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OSSEOINTEGRATION OF DENTAL IMPLANTS (LITERATURE REVIEW)

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ABSTRACT

Widespread use of dental rehabilitation through dental implantation has stimulated researchers' interest in the processes of implant integration with bone tissue. This study aims to analyze and systematize domestic and foreign data on the osseointegration of titanium implants. A review of the literature shows that the development of research technologies and an interdisciplinary approach in recent years have significantly changed traditional views on this process. Information on the physiological mechanisms and cellular interactions at the implant-bone interface at various stages of integration has been summarized. The results indicate the need to revise ideas about the bioinertness of titanium structures and to consider osseointegration in an immunological context. For adequate bone tissue regeneration in diseases of the maxillofacial region, traumatic injuries, and implantation, the balance of neural, endocrine, and immune mechanisms regulating osteogenesis is essential. This is mediated by a number of biologically active mediators, such as beta-endorphin, serotonin, and others. Today, dental implantation is widely used for orthopedic rehabilitation of patients with various types of dental defects. International experience in prosthetics based on dental implants demonstrates the possibility of applying this technology in a wide variety of clinical conditions - both for fixed structures and to increase the stability of removable prostheses — with predictable and stable treatment results.

Keywords: osteointegration, osteoconduction phase, alkaline phosphatase.

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ОСТЕОИНТЕГРАЦИЯ ДЕНТАЛЬНЫХ ИМПЛАНТАТОВ (ОБЗОР ЛИТЕРАТУРЫ)

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АННОТАЦИЯ

Широкое использование дентальной реабилитации с помощью дентальной имплантации стимулировало интерес исследователей к процессам интеграции имплантата с костной тканью. Цель данного исследования — проанализировать и систематизировать отечественные и зарубежные данные об оссеоинтеграции титановых имплантатов. Анализ литературных источников показал, что развитие исследовательских технологий и междисциплинарный подход в последние годы значительно изменили традиционные представления об этом процессе. Обобщены сведения о физиологических механизмах и клеточных взаимодействиях на границе «имплантат — кость» на различных этапах интеграции. Результаты указывают на необходимость пересмотра представлений о биоинертности титановых конструкций и рассмотрения оссеоинтеграции в иммунологическом контексте. Для адекватной регенерации костной ткани при заболеваниях челюстно-лицевой области, травматических повреждениях и имплантации важно поддерживать баланс нервных, эндокринных и иммунных механизмов, регулирующих остеогенез. Этот процесс опосредуется рядом биологически активных медиаторов, таких как бета-эндорфин, серотонин и другие. Международный опыт протезирования на основе дентальных имплантатов демонстрирует возможность применения этой технологии в самых разнообразных клинических условиях как для несъёмных конструкций, так и для повышения стабильности съёмных протезов с предсказуемыми и устойчивыми результатами лечения.

Ключевые слова: оссеоинтеграция, фаза остеокондукции, щелочная фосфатаза.

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INTRODUCTION

In recent decades, the steady growth in the popularity of dental implantation has sparked increasing interest among researchers in studying the mechanisms of interaction between the implant and bone tissue. The most favorable form of this process is traditionally considered to be osseointegration, which P.-I. Branemark, the founder of modern dental implantology, defined as "the apparent direct (immediate) attachment or connection of living bone tissue to the implant surface without an interposed layer of connective tissue" [2]. Achieving osseointegration is considered a prerequisite for the long-term success of implant prosthetics [1, 6,]. The phenomenon of osseointegration was accidentally discovered by P.-I. Branemark while studying microcirculation in bone tissue using a miniature optical camera surgically implanted in the tibia of a rabbit. In the more than four decades since this discovery, a significant amount of scientific data describing the mechanisms of implant integration with bone tissue has been accumulated and continues to expand [3–6].

According to A. A. Kulakov, the process of implant integration into bone tissue should be viewed as a dynamic interaction between biological and inert components, in which a balance of compensatory-adaptive and homeostatic mechanisms is achieved. This equilibrium ensures the coexistence of living and non-living components in a single system. The authors cite the following criteria for success: the absence of inflammatory, necrotic, and allergic reactions in the peri-implant tissues (i.e., signs of rejection), the formation of morphofunctional characteristics of the integration process (in dental implantation — osteo-like or bone tissue) in the contact zone between the implant and bone tissue, and the preservation of the stability of these characteristics over time [7,10].

According to the literature, there are several types of tissue organization at the implant/bone interface. Osteointegration, as interpreted by P. I. Branemark, is the direct contact of bone tissue with the implant surface. Fibro-osseointegration is characterized by the presence of a connective tissue layer between the bone and the implant, containing collagen fibers and coarse-fibrous connective tissue. Connective tissue integration occurs when the implant surface is completely surrounded by fibrous connective tissue. In the literature, the first two options are described as a normal bone response to the implant, while the latter is considered a manifestation of its rejection.

For a long time, the blood clot retraction theory remained widely accepted [10, 16]. According to this theory, the process of osseointegration begins with the osteoconduction phase, which consists of the migration and adhesion of mesenchymal cells and osteoblasts to the implant surface through the remnants of the thrombus. The next stage, osteoinduction, involves the formation of new bone and the deposition of mineral salts in the developing bone matrix. The final stage of regeneration is remodeling, which is a long process of alternating resorption and formation of bone tissue around the implant.

The implantation itself is considered a surgical trauma, accompanied by inflammation, initial signs of resorption, and the initiation of a cascade of vascular-tissue reactions leading to regeneration. The condition of the vascular bed and the level of blood supply in the area of intervention are important in this process: ischemia increases the likelihood of fibrous or cartilaginous tissue forming instead of normal bone structure [1,5,11,8].

It has been established that even when the implant is twisted at high speed and high primary stability is achieved during its installation, a gap of up to 60 μm remains between the implant surface and the adjacent bone. Depending on the traumatic nature of the operation, this gap can increase locally to 100–500 μm. The space is filled with blood and tissue fluid, which serve as a source of biologically active substances and proteins necessary to initiate osseointegration. Although the characteristics of the implant surface can modify the composition and spatial organization of adsorbed proteins, cell membrane receptors interact with the titanium surface, ensuring their initial attachment [19, 20].

In the early stages of osseointegration, the extracellular protein fibronectin and transmembrane heterodimers—integrins—are actively involved in the process of cell recognition and adhesion to the implant surface [21, 22]. Blood from the bone bed vessels forms a clot containing platelets, fibrin, vascular growth factors, transforming growth factor, insulinlike growth factor, and other mediators. These components stimulate neoangiogenesis and bone tissue healing [13,18, 23].

The fibrin network ensures the migration of osteogenic cells to the implant surface under the action of growth factors produced by platelets. The latter attract fibroblasts and other undifferentiated cells to the fibrin matrix zone and stimulate their differentiation [15]. The characteristics of this stage largely determine the further course of implant integration. The tight attachment of the blood clot to the surface and the formation of fibrin "bridges" between the implant and viable bone create conditions for the proliferation of osteogenic cells along the fibrin strands to the implant and the subsequent formation of bone tissue.

It is now clear that in the early stages of dental implant integration, the area and density of attachment of bone tissue cell elements and blood components to its surface are of key importance. In this regard, there is no doubt about the need to create a pronounced topography and developed micro-relief of the intraosseous part of the implant. Various technologies are used to create a complex relief with optimal roughness for , which are conditionally divided into two main groups:

1. Physicochemical surface treatment — sandblasting, acid etching, laser modification, etc.;
2. Application of biologically active coatings that stimulate bone formation processes (hydroxyapatite, tricalcium phosphate, amino acids, etc.) [3,9,19].

At the same time, implant integration solely due to contact osteogenesis is rather an idealized model. Most likely, both contact and distant osteogenesis processes occur simultaneously in different areas of the "bone-implant" zone.

The latter is characterized by the formation of bone tissue not on the surface of the implant, but on the surface of the surrounding bone: osteogenic cells of the implant bed synthesize bone matrix towards the surface of the implant.

Already in the first days after implant placement, osteoblasts attach to its surface. These cells synthesize osteogenesis marker proteins — osteopontin, osteocalcin, sialoprotein — which promote the adhesion of osteogenic cells to the implant and the fixation of mineral compounds in the newly formed organic bone matrix. The next stage is the formation of a collagen matrix directly on the implant surface, followed by the deposition of an osteoid substance that transforms into bone tissue [19].

Mineralization of the bone matrix is associated with the accumulation of calcium and phosphorus ions and is ensured not only by calcium-binding proteins, but also by the participation of phospholipids and chondroitin sulfate of the ground substance [4,17]. Subsequently, young bone tissue undergoes a long-term structural reorganization. This stage—remodeling—combines two opposing processes: bone resorption and new bone formation. Resorption of immature bone tissue is mainly carried out under the action of matrix metalloproteinases secreted by osteoclasts, which is accompanied by an increase in acid phosphatase activity. At the same time, the formation of new bone in the direction of the implant surface is ensured by the high functional activity of osteoblastic cells and is accompanied by the expression of alkaline phosphatase [22]. The remodeling process is closely dependent on the load conditions on the implant and ultimately leads to the replacement of immature bone with a more mature and functionally complete structure.

ETHICAL STATEMENT AND CONSENT TO PARTICIPATION

The study was conducted in accordance with the local ethical committee.

CONFLICT OF INTERESTS

The authors declare the absence of obvious and potential conflicts of interest related to the publication of this article.

SOURCES OF FUNDING

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AVAILABILITY OF DATA AND MATERIALS

All data generated or analysed during this study are included in this published article.

AUTHORS' CONTRIBUTIONS

All authors contributed to the design and interpretation of the study and to further drafts. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All applicable international, national and/or institutional ethical guidelines have been followed.

CONSENT FOR PUBLICATION

Not applicable.

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КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что данная работа, её тема, предмет и содержание не затрагивают конкурирующих интересов.

ИСТОЧНИКИ ФИНАНСИРОВАНИЯ

Авторы заявляют об отсутствии финансирования при проведении исследования.

ДОСТУПНОСТЬ ДАННЫХ И МАТЕРИАЛОВ

Все данные, полученные или проанализированные в ходе этого исследования, включены в настоящую опубликованную статью.

ВКЛАД ОТДЕЛЬНЫХ АВТОРОВ

Все авторы внесли свой вклад в подготовку исследования и толкование его результатов, а также в подготовку последующих редакций. Все авторы прочитали и одобрили итоговый вариант рукописи.

ЭТИЧЕСКОЕ ОДОБРЕНИЕ И СОГЛАСИЕ НА УЧАСТИЕ

Были соблюдены все применимые международные, национальные и/или институциональные руководящие этические принципы.

СОГЛАСИЕ НА ПУБЛИКАЦИЮ

Не применимо.

ПРИМЕЧАНИЕ ИЗДАТЕЛЯ

Журнал *"Интегративная стоматология и челюстно-лицевая хирургия"* сохраняет нейтралитет в отношении юрисдикционных претензий по опубликованным картам и указаниям институциональной принадлежности.

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