Objective. The objective of this study was to compare postsurgical neurosensory alteration and recovery patterns among different nerve fiber types and orthognathic surgeries by measuring current perception thresholds (CPT).

Study design. CPTs of 186 patients who underwent various orthognathic surgeries (Le Fort I or II, bilateral sagittal split [BSSRO] or intraoral vertico-sagittal [IVSRO] ramus osteotomy with or without genioplasty) were measured at 2000, 250, and 5 Hz, assessing 3 different nerve fiber types before surgery and at 3, 6, and 12 months after surgery.

Results. CPTs were highest at 3 months postsurgery and gradually returned to presurgical levels until 12 months postsurgery in most cases. CPT at 2000 Hz showed the largest amount of increase. Le Fort I and IVSRO caused less neurosensory alteration compared with Le Fort II and BSSRO, respectively.

Conclusion. Our data provide nerve recovery patterns following various orthognathic surgeries that may be applied to evaluating the patient’s severity and recovery of nerve damage. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:24-33)

Surgical repositioning of the skeletal components of the facial structure can be used to improve function and aesthetics. An extensive number of osteotomies are performed within the maxillofacial region to fulfill these purposes. The most commonly administered of these are the Le Fort osteotomy of the maxilla, the bilateral sagittal split ramus osteotomy (BSSRO) and intraoral vertico-sagittal ramus osteotomy (IVSRO) of the mandibular ramus, and genioplasty of the chin area.¹ There has been a proliferation of such treatments owing to the increasing desire to improve appearance and resolve functional deficits, such as difficulties in mastication and speech. Various benefits have been reported, including improved masticatory function,²,³ reduced temporomandibular joint pain,⁴ and improved facial aesthetics.⁵,⁶ However, as the number of surgical performances increases, numerous complications such as vascular problems,⁷,⁸ temporomandibular joint problems,⁹,¹⁰ nerve injuries,¹¹,¹² and infections¹³ have also been reported more frequently.

Neurosensory deficits have been reported to be the most common problem following orthognathic surgery.¹⁵ However, data on the incidence and recovery of sensory disturbances of the inferior alveolar nerve (IAN) after BSSRO, and of the infraorbital nerve (ION) after Le Fort I osteotomy show wide variations.¹¹,¹²,¹⁶-²⁴ Most of these results are based on conventional clinical neurologic tests such as 2-point discrimination, static light touch, brush directional stroke, pin-prick, and dental vitality tests; just a few involve studies that use objective methods including electrical sensimetry, vibratory threshold measurements, blink reflex, and trigeminal evoked potential recording for validating sensory disturbances. Conventional mech-
anoceptive tests based on tactile responses are subjective and ambiguous in character, rendering objective evaluation and quantification of the severity of sensory disturbance and its recovery difficult.\textsuperscript{25}

Among the quantitative sensory testing methods, measurement of the current perception threshold (CPT) using a Neurometer (Neurotron Inc., Baltimore, MD) has been successfully applied to objectively quantifying peripheral nerve function in many clinical studies.\textsuperscript{26-30} The Neurometer is an electrodiagnostic device that allows selective stimulation of nerve fibers with different diameters that have distinctive depolarization times that depend on the frequency of sine waves caused by electrical stimulation. The CPT is quantified at each frequency by stimulating \(\alpha\beta\) fibers at 2000 Hz, \(A\delta\) fibers at 250 Hz, and \(C\) fibers at 5 Hz with an output intensity range of 0.01 to 9.99 mA.\textsuperscript{31} \(A\beta\) fibers are large myelinated fibers responsible for vibration and pressure. \(A\delta\) fibers are small myelinated fibers responsible for tactile sensation and sharp pain. \(C\) fibers are unmyelinated fibers responsible for sensing temperature and dull pain.\textsuperscript{32} The Neurometer has proven to be more accurate than nerve conduction tests in determining the severity of diabetic sensory neuropathy.\textsuperscript{33}

In spite of the variety of surgical methods and the importance of neurosensory disturbance as a complication that lowers the patient’s satisfaction level for orthognathic surgery, few authors have differentiated and compared between distinct and/or combined osteotomies of the maxilla and mandible using an objective measuring device to evaluate neurosensory disturbances and only a few have recorded the course of recovery over time.\textsuperscript{20,22,34} Also, in contrast to the investigations of the IAN after BSSRO, the literature contains only a small number of studies concerning sensory disturbances affecting the ION after Le Fort I osteotomy.\textsuperscript{20,21,24,35,36} Furthermore, there are no studies specifically concerning neurosensory disturbances after IVSRO or Le Fort II osteotomy.

Therefore, in this study we evaluated the CPTs for 3 types of nerve fibers after different types of maxillary and mandibular osteotomies using the Neurometer to specify factors that should be considered for preoperative clarification and to define the prognosis of neurosensory disturbance and its recovery pattern following orthognathic surgery.

**METHODS**

**Subjects**

The clinical records of 186 patients (77 men and 109 women, mean age 30.0 ± 4.6 years, range 18 to 54 years) who underwent orthognathic surgery at Seoul National University Dental Hospital during a 10-year period between 2000 and 2009 were examined. The inclusion criteria of the subjects were those who had successfully completed a current perception threshold testing before the operation and at 3-, 6-, and 12-month follow-ups and who underwent Le Fort I or II procedures for maxillary osteotomy and BSSRO or IVSRO for mandibular ramus osteotomy. For the mandibular ramus osteotomy, the operations were performed with or without genioplasty. Patients who had conditions or histories with greater propensity to alter recovery patterns or contraindicated systemic conditions such as a preexisting orofacial sensory impairment, diabetes, a history of facial trauma or operation, or significant psychiatric disorders were excluded from the study group. All patients followed an ordinary recovery course after surgery and none showed severe postoperative complications such as persistent edema or infection. The study was approved by the Institutional Review Board of Seoul National University Dental Hospital.

The same surgeon, who is experienced in maxillary and mandibular osteotomies, performed all surgeries. The same basic operative technique was used in all cases, and all operations were done intraorally. Bimaxillary osteotomies (both maxillary and mandibular osteotomies) were performed on 118 patients and single-jaw osteotomies (only mandibular osteotomy) were performed on 68 patients. Table I shows the distribution of the different operations and gender of the patients.

BSSRO was performed according to the Obwegeser-Dal Pont modification of the original method of sagittal split osteotomy.\textsuperscript{37,38} IVSRO was performed by the method of Choong.\textsuperscript{39} To protect the IAN bundle proximal to the lingual from injury, the medial periosteal dissection was minimally performed in such a way that the bundle was not directly visualized. There was no direct IAN damage perioperatively. The total amount of setback did not exceed 10 mm in all cases. Le Fort I and Le Fort II osteotomies were performed by the intraoral methods modified by Choong.\textsuperscript{40,41} Mucoperiosteum was elevated, and conventional osteotomies were performed. The maxilla was down-fractured, mobilized, and segmented according to the orthodontic planning, and then placed accordingly. During the maxillary osteotomies, the ION was identified bilaterally at the foramen with minimal retraction before and during the osteotomy. Genioplasty was performed following the tongue-in-groove osteotomy method.\textsuperscript{37,42,43} Incision was made low to the vestibular sulcus with minimal submucosal dissection and nerve exposure. The incision was extended to both first premolar teeth, and the periosteum was dissected and the mental nerve was isolated and protected. Bone fixation was achieved with bone screws and titanium miniplates.
Current perception threshold measurements

The patients were seated comfortably in a quiet room to encourage the subject to focus on the stimuli. During the measurement, patients held a remote control device that they used during testing to stop the electrical stimulus. However, the main apparatus was kept behind the patient at all times. The procedure was explained to the patient before the test. The Neurometer (Neurotron Inc.) CPT electrodiagnostic testing device uses a standardized, automated procedure to generate objective, quantitative measures of the conduction and functional integrity of sensory nerve fibers. The unit emits nonaversive transcutaneous electrical stimuli through an 8-mm-diameter standard gold-plated paired electrode (Neurotron Inc.) coated with conductive gel that is held in place with nonconductive adhesive tape to quantify neuroselective CPT values. The Neurometer evaluates a patient’s sensory nerves by determining the lowest level of electrical stimulus that consistently evokes a painless sensation. Stimulation of a constant sinusoidal electrical current with 3 different frequencies (5, 250, 2000 Hz) were delivered to the test site. At each frequency, the current was slowly increased from 0.01 mA until the subject reported a sensation and pressed a button. The current was then terminated. A microprocessor-controlled forced choice methodology, which used 6 to 10 cycles of randomly selected real and false stimuli above and below the perception threshold level, was performed in a double-blind manner until the exact CPT value was determined within a 20-μA range.

The definition of a patient’s physiologic threshold level was the lowest stimulus that a patient was able to perceive 50% of the time.

CPT measurements were conducted on the IAN and ION area regardless of surgery, as some patients who did not receive any maxillary osteotomies were also included. For the evaluation of the IAN following mandibular osteotomies and genioplasty, the paired electrode was positioned on the chin area over the mental foramen with a 5-mm distance between the outer rims of each electrode (distance between the centers of each electrode was 1.7 cm). The electrodes were set at the intersection of a vertical line connecting the commisure of the lip to the inferior border of the mandible divided in half by a horizontal line. For the evaluation of the ION following maxillary osteotomies, the electrodes were positioned on the lateral side of the ala of the nose. Testing was conducted separately for each of the bilateral sites. Each test lasted approximately 10 minutes for all 3 frequencies at each side. The CPT of each patient was determined as the mean of the values obtained from both sides because of the high correlation between measures from the right and left sides of the face. The first measurements were performed 1 week before surgery, and 3 additional measurements were performed at 3, 6, and 12 months after surgery.

Statistical analysis

To evaluate the effect of maxillary orthognathic surgery on CPT values of the ION, repeated measures of analysis of variance (ANOVA) involving time (before surgery and 3 months, 6 months, and 12 months after surgery) as a within-subject factor, and type of maxillary osteotomy (no maxillary osteotomy, Le Fort I, Le Fort II) as a between-subjects factor were used with the dependent variables (CPT values of ION at 2000, 250, and 5 Hz). The time factor was treated as repeated measures.

To evaluate the effect of mandibular orthognathic surgery on CPT values of the IAN, repeated measures of analysis of covariance (ANCOVA) involving time (before surgery and 3 months, 6 months, and 12 months after surgery) as a within-subject factor, and type of maxillary osteotomy (no maxillary osteotomy, Le Fort I, Le Fort II) as a between-subjects factor were used with the dependent variables (CPT values of ION at 2000, 250, and 5 Hz). The time factor was treated as repeated measures.

Table 1. Patient distribution according to surgery method

<table>
<thead>
<tr>
<th>Operation</th>
<th>Total (n = 186)</th>
<th>Men (n = 77)</th>
<th>Women (n = 109)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary osteotomies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No maxillary osteotomy</td>
<td>62 (33.3%)</td>
<td>27 (35.1%)</td>
<td>35 (32.1%)</td>
</tr>
<tr>
<td>Le Fort I</td>
<td>106 (57.0%)</td>
<td>43 (55.8%)</td>
<td>63 (57.8%)</td>
</tr>
<tr>
<td>Le Fort II</td>
<td>18 (9.7%)</td>
<td>7 (9.1%)</td>
<td>11 (10.1%)</td>
</tr>
<tr>
<td>Mandibular osteotomies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No ramus osteotomy (GP only)</td>
<td>8 (4.3%)</td>
<td>2 (2.6%)</td>
<td>6 (5.5%)</td>
</tr>
<tr>
<td>BSSRO</td>
<td>90 (48.4%)</td>
<td>39 (50.6%)</td>
<td>51 (46.8%)</td>
</tr>
<tr>
<td>With GP</td>
<td>54</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Without GP</td>
<td>36</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>IVSRO</td>
<td>88 (47.3%)</td>
<td>36 (46.8%)</td>
<td>52 (47.7%)</td>
</tr>
<tr>
<td>With GP</td>
<td>35</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Without GP</td>
<td>53</td>
<td>20</td>
<td>33</td>
</tr>
</tbody>
</table>

GP, genioplasty; BSSRO, bilateral sagittal split ramus osteotomy; IVSRO, intraoral vertico-sagittal ramus osteotomy.
IAN at 2000, 250, and 5 Hz). All statistical analyses were performed with the SPSS 12.0 program (SPSS Inc., Chicago, IL, USA).

**RESULTS**

Among the 3 CPT measurements taken after surgery, the 3-month postsurgical follow-up showed the highest levels indicating a significant amount of sensory disturbance in most cases after orthognathic surgery. During the course of the 12-month investigation, a continuous decrease in the level of CPT was observed for most surgery cases and nerve fiber types after the 3-month postsurgical follow-up.

In the case of mandibular surgery, CPT level recovery took slightly longer than after maxillary surgery. Although an appreciable recovery was found following maxillary surgery after only 6 months, recovery after mandibular surgery took 6 to 12 months and sometimes did not return to presurgical levels at the 12-month postsurgical follow-up. The descriptive values and results are shown in Tables II and III and Figs. 1 and 2.

When we performed the ANOVA including gender and age groups as between-subjects factors, the main effects for gender and age groups were not statistically significant, and none of the interaction terms including gender and age groups reached statistical significance (data are not shown in the tables).

**CPT change and recovery patterns of the infraorbital nerve after maxillary osteotomies**

Le Fort II osteotomy caused a higher and steeper increase in CPT values at the 3-month postsurgical follow-up and the values remained higher at all follow-up sessions for all nerve fiber types compared with Le Fort I osteotomy.

**Table II.** Comparison of current perception threshold (mA × 100) of the infraorbital nerve before and after maxillary osteotomy

<table>
<thead>
<tr>
<th>Operation</th>
<th>CPT frequency (nerve fiber)</th>
<th>Presurgery</th>
<th>3 month</th>
<th>6 month</th>
<th>12 month</th>
</tr>
</thead>
<tbody>
<tr>
<td>No maxillary osteotomy</td>
<td>2000 Hz (Aβ)</td>
<td>157.76 ± 60.36</td>
<td>164.16 ± 97.18</td>
<td>150.01 ± 58.00</td>
<td>144.29 ± 47.64</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>50.77 ± 35.77</td>
<td>52.63 ± 57.51</td>
<td>50.51 ± 51.86</td>
<td>46.35 ± 40.20</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>27.61 ± 19.39</td>
<td>31.91 ± 35.00</td>
<td>29.30 ± 42.51</td>
<td>26.73 ± 24.22</td>
</tr>
<tr>
<td>Le Fort I</td>
<td>2000 Hz (Aβ)</td>
<td>156.83 ± 58.57</td>
<td>219.77 ± 109.39</td>
<td>176.06 ± 75.00</td>
<td>152.57 ± 51.61</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>51.14 ± 39.68</td>
<td>64.39 ± 51.27</td>
<td>53.06 ± 66.31</td>
<td>42.40 ± 29.67</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>27.88 ± 23.26</td>
<td>40.08 ± 40.89</td>
<td>30.86 ± 44.69</td>
<td>25.02 ± 23.37</td>
</tr>
<tr>
<td>Le Fort II</td>
<td>2000 Hz (Aβ)</td>
<td>161.06 ± 62.46</td>
<td>294.83 ± 141.62</td>
<td>223.97 ± 118.41</td>
<td>163.08 ± 59.95</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>48.83 ± 30.01</td>
<td>94.58 ± 55.76</td>
<td>76.89 ± 50.97</td>
<td>53.58 ± 35.22</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>26.33 ± 17.08</td>
<td>57.50 ± 42.82</td>
<td>44.86 ± 31.45</td>
<td>27.70 ± 22.89</td>
</tr>
</tbody>
</table>

**Table III.** Comparison of current perception threshold (mA × 100) of the inferior alveolar nerve before and after mandibular osteotomy

<table>
<thead>
<tr>
<th>Operation</th>
<th>CPT frequency (nerve fiber)</th>
<th>Presurgery</th>
<th>3 month</th>
<th>6 month</th>
<th>12 month</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ramus osteotomy (GP only)</td>
<td>2000 Hz (Aβ)</td>
<td>172.88 ± 60.88</td>
<td>192.75 ± 63.59</td>
<td>181.00 ± 75.12</td>
<td>175.25 ± 74.41</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>53.12 ± 19.55</td>
<td>57.75 ± 21.03</td>
<td>58.00 ± 25.18</td>
<td>53.63 ± 42.92</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>28.62 ± 8.83</td>
<td>33.12 ± 11.20</td>
<td>31.75 ± 15.91</td>
<td>31.12 ± 25.65</td>
</tr>
<tr>
<td>BSSRO with GP</td>
<td>2000 Hz (Aβ)</td>
<td>174.05 ± 76.51</td>
<td>419.69 ± 238.17</td>
<td>280.45 ± 127.98</td>
<td>234.81 ± 131.34</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>62.20 ± 64.75</td>
<td>196.01 ± 204.38</td>
<td>96.63 ± 80.36</td>
<td>77.73 ± 71.14</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>34.66 ± 36.30</td>
<td>141.80 ± 180.42</td>
<td>62.04 ± 61.00</td>
<td>54.05 ± 63.44</td>
</tr>
<tr>
<td>BSSRO without GP</td>
<td>2000 Hz (Aβ)</td>
<td>183.30 ± 96.89</td>
<td>355.89 ± 223.11</td>
<td>269.42 ± 164.05</td>
<td>220.83 ± 106.44</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>64.26 ± 66.96</td>
<td>148.98 ± 143.39</td>
<td>108.26 ± 116.99</td>
<td>73.40 ± 65.76</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>39.05 ± 39.74</td>
<td>102.51 ± 113.29</td>
<td>74.98 ± 97.51</td>
<td>44.68 ± 42.75</td>
</tr>
<tr>
<td>IVSRO with GP</td>
<td>2000 Hz (Aβ)</td>
<td>171.08 ± 68.77</td>
<td>269.20 ± 177.89</td>
<td>239.58 ± 134.21</td>
<td>181.03 ± 69.15</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>52.93 ± 37.67</td>
<td>80.28 ± 77.10</td>
<td>77.36 ± 88.56</td>
<td>50.69 ± 44.81</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>35.74 ± 70.57</td>
<td>54.23 ± 74.55</td>
<td>48.00 ± 70.57</td>
<td>36.52 ± 45.99</td>
</tr>
<tr>
<td>IVSRO without GP</td>
<td>2000 Hz (Aβ)</td>
<td>160.49 ± 80.42</td>
<td>231.68 ± 165.55</td>
<td>201.27 ± 112.24</td>
<td>185.79 ± 101.57</td>
</tr>
<tr>
<td></td>
<td>250 Hz (Aα)</td>
<td>49.19 ± 41.94</td>
<td>78.26 ± 90.41</td>
<td>66.03 ± 70.47</td>
<td>55.23 ± 60.27</td>
</tr>
<tr>
<td></td>
<td>5 Hz (C)</td>
<td>30.70 ± 32.37</td>
<td>52.52 ± 71.80</td>
<td>41.70 ± 57.81</td>
<td>31.90 ± 35.36</td>
</tr>
</tbody>
</table>

CPT, current perception thresholds; GP, genioplasty; BSSRO, bilateral sagittal split ramus osteotomy; IVSRO, intraoral vertico-sagittal ramus osteotomy.
In case of Le Fort I, the CPT values at 250 and 5 Hz (Aβ and C fiber) returned to a level comparable to that of patients who did not have maxillary surgery at the 6-month postsurgical follow-up. All the CPT values returned to presurgical levels at the 12-month postsurgical follow-up for both Le Fort I and Le Fort II osteotomies. The Aδ nerve fiber (CPT at 2000 Hz) showed the largest amount of increase in CPT value after all maxillary procedure types.

The repeated measures ANOVA results are given in Table IV. For CPT value at 2000 Hz, the main effects for time (P < .001) and type of osteotomy (P < .001) were significant. A 2-way ANOVA using time as a within-subject factor and type of osteotomy as a between-subjects factor gave a significant interaction (P < .001). These results signify that the CPT value for

Fig. 1. CPT changes and recovery patterns of the infraorbital nerve after orthognathic surgery according to the type of maxillary osteotomy. a, Aβ; b, Aδ; c, C fiber.

Fig. 2. CPT changes and recovery of the inferior alveolar nerve after orthognathic surgery according to the type of mandibular osteotomy. a, Aβ; b, Aδ; c, C fiber.
the Aβ nerve fiber changed differently according to each type of maxillary osteotomy procedure during the 12-month period.

For CPT values at 250 and 5 Hz, the main effect for time (P < .001) was significant, but interactions between time and type of osteotomy did not reach statistical significance.

**CPT change and recovery patterns of the inferior alveolar nerve after mandibular osteotomies**

BSSRO caused a larger increase in CPT values after surgery and the values remained higher compared with IVSRO at all follow-up sessions for all nerve fiber types. All CPT values recovered to the level close to that of before surgery at the 12-month postsurgical follow-up after IVSRO but the value did not return to presurgical level after BSSRO. The Aβ nerve fiber showed the largest amount of increase in CPT value after all mandibular ramus osteotomy types.

Genioplasty combined procedures caused the CPT value to increase more than after single procedures. The aggravating effect was more prominent after the BSSRO-genioplasty combined surgery. In case of IVSRO, genioplasty caused an insignificant increase of CPT value except for the Aβ nerve fiber.

All the CPT values remained at presurgical levels during the 12-month follow-up period for patients who underwent genioplasty only without mandibular ramus osteotomy.

The repeated measures of ANCOVA results are shown in Table V. For all CPT values at 2000, 250, and 5 Hz, the CPT values of the IAN territory showed a significant interaction between time and type of mandibular ramus osteotomy (P < .001). These results signify that the CPT value for all nerve fibers changed according to each type of mandibular ramus osteotomy procedure during the 12-month period. Interaction between time and genioplasty did not reach statistical significance for all CPT values.

**DISCUSSION**

Over a 12-month postsurgical period, this study aimed to evaluate the neurosensory alteration and spontaneous nerve recovery pattern of each nerve fiber type of the ION and IAN after maxillary and mandibular orthognathic surgeries using CPT measurements. A previous study has reported that disparity was observed between clinical neurosensory testing and CPT results in the evaluation of the IAN following injury.45 However, CPT measurements of patients in this study who had undergone mandibular orthognathic surgery yielded recovery curves with a shape similar to that of the recovery of subjective sensory disturbance following injury to a major sensory branch of the trigeminal nerve based on grating orientation measurements.46 Recovery of nerve damage was most marked following the first 3 months after surgery, which is in line with the results reported in previous prospective 1-year follow-up studies on IAN recovery after BSSRO.23,47,48 It is possible that CPT measurements conducted earlier than the 3-month postsurgical follow-up could have resulted in higher levels reflecting more severe sensory disturbance. Postoperative CPT measurements with a shorter interval between each testing should be considered for more detailed follow-up of the sensory disturbance recovery pattern in future studies. In the case of BSSRO, most nerve damage occurs during the subperiosteal retraction on the medial side of the mandibular ramus, mainly resulting in demyelinating lesions owing to compression.49 Demyelinating nerve lesions are generally known to recover during the first 4 months after injury.50 Especially, the CPT results indicated further nerve regeneration even after 6 months and continuing recovery up to the 1-year follow-up. This corresponds to findings from other studies reporting improvement of sensory alteration up to 1 year after BSSRO.11,19

### Table IV. Statistical results (P values) of repeated measures ANOVA for CPT changes of the infraorbital nerve after maxillary osteotomy

| Dependent variable (CPT) | Independent variables* |                           |                           |                           |
|--------------------------|------------------------|--------------------------|--------------------------|
|                          | Time | Surgery type | Time × Surgery type  |
| 2000 Hz (Aβ)             | 0.000 | 0.000      | 0.000                    |
| 250 Hz (Aβ)              | 0.001 | 0.055      | 0.243                    |
| 5 Hz (C)                 | 0.000 | 0.207      | 0.288                    |

ANOVA, analysis of variance; CPT, current perception thresholds.
*Time (before, 3 month, 6 month, 12 month), Surgery type (No maxillary osteotomy, Le Fort I, Le Fort II).

### Table V. Statistical results (P values) of repeated measures ANCOVA for CPT changes of the inferior alveolar nerve after mandibular osteotomy

| Dependent variable (CPT) | Independent variables* |                           |                           |                           |
|--------------------------|------------------------|--------------------------|--------------------------|
|                          | Time | Surgery type | Time × Surgery type | Time × Genioplasty |
| 2000 Hz (Aβ)             | 0.021 | 0.000      | 0.000                | 0.099                  |
| 250 Hz (Aβ)              | 0.107 | 0.000      | 0.000                | 0.265                  |
| 5 Hz (C)                 | 0.198 | 0.000      | 0.000                | 0.147                  |

ANCOVA, analysis of covariance; CPT, current perception thresholds.
*Time (before, 3 month, 6 month, 12 month), Surgery type (No ramus osteotomy, bilateral sagittal split ramus osteotomy, intraoral vertico-sagittal ramus osteotomy).
Covariate: Genioplasty (with genioplasty, without genioplasty).
IVSRO was initially designed to decrease neuromuscular disturbances and has the advantages of both introrastral vertical ramus osteotomy (IVRO) and sagittal split ramus osteotomy (SSRO). The osteotomy is performed without exposing the IAN, and if possible without exposing the medial side of the ramus to minimize nerve damage, and, as the coronoid process is divided, the osteotomy is easier to perform and safe from injury to the IAN. Previous reports based on large study groups and long-term experience showing fewer intraoperative complications and low morbidity support this fact. In spite of the superiority of the IVSRO technique in decreasing neuromuscular disturbance, there are no objective data evaluating and comparing the recovery time of the IAN with other surgical methods using reliable and standardized tests to verify nerve damage. Our results are the first to verify the nerve recovery pattern after IVSRO and objectively compare its advantages with the SSRO technique. The recovery pattern after IVSRO shows similarity with the recovery curve of BSSRO but the amount of sensory disturbance is significantly less than that of BSSRO and the CPT returns to the level of before surgery more quickly. This reflects the fact that IVSRO causes less nerve damage to the IAN. Considering our findings, the benefits of the IVSRO technique demonstrate that this technique can easily replace the IVRO technique to treat mandibular prognathism and is a viable alternative to the SSRO technique to provide mandibular setback.

Genioplasty tends to aggravate the nerve damage caused by BSSRO or IVSRO. Genioplasty alone is very rarely associated with neurosensory disturbances, because compared with SSRO and IVRO, incisions are usually made at more peripheral sites of the IAN. There are only a small number of articles that evaluate the effect of genioplasty on neurosensory disturbance and these are based on light touch discrimination tests. These studies report a relatively low incidence of hypoesthesia after genioplasty. Our results are in accordance with these results showing only minimal increase of CPT values after genioplasty. But there are previous studies that show the recovery of the IAN is much slower in patients undergoing mandibular osteotomy combined with genioplasty. This is probably attributable to the double insult caused by the combined procedures. The damaging effect seems to be more severe in case of BSSRO with genioplasty because the amount of increase of CPT is larger and it takes longer to recover compared with the IVSRO-genioplasty combined procedure. This could be explained by the fact that the incidence of IAN injury after IVSRO is originally lower compared with BSSRO. It is also known that genioplasty appears to be more detrimental for sensitivity when evaluated with quantitative tests. Based on these results we may state that it is important to evaluate the situation following multiple surgical procedures because genioplasty performed at the same time as a mandibular osteotomy may lead to nerve lesions at different levels and thus hinder satisfactory recovery of the altered sensation from these procedures. However, the repeated measures ANOVA shows that the effect of genioplasty on the CPT of each nerve fiber is not as great as the effect of the main osteotomy type. So, the operator should not be overly reluctant to combine genioplasty with other mandibular osteotomies when superior aesthetics is achievable through additional procedures. At the same time, more care should be given in conducting the overall surgical procedures with atraumatic technique and selecting a main mandibular osteotomy technique that will better conserve the IAN.

Le Fort osteotomies are known to inevitably result in disturbance of the sensibility of the palatal mucosa of the premaxilla and facial area of the ION distribution with the down-fracture technique in which the 3 superior alveolar nerves and terminal labial branches of the ION are cut through. Nevertheless, partial to total recovery of sensation to the area has been reported 1 year postoperatively and was seen in our material as well. In most cases, the nerve damage is caused by direct laceration or traction injury, as a result of the forceful use of retractors during the operation. The CPT results show that Le Fort II procedures result in more severe neurosensory disturbance than Le Fort I. This is probably caused by the broader surgical area of Le Fort II that includes the nasal bone for the overall correction of midfacial hypoplasia. The Le Fort osteotomy has gained broad use in maxillofacial surgery. This is attributable to a seemingly low incidence of long-term side effects of a relatively simple procedure. Only a few studies concerning somatosensory problems related to Le Fort I have been published, and articles concerning Le Fort II do not exist. Although Le Fort II caused a higher level of neurosensory disturbance than Le Fort I, sensory recovery occurred in most patients between 6 and 12 months after the operation. Our results tell us that Le Fort osteotomies are a safe and efficient procedure for the correction of maxillary deformities and the incidence of complications can be lowered to acceptable levels through the exercise of careful surgical techniques.

In the case of the IAN, the neurosensory alterations after the orthognathic surgery was larger and sensory recovery took slightly longer than the ION. This indicates that mandibular surgeries are more aggressive in nature, resulting in more nerve damage. The operator must exercise additional care when conducting man-
dibular surgical procedures such as placing incisions and retracting soft tissue.

The neurosensory alteration and recovery pattern differs not only among surgical techniques, but also between different sensory nerve fiber types. CPT values showed a common pattern of increase after surgery and decrease after the 3-month follow-up to presurgical value until 12 months postsurgery. But the amount of CPT increase was largest for the Aβ fibers (CPT measured at 2000 Hz), whereas the Aδ fibers (CPT at 250 Hz) and C fibers (CPT at 5 Hz) showed similar amounts of increase that were less than that of Aβ fibers. For the ION after maxillary orthognathic surgery, only Aβ fibers showed significant interactions between time and type of maxillary osteotomy. The differences in the diameters of each nerve fiber type may be the possible cause of the different neurosensory alteration and recovery patterns. Larger nerves are more prone to damage during the osteotomy procedure. Aβ fibers have a larger diameter compared with Aδ and C fibers, which may have caused more nerve damage, resulting in the different neurosensory alteration and recovery patterns. The diameter of Aβ fibers ranges from 6 to 13 μm, whereas Aδ fibers range from 1 to 5 μm and C fibers from 0.5 to 1.0 μm.32 It is also possible that CPT values at 250 and 5 Hz are not as significantly related to sensory disturbance in the involved area as values measured at 2000 Hz. A study that assessed the sensory function improvement of lumbar spinal disease patients after lumbar discectomy showed that CPT value at 5 Hz recovered significantly after the surgery irrelevant to the improvement of tactile sensation measured with the brush stroke test.25 The results of our study also show that CPT values of Aβ fibers took longer to recover. This phenomenon could be explained on the same grounds as above. The order of recovery is also known to be determined largely by the relative dependencies on functional innervation density and the gradual increase of innervation density.40 Reinnervation may be accomplished by nerves of adjacent areas in a collateral fashion or through regeneration of the individual fibers of the sectioned IAN or ION, and the subsequent reinnervation of the peripheral receptors. In future studies, to verify the modalities of reinnervation, the measurement area should be mapped into small identical sections that can be measured to gain separate recovery patterns of each section.

It appeared that age did not affect the neurosensory alteration and recovery pattern in this study. This is contradictory to previous studies that indicate older age as a risk factor for prolonged sensory disturbance.60 This difference is probably caused by the fact that the patient group of this study is mainly composed of adults in their 20s and 30s, and very few from other age groups. To investigate the effect of aging, future studies based on subjects with an indiscriminate age distribution should be performed.

Based on the results of this study, at least 1 year is generally necessary to verify resolution of a neurosensory alteration, because it has been shown that patients may show sensory disturbances in the immediate postoperative period, but most experience almost total recovery within 12 months postsurgery.

Considering that most reports on the neurosensory dysfunction after orthognathic surgery are based on results obtained through qualitative studies exclusively based on subjective tests or on the use of questionnaires, our results of CPT measurements are reproducible and quantitative, therefore reliable. The usefulness of clinical neurosensory testing depends on its ability to accurately determine neurosensory deficit and to predict the potential for recovery and the possible future need for further intervention. By selectively assessing the Aβ, Aδ, and C fiber involved in postoperative neurosensory disturbance with a Neurometer, it is possible to accomplish improved diagnosis and treatment by accurately evaluating the recovery from nerve damage, which is one of the clinically most discomforting complications for patients.15,60

Although retrospective studies may underestimate problems in treatment, this study offers valuable information that can be summarized by pointing out that neurosensory disturbance does appear after orthognathic surgery but progressively resolves to almost presurgical levels at 12 months postsurgery. The type of surgery is the main factor that causes differences in nerve recovery patterns so the operator should exercise care in selecting the main osteotomy technique more than any other factor.

CONCLUSION

Neurosensory disturbance is a major complication of orthognathic surgery that lowers the satisfaction level of patients. The extent and recovery of neurosensory disturbance can be objectively and repeatedly measured using a Neurometer and the CPT values obtained can be applied to accurately evaluate the patient’s level and recovery of nerve damage. The results of this study provide objective data concerning the pattern of nerve recovery following various orthognathic surgeries that urges the operator to lessen nerve damage by selecting an appropriate surgical method. And it is also possible to assess a patient’s severity of nerve damage based on these results for further treatment planning and prognostication.
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Reprint requests:
Jin Woo Chung, DDS, PhD
Associate Professor
Orofacial Pain Clinic, Department of Oral Medicine and Oral Diagnosis
School of Dentistry and Dental Research Institute
Seoul National University
28 Yunkeun-Dong, Chongro-Ku
Seoul 110-749, Korea
jwchung@snu.ac.kr