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Importance of Bone Tissue Attachment Features in Dental Implantation Planning

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Abstract Improvement of dental implantation techniques is impossible without improving the results of restoring the volume of alveolar bone tissue of the jaws. For this purpose, various methods of reconstructive interventions are used, the result of which should be an increased or restored bone volume necessary for optimal positioning and full functioning of the implants, based on their number and size, as well as the possibility of correcting the condition of mobile and immobile soft tissues in the implantation area. This article is devoted to a critical analysis of modern methods of implantological treatment in complex anatomical conditions that have developed due to significant bone atrophy.

Keywords Atrophy, Dental implantation, Osteoplastic materials, Resorption, Subcostal implants

1. Introduction

There are many risk factors for dental implantation, such as lower anatomical structures and insufficient distance between the implants, the location of the implant with different characteristics of the alveolar bone, infection, smoking, surgical procedure and surgery planning, as well as medical complications such as osteopenia/osteoporosis and diabetes mellitus. In fact, X-ray information can reflect several risk factors that may affect the outcome of implantation, including insufficient bone volume, poor bone quality, and periodontal bone loss. Nicolielo et al. suggested that the preoperative structure of the mandibular trabecular bone according to cone beam computed tomography (CBCT) It can serve as an important indicator of the risk of early implant rejection. This is confirmed by clinical observations that implant rejection is more common in dense bone, which is usually characterized by low blood flow. In addition, X-ray images were used in the research to create models for predicting implantation. Although CBCT has an obvious advantage in the form of a three-dimensional image, this method, as a rule, requires a higher radiation dose compared to conventional 2-dimensional panoramic or sighting images [1,3].

2. The Purpose of the Study

Improving the methods of studying bone architectonics in the planning of dental implantation. Moreover, in most cases, CBCT is used for preoperative diagnosis and surgery planning. However, the postoperative use of CBCT is limited due to titanium artifacts and excessive radiation dose compared to sighting images, which can lead to insufficient osseointegration, marginal bone loss, or implant failure [2,4,5]. For a long time, successful osseointegration of an implant was directly related to the amount and density of bone [9], while a higher frequency of rejection was observed in bones with low density, such as the back of the upper jaw. Currently, the success of rehabilitation using implants in the back of the upper jaw has become more predictable due to changes in the surface treatment of implants and new surgical methods. This has led to a change in perceptions about the quality of bones. The quality of bones depends not only on the content or quantity of minerals, but also on the structure. Sclerosed bone caused by chronic infections or bisphosphonate treatment is not an ideal place for implantation, although it still has a higher bone density. In contrast, a well-structured thin trabecular bone may indicate a high vascularization of the area, which may promote faster bone regeneration around the implant. Therefore, before surgery, other parameters, such as the trabecular structure at the implant site, should be considered to help the doctor choose the appropriate implantation protocol [6,7]. Bone architectonics is a term denoting the proportional ratio of compact and spongy matter of bone tissue, while additionally taking into account the density of trabeculae of the spongy layer. One of the modern requirements for planning dental implantation is to take into account bone architectonics in the field of implant placement. This provision is most fully disclosed in the classification of jaw bone quality by S. E. Misch, which describes the variants of architectonics and provides the clinical characteristics of each phenotype in

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relation to the causes and methods of preventing complications of dental implantation.

S. E. Misch also studied the occurrence of bone phenotypes in various jaw sections. The D1 phenotype occurs in the lower jaw in 9% of cases, in the mental region 2 times more often than in the lateral. The D2 phenotype is most characteristic of the lower jaw, where it occurs in half of cases in the distal regions and in 66% of cases in the frontal region, but is also observed in the upper jaw: in a quarter of cases in the anterior region and in 10% in the lateral regions. The D3 phenotype on the upper jaw is observed in 65% of cases in the anterior region and in 50% in the posterior region. In the lower jaw, the D3 bone occurs in less than half of cases in the distal regions and in 25% in the chin region. The D4 phenotype occurs in 4-5% of cases in the lower jaw, in 10% of cases in the frontal part of the upper jaw, and in 40% in the posterior part of the upper jaw [8,10,11]. The most commonly used clinical method for assessing trabecular bone is based on a subjective assessment of intra-trabecular spaces (from small to large) and the degree of trabeculation (from sparse to dense) on two-dimensional (2D) radiographs. Three-dimensional (3D) analysis of bone structure became possible due to the introduction of microcomputer tomography (micro-CT), which allows quantifying bone morphometry using parameters originally developed in histomorphometry [21]. This method objectively shows the structural changes of bone after specific drug treatment and the differences between healthy and osteoporotic bone. In implantology, it has been shown that the morphometric parameters of the trabecular bone are related to the stability of the implant, indicating their importance for assessing bone quality before implant placement. However, due to the limited scanning range and excessive radiation doses, micro-CT is unsuitable for clinical diagnosis. The clinical application of this method became possible only after the latest advances in CBCT technology, which makes it possible to obtain an image of the trabecular structure with sufficient resolution. The parameters of the trabecular bone obtained by CBCT showed a significant correlation with micro-Gold standard CT scan using adequate scanning protocols [22,23]. However, the issue of how the trabecular pattern can affect the implantation outcome is still a matter of debate. The lack of reliability of bone quality assessment has led to conflicting results regarding how this may affect the implantation outcome. Previous studies have shown different repeatability of the results of qualitative analysis of bone tissue on 2D radiographs between researchers and tactile perception. In addition, quantitative assessment of bone density is often performed on MSCT images, but it does not take into account density changes within a specific implantation site and is associated with a higher radiation dose compared to CBCT. Studies have shown that for accurate prediction of implant survival, not only bone density is important, but also structural and biological properties (for example, bone vascularization), which play an important role in the results of osseointegration. In light of this, Lind et al. proposed a qualitative classification based on the architecture of the trabecular bone. The authors described that a qualitative assessment based on three classes of trabecular network is more reliable than the classic Lekholm and Zarb bone quality index. However, their classification was based on two-dimensional contact radiographs, which limits the spatial characteristics of the trabecular bone [9,12,15]. Early and long-term success largely depends on the quantity and quality of alveolar bone, since a small amount and inadequate quality of alveolar bone can be considered as a risk factor for biological complications associated with lack of primary stability and impaired healing/osseointegration, which can lead to early rejection of the implant. Bone quality refers to the quantity and topographical ratio of cortical and spongy bone tissues, including characteristics such as mineral density, thickness, trabecular microarchitecture, bone metabolism, cells, intercellular matrix, and vascularization. Bone density is one of the parameters of bone quality, being a key factor for bone tissue development [11,13,14,17].

It is believed that the quality of bone tissue is one of the most important etiological factors influencing early implant rejection. To achieve this goal, the Lekholm and Zarb classification is usually used, which makes it possible to assess bone quality in cone beam computed tomography (CBCT) according to four types: type I is a completely homogeneous compact or cortical bone; type II is a thick layer of compact bone surrounding dense trabecular bone; type III is a thin layer of compact bone surrounding dense trabecular bone; and type IV is a thin layer of compact bone surrounding dense, low–density trabecular bone. In this regard, it was reported that, on average, the "survival rate" of dental implants installed in jaws with type I, II, and III bones is decreasing and amounts to 97.6%, 96.2%, 96.5%, and 88.8%, respectively. Typically, the condition of the jawbone is determined by measuring the density of the spongy bone and the thickness of the cortical or compact bone. In addition, it is known that the density of spongy bone is highest in the anteromandibular region, followed by the anterior maxillary region, the posterior mandibular region and the posterior maxillary region. In contrast, it has been reported that the cortical bone is usually thickest in the posterior part of the mandible, followed by the anterior part of the mandible, the anterior part of the upper jaw, and finally the posterior part of the upper jaw [16,18]. When planning treatment, it is very important to determine the quality of the jaw bone tissue, as it is extremely important to diagnose and recognize the condition of the bone tissue before installing the implant in order to make decisions based on the information received. In this sense, CBCT is considered one of the best radiographic methods for morphological and qualitative analysis of residual bone, as it allows to identify anatomical boundaries, assess bone morphology, volume, and quality, and is also a valuable verification tool for assessing the distribution of cortical and spongy bone in the jaws. Thus, the usefulness of CBT at the preoperative planning stage is based on the need for a detailed assessment of the patient's specific anatomy, the need to use more advanced surgical methods such as transplantation, zygomatic implants, and others. If, as a result of the preliminary analysis, it is concluded that the conditions are suitable for the installation of the implant, the patient can be immediately enrolled for examination [19]. To assess the quality of bone tissue, the Lekholm and Zarb classification is most often used. Due to the subjectivity, lack of accuracy, and low level of interaction according to the bone quality classification proposed by Lekholm and Zarb in 1985, some changes were proposed to improve the bone quality assessment, taking into account all possible combinations of cortical and spongy bones, in order to provide recommendations for improving the reproducibility of the classification. Important characteristics such as the number and visibility of bone trabeculae and the size of bone marrow spaces, which are vital for determining bone density and morphometric parameters of the trabecular bone, have not yet been included. In addition, in order to reduce subjectivity in the analysis of bone density in CBCT in accordance with the classification of Lekholm and Zarb, it is advisable to add and redefine the types of bones considered in this classification.

In connection with the above, A.A.Al-Ekrish et al. (2018) developed a modified classification based on the results of a study of CLT in 47 patients. The authors identified the following types of jaw bone tissue: Type 1: Completely homogeneous compact bone. Type 2a: A thick layer of dense bone surrounding the core of dense trabecular bone. Type 2b: A thick layer of dense bone surrounding the core of a medium-density trabecular bone. Type 2c: A thick layer of dense bone surrounding a low-density trabecular bone core. Type 3a: A thin layer of dense bone surrounding the core of dense trabecular bone. Type 3b: A thin layer of dense bone surrounding the core of a medium-density trabecular bone. Type 4: A thin layer of dense bone surrounding the core of a low-density trabecular bone [3]. J.C. Rosas-Diaz et al. (2022) also proposed a modified classification by Lekholm and Zarb. Based on the study of CBT in 154 patients, the authors identified the following types of bone: Type I: Predominant cortical bone surrounding sparse spongy bone, with distinct trabeculae throughout the image and the presence of small visible bone marrow spaces. Type II-A: Thick cortical bone surrounding abundant spongy bone, with clear trabeculae throughout the image and the presence of small visible bone marrow spaces. Type IIB: Thick cortical bone surrounding abundant spongy bone, with a predominance of diffuse trabeculae in the basal bone and the predominant presence of wide and visible bone marrow spaces. Type II-C: Thick cortical bone surrounding abundant spongy bone, with a predominance of very thick and sharp trabeculae in the basal bone, with the presence of small and noticeable bone marrow spaces. Type III-A: Thin cortical bone surrounding abundant spongy bone, with clear trabeculae throughout the image and the presence of small visible bone marrow spaces. Type III-B: Thin cortical bone surrounding abundant spongy bone, with a predominance of diffuse trabeculae and the presence of diffuse bone marrow spaces. Type IV: Diffuse cortical bone surrounding extensive spongy bone, with a predominance of diffuse trabeculae and the presence of diffuse bone marrow spaces. Type V: Regenerated bone; trabeculae and bone marrow spaces of varying visibility and number. Type VI: Bone with pathology; trabeculae and bone marrow spaces with varying visibility and number [16]. Previous studies have shown that the morphometric parameters of the trabecular bone can be used in cluster analysis to automatically identify bone types. Based on these parameters, the automatic classifier identified three types of three-dimensional trabecular pattern, namely sparse, intermediate and dense. The presented results showed that in cases of implant rejection, a sparse type of bone was significantly more common. Previous studies have shown that dense bone is associated with decreased blood flow, while very soft bone can lead to insufficient implant stability [20]. As a rule, the analysis of bone microstructure, as well as bone volume, plays an important role in predicting biomechanical properties and the risk of bone fractures in patients with osteoporosis. In implantology, some studies have shown a correlation between the structural parameters of the trabecula and the stability of the implant. However, this remains controversial, since the stability of the implant and high mechanical quality do not always represent a high potential for biological integration, and can also be a stress factor for cells. The structural characteristics of bone are also related to the stimulation of mechanical stress, such as chewing movements. The anterior sections of the upper and lower jaw usually have more compact trabeculae compared to the posterior ones [21,22].

The trabecular architecture is a very complex factor and can have many network configuration options, even within individual bone sections and between different samples with the same proportion of bone volume. A sample with a trabecular perforation may have the same bone volume fraction values as a sample with thin trabeculae. Existing methods for evaluating the three-dimensional architecture of the trabecular bone at the implant site depend on bone biopsy during preparation of the implant site. These are invasive methods, and therefore they cannot provide a realistic and clinically useful 3D reconstruction of the entire implant placement site. An accurate representation of the trabecular network requires a voxel size of less than 200 microns, otherwise the trabecular bone may appear blurred due to partial volume artifacts. This prevents proper segmentation and often leads to an overestimation of bone volume [23]. To date, there is no reliable method for an objective assessment of the condition of the alveolar bone around implants on X-ray images. Artificial intelligence algorithms can become a powerful diagnostic tool for identifying characteristic features using radiographic images in dentistry. It is currently assumed that the radiographic characteristics of the alveolar bone can predict implant rejection, and some methods have shown effectiveness in extracting characteristics from radiographs. One study used CBCT images with model learning algorithms to analyze risk factors affecting dental implantation outcomes. Currently, the use of artificial intelligence for the analysis of X-ray images is gaining popularity. So in the study by Chunan Zhang et al. (2023), an attempt was made to systematize X-ray signs in order to create an algorithm for predicting the risk of implant rejection. The set of studied data consisted of a total of 529 targeted radiographs in three categories: (I) adverse outcome with minor bone loss – 91 images; (ii) adverse outcome without minor bone loss – 155 images; and (III) successful dental implantation (283 images). The dataset also included a total of 551 panoramic images of the same three categories: adverse outcome with minor bone loss – 87 images, adverse outcome without minor bone loss – 171 images, and successful dental implantation (293 images). As a result, the deep learning model studied the features of periapical and panoramic images and effectively predicted the occurrence of implant rejection, which, according to the authors, may contribute to early clinical intervention [24,25].

3. Conclusions

The main limitation of the above-described study is its retrospective nature, especially with regard to comparison with the sex, age and professional qualities of the implantologist surgeon, which could affect the results of the analysis. Since the authors focused on the characteristics of the alveolar bone on X-ray images, in the future the relevant parameters should include bone quality, its quantity and the state of osseointegration, periimplant tissues before loading. In addition, to increase the effectiveness of training and the application of this system in clinical practice, more implant images and longer follow-up will be required in subsequent studies. The authors also noted the need for future research on combining CBCT images to obtain a more complete forecasting model.

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