Perceptual Changes in the Peri-Implant Soft Tissues Assessed by Directional Cutaneous Kinaesthesia and Graphaesthesia: A Prospective Study

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ABSTRACT

Background: The innervation of skin and oral mucosa plays a major physiological role in exteroception. This innervation is also clinically relevant as sensory changes occur after neurosurgical procedures.

Purpose: The goal of this study was to compare the perception of mechanical stimuli applied to the buccal mucosa in the vicinity of osseointegrated oral implants with that in the controlateral dentate side. The role of the previously reported increased innervation in the peri-implant soft tissues in the oral sensorimotor function was thus examined.

Materials and Methods: Seventeen subjects with 20 implants were tested. Directional cutaneous kinaesthesia (DCK) and graphesthesia (G) were performed on the buccal side of the alveolar mucosa before and at planned intervals after implant placement. The observation was pursued until 6 months after the prosthetic rehabilitation. In each subject, the contralateral mucosa served as a control to the implant sites. Average percentages of correct responses in a four-choice task for DCK and a three-choice task for G were calculated.

Results: Despite an intersubject variation in both the DCK and G, high intraindividual correlations were found ($p < .005$). The implant sites showed a significant difference toward the control sites at the four interval test for both tests. For DCK and G, the average of correct responses decreased after abutment connection (i.e., after the implant uncovering surgery) to increase afterwards to reach a level close to, but still lower than, the control sites 3 to 6 months after the prosthetic rehabilitation.

Conclusion: The DCK and G are simple but reliable sensory tests that can be easily applied in the oral region. This prospective study indicates that tooth loss reduces tactile function compared with implant-supported prostheses. The peri-implant soft tissues could be partially involved in the osseoperception function.

KEY WORDS: direction discrimination, oral implants, osseoperception, psychophysical tests, sensory changes, tactile function

INTRODUCTION

To evaluate oral sensorimotor function of a patient, psychophysical studies can be carried out determining tactile threshold levels,[1] as well as Oral Stereognostic Ability and Oral Motor Ability.[2,3] Other functional tests such as the directional cutaneous kinaesthesia (DCK) and graphaesthesia (G) have been used as early as 1858[4] but not intraorally. DCK is the ability to recognize the

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direction of movement of a cutaneous stimulus. G is the perception of figures, drawn on the skin. Both DCK and G assess the kinesthetic functions implying orientation in cutaneous sensory space and are thus considered as valuable adjuncts to the clinical sensory examination.[5]

Clinical neurological examinations involving the latter functions have been found to be more sensitive to disturbances of the nervous system than two point discrimination, or point localization tests.[5–7] The friction between the moving object and the skin might also activate receptors which are sensitive to lateral stretching, and probably essential for directional sensibility.[4]

Edin and Abbs found that slowly adapting skin receptors can reproducibly measure small changes of lateral skin tension.[8] In addition, the transsection of the dorsal columns of the spinal cord did not affect the ability to detect tactile sensation or tactile movements, but only impaired the ability to determine the direction of movement of the cutaneous stimuli.[9] Many neurons in the primary somatosensory cortex respond most rapidly to the movement of a cutaneous stimulus in a particular direction.[10]

The afferents in the buccal mucosa are very sensitive; they respond to contact between the lips and to environmental objects, to changes in air pressure generated for speech, sounds, and to facial skin and mucosa deformations that accompany lip and jaw movements associated with chewing and swallowing.[11]

These sensory receptors are more frequently found in the anterior part of the mouth. It has been histologically documented that the number of nerve fibers per unit area is greater in the anterior areas of the oral cavity, making this region the most sensitive part of the oral mucosa.[12] They demonstrate a lower sensitivity when localized on the ridge (crest) when compared with the vestibular areas, suggesting that receptor density is more important in the former.[12,13] The changes of the dental representation in the primary somatosensory cortex (SI) was investigated after the extraction of a single lower tooth in the naked mole-rats.[14] Five to eight months after tooth extraction, a dramatic reorganization of the orofacial representation in SI was observed for the zone that lost input from the extracted teeth. Neurons in the cortical lower tooth representation were responsive to tactile inputs from surrounding orofacial structures, including the contralateral upper incisor, ipsilateral lower incisor, tongue, chin, gums, and buccal pad.[14] These results suggest that the representation of the dentition in mammals is capable of significant reorganization after the loss of sensory inputs from the teeth.[14]

Histological findings reported an increased innervation in the peri-implant epithelium after implant placement.[15]

Yet, the functional role of the peri-implant innervation remains unclear and when focused on the kinesthetic function of the oral mucosa, no information is present to enable to differentiate peri-implant from periodontal soft tissues.

The aim of this study was therefore to evaluate the sensory changes that occur in the soft tissues after installation of an oral endosseous implant. Such information might give a better insight to the functional role of the peri-implant soft tissue innervation.

To reach this goal, two simple oral sensory tests (DCK and G) were performed at the implant sites and the responses were compared with the controlateral dentate sites at four different intervals: (1) before implant placement, (2) after implant placement but before implant loading, (3) 3 months after prosthetic rehabilitation, and (4) 6 months after prosthetic rehabilitation.

MATERIALS AND METHODS

Subjects

Seventeen subjects (ages 19–60 years, mean 35.28; SD 11.62), nine males (11 implants) and eight females (nine implants), were selected based on their dental status. Subjects had a complete natural dentition with the exception of one or two missing teeth in the maxilla or the mandible. They had to be rehabilitated with osseointegrated implants. The implant insertion was made at modum Brånemark by the same surgeon. The implants healed under the closed mucosa during a period of 3 to 5 months. The abutments were mounted on the implants 1 month after the implant uncovering surgery. None of the subjects had a history of any neurologic disorder such as dysesthesia or periodontitis in the oral cavity. Informed consent was obtained from each participant prior to investigation. The subjects were tested in a quiet room with stable illumination while seated comfortably in a chair with a headrest. They were instructed to close their eyes during the whole testing procedure and were familiarized with the set-up following a standardized instruction sheet including some test trials prior to the actual start of the experiments.

The same operator performed four consecutive measurements; before implant placement, at abutment connection, at 3 and at 6 months after the prosthetic rehabilitation. In each subject, two sensory tests were applied, the DCK and G. Both tests were performed at the buccal site of the keratinized or alveolar mucosa (at 1 mm from gingival or soft tissue margin) in the maxilla or the mandible for both implant and control sites. Cheek retractors were used to avoid stimulation of any other oral structures.

The Testing Procedure

DCK is the ability to recognize the direction in which a cutaneous stimulus is moving. This technique was described in details by Norrsell and Olausson.[16,17] The examiner of this study drew a line of 5 mm with a rubber tip gum stimulator (Oral B®, Oral B Laboratories, Belmont, CA, USA) at the buccal side of the alveolar mucosa. This device was chosen because it is gentle and flexible yet firm enough to stimulate the soft tissue.The subject was asked to report the direction corresponding to the line: up, down, left, or right.

G has been described as the perception of figures, ranging from simple lines to complex symbols, such as numbers and letters, drawn on the skin or the mucosa.[5] In this study, a circle, triangle ,or a square shape was drawn 5×5 mm in size at the buccal side of the alveolar mucosa with the rubber tip gum stimulator, at the speed of ~1 to 2 seconds per shape.

The patients were asked to recognize the shape that was drawn in the testing area.

For both tests, the number of experimental runs was limited to four in DCK and three in G. The sessions were interleaved by resting periods of 3 minutes to maintain the perceptual acuity of the patients throughout the experiments and to avoid fatigue.

Data and Statistical Analysis

The method used was the method of constant stimuli, with four-alternative forced-choice for DCK[18] and three for G. This approach has the drawback that a large amount of data are required to avoid response bias or guessing strategies.

The order of presentation of the forms or lines was randomized and the percentage of correct answers was calculated. Data are expressed as percentages (%), calculated by multiplying the mean number (n) of correct responses out of the number of trials (t) within each group by 100: $\% = (n/\mathrm{t}) - 100$. In each testing session, the number of trials (t) is 30 for G (10 for square, 10 for circle, and 10 for triangle) and 28 for DCK (7 for up, 7 for down, 7 for left, and 7 for right).

The SPSS software for windows version 15.0 (SPSS Inc., Chicago, IL, USA) was applied for statistical analysis. A 5% level of significance was chosen.

Despite an intersubject variation in both the DCK and G, significantly high intra-individual correlations were found ($p < .005$). Repeated measures analysis of variance (ANOVA), with three within-units factor (4 measurement times, 3 measurement forms, 2 measurements groups) for G and (4 measurement times, 4 measurement directions, 2 measurement groups) for DCK were conducted to simultaneously explore the effect of each of the independent variable: time, groups, and forms or directions on the percentage of right answers and to also identify any interaction effect.

Because of interaction, further analysis was carried out at particular time, for particular groups and forms or directions.

For each form and each direction, one-way repeated measure ANOVA and Bonferroni posttest analysis were applied to test if the percentage of right answers varied significantly over time for implant or control sites.

For each form and each direction, paired t test was used to examine if the percentage of right answers are significantly different at each time between implant and control sites.

At each time and for each group, other one-way repeated measure ANOVA and Bonferroni posttest analysis were applied to explore if significant difference in "Percentage of right answers" occurred, among forms (G) or among directions (DCK), or between forms and directions.

RESULTS

The results of the tests with regard to the number of correct responses on both implant and control sites, before implant placement, at abutment connection, and at 3 and 6 months after prosthetic rehabilitation are listed in Tables 1 and 2 and Figures 1–7.

Data are expressed as percentages (%), calculated by multiplying the mean number (n) of correct responses out of the number of trials (t) within each group by 100: $\% = (n/\mathrm{t}) \times 100$ (the number of trials is 30 for G and 28 for DCK).

TABLE 1 Average of Correct Responses for Graphaesthesia, from Initial to Follow-Up Examination – Implant-Site and Control-Site for All Subjects

	Graphaesthesia							
	BI		AC		3 months		6 months	
	Implant	Control	Implant	Control	Implant	Control	Implant	Control
Triangle								
Mean (%)	66.5	73.0	62.5	73.5	68.0	74.5	69.0	74.0
SD	6.7	6.6	6.4	7.4	7.0	8.9	7.2	9.4
Square								
Mean (%)	58.5	72.0	56.0	72.0	65.0	70.5	67.0	75.0
SD	7.45	7.7	8.2	7.7	6.9	7.6	7.3	5.1
Circle								
Mean (%)	71.5	80.5	71.0	79.5	76.5	84.0	79.5	84.0
SD	12.3	8.9	10.7	9.4	10.4	8.8	10.0	7.5

$p \leq .005$ compared with natural dentition.
AC = at the abutment connection; BI = before implant placement; SD = standard deviation; 3 months = 3 months after the prosthetic rehabilitation; 6 months = 6 months after the prosthetic rehabilitation.

At the Control Site

The percentage of correct responses was not significantly different at the four test periods. The control sites remained stable over time; this is illustrated in the Figures 1–7 and confirmed by statistic analysis (one-way repeated measure ANOVA $p > .05$). The control site achieved a significantly higher level of correct responses than the implant site for both G (paired *t*-test $p < .05$) and DCK (paired *t*-test $p < .05$).

At the Implant Site

A significant difference was found for both tests among the four observation periods. A reduced level of perception was revealed before implant installation in

TABLE 2 Average of Correct Responses for Kinaesthesia, from Initial to Follow-Up Examination – Implant-Site and Control-Site for All Subjects

	Kinaesthesia							
	BI		AC		3 months		6 months	
	Implant	Control	Implant	Control	Implant	Control	Implant	Control
Up								
Mean (%)	76.4	88.6	76.4	90.0	80.7	91.4	85.0	90.0
SD	9.6	11.9	7.0	9.4	9.6	9.7	5.6	9.4
Right								
Mean (%)	77.9	82.8	73.6	85.8	80.0	87.8	82.7	89.3
SD	11.5	8.8	8.4	14.3	11.7	13.0	7.5	7.9
Down								
Mean (%)	79.3	90.0	78.6	87.8	84.3	89.3	83.6	88.6
SD	7.3	8.2	8.7	8.4	9.1	7.9	9.6	10.9
Left								
Mean (%)	74.3	82.2	75.0	85.0	80.1	85.1	82.9	87.1
SD	7.5	12.7	6.3	11.8	13.1	12.3	8.8	11.3

$p \leq .005$ compared with natural dentition.
AC = at the abutment connection; BI = before implant placement; SD = standard deviation; 3 months = 3 months after the prosthetic rehabilitation; 6 months = 6 months after the prosthetic rehabilitation.

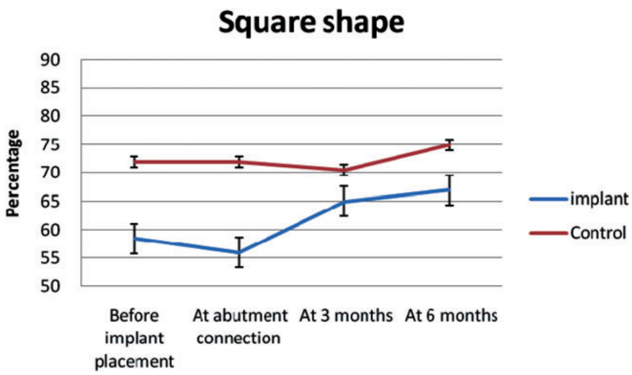

Figure 1 Graph showing the average of correct responses for the square shape from initial to follow-up examination for all subjects.

comparison with the dentate control site. The average of correct responses decreased at the time of abutment connection (after the implant uncovering surgery). Then it started to increase to reach a level near but still lower than the control site after 3–6 months of function. These results are statistically significant for both tests: G (one-way repeated measure ANOVA followed by Bonferroni posttest comparisons, $p < .05$) and DCK (one-way repeated measure ANOVA followed by Bonferroni posttest comparisons, $p < .05$).

The recognition of the circle shape was more significant than the two other shapes at the four test periods (one-way repeated measure ANOVA followed by Bonferroni posttest comparisons, $p < .05$). However, no difference in perception for different directions was found (one-way repeated measure ANOVA, $p > .05$).

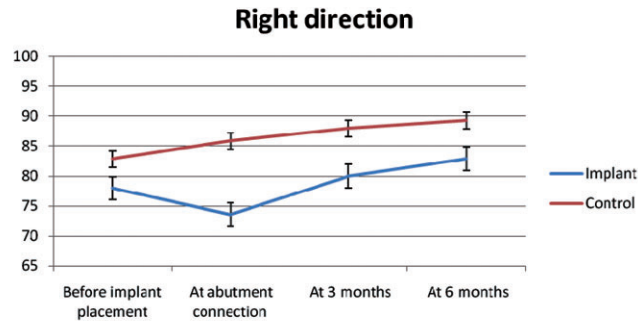

Figure 4 Graph showing the average of correct responses for the right direction from initial to follow-up examination for all subjects.

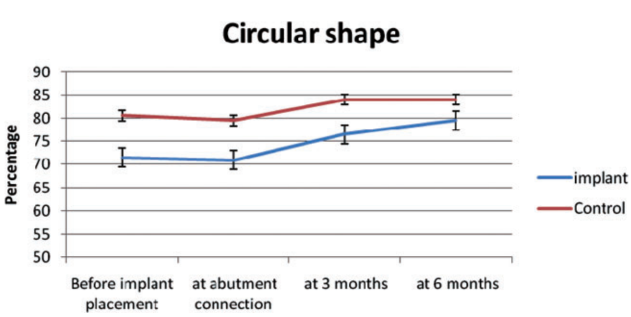

Figure 2 Graph showing the average of correct responses for the circular shape from initial to follow-up examination for all subjects.

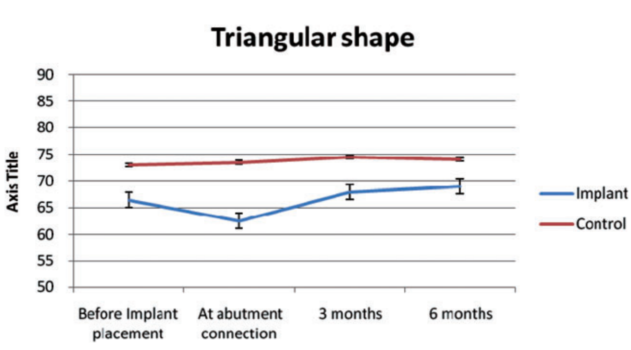

Figure 3 Graph showing the average of correct responses for the triangular shape from initial to follow-up examination for all subjects.

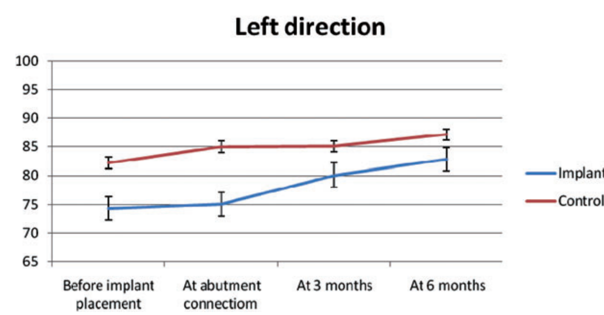

Figure 5 Graph showing the average of correct responses for the left direction from initial to follow-up examination for all subjects.

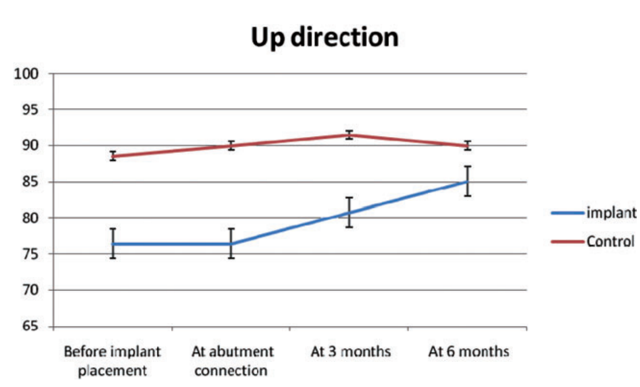

Figure 6 Graph showing the average of correct responses for the up direction from initial to follow-up examination for all subjects.

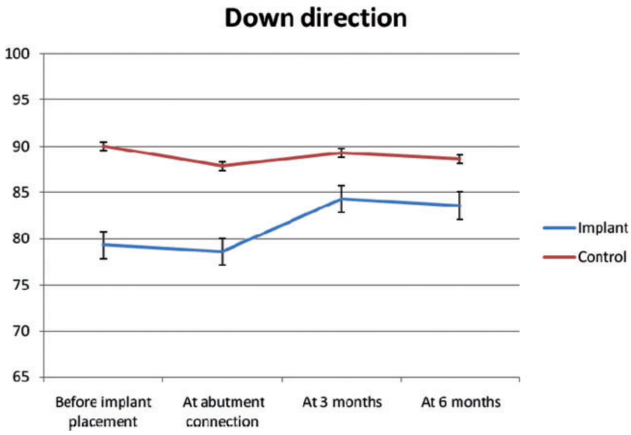

Figure 7 Graph showing the average of correct responses for the down direction from initial to follow-up examination for all subjects.

DISCUSSION

After tooth loss, the alveolar socket fills up with bone and the periodontal ligament innervation degenerates partially[19] or starts innervating other structures like overlying scarless healed tissues.[20,21]

In the present experiment for the control sites, the percentage of correct responses was not significantly different over time at the four test periods, and achieved systematically a higher level of correct responses than the edentulous site even before the implant placement for both tests. This seems to be in accordance with previous findings on the skin, that the soft tissue sensitivity decreases for light-touch sensation, two-point discrimination, and vibrotactile function following amputation.[22]

This reinnervation along with the receptor density was less dense toward the superficial mucosa in comparison with the innervation of the buccal and lingual vestibules.[23] In fully edentulous patients, the mucosa-borne denture can only partly restore sensory function.[24]

Yet, the number of Merkel cells in the gingiva was found to be significantly higher in edentulous areas when compared with dentate ones.[25] This increase in the Merkel cell population might compensate for the loss of the teeth.

The directional sensitivity is most responsive for small distances than the two-point discrimination and point localization[26,27] because the moving stimulus causes a continuous afferent flow during the period of motion and may be more efficient. The friction between the moving stimulus and the underlying skin is critical for the determination of the direction of motion.[28,29] It induces a chronological activation of adjacent receptors and a friction-induced activation of stretch-sensitive receptors.[16,17,30,31] These "friction" receptors are activated to the relative lateral tensions of the skin. The moving object seems to reorient, elongate, or shorten the friction receptors. The transmission of lateral forces may depend on the skin's elasticity and resistance. These factors are determined by the mechanical properties of the skin, and consequently vary with the skin's thickness as well as the subject's age and sex.[16,32] The thickness of the healed mucosa is not related to the original gingival thickness[33,34] and could affect its mechanical properties, such as elasticity.[35] This remains undocumented so far in literature. Olausson and Norrssel[16] were able to demonstrate that the mechanical properties of the skin are critical for the friction-induced activation of stretch-sensitive receptors. This is in agreement with our findings which suggest that the scarless healed oral tissues may lower the sensitivity to the frictional stimulus.

At the implant site, a significant difference was found for G and DCK over time, for the four test period. A reduced level of perception was already revealed before implant installation in comparison with the dentate control site revealing the impact of the tooth extraction. After 3 to 6 months of implant function, tactile responses increased and approached but were still significantly less than the control.

At the abutment connection, after the implant uncovering surgery, the tactile response decreased. This could be easily explained by the trauma caused by two surgical interventions (flap surgery for implant placement and implant uncovering surgery), with periosteal elevation. Considering the rich periosteal innervation with Pacinian corpuscules and free nerve endings,[36] which are both sensitive to stretching, the present observation of reduced sensory function might be partly attributed to a disrupted or damaged periosteal innervation.

It is interesting to note that animal studies have demonstrated that regenerated nerve fibers in the peri-implant gingiva show the same neural characteristics as those in the normal, dental junctional epithelium.[37,38] Regenerative nerve fibers invade the superficial layer of the peri-implant epithelium. These nerve fibers contain substance P and possess free nerve endings. They may respond to pain, touch, and pressure.[15,39] Unfortunately, none of the reports was able to characterize the function of the detected fibers. Merkel cells are important in tactile function and they are normally found in both the oral mucosa and in the gingiva. They seem to be absent in the hamster's peri-implant epithelium mucosa[15] but were found in the peri-implant mucosa in humans.[37] However, their presence in the periosteum has not been described in the literature.[36] Histological findings report an increased innervation in the peri-implant epithelium after implant placement.[15]

When applying forces to osseointegrated implants in the jaw bone, the pressure build-up in the bone is sometimes large enough to allow deformation of the bone and its surrounding periosteum.[40] It is already established that Pacinian corpuscles have an exquisite sensitivity to brisk mechanical events and could respond to such stimuli transmitted through the bone to a remote receptor.[36]

Consequently, the presence of a functional implant may induce the improvement of the ability to detect a moving stimulus on the peri-implant soft tissues, shown in our findings.

Moreover, the presence of the implant restores the orofacial functions and stimulates the surrounding tissues which may lead to changes in the cortical reorganization. After amputation of a limb, the regions of the cortex deprived of a target acquire new targets. It has been demonstrated that several changes take place at the cortical or subcortical level.[19] But even if a reorganization of these regions occurs very fast (within hours),[41,42] what happens in the intrinsic connections of the cortical areas is still unrevealed.[43,44] In humans, the possible cortical adaptive processes (cortical plasticity) that can be associated with the loss of teeth, or with their replacement by means of oral implants, has not been explored extensively.[45,46] This hypothesis may also explain the improvement of the ability to detect a moving stimulus on the peri-implant soft tissues.

CONCLUSIONS

Postsurgical sensory changes may be bothersome to patients, even though the main goal of the surgery has been completely accomplished. To assess this observation, one cannot simply rely on the patient's subjective report. The directional cutaneous/mucosal kinaesthesia and the G are simple but reliable sensory tests that can be easily applied in the oral region and thus allow to evaluate sensorimotor function during oral rehabilitation by means of implants. Both tests correlate the physiologic function of the receptors to the subjective response of the patient.[47]

The present study reveals that tooth loss decreases the sensory function of the oral mucosa, while this function seems partially restored after implant installation. Whether this peri-implant soft tissue innervation may contribute to the osseoperception phenomenon remains to be unraveled. Brånemark defined osseoperception as "the perception of external stimuli transmitted via the implant through the bone by activation of receptors located in the peri-implant environment, the periostium, the skin, the muscles and /or the joints."[48]

Because this study confirmed that mucoperiosteal-flap procedures reduce the directional sensitivity, further investigation may demonstrate the merit of the flapless approach during implant surgery.

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