

Osseoperception in Dental Implants

Rupinder Singh Dhall¹, Gaurav Gupta², Shivika Ahluwalia^{3,*}, Ankit Rawat⁴, Anshul Gaur⁵

^{1,2}Professor, ^{3,4,5}PG Student, Dept. of Prosthodontics

***Corresponding Author:**

Email: shivika.ahluwalia@gmail.com

Abstract

Since the discovery of osseointegration and the introduction of dental implants in the field of dentistry, a whole new era began of prosthetic rehabilitation for missing teeth. However, very little is known about the neural mechanisms that entail the process of osseointegration of dental implants. Osseoperception is the term given to the patient-reported with feeling of heightened perception of the environment with osseointegrated prostheses. In other words, the dental implant placed in alveolar bone allows the patient to perceive pressure, load, position and balance. It has been shown that the sensory-motor and tactile discriminative capabilities are improved with the implant supported prosthesis in comparison to the tissue born denture prosthesis, yet it has been ascertained that these capabilities are less as compared to natural dentition. However, it is also likely that an appropriately designed implant-supported restoration, being fixed to bone, more closely resembles the dental status before tooth loss, and this may more appropriately restore optimal motor and sensory function of the masticatory system.

Hence, the purpose of this review is to provide concise information about the presence of osseoperception in relation to dental implants and to give a general view about neurophysiological capability of osseointegrated implants in the field of dentistry.

Keyword: Osseoperception, Osseoperception in Dental Implants, Osseoperception in Natural Dentition, Oral Tactile Sensibility.

Introduction

In recent times, dental implant therapy has become a popular method of replacing one or more missing teeth. But, to ensure long term function, it is important that implant prostheses harmonize functionally and biologically with the stomatognathic system.⁽¹⁾ Between 1950 and 1960, Branemark established that bone is a dynamic living tissue. But, the importance of nerve fibers accompanying the bone vessels was recognized only about 10 years later.⁽²⁾

Since its introduction, osseointegration of dental implants has been researched extensively but physiologic integration of implants and the associated prosthesis in the body has received very little attention.⁽³⁾ However, inspired by the report of lower limb amputees with bone-anchored prostheses who are able to differentiate between walking on different soils, the concept of 'osseoperception' emerged.⁽⁴⁾

Osseoperception is the term given to the patient-reported with feeling of heightened perception of the environment with osseointegrated prostheses. In other words the implant placed in bone allows a person to perceive pressure, load, position and balance through a process called Osseoperception.⁽⁵⁾ It has been suggested that osseoperception might stem from mechanoreceptors in the remote nerve endings, periradicular tissues of the antagonist teeth, cortical synaptic remodeling in the brain, or probable innervation of peri-implant tissues, called neurointegration.⁽⁶⁾

Historical background

In 1983 Haraldson, in an electromyographic study of masticatory muscle activity, reported that patients with implant FPDs chewed with consistent muscle activity during the whole chewing sequence, compared with dentate patients who had a decrease in muscle activity at the end of the chewing act. It was theorized that this change in the chewing pattern might be due to a decrease in oral tactile sensibility that could cause a change in neurophysiological feedback mechanisms.⁽⁷⁾

The term "silent period" represents a period of inhibition of muscle activity upon sudden decrease of isometric closure. During tooth tapping or tooth contact in mastication the electrical activity of the masticatory muscles may be depressed or absent for a short period after tooth contact. This phenomenon has been said to be a reflex response evoked by periodontal mechanoreceptors in individuals with natural teeth. This however, has also been recorded in individuals with complete dentures where, it is hypothesized to be evoked by receptors in the oral mucous membrane. An explanation proposed for the occurrence of silent period is that it is due to influence from muscle spindles.^(7,8)

Another variable measuring the functional state of the masticatory system, the 'jaw jerk' reflex, a stretch reflex, can be evoked by a sharp tap on the chin when the mandible is at rest or when the masticatory muscles are isometrically contracted. Electromyographic (EMG) studies by Haraldson and Ingervall, conducted on

subjects with oral implant bridges and individuals with natural teeth with respect to the existence and characteristics of jaw jerk reflex reported that the latency of the silent period was the same in oral implant bridges group and individuals with natural dentition.⁽⁸⁾

Possible mechanisms for the release of the silent period even in edentulous subjects, besides periodontal and mucous membrane receptor influence, may be signals from labial mechanoreceptors or from temporomandibular joint receptors. Moreover, free nerve endings have been found in cortical bone but their neurophysiologic role is so far unknown; and they may be of importance for the proprioception during chewing in patients with osseointegrated oral implant bridges.⁽⁸⁾

Mechanoreceptors contributing to osseoperception

To control oral motor behaviours such as biting, chewing, speech and oral manipulation, the brain relies on information from sense organs in the orofacial structures. Natural teeth are equipped with extremely sensitive tactile sensors – periodontal mechanoreceptors. These sensors provide information about tooth loads and are located in periodontal ligaments. In the context of implant-supported prostheses, the following mechanoreceptors have been postulated to play a pivotal role^(9,10)

1. **Joint Mechanoreceptors:** Low-threshold mechanoreceptors are present in the TMJs and in other joints of the body. While it is generally considered that joint receptors play a limited role in signaling movements and appear to be more concerned with protective reflexes, it appears that TMJ receptors may play a more significant role.
2. **Muscle Mechanoreceptors:**
 - i. **Golgi tendon organs:** found at the musculo-tendinous junction in series, with a small number of extrafusal muscle fibers. They get activated by the pull of the muscle fibers and with muscle contraction. Golgi tendon organs have been reported in jaw muscles and play an important role in regulating muscle contraction and are the most appropriate mechanoreceptors for signaling during voluntary contractions such as biting.
 - ii. **Muscle spindles:** are the most complex somatosensory receptor in the body with sophisticated physiological properties and they provide detailed information on muscle length and rate of length change. It is likely that intramuscular receptors in jaw muscles perform a similar function in the assessment of jaw position and movement.
 - iii. **Cutaneous Mechanoreceptors:** There is little information on the magnitude of skin deformation caused by associated joint movements, and it is not clear how cutaneous receptors respond to such deformations or what contributions to kinesthesia are made by

cutaneous receptors. It is likely that orofacial cutaneous mechanoreceptors exhibit response properties similar to those of limbs for which five cutaneous mechanoreceptor classes have been identified. These properties include low thresholds to applied mechanical stimuli and graded increases in firing rate with the magnitude of the applied mechanical stimulus. Such response properties may therefore provide information to the CNS concerning jaw position and movement.

- iv. **Mucosal Mechanoreceptors:** Where natural teeth are present, periodontal mechanoreceptors are important for refined interdental discriminative function. With implant-supported prostheses opposing complete dentures, a contribution to oral kinesthetic perception could come from the activation of mucosal receptors beneath the complete denture and possibly periosteal and/or mucosal mechanoreceptors in the vicinity of the implant fixture.
- v. **Periosteal Mechanoreceptors:** There is few physiological data on the potential role of periosteal mechanoreceptors in kinesthetic perception.

Neural mechanisms of oral kinesthesia

The CNS has two mechanisms for obtaining information about the positions and movements of limbs and forces of limb muscle contraction, i.e., limb kinesthesia. The following mechanisms are likely to operate for oral kinesthetic perception also.⁽⁹⁾

1. **First Mechanism:** It is by monitoring a corollary discharge (or efference copy or collateral discharge) of the descending central command to muscles. This mechanism is thought to provide the sensation of muscular force or effort which accompanies centrally generated voluntary motor commands. Corollary discharge, possibly together with an input from Golgi tendon organs (GTOs) associated with the jaw-closing muscles, is therefore presumably important in the sensation of effort in voluntary biting. In studies of limb kinesthetic sensation, subjects appear to use corollary discharge in judging muscular tension or the weights of lifted objects. Corollary discharge, however, does not provide a sensation of movement or altered position.
2. **Second Mechanism:** It is derived from mechanoreceptors activated during limb and jaw movements and at different limb and jaw positions. In the context of implant-supported prostheses, the term osseoperception was proposed to recognize oral kinesthetic perceptual abilities, in the absence of a functional periodontal mechanoreceptive input. This input is derived from temporomandibular joint (TMJ), muscle,

cutaneous, mucosal, and/or periosteal mechanoreceptors, and provides mechanosensory information for oral kinesthetic sensibility in relation to jaw function and artificial tooth contacts.

Theories of Osseoperception

Based on neural inputs, associated with jaw movements, various theories have been put forth by different authors. These theories are beneficial to understand the implant-mediated osseoperception.⁽³⁾ The theories that explain the phenomenon of osseoperception around dental implants are:

1. **Linden and Scott (1989):** Postulates that following tooth extraction, although periodontal tissues breakdown and are absorbed, some PD receptors remain within the bone. Further responses can be recorded in the trigeminal mesencephalic nucleus following electrical but not mechanical stimulation of the bone. These receptors can also play major role in jaw muscle coordination, but one cannot decide that the extraction was atraumatic and remaining periodontal receptors were not damaged.
2. **Bonte (1993):** Documented that reinnervation in association with controlled forces directed to implants occur that result in proprioception. This theory got the maximum support because it is fact that loaded implants show better proprioception than immediate non-functional implants. The reason could be that with physiologic loading, osseointegration is near to woven bone with the development of new nerve fibers around the implant.
3. **Klineberg and Murray (1999):** Associate these responses with muscle spindle and joint receptors that substitute for periodontal ligament of natural teeth. However, because these receptors are not in direct contact with the implants, these may not have role in better osseceptive ability with osseointegrated implants. Also these receptors are functional even with removable prosthesis.
4. **Van Stenberghe (2000):** Suggests that periosteum may be a source of proprioceptive response. Mechanoreceptors, which are in the periosteum, are around the implants and send the proprioceptive impulses. This theory is most acceptable but only few receptors are present in the periosteum, which may not suffice for the neural input that can result in precise jaw movements.
5. **Weiner (2004):** Suggest that bone in the regions adjacent to implant contains nerve fibers that may serve as sensory nerve response. This theory carries good support as far as intensity of neural input is concerned.
6. **Yamashiro (2001):** Postulate that occlusal load results in strain of bone that is interpreted by the cytostructure of osteocytes resulting in action

potential generated in axons of adjacent Haversian systems. This theory was suggested based on the ingrowth of nerve fibers in the threads of the implant that is osseointegrated. This theory can be given weightage in terms of good neural inputs.

Tactile function of oral implants

Periodontal mechanoreceptors play the primary role in tactile function of teeth. This functional property has been studied extensively in a clinical and a kinesiologic perspective. Information on oral tactile function can be examined by neurophysiological as well as psychophysical methods.^(10,11)

1. **Neurophysiological Studies:** Neurophysiological evidence is provided by a series of neurophysiological studies in animals and humans to prove the tactile function of dental implants which suggests that the sensory cortex can reorganize itself extensively, by training of or losing afferent inputs.⁽¹²⁾

The neurophysiological approach is the recording of the trigeminal somatosensory evoked potentials (TSEP) after stimulation of receptors in the oral cavity. This set-up has the advantage of obtaining information on the cortical response of the trigeminal afferent system upon noninvasive stimulation of oral receptors.⁽¹²⁾ Another method to assess sensory function is the visualization of brain activities by fMRI. It is a very promising technique, which has so far received hardly any attention in relation to tactile function of teeth and implants.⁽¹¹⁾

2. **Psychophysiological Studies:** These include a series of well-defined methodologies to help determine the threshold level of sensory receptors in man. Psychophysical methods allow connecting the psychological response of the patient to the physiological functions of the receptors involved.⁽¹¹⁾ In the literature, psychophysical threshold determination studies confirmed that patients might perceive mechanical stimuli exerted on osseointegrated dental implants in the bone.⁽¹²⁾ The tactile sensibility of teeth and/or implants can be expressed as:

- i. **Active tactile sensibility:** It is the interocclusal detection of small objects such as strips, where various groups of receptors are activated. It provides a means to observe a parameter of jaw motor control.

Active threshold determination: An interocclusal discrimination task of small objects determines the differential threshold level. The active differential threshold level varies according to the experimental set-up, but the most important variable is the dimension of the test sticks (Fig. 1). For an inter incisor distance of 5 mm or more, non-periodontal receptors such

a muscular or articular receptors play a predominant role.⁽¹⁰⁾

The active absolute threshold level is determined by inter occlusal detection of small objects such as foils. When using foil materials with a high thermal conductivity such as aluminum or steel, a lower inter occlusal threshold level is obtained. This is due to the interaction of thermal receptors in the dental pulp.⁽¹⁰⁾



Fig. 1: Evaluation of active tactile sensibility tooth vs tooth situation

- ii. **Passive tactile sensibility:** It is the detection of forces applied to the teeth where it evaluates more precisely the role of periodontal mechanoreceptors although not in a very physiological situation.

Passive threshold determination: The passive differential threshold level is the ability to differentiate between intensities of forces applied to a tooth. It depends on the force characteristics, such as rate of force application, and on the range of forces presented. Teeth are more sensitive than endosseous implants for the passive DL level of forces. At force levels in the order of chewing forces, implants and teeth seem equally sensitive.⁽¹⁰⁾

Different stimulating devices are proposed for the passive detection of forces applied to a tooth (Fig. 2). The exact replacement of both the tooth and the stimulating device after a force application can only be obtained by connecting the teeth to the device.⁽¹⁰⁾

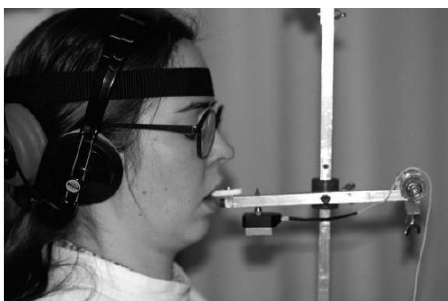


Fig. 2: Set-up for the determination of passive tactile sensibility by applying axial pushing forces against the tooth

In comparison with the tactile function of natural dentitions, the active threshold is seven to eight times higher for dentures but only three to five times higher for implants. For the passive detection of forces applied to upper teeth, thresholds for dentures are 75 times increased and for implants 50 times (Table 1).⁽¹¹⁾

Table 1: Active and Passive detection threshold in natural teeth, removable prosthesis and implant-supported prosthesis.

S.N.	Dental Status	Active detection threshold (μm)	Passive detection threshold (g)
1.	Vital tooth	20	2
2.	Non-vital tooth	20	2
3.	Removable prosthesis	150	150
4.	Implant-supported prosthesis	50	100

The large discrepancies between active and passive thresholds can be explained by the fact that several receptor groups may respond to active testing, while the passive method selectively activates periodontal ligament receptors. The latter are eliminated after extraction, which may explain the reduced tactile function in edentulous patients. After rehabilitation with a bone-anchored prosthesis however, edentulous patients seem to function quite well. These patients perceive mechanical stimuli exerted on osseointegrated implants in the jaw bone.⁽¹¹⁾

Recent advancements

The osseointegrated dental implants physiologically differ from natural teeth as they lack periodontal ligament support and hence when loaded mechanically, evoke a peculiar sensation, which has been termed as osseoperception. However, to date, there has been a major disconnection between the principles of periodontal regeneration and oral implant osseointegration as the presence of a periodontal ligament to allow for a more dynamic role beyond the functionally ankylosed implant.⁽¹³⁾

Osseoperception of dental implants involves many adaptive changes, from the peripheral sensory nerve mechanoreceptors to the central nervous system, and sensory nerve regeneration plays an important role. Peripheral nerve regeneration involves axons, Ruffini's nerve endings and other receptors. The expression levels of a variety of biologically active substances change during nerve regeneration, such as neuropeptide Y, growth-associated protein-43, calcium binding proteins and various neurotrophic factor receptors.⁽¹⁴⁾

Implantation of Schwann cells, neural stem cells and mesenchymal cells can contribute to nerve regeneration surrounding the implant. Guided tissue regeneration can be applied to reconstruct periodontal

tissue. This technique implants periodontal ligament stem cells that express high levels of bone morphogenetic protein, and platelet-derived growth factor and has achieved some success. Nerve regeneration and tissue engineering has made significant progress in recent years. Mesenchymal stem cells can be induced to become Schwann cells or their precursor cells, which can promote nerve regeneration surrounding an implant after transplantation so as to reconstruct the sensory projection to the midbrain and cortex.⁽¹⁴⁾

i. Schwann Cell Graft⁽¹⁵⁾

Since Schwann cells are closely associated with neural development and regeneration, it has been hypothesized that Schwann cells graft can enhance nerve regeneration around osseointegrated implants, and promote the sensory responses of implants to the similar level with the natural teeth.

Schwann cell, the glial cell of peripheral nerve system, has been widely accepted to play indispensable roles during neural development and regeneration. When peripheral nerve injury occurs, Schwann cells form a cellular band (Bünger's band) to accept regenerating sprouts from the axonal stump. Second, it is able to produce many neurotrophic factors and receptors, including NGF, BDNF, NT3, CNTF, and GDNF, which are essential for axonal outgrowth after nerve injury, as well as the development and maturation of the periodontal Ruffini endings.

When Schwann cells combined with artificial conduit are used to repair peripheral nerve defect, it has a preferential effect both on the functional recovery and the size of the defect to be bridged. More importantly, Schwann cells have been shown to be effective in inducing regeneration from central nerve system tissues. These findings strongly suggest that Schwann cells may be helpful as potent agents to improve nerve regeneration in peri-implant environment and as a substitute for grafts.

Morphologically, Schwann cells are closely associated with Ruffini endings and serve as one part of them. The cell body of Schwann cell extends its cytoplasmic process toward the axon terminals and covering around them.

Based on such situation, it is believed that Schwann cell graft may have a better performance to promote the sensitivity of implants than the single use of certain bioactive molecules.

ii. Periodontio-integrated Implants⁽¹³⁾

The presence of a periodontal ligament allows for a more dynamic role beyond the functionally ankylosed implant. Therefore, an innovative approach is mandatory to create "periodontio-integrated implants" i.e., an implant suspended in the socket through periodontal ligament as opposed to functionally ankylosed osseointegrated implants.

The discovery of stem cells in periodontal tissue and the outstanding progress in biomaterial research has

opened up many possibilities for periodontal regeneration. To achieve successful periodontal regeneration, it will be necessary to utilize and recruit progenitor cells that can differentiate into specialized cells with a regenerative capacity, followed by the proliferation of these cells and synthesis of the target specialized connective tissues. Clearly, a tissue-engineering approach for periodontal regeneration will need to utilize the regenerative capacity of these cells residing within the periodontium and would involve the isolation of such cells and their subsequent proliferation within a three-dimensional framework.

Conclusion

Endosseous implants have been proven to rehabilitate amputations of limbs or teeth. To achieve satisfactory clinical success, the physiological and psychological integration of dental implants needs to be understood. The available evidence on the plasticity of the CNS provides a possible neural basis for the accommodation of patients to changes in their dental status. However, long term research involving long term clinical trials is required to understand the concept of osseoperception and to help design optimized dental implants with greater success and better masticatory results.

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