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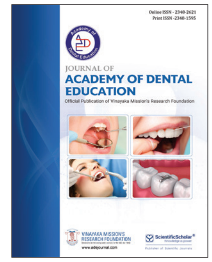

Review Article

Osseoperception in dental implants

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ABSTRACT

Osseoperception refers to the mechanosensory feedback generated through dental implants despite the absence of the periodontal ligament (PDL). This phenomenon plays a key role in patient adaptation, proprioception, and long-term success of implant-supported prostheses. While often overshadowed by osseointegration, osseoperception provides essential insights into implant functionality and neurosensory integration. This review aims to explore the biological mechanisms of osseoperception, highlight the influence of peri-implant mechanoreceptors, muscles, mucosa, and temporomandibular joint in contributing to it, and describe the clinical implications, including methods for evaluating active and passive tactile sensibility. The review further integrates recent advances and proposes future directions for enhancing implant-mediated sensory feedback.

Keywords: Dental implants, Mechanoreceptors, Osseointegration, Osseoperception, Proprioception

INTRODUCTION

Osseoperception is an emerging concept in the field of dental implants that refers to the bone's inherent ability to sense and respond to mechanical stimuli. In the context of dental implants, it plays a critical role in ensuring the long-term success of the implant by promoting optimal osseointegration – the process by which the implant surface fuses with the surrounding bone.[1,2] Osseoperception is influenced by a range of factors, including the mechanical forces placed on the implant during functional loading, the bone quality and density surrounding the implant, and the biological processes involved in bone remodeling.[3] When a dental implant is surgically placed into the jawbone, it must undergo osseointegration to achieve a stable, functional bond with the surrounding bone. This bond allows the implant to function similarly to a natural tooth root, transferring forces from chewing and other daily activities to the surrounding bone.[1,3] However, the success of this process is not solely dependent on the mechanical stability of the implant itself but also on the bone's ability to detect and react to these forces. The bone can "perceive" changes in load and mechanical stress, and based on this perception, it adjusts the remodeling process to ensure that the bone surrounding the implant is adequately maintained, avoiding overloading or excessive stress that could lead to bone resorption or implant failure.[3,4] Research has shown that, while the bone surrounding dental implants does not possess the same sensory feedback as the PDL, it can still detect mechanical forces through osteocytes in the bone matrix, although at a less sensitive level than in natural teeth.[3] The challenge, however, remains in translating this ability into meaningful sensory feedback that could help patients better control and adapt their bite forces, which is essential for long-term implant success.[5]

Understanding osseoperception is important for advancing dental implantology because it offers insights into how implants can be designed, placed, and loaded in ways that maximize their chances of success. Implant design, surface characteristics, and the manner in which functional forces are distributed to the surrounding bone can all influence osseoperception.[6,7] Furthermore, the concept highlights the need for a deeper understanding of the interplay between biomechanical forces and biological responses to optimize implant outcomes. By incorporating principles of osseoperception into clinical practice, dental professionals can minimize the risk of implant failure and complications such as bone loss or implant loosening.[8] As research in the field of osseoperception continues to evolve, it holds promise for enhancing both the materials used in dental implants and the techniques for implant placement. Improved understanding of the bone-implant relationship, as well as how osseoperception affects bone healing and remodeling, can lead to more personalized treatment approaches, ensuring better functional and esthetic outcomes for patients.[9,10]

Although osseoperception has been reviewed in prior narrative and systematic reviews, this article seeks to integrate current knowledge by combining mechanisms, evaluation methods – including active and passive tactile sensibility – and clinical implications in a comprehensive manner. This provides an updated perspective linking sensory evaluation with clinical practice, differentiating this work from prior literature focused mainly on mechanical integration.

MECHANISM OF OSSEOPERCEPTION

Osseoperception is essentially determined by the mechanosensation properties of bone cells, specifically osteocytes, which are embedded in the mineralized matrix of the bone. Osteocytes communicate with one another as well as with osteoblasts and osteoclasts on the bone surface through a network of canaliculi. When mechanical stresses are applied to the bone around an implant, they are passed through the bone matrix and detected by osteocytes. Mechanical inputs are transformed into biochemical signals, which controls bone remodeling and homeostasis. While dental implants lack the natural proprioceptive feedback, several mechanisms have been explored to restore or simulate osseoperception.[2,11]

Implant design and material innovation

Recent research suggests that changes to implant design and materials may influence the transmission of forces from the implant to the surrounding bone, potentially enhancing osseoperception. Features such as flexible implants, dynamic interfaces, or biocompatible materials like hydroxyapatite may promote a more natural force distribution between the implant and the bone, improving the feedback mechanism. Implants with surface coatings or bioactive materials could also improve osseointegration by enhancing bone remodeling around the implant, which may indirectly influence the sensory feedback mechanisms.[12]

Neural interface technology

The development of neuroprosthetics or sensory feedback systems integrated with dental implants holds promise for restoring osseoperception. These systems would involve embedding sensors, such as piezoelectric devices, into the implant to detect mechanical forces and convert them into electrical signals. These signals could then be transmitted to the brain through the trigeminal nerve, mimicking the proprioception provided by the periodontal ligament (PDL) in natural teeth. By converting mechanical force into electrical signals, these devices may allow patients to sense bite forces, pressure, and the position of the implant.[13]

Biological approaches

Stem cell therapy and tissue engineering offer additional possibilities for restoring osseoperception in dental implants. Through the use of stem cells or biological scaffolds, researchers are exploring ways to regenerate tissue around the implant that mimics the natural PDL. These tissues could potentially form a functional, ligament-like structure that might transmit sensory signals to the brain, similar to the feedback provided by the PDL. The goal is to stimulate the growth of tissues that can perform similar functions to the PDL and restore sensory feedback in the area surrounding the implant.[14]

Electrical stimulation

Electrical stimulation is another strategy for restoring osseoperception. Microelectrode arrays or electrical stimulators placed around the implant or in the bone could simulate sensory feedback by providing electrical impulses to the trigeminal nerve. This method could activate sensory pathways that help patients detect mechanical stimuli such as bite force and pressure, similar to the feedback from natural teeth. The challenge in this approach is ensuring that the stimulation is both effective and comfortable for the patient while mimicking natural proprioceptive feedback.[15]

In addition to the mechanosensation properties of osteocytes, osseoperception also involves sensory input from multiple other sources. These include residual periodontal mechanoreceptors, periosteal mechanoreceptors, temporomandibular joint receptors, muscle spindles of the masticatory muscles, oral mucosal receptors, and cutaneous mechanoreceptors in the oral and facial region. These sensory pathways contribute afferent signals through the trigeminal nerve to the central nervous system. Despite the absence of PDL proprioceptors, these alternative sensory inputs provide compensatory mechanisms that support perception of mechanical stimuli, although at reduced sensitivity. Neural plasticity and cortical adaptation further enhance this sensory feedback over time, contributing to functional osseoperception.[4,11]

INFLUENCING FACTORS

Implant design and material properties

The surface characteristics of the implant, such as roughness, porosity, and surface coatings, can significantly affect osseoperception. Materials such as titanium and zirconia have been extensively studied for their ability to promote osseointegration, but their mechanical properties also influence how the bone perceives the implant's presence.[16,17]

Bone quality and density

The type and density of bone at the implant site are critical factors in osseoperception. High-density bone tends to transmit mechanical forces more effectively, enhancing the bone's adaptive response to stimuli. On the other hand, low-density bone may lead to reduced osseoperception and less effective osseointegration.[4,18]

Functional loading

The forces exerted on the implant during chewing and other daily activities directly influence osseoperception. Properly distributed functional loads promote bone remodeling and enhance implant stability, whereas excessive or poorly distributed forces can lead to implant failure.[8,19]

Patient-specific factors

Systemic conditions such as osteoporosis, diabetes, and aging can affect bone quality and osseoperception. Age-related changes in bone physiology may lead to decreased osteocyte function and reduced responsiveness to mechanical stimuli.[7,20]

METHODS TO EVALUATE OSSEOPERCEPTION

Assessing osseoperception in dental implants is essential for determining how well the implant integrates and remains stable in the bone, it is also important to distinguish that evaluating osseoperception also requires specific sensory assessment approaches, such as testing tactile sensibility. This assessment can be conducted using a variety of techniques:

Sensory evaluation of active and passive tactile sensibility

Active tactile sensibility refers to the patient's ability to detect an object placed between implant prostheses during voluntary biting or chewing. Studies have shown that detection thresholds for thin foils are higher in implant patients (50–70 μm) compared to natural teeth (10–30 μm), indicating reduced active tactile feedback.[4,11] Sensory adaptation over time has been reported, but thresholds remain higher than in natural dentition.[11,18]

Passive tactile sensibility involves perception of externally applied mechanical stimuli without active participation. Passive thresholds in implants range from 1 to 10 Newtons, while natural teeth detect at 0.1–1 Newton.[4,18] This reduction is attributed to the absence of PDL mechanoreceptors.

These findings highlight that although tactile sensibility is diminished around implants, sufficient functional perception is achieved for prosthesis adaptation.

Mobility test for clinical evaluation

One of the most fundamental examinations. Poor osseointegration may be indicated by a loose implant. It is frequently examined by touching gently or using a clinical probe. Implants with visible mobility or movement may not have integrated well.

Soft-tissue response

Good osseointegration may be indicated by healthy soft-tissue surrounding the implant. A disturbed osseointegration process may be indicated by symptoms of infection, inflammation, or recession.[21]

The peri-implant sensitivity

Osseoperception can be gleaned by evaluating any pain or discomfort felt when palpating the area surrounding the implant.[21]

Radiographic evaluation

X-ray (cone-beam computed tomography, panoramic, and periapical) are frequently used to evaluate the amounts of peri-implant bone and bone-implant integration. Radiographs aid in detecting indications of infection, inflammation, or bone loss surrounding the implant.[22]

Bone density mapping is done by measuring the density of the bone surrounding the implant, certain cutting-edge imaging techniques can measure the density of the bone surrounding the implant to provide information about osseointegration.[21]

Measurement of implant stability

Resonance frequency analysis (RFA)

This method uses the Osstell device to determine implant stability by calculating the implant stability quotient (ISQ). Higher ISQ values indicate better osseointegration.[18,23]

Periotest

This technique provides an objective value for osseointegration by measuring the implant's mobility using an electronic device.[24]

Biomechanical testing

RFA

By identifying the implant's resonance frequency, an Osstell device is frequently used to gauge implant stability and osseointegration. Better osseointegration is usually indicated by higher resonance frequencies.[25]

The percussion test

Which involves tapping an implant with a dental tool, can reveal some details about how stable the implant is. A metallic sound can imply a lack of fusion, whereas a dull sound might signify excellent osseointegration.[19]

ISQ

A numerical value indicating implant stability. Better osseointegration is linked to higher ISQ readings.[26]

Functional evaluation

Load testing

To evaluate how effectively the implant integrates with the bone, a regulated functional load can be applied to it through occlusal loading or a prosthetic. Poor osseointegration may be indicated by an inability to withstand forces.[27,28]

Thermal perception testing (emerging methods)

A relatively new technique that measures how well an implant integrates with bone by gauging its thermal conduction.[18]

DIVERSE OUTCOMES AND THEIR IMPLICATIONS

The result of osseoperception in dental implants is the successful bonding or fusion of the implant to the surrounding bone, which is crucial for the long-term stability and function of the implant. The outcomes can vary based on various factors, but here's a general overview of the possible results:

Successful osseointegration

Stable implant

The implant becomes firmly embedded in the bone, allowing it to support dental restorations (e.g., crown, bridge, or denture) without movement.[1,4]

Bone growth around the implant

Ensures the implant can withstand normal chewing forces and maintain in its position.[3,18]

Functionality restored

A well-integrated implant restores lost functionality (e.g., biting, chewing, and speaking), improving the patient's quality of life.[3,18]

Long-term success

In most cases, if osseointegration is achieved, the implant will remain stable for many years, often lasting decades with proper care.[3,18]

Partial osseointegration

Delayed healing

Often due to factors such as bone quality or systemic health issues.[6]

Partial integration

May result in instability or some mobility.[7,19]

Failed osseointegration

Implant mobility

If the implant does not fuse with the bone adequately, it will be unstable, resulting in implant mobility. This could lead to the need for implant removal and replacement.[7]

Bone resorption

Failure of osseointegration may be accompanied by bone resorption or loss around the implant, often due to infection (peri-implantitis) or trauma during surgery.[8]

Infection and inflammation

Infected or inflamed tissue around the implant, often related to bacterial colonization, can prevent proper osseointegration. Signs of peri-implantitis, such as swelling, bleeding, and discomfort, may occur.[8]

CONCLUSION

Osseoperception, though diminished compared to natural dentition, plays a crucial role in sensory feedback and implant adaptation. This narrative highlights its multifactorial mechanisms, clinical evaluation methods, and implications for optimizing implant success. Future innovations in biomimetic implant designs and neurosensory interfaces may further enhance this sensory feedback, improving long-term patient outcomes.

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