Abstract: We examined the short-term surgical effects of orthognathic surgery on somatosensory function. Observations were made over a short period: 3 months postoperatively. In total, 14 patients and 32 healthy controls participated. Among the 14 patients, one underwent bilateral sagittal split osteotomy alone and 13 underwent bilateral sagittal split osteotomy in combination with a Le Fort I osteotomy. A modified quantitative sensory testing (QST) protocol (the German Research Network on Neuropathic Pain, DFNS) was used to evaluate clinically the skin of the chin for sensory disturbances before surgery and at 1 week, 1 month, and 3 months postoperatively. A visual analog scale and the Japanese Version of the McGill Pain Questionnaire were completed by all participants. Both sides of the mandible showed postoperative functional loss in cold detection threshold, warmth detection threshold, thermal sensory limen, and mechanical detection threshold. All function gradually recovered to baseline conditions at 3 months postoperatively. Cold detection threshold, warmth detection threshold, thermal sensory limen, and mechanical detection threshold appeared to be useful QST parameters for evaluating neurosensory disturbances during the early postoperative period. (J Oral Sci 58, 177-184, 2016)

Keywords: orthognathic surgery; bilateral sagittal split ramus osteotomy; quantitative sensory testing; the German Research Network on Neuropathic Pain.

Introduction

Neurosensory deficits are one of the most common complications associated with orthognathic surgery, and the incidence of inferior alveolar nerve (IAN) injury resulting in perioperative demyelination or axonal damage is close to 100% (1). In most patients with demyelinating IAN lesions, sensory recovery occurs within 3 months after surgery (2,3), although a small proportion develop post-traumatic neuropathic pain (3). Severity of nerve dysfunction at 1 month after surgery is an important prognostic factor for persistence of subjective symptoms and development of neuropathic pain (1). Previous studies of neurosensory deficits used several neurosensory testing methods, including questionnaires assessing subjective symptoms (4) and qualitative and quantitative sensory tests that involved application of thermal stimuli and static and dynamic mechanical stimuli (5-8). Various methods have been developed to detect sensory distur-
The German Research Network on Neuropathic Pain (DFNS) developed a standardized, comprehensive quantitative sensory testing (QST) battery with demonstrated reliability for the orofacial region (10,11), although the instrument was originally designed for testing the extremities, trunk, and face (12). Recently, Luo et al. conducted a longitudinal study of the effects of orthognathic surgery on trigeminal somatosensory function (13). The ultimate goal in evaluating QST data in the early postoperative recovery is to determine the likelihood of persistent pain and discomfort. Achieving this goal requires extensive longitudinal observations that connect initial signs/symptoms with the natural course of the condition or treatment outcome. When studying the effectiveness of certain treatment methods, or the natural course of a disease, patients with equivalent baseline severity of nerve damage should be enrolled. Although our clinical experience has yielded information regarding the best time point to determine the severity of nerve damage, such as 1 week or 1 month postoperatively, we lack sufficient data on somatosensory changes during the early postoperative period. This preliminary study aimed to clarify the above-mentioned ultimate goals.

Little is known about somatosensory alterations in trigeminal innervation, especially during the early period after orthognathic surgery. Thus, the present quantitative study used the DFNS protocol to examine patients who underwent scheduled orthognathic surgery, to identify possible somatosensory changes in the IAN region and patterns of early postoperative recovery.

Materials and Methods

Participants
This study was approved by the Ethical Committee of Nihon University School of Dentistry (EP2012-16) and was performed in accordance with the Helsinki Declaration II. Written informed consent was obtained from all participants.

The patient group included 14 patients (7 men, 7 women; mean age, 24.2 ± 2.1 years) who underwent orthognathic surgery at the Department of Oral and Maxillofacial Surgery, Nihon University Dental Hospital, Japan. We recruited 30 patients, 14 of whom completed the study. Of these patients, one underwent bilateral sagittal split osteotomy (BSSO) to the mandibular rami with no other surgery, and 13 underwent BSSO in combination with a Le Fort I osteotomy. We also included 32 healthy subjects (16 men, 16 women; mean age, 24.7 ± 0.5 years) without orthodontic braces as a control group.

All participants in this study were naive to sensory testing. We excluded patients and controls who had medical conditions or histories that were likely to alter recovery patterns, as well as those with contraindicated systemic conditions such as preexisting orofacial sensory impairment and diabetes, those with a history of facial trauma or facial surgery, and those with significant psychiatric disorders. Somatosensory function in the patient group was evaluated preoperatively (Pre) and at 1 week (PO1W), 1 month (PO1M), and 3 months (PO3M), postoperatively.

Assessment of the psychophysical quality of pain

All participants were evaluated at the specified time points by using a Japanese Version of the McGill Pain Questionnaire (JMPQ), which was translated and back-translated between English and Japanese. The JMPQ consists of 78 questions with 20 subgroups that can be classified into four categories (sensory, affective, evaluative, and miscellaneous). Patients were asked to choose the best response from each subgroup if there were any words that reflected his/her “pain” sensation (14). To evaluate the degree of pain, we administered a 100-mm visual analogue scale (VAS) that ranged from 0 (no pain) to 100 (worst pain possible).

Quantitative sensory testing protocol

All participants were examined in a quiet temperature-controlled room (20-23°C). The examiner was not blinded to the status (pre, post, healthy) of the subjects. Data on self-reported pain and somatosensory disturbances were collected, and a QST battery was performed. A standard QST battery was used in this study (12) and consisted of six tests measuring 11 different thermal and mechanical parameters: cold detection threshold (CDT), warmth detection threshold (WDT), thermal sensory limen (TSL), paradoxical heat sensation (PHS), cold pain threshold (CPT), heat pain threshold (HPT), mechanical detection threshold (MDT), mechanical pain threshold (MPT), vibration detection threshold (VDT), pressure pain threshold (PPT), and wind-up ratio (WUR).

In the present study, the skin covering the central portion of the left and right mental foramina was investigated in all participants. For a detailed discussion, refer to the comprehensive QST protocol of the DFNS (12). Thermal thresholds were determined using a TSA 2001-II (MEDOC) thermal sensory testing device with a thermode composed of Peltier elements (contact area
Table 1 Mean values (±SEM) for raw and log-transformed data

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Pre</th>
<th>PO1W</th>
<th>PO1M</th>
<th>PO3M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
</tr>
<tr>
<td>CDT (ºC)</td>
<td>-3.3 ± 0.4</td>
<td>-3.0 ± 0.3</td>
<td>-2.7 ± 0.4</td>
<td>-4.0 ± 0.5</td>
<td>-11.1 ± 2.5**</td>
</tr>
<tr>
<td>WDT (ºC)</td>
<td>3.7 ± 0.4</td>
<td>4.1 ± 0.3</td>
<td>7.6 ± 1.1</td>
<td>7.2 ± 0.8</td>
<td>20.5 ± 8.1**</td>
</tr>
<tr>
<td>TSL (ºC)</td>
<td>2.5 ± 0.2</td>
<td>2.8 ± 0.2</td>
<td>5.1 ± 0.7</td>
<td>6.0 ± 1.1</td>
<td>12.1 ± 2.2**</td>
</tr>
<tr>
<td>PHS (s/3)</td>
<td>0.03 ± 0.03</td>
<td>0.03 ± 0.03</td>
<td>0.0</td>
<td>0.007 ± 0.07</td>
<td>0.14 ± 0.09</td>
</tr>
<tr>
<td>CPT (ºC)</td>
<td>17.9 ± 1.4</td>
<td>19.8 ± 1.4</td>
<td>14.4 ± 2.4</td>
<td>16.0 ± 2.3</td>
<td>11.5 ± 2.0**</td>
</tr>
<tr>
<td>HPT (ºC)</td>
<td>41.4 ± 0.6</td>
<td>41.1 ± 0.6</td>
<td>44.6 ± 1.2</td>
<td>43.0 ± 1.4</td>
<td>47.3 ± 0.8**</td>
</tr>
<tr>
<td>MDT (log 10 F mg)</td>
<td>0.4 ± 0.1</td>
<td>0.3 ± 0.1</td>
<td>0.7 ± 0.1</td>
<td>0.6 ± 0.04</td>
<td>5.9 ± 0.4**</td>
</tr>
<tr>
<td>MPT (log 10 F mg)</td>
<td>1.2 ± 0.2</td>
<td>2.1 ± 0.2</td>
<td>2.2 ± 0.1</td>
<td>1.9 ± 0.03</td>
<td>3.8 ± 0.2**</td>
</tr>
<tr>
<td>VDT (8/8 scale)</td>
<td>6.5 ± 0.1</td>
<td>6.7 ± 0.1</td>
<td>6.7 ± 0.2</td>
<td>6.6 ± 0.2</td>
<td>6.0 ± 0.4</td>
</tr>
<tr>
<td>PPT (kg)</td>
<td>1.2 ± 0.1</td>
<td>1.1 ± 0.1</td>
<td>1.3 ± 0.2</td>
<td>1.2 ± 0.1</td>
<td>1.1 ± 0.2</td>
</tr>
<tr>
<td>WUR (0-100 NRS ratio)</td>
<td>2.9 ± 0.3</td>
<td>3.8 ± 0.3</td>
<td>3.9 ± 0.7</td>
<td>3.7 ± 0.7</td>
<td>3.2 ± 0.3</td>
</tr>
</tbody>
</table>

*Significant difference vs. control (*P < 0.05, **P < 0.01, t-test). Bold values indicate P < 0.05. CDT or WDT indicates thermal change from baseline. M is calculated as the logarithm of 10 times the force (in mg) to bow the filament for MDT or MPT, i.e., M = log (10 \cdot F mg).

Pre, preoperatively; PO1W, 1 week; PO1M, 1 month; PO3M, 3 months postoperatively; CDT, cold detection threshold; WDT, warmth detection threshold; TSL, thermal sensory limen; PHS, paradoxical heat sensation; CPT, cold pain threshold; HPT, heat pain threshold; MDT, mechanical detection threshold; MPT, mechanical pain threshold; VDT, vibration detection threshold; PPT, pressure pain threshold; WUR, wind-up ratio; R, right; L, left; NRS, Numerical rating scale.

Results

QST data

Table 1 shows the absolute data. The QST yielded CDT results showing significantly lower values at PO1W (R+L) (P = 0.021 and P = 0.043, respectively) and PO1M (R) (P = 0.041; Fig. 1) postoperatively, as compared with the preoperative control. The WDT for the right side was significantly higher at PO1W than that of the respective preoperative control value (P = 0.041); however, there was no significant change on the left side after surgery (Fig. 1). The TSL for the right side was significantly larger at PO1W than before surgery (P = 0.041), whereas the TSL on the left side was not significantly different from the preoperative control at the same time point (Fig. 1). The HPT for the left side was significantly higher at PO1W than the respective value for the preoperative control (P < 0.05); however, there was no significant

16 × 16 mm; 32°C baseline temperature; ramped stimuli with 1°C/s; method of limits. MDT was assessed using a standardized set of modified von Frey filaments (Optihair-2Set; Marstock Nervtest, Schriesheim, Germany) exerting forces between 0.25 and 512 mN. MPT was assessed using custom-made, weighted, pinprick stimuli with fixed stimulus intensities (8, 16, 32, 64, 128, 256, and 512 mN; diameter of flat contact area, 0.2 mm; PinPrick; MRC Systems GmbH, Heidelberg, Germany). VDT was assessed with a Rydel-Seiffer tuning fork (64 Hz, 8/8 scale; example available at Arno Barthelmes & Co. GmbH, Tuttingen, Germany) applied with suprathreshold vibration intensity. PPT was assessed using a pressure gauge device (FDN200; Wagner Instruments, Riverside, CT, USA) with a probe area of 1 cm².

Data processing

Ten-fold original threshold data for MDT and MPT were first log-transformed. QST findings were analyzed according to time point (Pre, PO1W, PO1M, and PO3M) by one-way analysis of variance (ANOVA). Post hoc comparisons were estimated using Dunnett’s post hoc test with correction for multiple comparisons. All data in the text and tables are presented as mean ± SEM. To compare the QST profiles independent of the units of the parameters, a Z-score was calculated from the baseline data of healthy controls, and pre- and postoperative data of patients who underwent surgery, at every evaluation time point and for every QST test. The detailed method of Z-score calculation has been described elsewhere (10,12). Briefly, Z-score = (single patient X – healthy control mean)/healthy control SD (12). A Z-score greater than ±1.96 (i.e., outside the 95% confidence interval [CI]) was considered an abnormal value. A positive Z-score indicated a sensory gain, and a negative Z-score indicated a sensory loss. We further investigated whether early evaluation of objective signs (QST) helped predict future subjective symptoms (JMPQ), using linear regression analysis and correlation coefficients. SPSS software (ver. 20.0 for Windows; IBM, Tokyo, Japan) was used for these analyses, and a P-value of <0.05 was considered to indicate statistical significance.
Z-score

With the exception of the CDT, WDT, TSL, and MDT, responses to the sensitivity tests were within the 95% CI of the baseline reference database (Z-scores were within ±1.96; Fig. 2). Both sides of the inferior alveolar nerve showed postoperative loss of somatosensory function, as detected by CDT, WDT, TSL, and MDT. These tests revealed that hypo-sensation was most pronounced 1 week after surgery and remained outside the 95% CI throughout the observation period, although the data showed a time-dependent, gradual recovery (Fig. 2). On the right side, a sensory gain for WUR was detected at PO1M and PO3M (14%, n = 2; 14%, n = 2, respectively). In 7% (n = 1) of patients, a sensory gain for MDT was detected at POM1. A sensory gain for VDT was detected at PO1W and PO1M (14%, n = 2; 14%, n = 2, respectively). On the left side, a sensory gain for WUR was detected at PO1W and PO1M (14%, n = 2; 14%, n = 2, respectively). A sensory gain for VDT was detected at PO1W, PO1M, and PO3M (7%, n = 1; 7%, n = 1; and 14%, n = 2, respectively).
Table 2 shows JMPQ scores at PO1W, PO1M, and PO3M. All patients chose at least one term reflecting pain or discomfort at every observation point. “Dullness” was one of the most frequently chosen subcategories throughout the observation period. The average VAS pain scores at PO1W, 1POM, and 3POM were 10.7 ± 0.6 mm, 6.8 ± 0.3 mm, and 9.1 ± 0.4 mm, respectively. However, among the 14 patients, 10 marked zero on the pain VAS at PO3M, suggesting that the terms they chose from the vocabulary reflected discomfort but not necessarily pain.

To investigate the relationship between subjective symptoms and objective findings linear regression analyses were performed, and correlation coefficients were calculated with a combination of JMPQ scores at the three observation time points and changes in QST scores at every time point relative to the preoperative controls. On the left side, linear regression analysis revealed that MDT at PO1W significantly predicted JMPQ scores at PO1M (P < 0.05) and PO3M (P < 0.001). MDT at PO1W most significantly predicted “evaluative” complaints at PO3M (P < 0.001). Furthermore, there were strong correlations between mechanosensory QST data (MDT and MPT) at early time points and various JMPQ scores at later time points (PO1W vs. PO1M and PO3M; PO1M vs. PO3M; Table 3).

**Discussion**

In the current study, as expected, alteration of nerve function was greatest immediately after surgery (PO1W). In contrast, HPT, CPT, MPT, and PPT showed less severe sensory impairment as compared with mechanical detection thresholds. These findings suggest that surgery had a greater adverse effect on large fibers than on smaller fibers. The main type of injury might be nerve compression (15), which causes more damage to A-beta fibers than to A-delta or C fibers (3). These results are consistent with the findings of Park et al. (16). Recently, Luo et
al. (13) reported that elevated VDT might be a potential indicator of the effect of postoperative pain on trigeminal somatosensory functions, which suggests that damage to A-beta fibers is also inevitable. In the present study, bilateral CPT, HPT, MPT, WUR, and PPT Z-scores in the early postoperative stage were similar to those reported by Luo et al, whereas bilateral CDT, WDT, TSL, and MDT Z-scores seemed to be more sensitive than VDT in detecting all QST parameters in patients with nerve injury during the early period after orthognathic surgery. The discrepancy between past and present findings may be attributable to the testing method for VDT. We used a tuning fork, in accordance with the original DFNS protocol for VDT.

CDT, WDT, TSL, and MDT reflected recovery of somatosensory nervous function, although VAS may not have purely reflected functional recovery of the PNS and CNS. Pain is influenced by emotion. Persistent somatosensory disturbance may have made patients uneasy and depressed.

Linear regression analyses revealed that MDT at PO1W was useful in predicting subjective symptoms (JMPQ) at PO3M, and that sensory loss was strong correlated with mechanical stimuli (MPT and MDT) at PO1W and PO1M and with patient reports of pain sensation (JMPQ scores) at PO3M. JMPQ and QST probably assess different functions of the peripheral nervous system (PNS) and central nervous system (CNS). QST mainly reflects the function of the PNS and, to some extent, of the CNS; brain areas associated with sensory detection and cognition may be involved (17,18). In contrast, MPQ reflects psychophysical function (19), including cognition, affect, and memory, which is not evaluated by the QST. The reason that sensory loss relative to noxious and innocuous mechanical stimuli (MPT and MDT) at PO1W and PO1M was strongly associated with patient pain sensation (JMPQ) at PO3M is not known, although it is interesting that the correlation between MDT at PO1W and JMPQ at PO3M was stronger than that between MDT at PO1W and JMPQ at PO1M. This finding suggests a temporal effect of prolonged sensory deficit, making patient discomfort more severe, even though QST tests showed severe impairment in function during the early postoperative period (PO1W and PO1M) and significant recovery at PO3M. Future studies should attempt to clarify the relationship between subjective symptoms and objective signs.

Although the DFNS is reported to have good test–retest and interobserver reliability (20), the protocol for a complete battery of tests is time-consuming. We needed 1 h, on average, of examination time to obtain QST data for both sides. We were required to modify the QST battery in this study to comprise six tests, and our data suggest that CDT, WDT, TSL, and MDT are useful parameters for examining neurosensory damage in the early period after orthognathic surgery, which could shorten the time required for the tests and decrease the burden on patients.

This study has some limitations. First, to evaluate IAN injury after orthognathic surgery, we selected the most standardized and widely used clinical testing procedure for somatosensory function, which can easily be adapted to routine chair-side postoperative follow-up (21). However, many patients requested that we discontinue the SR-function measurement protocol, resulting in missing MPA and DMA data. The DMA test is believed to provide extremely important information on change in pain threshold and extension of receptive fields, which

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**Table 3** Correlations between mechanosensory QSTs (MDT and MPT) at PO1W and PO1M and JMPQ scores at PO1M and PO3M

<table>
<thead>
<tr>
<th>QST</th>
<th>JMPQ PO1M</th>
<th>PO1M</th>
<th>PO3M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensory</td>
<td>Affective</td>
<td>Evaluative</td>
</tr>
<tr>
<td>MDT</td>
<td>0.6684**</td>
<td>0.4129</td>
<td>−0.1147</td>
</tr>
<tr>
<td>MPT</td>
<td>0.6318*</td>
<td>0.1142</td>
<td>−0.1673</td>
</tr>
<tr>
<td>MDT</td>
<td>0.6944**</td>
<td>0.4277</td>
<td>−0.1267</td>
</tr>
<tr>
<td>MPT</td>
<td>0.6375*</td>
<td>0.1716</td>
<td>−0.1701</td>
</tr>
</tbody>
</table>

*P < 0.05, **P < 0.01. Bold values indicate P < 0.05.

MDT, mechanical detection threshold; MPT, mechanical pain threshold.
could help explain central sensitization and altered pain processing in the CNS (22). The lack of data from these important tests limited our analysis of detailed sensory changes and subsequent alterations in the CNS during the early stages after trigeminal nerve injury. The MPT results indicate that the SR-function protocol should be modified to exclude strong pinprick stimulation of the trigeminal territory during MPS testing. Second, the WDT or the TSL on the right side and the HPT on the left side were significantly higher at PO1W as compared with preoperative control values. This left-right difference in neurosensory disturbance might depend on the magnitude of mandibular advancement or setback. Future studies are needed in order to evaluate carefully the correlation between neurosensory disturbance and the magnitude of mandibular movements. Finally, the study sample was relatively small (n = 14); therefore, the statistical power may have been insufficient to allow for detection of differences in some of the analyses. Further studies with larger samples and a standardized QST protocol could provide more definitive findings regarding recovery patterns after orthognathic surgery.

The current study showed that some QST data associated with A-beta fiber function were more sensitive in examining objective sensory deficits. QST test data for the early period after surgery, which reflect sensory loss related to noxious and innocuous mechanical stimuli, were strongly correlated with patient pain and discomfort in the later period. Quantitative mechanosensory tests at 1 week postoperatively helped predict patient pain at 3 months postoperatively. Future longitudinal studies of the relationship of objective sensory impairment with patient pain and discomfort should have a longer observation period.

Acknowledgments

Conflict of interest
The authors declare no conflict of interest.

References


