Some aspects of bone remodeling around dental implants

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INTRODUCTION

Bone, a type of connective tissue, presents cells, and in spite of being mineralized, it is constantly renewed by the bone remodeling process. This process is characterized by bone resorption by osteoclasts, followed by bone formation by osteoblasts. Several studies have demonstrated the relevance of bone remodeling to tissue responses that guarantee osseointegration, which is defined as the direct structural and functional connection between the organized vital bone and the surface of a titanium implant, capable of receiving functional loads.

The success of implants is associated first with their osseointegration, and later on with their survival rate; that is to say, their long-term permanence in function. Although there are some studies on bone remodeling around dental implants, the majority of the investigations have elucidated the tissue responses that constitute the initial process of bone-implant integration.

Considering that the remodeling process is continuous, it may be of relevance not only to osseointegration, but also to the longevity of dental implants. Therefore, the purpose of this study was to conduct a review of the literature with a view of elucidating the events associated with bone remodeling after osseointegration of implants. In addition, it was also performed a search to data regarding a possible influence of implant surface treatments on bone remodeling that occurs after osseointegration. Only studies involving implants with machined surfaces have been conducted up to now.

LITERATURE REVIEW

Considerations about bone tissue and bone remodeling

Bone, a connective tissue, has cells, and in spite of presenting the particularity of being mineralized, it is constantly renewed by the bone remodeling process. Several studies have demonstrated that bone remodeling is characterized by bone resorption by osteoclasts, followed by bone formation by osteoblasts. Several studies have demonstrated the relevance of bone remodeling to tissue responses that guarantee osseointegration, which is defined as the direct structural and functional connection between the organized vital bone and the surface of a titanium implant, capable of receiving functional loads.

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MATERIALS AND METHODS

In order to conduct this literature review, a detailed search strategy was used in various data bases, between the years 1930 and 2012. The following descriptors were used: “Osseointegrated Implant”, “Bone remodeling”, “Osteoclast”, “Osteoblast” and “Surface treatments”. The inclusion criteria were systematic reviews, meta-analyses, conventional reviews of the literature, controlled and randomized case studies, non-randomized clinical cases and articles of opinion, with an approach to the above-mentioned units. Studies that were not written in the Portuguese and English languages were excluded. After critical analysis of the bibliography surveyed, the suitable articles were selected. The data obtained were carefully analyzed and correlated for discussion of the results pointed out in the literature.

KEYWORDS

Dental implants, Bone remodeling, Osteoclast, Osteoblast.

Osteoclasts are responsible for the phagocytosis of these osteocytes, and covered the entire implant 30 days after osseointegration. However, the formation of bone tissue proceeded in the direction of the damaged bone. In these areas, medullary spaces containing small blood capillaries were found many regions of newly formed bone (NB), which are represented in white color, mainly in the regions of damaged bone (DB), in yellow color. (2B, 2E) Two months (60 days) post-osseointegration, the woven bone seems to reduce in volume when compared with 1-month period. Moreover, the woven bone previously in contact with the implant is being replaced by cortical bone. 

Concomitantly with osseointegration, damaged bone was observed, exhibiting lacunae of empty osteocytes, or osteocytes with a picnotic appearance between the pre-existent and neoformed bone around the implants. Considering that the remodeling process is continuous, it may be of relevance with respect not only to osseointegration, but also to the longevity of dental implants, the purpose of this study was to conduct a review of the literature with a view to elucidating the events associated with bone remodeling after the osseointegration of implants. In addition, it was performed a search to investigate the existence of data regarding the possible influence of treatments for modifying implant surfaces on these same events. A long term study investigating the response of bone tissue presents around osseointegrated machined titanium implants was performed in rats by Haga et al. These authors showed by means of active bone remodeling, with osteoclasts and osteoblasts working in synchrony, the spongy bone initially formed around the implant is gradually resorbed and completely replaced by compact bone at the end of 90 days. The morphological and biochemical alterations associated with the bone remodeling process, which occur around machined implants from 1 to 3.5 months after osseointegration are illustrated in Fig. 2.

Figure 1. Light micrographs of portions of tibiae which were surrounding the implants. (1A) Several bone trabeculae (B) and bone marrow regions (BM) are observed. Osteoblasts (Ob) and osteoclasts (Oc) are located on bone surface, whereas osteocytes (Ot) are located inside the bone matrix (B). H&E. Bar: 100μm. (1B) Osteoblasts (Ob), located on bone surface (B), show alkaline phosphate (ALP)-positive cytoplasm (brown-yellow color). Immunohistochemistry for detection of ALP (osteoblast marker) counterstained with Hematoxylin. Bar: 30μm. (1C) Giant multinucleated osteoclasts (Oc) exhibiting intense TRAP-positivity in the cytoplasm (brown color) are observed. n: nuclei. Ot: osteocytes. Arrowhead: Howship lacunae. Immunohistochemistry for detection of TRAP (osteoclast marker) counterstained with Hematoxylin. Bar: 90μm.

Figure 2. Light micrographs showing morphological changes in the surrounding bone around implants at 1, 2 and 3 months after osseointegration (2A–2C). Bar: 100μm. The schematic representation of each light micrograph summarizes the main histological events in the replacement of the injured bone by newly formed bone (2D–2F). One month (30 days) after implant osseointegration, woven bone and bone marrow regions (BM) are observed in the light micrograph. Many osteoblasts (Ob) and osteoclasts (Oc) are located on bone surface. It can be found many regions of newly formed bone (NB), which are represented in pink color in the scheme. Inside the bone matrix, several osteocytes (Ot) are observed. However, empty osteocytes lacunae are still observed (white color), mainly in the regions of damaged bone (DB), in yellow color. (2B, 2E) Two months (60 days) post-osseointegration, the woven bone seems to reduce in volume when compared with 1-month period. Moreover, the woven bone previously in contact with the implant is being replaced by cortical bone.

One month after implant placement

Osseointegration is observed in all the surfaces of the implants. There is a thin layer of neofomed bone on the implant surface. However, a part of this surface is shown not to be in contact with the neofomed bone. In these areas, medullary spaces containing small blood capillaries are shown to be in contact with the implant surface. The neofomed bone contains osteocytic lacunae exhibiting intact osteocytes. In the region of pre-existent bone, a cement line is easily identified beyond the empty osteocytic lacunae. The double staining of TRAP and ALP enzymes for the detection of osteoclasts and osteoblasts, respectively, show positivity for both cells on the neofomed bone surface. ALP-positive osteoblasts are found close to the area occupied by TRAP-positive osteoclasts, suggesting the occurrence of synchrony and equivalence of the activity of these cells, and therefore, of bone remodeling.

From 1.5 to 2.5 months after the implant placement

The formation of bone tissue proceeds in the direction of the damaged bone matrix, which is represented in white color. (2B, 2E) Two months (60 days) post-osseointegration, the woven bone seems to reduce in volume when compared with 1-month period. Moreover, the woven bone previously in contact with the implant is being replaced by cortical bone.
bone containing empty osteocytic lacunae, resulting in a reduction in it. Almost the entire implant surface is covered by neoformed bone. The portion of neoformed bone exhibits characteristics of spongy bone. Some empty osteocytic lacunae remain, however, the area containing this type of structure is shown to be smaller. There is the presence of an evident cortex in the pre-existent bone (containing empty osteocytic lacunae) and the neoformed bone. A lower number of ALP-positive osteoblasts and TRAP-positive osteoclasts are observed. In addition, both cell types present reduced volumes, suggesting less cell activity.(29)

Three months after the implant placement

The area of pre-existent bone has been replaced by neoformed bone containing intact osteocytes. The neoformed bone presents the morphological characteristics of compact bone. There are no capillaries found between the implant and neoformed bone. ALP-positive osteoblasts and TRAP-positive osteoclasts are rarely observed around the implants, except in the bone marrow regions.

In the period comprised between 3 and 3.5 months after acquisition of osseointegration, minimal morphological and biochemical changes are related, such as for example, a slight increase in neoformed bone thickness (with its corticalization proceeding for up to 12 months after osseointegration).

The distribution and density of ALP-positive osteoblasts and TRAP-positive osteoclasts, and the distance between the bone cells are identical to those observed in the period of 3 months after implant placement. Once again it is important to emphasize that the neoformed bone undergoes gradual changes from spongy to compact bone due to its continuous remodeling. However, it exhibits the same biological properties as intact bone after osseointegration is acquired.(29)

Implant surface treatments and bone remodeling after acquisition of osseointegration

Commercially pure titanium (cpTi), biocompatible material, shows no biological properties of osteoinduction or osteogenesis. For this reason, various surface treatments of titanium implants have been proposed, and carefully investigated. These studies have allowed observing that the process of osseointegration is favored by surface treatments, not only by showing the speed up of the complete osseointegration, but also by showing the favoring of the process where bone quality and quantity are not suitable(30,47). The biological logic of these treatments is to make this microenvironment as similar as possible to the bone microenvironment. For this purpose, the implant surfaces provided have been mimicking the morphology and composition of the constituents of bone tissue itself.(30,31,47)

The process of changing the cpTi surface may be performed by the techniques of subtraction, particle adhesion or by association of both.(29)

The treatments of subtraction consist of removal of portions of the implant surface. An example of subtraction treatment is irradiation of the implant surface with a LASER beam. This process results in an increase in resistance to corrosion and biocompatibility of titanium, due to its oxidation and subsequent formation of oxides and nitrates.(52) Moreover, irradiation with LASER joins advantages characteristics, such as non-thermal origin of the surface and high degree of reproducibility of this technique, which produces a complex and homogeneous surface morphology, with a high degree of purity, thus favoring osseointegration and increasing the removal torque.(50,52-55) In addition to these techniques, treatments with acids either associated with airborne, particle abrasion with titanium oxide – TiO2 or aluminum oxide – Al2O3, or not, are also forms of subtraction techniques.

As opposed to subtraction treatments, addition treatments consist of the addition of substances to the implant surface, such as, for example, the incorporation of ceramics such as hydroxyapatite (HA) [Ca10(PO4)6(OH)2].(56,57) It has been shown that coating implant surfaces with calcium phosphate accelerates osseointegration, especially under coated with HA, than in cpTi implants.(38)

When materials such as HA, considered bioactive, are in contact with the live tissue, they undergo superficial dissolution induced by cell activity, releasing calcium and phosphorous ions into the extracellular matrix. These ions are incorporated into the microcrystals of HA of the bone; that is to say, bone matrix is deposited on the HA surface, leading to biointegration.(53) Furthermore, HA is commonly used for coating metal implants, due to the mechanical advantages of metals added to the excellent biocompatibility and bioactivity of HA. This association (cpTi and HA) provides an increase in the strength of the interface with bone cement when compared with clinical deposition of HA.(39) KA study was conducted to improve the bond of the coating to the implant surface. Among these, there is emphasis on the biominerall method, which mimics the body’s biological process of hard tissue formation and consists of immersion of the substrate to be coated in a synthetic solution denominated body fluid solution (SBF).(36,40) BSBF has chemical composition, temperature and pH that simulate blood plasma.

The implant surface treatment methods may also be classified according to the topographic characteristics they give implants. Implant surface topography varies according to the method by which it is obtained; that is to say, by means of macro, micro or nanotechnology. By implant surface treatments greater implant surface roughness may be obtained. Roughness represents a micro or nanomorphological structural modification that provides an increase in the area of contact between the bone and implant.(56) It is possible to distinguish between macroroughness (100μm to millimeters), microroughness (100nm–100μm) e nanoroughness (less than 100nm).(57) Each type of topography has a specific influence on the mechanisms involved in osseointegration. For example, accumulation and organization of the blood clot on the rough surface has an important physical phenomenon, for osteogenensis, such as greater adhesion, proliferation and expression of osteoblast differentiation markers. This leads to an increase in the bone-implant bond strength, and consequently, to success of therapy with implants in the long term.(45-47) Clinical proof of the positive influence of surface roughness on osseointegration is the higher torque required for removal of implants with rough surfaces, when compared with those that have smooth surfaces.(11,48)

The cpTi implants modified on a nanometric scale by LASER beam with HA deposition by the biomimetic method, with and without afterwards receiving heat treatment in an oven at 600°C, favor osseointegration in the periods of evaluation of 30 and 60 days after implant placement in rabbit tibias. Moreover, the surface containing HA that did not undergo heat treatment presented greater biological activity, reducing the time of osseointegration. This latter result is probably associated with the lower degree of crystallinity of hydroxyapatite, which therefore becomes more soluble and similar to biological hydroxyapatite.(29)

In general, the goal of surface treatments is to reduce the time of loading after surgery; accelerate bone growth and maturation to allow immediate loading; increase primary stability; guarantee the success of implants when they are placed in regions that present bone with lower quality and quantity; obtain bone growth directly on the implant surface; obtain the largest possible area of osseointegration; obtain bone-implant contact without the interposition of amorphous protein layers; attract mesenchymal, pre-osteoblastic and osteoblastic cells, in addition to providing specific binding to osteogenic cells.(44,49,50)

The success of osseointegration, and the maintenance of implants is dependent on adequate rates of bone remodeling.(44,51) However, up to the present time, we have not found any studies in the literature, which describe possible differential effect of these surface treatments of implants on the bone remodeling that occurs after the acquisition of osseointegration.

DISCUSSION

Osseointegration is described as an effective interaction between bone tissue and the implant surface.(7-9) However, damaged bone tissue, with empty osteocytic lacunae, resulting from cutting of the bone for implant placement, remains in the microenvironment around the implant, even after its osseointegration.(29) In the literature, studies with respect to bone remodeling around implants that have already become osseointegrated are rare. Of the articles selected for this review, only one study directly analyzed the events involving renewal of bone tissue in the microenvironment around the implant after osseointegration, in the long term, in an animal model (rabbits).(29) In this study, conducted on the basis of the results obtained by Fuji et al.(31) who demonstrated that this type of investigation could be conducted in animal models (rats) 30 days after the placement of a conventional implant with a machined surface, which was shown to be almost completely covered by bone tissue.

Haga et al.(29) observed that one month after osseointegration, there was still bone tissue around the implant, presenting empty or picnotic osteocytic lacunae. By means of balanced bone remodeling, in which bone
resorption by TRAP-positive osteoclasts and bone neoformation by ALP-positive osteoblasts are synchronous and equivalent, the damaged bone is remodeled in a gradual manner and disappears completely 3 months after implantation. Initially, there is replacement of the pre-existent bone, damaged by cutting, by spongy bone, and of this, by compact bone, thus improving bone quality. These data clearly demonstrated that continual bone remodeling, even after osseointegration is essential for the survival and success of dental implants in the long term.

It is important to emphasize that the studies investigating events associated with bone remodeling after the acquisition of osseointegration, mentioned in this review of the literature, were conducted in the absence of loads. In the presence of loading and depending on the value of the load applied, modifications occur in the bone tissue located around the implant, which must have its structure adequately adapted to receive the forces applied. Furthermore it requires continual remodeling to replace the regions damaged by fatigue, in order to prevent the occurrence of fractures and loss of the implant. Therefore, there are higher bone remodeling rates in implants submitted to the action of loads.

In spite of the large number of studies on the topographical, physical and chemical changes on implant surfaces, up to the present time, we have found no articles in the literature, which have investigated a possible differential effect of these surface treatments on the bone remodeling that occurs after osseointegration has been established.

CONCLUSIONS

It is reasonable to suggest, for example, that bioactive surfaces may continue to be active in the long term, stimulating the bone cells and leading to a higher degree of tissue turnover. On the other hand, it is also possible that the properties obtained by means of the surface treatments may influence osseointegration only, seeing that at this time the bone cells have greater access to the treated surface.

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CONFLICT OF INTEREST

No conflicts of interest have been declared.

References


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