Osseoperception in Dental Implants: A Systematic Review

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Keywords
Dental implants; osseointegration; osseoperception.

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Abstract

Purpose: Replacement of lost teeth has significant functional and psychosocial effects. The capability of osseointegrated dental implants to transmit a certain amount of sensibility is still unclear. The phenomenon of developing a certain amount of tactile sensibility through osseointegrated dental implants is called osseoperception. The aim of this article is to evaluate the available literature to find osseoperception associated with dental implants.

Materials and Methods: To identify suitable literature, an electronic search was performed using Medline and PubMed database. Articles published in English and articles whose abstract is available in English were included. The articles included in the review were based on osseoperception, tactile sensation, and neurophysiological mechanoreceptors in relation to dental implants. Articles on peri-implantitis and infection-related sensitivity were not included. Review articles without the original data were excluded, although references to potentially pertinent articles were noted for further follow-up. The phenomenon of osseoperception remains a matter of debate, so the search strategy mainly focused on articles on osseoperception and tactile sensibility of dental implants. This review presents the histological, neurophysiological, and psychophysical evidence of osseoperception and also the role of mechanoreceptors in osseoperception.

Results: The literature on osseoperception in dental implants is very scarce. The initial literature search resulted in 90 articles, of which 81 articles that fulfilled the inclusion criteria were included in this systematic review.

Conclusion: Patients restored with implant-supported prostheses reported improved tactile and motor function when compared with patients wearing complete dentures.
Materials and methods

Objectives

The main objectives were to review the literature regarding osseoperception and related studies, and to determine how the research has been conducted from the time Branemark coined the term osseoperception. Questions raised and discussed in this article are:

1. Does the implant stimulate the bone due to osseoperception?
2. What amount of neural signal enhances osseointegration?

Data source and search strategies

This systematic review on osseoperception was made following PRISMA statement suggestions. An electronic search from 1960 to June 2014, without language restrictions was done on the PubMed website (U.S. National Library of Medicine, National Institutes of Health).

The keywords searched were “dental implant” and “osseoperception,” “osseointegration” and “osseoperception,” “osseointegration” and “tactile sensibility,” “osseoperception” and “tactile sensibility,” “tactile sensibility” and “dental implant.” The publication had to be included in the electronic database to be considered in the review. All reference lists of the selected studies were then hand-searched for additional articles that might meet the eligibility criteria for inclusion in this study. All the authors read the titles and abstracts from the obtained results to identify the articles meeting the inclusion criteria. For articles with insufficient data in the title and abstract to make a clear decision, the full report was obtained, read, and assessed.

Selection criteria

Inclusion

Eligibility criteria included both animal and human studies from the articles published from 1960 to 2014. All the articles selected for the review were in English. The articles included in the review were based on osseoperception, tactile sensation, and neurophysiological mechanoreceptors in relation to dental implants.

Exclusion

Articles on peri-implantitis and infection-related sensitivity were not included. Review articles were excluded, although references to potentially pertinent articles were noted for further follow-up.

Results

Concept of osseoperception

Osseoperception can be considered an associated mechanosensitivity with osseointegrated implant rehabilitation. For 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.

The amount of Merkel cells in the gingival mucosa was found to be significantly higher in edentulous areas than in the dentate mucosa. This increase in the number of Merkel cell population might be to compensate for the loss of teeth. Studies have shown an increase in the tactile perception capability of osseointegrated implants over time.

Tactile function of oral implants

Neural receptors of the periodontium play an essential role in oral tactile function. Most receptors, which are found in the PDL, are evidently absent around the perimucosa of dental implants. In those cases, remaining receptors of the gingiva, alveolar mucosa, and periosteum may take over the role of normal exteroceptive function.

Psychophysical studies

In the literature, psychophysical threshold determination studies confirmed that patients might perceive mechanical stimuli exerted on osseointegrated dental implants in the bone (Table 1). Psychophysics includes a series of well-defined methodologies to help determine the threshold level of sensory receptors in man. Many variables contribute to the subjective nature of psychophysical sensory testing.

The tactile sensibility of teeth and/or implants can be expressed as active tactile sensibility or passive tactile sensibility. The difference between the active and passive tactile perception in implants can be explained by the fact that in active perception, various groups of receptors are activated; whereas passive perception electively addresses the PDL receptors missing after the extraction of the tooth (i.e., those previously present in the region of the implant). It is assumed that sensibility can be restored using dental implants because of the activation of receptors in the bone, the periosteum, the joint capsule, or other tissues. There are two different explanations: (i) activation of local receptors located in the peri-implant bone, or (ii) activation of more remote receptors.

After being restored with an implant-supported prosthesis, patients seem to function well, perceiving mechanical stimuli exerted on osseointegrated implants in the jawbone. In patients followed up after implant placement, a noticeable improvement in tactile function with dental implants following a 3-month healing period has been observed, potentially indicating that the feedback pathway to the sensory cortex is partly restored with a hypothetical representation of the prosthesis in the sensory cortex, allowing a more appropriate modulation of the motor neuron pool, and leading to a more natural functioning and avoiding overload.

Neurophysiological studies

Neurophysiological evidence is provided by a series of neurophysiological studies in animals and in humans to prove the tactile function of dental implants (Table 2). Neurological research suggests that the sensory cortex can reorganize itself extensively, by training of or losing afferent inputs, even after the critical developmental time of the brain has expired.
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<tr>
<th>Author</th>
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<th>Summary</th>
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<tbody>
<tr>
<td>Jacobs et al&lt;sup&gt;23&lt;/sup&gt;</td>
<td>Human study</td>
<td>Influence of temperature and foil hardness on interocclusal tactile</td>
<td>20 subjects were tested for their absolute threshold level (RL)</td>
<td>Although active RL determination may involve the activation of nonperiodontal receptors, it remains a realistic parameter to monitor tactile function of teeth.</td>
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<tr>
<td>Jacobs and van Steenberghe&lt;sup&gt;16&lt;/sup&gt;</td>
<td>Human study</td>
<td>Comparative evaluation of the oral tactile function by means of teeth- or implant-supported prostheses</td>
<td>An interocclusal thickness detection and discrimination task was carried out in four different test conditions on 37 patients: t (tooth)/t, i (implant)/t, i/i and d (denture)/o (overdenture supported by implants)</td>
<td>The tactile sensibility of implants is reduced with regard to natural teeth. Remaining receptors of the peri-implant tissues might play a compensatory role in the decreased exteroceptive function.</td>
</tr>
<tr>
<td>Jacobs and van Steenberghe&lt;sup&gt;24&lt;/sup&gt;</td>
<td>Human Study</td>
<td>Comparison between implant-supported prostheses and teeth regarding passive threshold level</td>
<td>31 patients subdivided into four test groups according to different prosthesis types supported by osseointegrated implants</td>
<td>The threshold level of implants is 50 times higher than that of natural teeth when tapping is avoided, which might otherwise trigger distant receptors. Bone deformation triggering the periosteal mechanoreceptors is the most logical explanation for the sensation reported.</td>
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<tr>
<td>Hammerle et al&lt;sup&gt;25&lt;/sup&gt;</td>
<td>Human study</td>
<td>Threshold of tactile sensitivity perceived with dental endosseous implants and natural teeth</td>
<td>22 subjects with implants of the ITI Dental Implant System were included in the study</td>
<td>More than eight-fold higher threshold value for tactile perception exists for implants compared with teeth.</td>
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<tr>
<td>Schulte&lt;sup&gt;26&lt;/sup&gt;</td>
<td>Human study</td>
<td>Compares the morphology and function of the natural periodontium with peri-implant tissues and tissue reactions.</td>
<td>Tactile sensibility of implants versus natural teeth was studied</td>
<td>Passive tactile sensibility seems to be less clearly localized in the case of implants vs. natural teeth and is perceived by the test persons as being transmitted more deeply in the skull, that is, the deformation of the peri-implant bone, which might cause stretching of the periosteum.</td>
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<tr>
<td>Lundqvist and Haraldson&lt;sup&gt;27&lt;/sup&gt;</td>
<td>Human study</td>
<td>Occlusal perception of thickness in patients with fixed partial dentures on osseointegrated oral implants</td>
<td>Subjects with osseointegrated oral implant bridges (OIB), complete denture wearers, and subjects with complete natural dentitions were estimated</td>
<td>Partial or complete lack of periodontal receptors is compensated for by other perceptive organs and that OIB therapy partly restores occlusal sensibility.</td>
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<tr>
<td>Keller et al&lt;sup&gt;28&lt;/sup&gt;</td>
<td>Human study</td>
<td>Determination of the tactile pressure thresholds perceived with dental implants during a 3-month healing phase</td>
<td>The absolute threshold of tactile perception was measured in a group of patients 1 week, 1, 2, and 3 months following implant placement</td>
<td>The absolute threshold of tactile perception with dental implants during the phase of osseointegration is not affected by bone and soft tissue healing taking place during the time period.</td>
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<tbody>
<tr>
<td>Jacobs and van Steenbergh</td>
<td>Human study</td>
<td>Evaluation of the psychophysical detection threshold level for vibrotactile and pressure stimulation of prosthetic limbs using bone anchorage or soft tissue support</td>
<td>Prosthetic limbs were anchored to the bone by means of an implant ($n = 17$) or supported by a socket enclosing the amputation stump ($n = 15$)</td>
<td>Prosthetic limb design with bone-anchored prostheses yields better perception than socket prostheses.</td>
</tr>
<tr>
<td>Jacobs et al</td>
<td>Human study</td>
<td>Perceptual changes in the anterior maxilla after placement of endosseous implants</td>
<td>Five groups of subjects were selected; test groups included patients with a complete denture, an implant-supported fixed prosthesis (full or partial), or a single-tooth replacement.</td>
<td>Natural dentitions offer superior vibrotactile function compared to any other dental status. Complete dentures often show a stronger deterioration of the (vibro) tactile function compared with implant-supported prostheses.</td>
</tr>
<tr>
<td>El-Sheikh et al</td>
<td>Human study</td>
<td>Changes in passive tactile sensibility associated with dental implants following their placement.</td>
<td>Five edentulous subjects treated with two or more NobelBiocare dental implants in the anterior mandible were studied</td>
<td></td>
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<tr>
<td>Enkling et al</td>
<td>Human study</td>
<td>Tactile sensibility of single-tooth implants and natural teeth</td>
<td>Active tactile sensibility between single-tooth implants and opposing natural teeth were compared with the tactile sensibility of pairs of natural teeth on the contralateral side</td>
<td>The active tactile sensibility of single-tooth implants, both in the anterior and posterior region of the mouth, in combination with a natural opposing tooth is similar to that of pairs of opposing natural teeth.</td>
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<td>Batista et al</td>
<td>Human study</td>
<td>Progressive recovery of osseoperception as a function of the combination of implant-supported prostheses</td>
<td>Evaluate the recovery of interocclusal sensory perception for micro-thickness in individuals with different types of implant-supported prostheses</td>
<td>Conventional CDs presented a significant loss of the inter-occlusal tactile threshold for micro-thickness. Fixed or removable implant-supported prostheses allowed for the recovery of the interocclusal tactile threshold at levels similar to that of natural teeth. This clinical evidence strengthens the premise of the connection of global neurophysiological integration of the implant to the stomatognathic system.</td>
</tr>
<tr>
<td>Enkling et al</td>
<td>Human study</td>
<td>Active tactile sensibility of osseointegrated dental implants</td>
<td>Active tactile sensibility can be tested by having the subject bite on test bodies</td>
<td>Active tactile sensibility of implants with natural antagonistic teeth is very similar to that of teeth. Significant differences in tactile sensibility as a function of different implant surfaces may indicate that receptors near the implant form the basis of osseoperception.</td>
</tr>
<tr>
<td>Enkling et al</td>
<td>Human study</td>
<td>Tactile sensibility of single-tooth implants and natural teeth under local anesthesia of the natural antagonist</td>
<td>Study aims at clarifying the question of how far tactile sensibility is to be attributed to the periodontium of the natural opposing tooth of the implant</td>
<td>The active tactile sensibility of single-tooth implants with natural opposing teeth is not only to be attributed to the periodontium of the opposing tooth but also to a perception over the implant itself. This could support the hypothesis according to which the implant may have a tactile sensibility of its own.</td>
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### Table 2: Neurophysiological studies to prove tactile function of oral implants

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<tr>
<td>Desjardins et al&lt;sup&gt;35&lt;/sup&gt;</td>
<td>Human study</td>
<td>Comparison of nerve endings in normal gingiva with those in mucosa covering edentulous alveolar ridges</td>
<td>A cholinesterase whole-mount staining technique was used to study and compare the quality and quantity of neural elements in 109 sections of gingiva and edentulous mucosa.</td>
<td>All organized endings observed in gingiva and edentulous mucosa appeared the same morphologically. Removal of teeth does not alter appreciably the neural innervation of oral mucosa; however, a prosthesis may be a stimulus to altered neural anatomy. The quality of the fit of a tissue-supported prosthesis is critical in determining its ability to stimulate or destroy neural innervation.</td>
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<td>Linden and Scott&lt;sup&gt;36&lt;/sup&gt;</td>
<td>Animal study: cat jaw bone</td>
<td>The effect of tooth extraction on PDL mechanoreceptors in the mesencephalic nucleus</td>
<td>Electrical stimuli applied to the remains of the mandibular nerve in the jaw bone after tooth extraction</td>
<td>Electrical stimuli resulted in afferent signals, which were not elicited by mechanical stimuli. There was stimulation of nerves of periodontal origin in healed extractions sockets, implying that some nerve endings remain functional.</td>
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<td>Buser et al&lt;sup&gt;37&lt;/sup&gt;</td>
<td>Animal study: monkey mandible</td>
<td>Cementum formation with inserting collagen fibers can be accomplished on dental implants</td>
<td>Titanium implants were placed in the mandible of monkeys, where apical root portions were retained.</td>
<td>The histological examination revealed that a cementum layer with inserting collagen fibers was achieved around implants. These results demonstrate that dental implants with a true PDL can be accomplished.</td>
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<tr>
<td>Bonte et al&lt;sup&gt;38&lt;/sup&gt;</td>
<td>Animal study: cat jaw muscle</td>
<td>Role of periodontal mechanoreceptors in evoking reflexes in the jaw-closing muscles</td>
<td>Left maxillary and mandibular canine and incisor teeth were extracted. Nine weeks later titanium implants were placed into the edentulous area. Recordings were made from the trigeminal ganglia and peripheral nerves.</td>
<td>When forces are applied to a tooth, periodontal mechanoreceptors, which evoke reflex inhibitions to motor units in the jaw-closing muscles, are stimulated; however, there is evidence that mechanoreceptors situated distant to the periodontium can also evoke such reflexes.</td>
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<tr>
<td>Dong et al&lt;sup&gt;39&lt;/sup&gt;</td>
<td>Animal study</td>
<td>Static and dynamic responses of PDL mechanoreceptors (PDLMs) and intradental mechanoreceptors (IMs)</td>
<td>The functional similarities of PDLMs and IMs, respectively, to slowly adapting type II mechanoreceptors and pacinian corpuscle receptors in the skin are discussed.</td>
<td>Findings, which complement earlier anatomic and behavioral evidence, strongly suggest that IMs subserve nociceptive and nonpain functions. Both PDLMs and IMs may provide a continuum of dynamic afferent inputs necessary for tactile sensibility of teeth.</td>
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<tr>
<td>Takata et al</td>
<td>Animal study/ cat</td>
<td>Whether a new connective tissue attachment can occur on a hydroxyapatite</td>
<td>Six maxillary canines from three cats were used for this experiment. A synthetic HA block</td>
<td>A PDL-like connective tissue layer was seen between the cementum-like layer covering the</td>
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<td>canine</td>
<td>attachment can occur on a hydroxyapatite surface (HA) when PDL-derived</td>
<td>was inlaid and cemented into the root cavity. A Teflon membrane was then placed to cover the</td>
<td>exposed HA surface and the newly formed alveolar bone sealing the bone fenestration.</td>
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<td>cells with the ability to form new connective tissue attachment are</td>
<td>access opening of the alveolar bone to guide PDL-derived cell proliferation into the surface of</td>
<td>Collagen fibers in the PDL-like tissue inserted their ends into the newly formed bone and</td>
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<td>allowed to populate the surface of HA</td>
<td>the HA block.</td>
<td>the cementum-like tissue. The present findings demonstrated that PDL-derived cells can</td>
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<td>form a new connective tissue attachment on HA.</td>
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<td>Warrer et al</td>
<td>Animal study: monkey</td>
<td>If a PDL can form around self-tapping, screw type titanium dental implants</td>
<td>Implants were inserted in contact with the PDL of root tips retained in the mandibular jaws of</td>
<td>A PDL can form on titanium dental implants in areas where a void is present between the</td>
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<td>mandibular jaw</td>
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<td>seven monkeys.</td>
<td>surrounding bone and the implant at the time of insertion.</td>
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<td>Tanaka et al</td>
<td>Animal study: rat</td>
<td>Immunocytochemical study of nerve fibers containing substance P</td>
<td>Nerve fibers with substance P-like immunoreactivity (SP-IR) in the JE of 32-42-days-old rats</td>
<td>Nerve fibers contain substance P and possess free nerve endings. They may respond to pain,</td>
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<td>junctional epithelium</td>
<td>in the junctional epithelium (JE) of rats</td>
<td>were examined by both light and electron microscopy using the avidin-biotin-peroxidase</td>
<td>touch, and pressure.</td>
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<td>complex method.</td>
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<td>Lambrichts</td>
<td>Animal study: cat</td>
<td>Histological and ultrastructural aspects of bone innervation</td>
<td>Studied the histological and ultrastructural aspects of bone innervations</td>
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<td>jaw</td>
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<td>Wang et al</td>
<td>Animal study: dog</td>
<td>Nerve regeneration after implantation in peri-implant area</td>
<td>A histological study on different implant materials in dogs</td>
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<tr>
<td>Choi</td>
<td>Animal study: dog</td>
<td>Whether a new periodontal ligament attachment will form on titanium</td>
<td>The implants with the cultured autologous PDL cells were placed in the mandibles of the dogs.</td>
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<td></td>
<td>mandible</td>
<td>implants</td>
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<td>Cultured PDL cells can form tissue resembling a true PDL around implants.</td>
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<tr>
<td>Ysander et al</td>
<td>Animal study: rat</td>
<td>Study of histology and neuropeptide changes around titanium implants</td>
<td>Explore intramedullar osseointegration in a rodent model.</td>
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<td></td>
<td>femur</td>
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<td>Nerve fibers were detected in the remodeled bone adjacent to the implants.</td>
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<tr>
<td>Wada et al</td>
<td>Animal study: dog</td>
<td>The effects of occlusal forces on the distribution of neurofilament</td>
<td>The bilateral 2nd, 3rd, and 4th mandibular premolars and the 1st molars were extracted. After</td>
<td>In early-loaded screw-type implants, sprouting of new fibers is observed, and the number of</td>
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<td>mandible</td>
<td>protein (NFP)-positive nerve fibers in the tissue of peri-implant bone</td>
<td>4 months of healing, four screw-type implants were inserted in the oral cavity. Three</td>
<td>free nerve endings close to the bone-to-implant interface gradually increases during the</td>
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<td>months after insertion, the implants on the molar site were loaded by occlusal forces, while</td>
<td>first weeks of healing, irrespective of the kind of implant surface.</td>
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<td>those on the premolar site were unloaded.</td>
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<tr>
<td>Fujii et al</td>
<td>Animal study: rat maxilla</td>
<td>The response of nerve fibers in the peri-implant epithelium to titanium implantation was investigated</td>
<td>The upper first molars on both sides were extracted. One month after extraction, the custom-made titanium cylindrical implants were inserted.</td>
<td>The findings indicate that the peri-implant epithelium shows the same innervations as that in normal junctional epithelium.</td>
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<td>Jahangiri et al</td>
<td>Animal study: beagle dog</td>
<td>Feasibility of PDL generation on an implant surface by approximating a tooth-to-implant contact using orthodontics</td>
<td>Maxillary second premolars of six beagle dogs were extracted bilaterally. After 2 weeks of healing, hydroxyapatite (HA) coated titanium implants were placed. One side of the arch was used as control. Orthodontic tooth movement was initiated following implant placement to tip the first premolar roots into contact with the implant.</td>
<td>An animal model was established in which the proximity of tooth-to-implant contact lead to partial generation of PDL on a bioactive implant surface.</td>
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<tr>
<td>Parlar et al</td>
<td>Animal study: mongrel dogs</td>
<td>Explore the formation of periodontal tissues around titanium implants</td>
<td>The implants were placed in a novel dentin chamber model obtained from the canine of mongrel dogs.</td>
<td>A remarkable amount of new periodontal tissue formation occurred in the peri-implant chamber at a site where no such tissues ever existed.</td>
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<tr>
<td>Suzuki et al</td>
<td>Animal study: hamster palatine mucosa</td>
<td>Investigate the relationship between Merkel cells and nerve elements during tissue regeneration after receiving dental implants</td>
<td>Golden hamsters were divided into three groups, and titanium alloy implants were fixed in their left-side maxilla through the third palatine rug.</td>
<td>There was invasion of regenerative nerve fibers in the superficial layer of the peri-implant epithelium.</td>
</tr>
<tr>
<td>Zhu et al</td>
<td>Animal study: beagle dog mandible</td>
<td>Investigate the existence of functional neuroreceptors in peri-implant bone tissue and to test the peri-implant neural feedback pathway reconstruction</td>
<td>After the extraction of three premolars and one molar of the bilateral mandible, 27 implants were placed immediately or delayed. The implants were loaded for 3 to 6 months, then sensory nerve action potential (SNAP) tests were performed.</td>
<td>Functional neuroreceptors, though much less than that of natural tooth, exist in peri-implant bone tissue. Surgical methods and loading time do not have obvious influences on peri-implant neural feedback pathway reconstruction.</td>
</tr>
<tr>
<td>Van Loven et al</td>
<td>Human study</td>
<td>Sensations and trigeminal somatosensory-evoked potentials elicited by electrical stimulation of endosseous implants in humans</td>
<td>The stimuli were delivered to permucosal oral endosseous implants in 15 individuals, who then reported tapping to beating sensations.</td>
<td>The author concluded that for the first time a sensation (osseoperception) was elicited by electrical stimulation of endosseous oral implants and correlated with simultaneously recorded trigeminal somatosensory-evoked potentials (TSEPs).</td>
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<td>Marchetti et al</td>
<td>Human study</td>
<td>Microscopic, immunocytochemical, and ultrastructural properties of peri-implant mucosa in humans</td>
<td>The study was performed on samples of peri-implant mucosa from patients who had undergone implant treatment 16 to 18 months before.</td>
<td>The results demonstrated that all the epithelial and connective components of the mucosa are involved in the substantial regrowth of the peri-implant tissue and subsequently in the success of the implant.</td>
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Evidence from the literature mentions that after limb amputation or tooth extraction, regions of the cortex deprived of a target will acquire new targets, and the remodeling takes place at the cortical or subcortical level.\textsuperscript{53,54} Several studies have noted the cortical adaptive changes after hand or thumb transplantation, re plantation, or implantation.\textsuperscript{55-57} However, the literature lacks evidence on detailed investigation of the possible sensorimotor cortical adaptive processes that could be associated with the loss of teeth or with their replacement in human jaws.\textsuperscript{57} In one study, the authors postulated that implant-supported complete dentures can restore the sensorimotor feedback by a reorganized pattern in the central nervous system. This sensation is generated from the temporal mandibular joint, masticatory muscle, mucosa, and periosteum and provides sensory and motor information related to mandible movements and occlusion.\textsuperscript{13}

Trigeminal somatosensory-evoked potential (TSEPs) upon implant stimulation, a piece of neurophysiological evidence, is found in some experimental studies. By stimulating sweeps in the electroencephalogram by means of a dental implant, and by cumulating advanced analysis of the sweeps, one can finally note significant waves generated. The experiments indicate that there are indeed endosseous and/or periosteal receptors around the dental implants that convey the sensation.\textsuperscript{50,58}

The involvement of the bone innervation in mechanical perceptions is still a controversial subject.\textsuperscript{59} The function of bone innervation may be limited to vasoregulatory and bone remodeling processes, whereby most nerve fibers have free nerve endings in the bone connected to the endosteum with vessels or with connective tissue components\textsuperscript{12,60,61} and may also respond to pressure and pain stimuli.\textsuperscript{52,63} In animal experiments, it has been shown that implant materials are surrounded by nerve fibers in the area of the bone/implant interface.\textsuperscript{4} More remote proprioceptors and exteroceptors excited by the mechanical load on the peri-implant bone may form the basis for osseoperception. The study of passive tactile sensitivity only allows the testing of individual neural receptors, but active tactile sensibility more effectively represents normal function, and hence it is more relevant for practical dentistry.\textsuperscript{64}

Clinical implications

Psychophysical findings on various bone-to-implant-supported prostheses confirm an improved tactile function leading to a better physiological integration of the limb.\textsuperscript{51} Due to dental implant-induced stimulation, one should consider a few clinical implications to understand the threshold levels. During restoration of implant-supported prostheses, specialists should not rely on the patient’s perception of occlusion. In this regards, the dentist should also take notice of gradually increasing tactile function during the healing period after implant placement. It will be of particular importance when dealing with immediate loading protocols. To avoid any kind of occlusal overloading related to suboptimal feedback mechanisms, patients should be instructed to limit chewing forces by having soft food during the implant healing period. Parafunctional habits such as grinding or clenching might also have a negative impact during the implant healing phase. Bruxism has been relatively contraindicated for immediate loading protocols.\textsuperscript{65,66} As it is known that the active threshold level for implant-supported prostheses is higher than the natural dentition, the dentist should not rely on the patient’s perception during occlusal evaluation.\textsuperscript{67} Patients should be informed to limit chewing forces for a few weeks, corresponding to the time required for the appearance of neural endings at the bone/implant interface and for perception through implants to improve.\textsuperscript{68}

Discussion

Tactile sensibility of the implants, in relation to that of natural teeth, is not affected by age.\textsuperscript{69} Tactile perception was found to depend on the implant surface structure and might point to receptors near the implants as the anatomical basis of osseoperception.\textsuperscript{32} Several studies demonstrated that even though the periodontal fiber was missing, the tactile sensibility of the prosthetic restorations would increase when placed on the implants, and that the implant-supported restorations were superior to soft tissue-supported restorations with regard to both stability and tactile sensibility.\textsuperscript{70-72} Mericske-Stern et al. concluded that oral function, chewing, and biting of overdenture wearers is similar with support of either implants or natural roots.\textsuperscript{72} The absence of a PDL did not lead to highly increased occlusal forces and subsequently to overload of the implants. Enkling et al. mentioned how far tactile sensitivity was attributed to the periodontium of the natural tooth opposing the implant restorations. They mentioned that the active tactile sensibility of single-tooth implants with that of opposing natural teeth was not only attributed to the periodontium of the opposing tooth, but also to a perception over the implant itself.\textsuperscript{11} This could support the hypothesis that the implant may have a tactile sensibility of its own.

Yan et al analyzed neuroplasticity of edentulous patients with implant-supported complete dentures.\textsuperscript{14} They suggested that sensory and motor response to the central nervous system could possibly be restored by implant-supported prostheses. Activation of the primary sensorimotor cortex in implant-supported denture patients might explain the improved tactile sensibility, stereognostic ability, and masticatory functions that were more similar to the natural dentition.

Habre-Hallage et al studied brain plasticity. Cortical correlates of osseoperception were revealed by punctate mechanical stimulation of osseointegrated dental implants, using functional magnetic resonance imaging (fMRI). They demonstrated that punctate mechanical stimulation of dental implants will activate both the primary and secondary somatosensory areas in the cortex.\textsuperscript{74} Further, they suggested that brain plasticity occurs when endosseous implants are placed in the extracted teeth region. This cortical activation may represent the underlying mechanism of osseoperception.

In their other study, they evaluated the sensory changes that occurred in the soft tissues after placement of endosseous implants. Such information might give a better understanding to the functional role of peri-implant soft tissue innervation. They revealed that loss of teeth would decrease the sensory activity of the oral mucosa, while this function seems partially restored after implant installation. Whether this peri-implant soft tissue innervation would contribute to osseoperception remains to be determined.\textsuperscript{75}
Use of directional cutaneous kinaesthesia (DCK) and graphaesthesia has been documented as early as 1858 but not intraorally. DCK has the ability to recognize the direction of movement of a cutaneous stimulus. Graphaesthesia is the perception of figures drawn on the skin. Both of these tests correlate the physiologic function of the receptors to the subjective response of the patient.

A study by Macefield et al confirmed that the tactile response decreased at the level of abutment connection, after stage-two surgery. This can be due to the trauma caused by two surgical procedures (flap surgery for implant placement and implant uncovering surgery) involving periosteal elevation. Considering the rich periosteal innervations with pacinian corpuscles and free nerve endings, which were both sensitive to stretching, it was observed that reduced sensory function might be partly attributed to a disrupted or damaged periosteal innervation. Directional sensitivity is reduced in mucoperiosteal flap procedures; further investigation might demonstrate the merit of the flapless approach during implant surgery. He et al proposed a novel design of dental implant, wherein nano-springs were used to construct a stress-cushioning structure inside the implant.

Several animal and clinical studies have concluded that nerve growth factor (NGF), a neurotrophin, is effective for nerve regeneration. Moreover, NGF has the potential to accelerate bone healing and improve osseointegration of the implant. The novel point of the implant design was to reduce stress concentration around peri-implant bone by cushioning masticatory forces, to dissipate these forces along the peri-implant bone through nano-springs, and to promote osseoperception and osseointegration by NGF-induced nerve regeneration and new bone formation. If proven, this novel design, which transfers the main biomechanical interface of the implant from outside to inside, can to some extent compensate for the functions of lost periodontium in stress cushioning and proprioception.

Jacobs and van Steenberghhe stated that due to the activation of mucosal receptors underneath the complete denture and periosteal or mucosal mechanoreceptors in the area of the dental implant, implant-supported prostheses opposing complete dentures can contribute to the oral kinesthetic perception. Wang et al found that nerve fibers become abundant around the bone/implant interface as the process of osseointegration progresses. Jacobs and Van Steenberghhe found that patients might perceive mechanical stimuli exerted on osseointegrated implants in the bone. Van Loven et al studied the perception of bipolar electrical stimuli generated through implants. Individuals reported sensations on tapping and beating on and around the oral dental implants. Sensation (osseoperception) was elicited by electrical stimulation of endosseous dental implants and was correlated with simultaneously recorded TSEPs. A histological description of free neural endings at the bone/implant interface provides a strong possibility to explain why osseoperception may improve over time.

Conclusion
Endosseous implants have been proven to rehabilitate amputations of limbs or teeth. To achieve satisfactory clinical success with such bone-anchored prostheses, physiological and psychological integration of the implant(s) needs to be understood. Clinical outcomes of patients with dental implant-supported restorations indicate the presence of sensory perception after some time, as documented in the literature. The evidence available on the plasticity of the CNS provides a possible neural basis for our understanding of the accommodation of patients to these changes in dental status. Thus, it becomes apparent that with the loss of teeth and periodontal structure, other peripheral receptors dominate and transmit the afferent projections to the sensorimotor cortex and compensate by providing stimulations to the area of bone-anchored implant restorations; however, further research involving more clinical trials with long-term outcomes is required to understand this phenomena of osseoperception and thus in turn help researchers to design optimized dental implants with better masticatory results and success of implant-supported restorations.

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