will enhance better prevention for bone resorption.

Conclusions

According to related literatures, osseointegration which depends on bone quantity and density, is a crucial stage of wound healing after implant placement. Differences in bone density demand a corresponding change in the bone-to-implant surface area and stress distribution. Another important factor to consider when placing implants is the area of the jaw where maximum bone density is found. The anterior mandible is shown to exhibit the highest bone density and the minimum bone density is found in posterior maxilla. Low bone density also causes more implant mobility and increased failure. Failures can be reduced by considering the use of dental implants with widers diameters or more surface areas, or bone grafting prior to implant placement to enhance implant stability. Low hardness bone grafting material is correlated with a higher bone remodeling rate. There is still no final verdict concerning the effect of loading time on the success rate of dental implants. However, in case of low bone density, it is recommended that ample loading time be provided to allow for better osseointegration.

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