Microsurgical Repair of the Inferior Alveolar Nerve: Success Rate and Factors That Adversely Affect Outcome

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Purpose: The objectives of this study were to determine the likelihood of regaining functional sensory recovery (FSR) after microsurgical repair of the inferior alveolar nerve (IAN), and which variables significantly affected the outcome of that surgery in a large series of patients.

Materials and Methods: This was a retrospective cohort study that evaluated all patients who had undergone microsurgical repair of the IAN by 1 of the senior surgeons (R.A.M.) from March 1986 through December 2005. The requirements for inclusion of a patient in the study included the availability of a complete chart record and a final follow-up visit at least 12 months after surgery. All other patients were excluded. The predictor variables were categorized as demographic, etiologic, and operative. The final outcome variable was the level of recovery of sensory function as determined by standardized neurosensory testing at the last postoperative visit of each patient and based on guidelines established by the Medical Research Council Scale. Risk factors for surgical failure to achieve useful sensory function were determined from analysis of descriptive statistics, including patient age, patient gender, etiology of nerve injury, chief sensory complaint (numbness, pain, or both), time from injury to surgical intervention (in months), intraoperative findings, and surgical procedure. Logistic regression methods and associated odds ratios were used to quantify the association between the risk factors and improvement. Receiver operator characteristic curve analysis was used to find the threshold of those variables that significantly affected patient outcome.

Results: In total, 167 patients (41 male and 126 female patients; mean age, 38.7 years [range, 15-75 years]) underwent 186 IAN repairs (19 patients sustained bilateral IAN injuries). The mean time from injury until surgery was 10.7 months (range, 0-72 months). Successful recovery from neurosensory dysfunction (FSR, defined by the Medical Research Council Scale as ranging from useful sensory function to complete sensory recovery) was observed in 152 repaired IANs (81.7%). With increasing duration from date of injury to IAN repair, the likelihood of FSR decreased (odds ratio, 0.898; \( P < .001 \)). The odds of achieving FSR exhibited a linear decline between the date of nerve injury and its repair, with a significant drop in rate of successful outcome (FSR) occurring beginning at 12 months after injury. There was also a...
Injury to the peripheral branches of the trigeminal nerve, especially the inferior alveolar nerve (IAN), has been well documented in the literature. Causes of IAN injuries include dentoalveolar surgery, maxillofacial trauma and the subsequent surgeries to repair such trauma, orthognathic surgery, removal of benign and malignant tumors, dental implant placement, local anesthetic injections, and endodontic therapy (Figs 1, 2). Because these injuries affect the highly evolved sensory nerve supply of the face and oral cavity, IAN deficits are perceived as detrimental to basic everyday functions of speech, saliva retention, hygiene, and mastication. Many patients achieve spontaneous resolution of their injury, but a small percentage have permanent neurosensory deficits and significant associated impairment of orofacial functions.

The laboratory studies and clinical experience in the 1960s and 1970s of Merrill in the United States and Hausamen et al. in Germany stimulated early interest in microneurosurgery within the maxillofacial region. Since then, a series of reports addressing the injury, pathophysiology, and surgical repair of the IAN, all claiming good surgical outcomes, have appeared in the literature. Pogrel in 2002 reported on the repair of 51 nerves (lingual nerve [LN] in 34 cases and IAN in 17) in which 28 (54.9%) showed “some improvement” (n = 18) or “good improvement” (n = 10) in sensory function as evaluated by objective criteria. In the study of Strauss et al., 28 IANs were surgically repaired, and 92.9% had a mild to significant improvement. Although these studies indicated that a majority of patients regained some degree of sensory function after the repair of the injured IAN, small sample sizes and lack of a uniform systematic grading scale for sensory nerve function make direct comparison of their results with other earlier or subsequent reports on nerve injuries difficult.

Zuniga and Essick devised a method—neurosensory testing (NST)—for evaluating the sensory function of the peripheral branches of the trigeminal nerve using indirect methods of assessment (responses to pain, light touch, 2-point discrimination, and so on), which was shown to be useful and accurate in the clinical setting. The Medical Research Council Scale (MRCS) was initially developed in Great Britain for the evaluation of sensory nerve injuries to the upper extremity and hand by Wynn Parry and other authors and has since been adopted by American hand surgeons. According to the MRCS, functional sensory recovery (FSR) ranges from a grade of S3 (useful sensory function [USF]) to S4 (complete sensory recovery [CSR]) (Table 1). The use of the MRCS for grading sensory recovery after peripheral trigeminal nerve injuries was first advocated by Dodson and Kaban in 1997. The grading of sensory nerve function by the MRCS, based on the results of NST, has given clinicians a method for evaluating and grading sensory function in a manner that is accurate and reproducible when examining patients at consecutive visits and can be used when comparing results of various studies, if the results of NST are available.

The purpose of this study was to assess the clinical outcomes of a large cohort of patients who sustained IAN injuries, underwent microneurosurgical repair of the IAN by the same surgeon, and had been followed up for at least 12 months postoperatively. We also sought to identify variables from demographic, clinical, or temporal data that might significantly adversely influence attainment of FSR. To these ends, we posited that a majority of these patients would achieve FSR but that certain risk factors that might adversely affect outcome could be identified. We aimed to analyze our data using standardized methods of NST and grading of sensory recovery (MRCS). To our knowledge, this is the first large (>100 patients), long-term (>1 year of follow-up) clinical study of the microneurosurgical repair of the IAN based on standardized methods of nerve injury evaluation and outcome assessment.

Materials and Methods

STUDY DESIGN/SAMPLE

A retrospective chart review was completed on all patients who had microneurosurgical repair of the IAN by 1
FIGURE 1. Some causes of IAN injury. A, The mandibular third molar has an intimate relationship with the IAN. B, The dental implant impinges on the IAN at the junction with the mental nerve. C, A mandibular angle fracture causes offset of the IAC with possible stretching or severance of the IAN. D, Overfilling of the mandibular molar root canal beyond the apex and into the canal causes mechanical and chemical injury to the IAN. E, Internal fixation screws in SSRO: The middle internal fixation screw (removed) has penetrated the IAN.

of the senior surgeons (R.A.M.) in his private practice from March 1986 through December 2005. Only those patients who had preoperative MRCS grades of S2 or less, had been followed up for at least 12 months after their IAN repair, and had complete records (hospital operative report, office records including results of NST) available for analysis were included in this study. NST included level A (static 2-point discrimination, brush-stroke identification, stimulus localization), level B (light touch by use of cotton wisps or Semmes-Weinstein filaments), and level C (pain/pinprick sensation) testing. Given the retrospective nature of this study, the research was exempt from review by our institutional review board ethics committee.

STUDY VARIABLES

Predictor Variables

The predictor variables were classified as demographic, etiologic, and operative. Demographic variables included age, gender, presenting chief complaint (numbness, pain, or a combination of both), and the time between injury and its repair (in months). The etiologic variable was the cause, incident, or procedure associated with the IAN injury. The operative variables were the findings at operation (compression, neuroma formation, internal scarring, discontinuity defect) and the method of repair (external decompression, internal neurolysis, neuroma excision, neurorrhaphy, reconstruction of nerve gap with autogenous nerve graft).

Outcome Variables

The primary outcome variable was the failure to attain FSR at 1 year after IAN repair. A grade of S3 or higher on the MRCS indicated FSR, based on the results of the final NST performed at 12 months or longer after the date of the IAN repair. All patients who achieved an MRCS grade of S2+ or lower were considered failures.

DATA ENTRY/ANALYSES

Data were gathered from individual chart reviews (MRCS grades were calculated for each patient, based
on NST results at each patient’s final visit at least 12 months after the date of surgery) and entered into a statistical database. For multivariate analyses, $P \leq 0.05$ was considered statistically significant. Logistic regression methods and associated odds ratios were used to quantify the association between the risk factors and improvement. Receiver operator characteristic curve analysis was used to find the threshold of age and duration that maximally separated patient outcome.

**Results**

In total, 167 patients who underwent 186 IAN repairs (19 bilateral) met eligibility requirements and were included in our study. In those patients who had bilateral operations, both repairs were included in our database.

The regaining of FSR after microsurgical repair (defined by the MRCS as ranging from USF [grades S3 and S3+] to CSR [grade S4]) (Table 1) occurred in 152 repairs (81.7%) (82 IANs [44.1%] with CSR and 70 IANs [37.6%] with recovery to USF), as shown in Table 2. In contrast, 34 IANs (18.3%) showed inadequate improvement (MRCS grade <S3) or no improvement (MRCS grade S0).

Demographic variables for our study population are summarized in Table 3. There were 126 female and 41 male patients, with a mean age of 38.7 years (range, 15-75 years). There was a significant negative relationship between increasing patient age and unfavorable outcomes (odds ratio, 0.97; $P = 0.015$), with a threshold drop of achieving FSR after 51 years of age and a decline in success rate of 3% per year. Most patients complained preoperatively of numbness (n = 62 [33.3%]) or numbness with pain (n = 91 [48.9%]), whereas 33 (17%) complained only of pain. The presence of pain did not affect the likelihood of achieving FSR after repair in a statistically significant manner ($P = .14$). Patients who did not complain of pain as a major symptom after nerve injury were not at risk of the development of chronic, intractable pain after microneurosurgery. In general, patients who had pain as a component of their chief complaint or as their only chief complaint were more likely to be female patients (79.8%) than those who complained of numbness only (64.5%) ($P = .023$), were operated on later, were more likely to have had a compression injury or the development of a lateral/exophytic neuroma, and underwent more external decompressions, internal neurolyses, and neuroma excisions. The mean time for all patients from injury until surgery was 10.7 months (range, 0-72 months). This duration was influenced by the much longer mean time from injury to surgery for those patients (n = 33) who complained only of pain. Whereas patients whose chief complaint was solely pain were not operated on until a mean 18.0 months after their nerve injury, the remaining 153 underwent nerve repair surgery at a mean of 12.0 months after injury. In other words, for whatever reason, patients who complained of pain after nerve injury tended to be operated on later than those who complained only of numbness ($P < .001$).

### Table 2. OUTCOMES DATA BASED ON MRCS GRADE (186 IAN REPAIRS)

<table>
<thead>
<tr>
<th>MRCS Grade</th>
<th>Interpretation</th>
<th>No. of Patients</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0 to S2</td>
<td>NSR or IASR</td>
<td>34</td>
<td>18.3</td>
</tr>
<tr>
<td>S3 to S3+</td>
<td>FSR: USF</td>
<td>70</td>
<td>37.6</td>
</tr>
<tr>
<td>S4</td>
<td>FSR: CSR</td>
<td>82</td>
<td>44.1</td>
</tr>
<tr>
<td>S3 to S4</td>
<td>FSR: USF or CSR</td>
<td>152</td>
<td>81.7</td>
</tr>
</tbody>
</table>

Abbreviations: NSR, no sensory recovery; IASR, inadequate sensory recovery.

### Table 3. DESCRIPTIVE STATISTICS: DEMOGRAPHIC VARIABLES

<table>
<thead>
<tr>
<th>Data</th>
<th>% of Total</th>
<th>$P$ Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size (No. of patients)</td>
<td>167</td>
<td>100</td>
</tr>
<tr>
<td>No. of IAN injuries (19 bilateral)</td>
<td>186</td>
<td>100</td>
</tr>
<tr>
<td>Age (yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>38.7</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>15-75</td>
<td>.015</td>
</tr>
<tr>
<td>Gender (No. of patients)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>41</td>
<td>24.6</td>
</tr>
<tr>
<td>Female</td>
<td>126</td>
<td>75.4</td>
</tr>
<tr>
<td>Chief complaint (No. of injured IANs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Numbness</td>
<td>62</td>
<td>33.3</td>
</tr>
<tr>
<td>Numbness and pain</td>
<td>91</td>
<td>48.9</td>
</tr>
<tr>
<td>Pain</td>
<td>33</td>
<td>17.7</td>
</tr>
<tr>
<td>Time from injury to repair (mo)</td>
<td></td>
<td>.14</td>
</tr>
<tr>
<td>All nerves (n = 186)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>0-72</td>
<td></td>
</tr>
<tr>
<td>Pain only (n = 33) (mean)</td>
<td>18.0</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

* $P$ value equal to or greater than 0.05 is not considered statistically significant.

The most common cause of IAN injury was third molar removal (n = 70 [37.6%]), followed by mandibular sagittal split ramus osteotomy (SSRO) (n = 31 [16.7%]) and mandibular fracture (n = 21 [11.3%]) (Table 4). Other significant causes of injury included dental implant placement (n = 15 [8.1%]), endodontic treatment (n = 9 [4.8%]), and resection of pathology (tumors or cysts) (n = 9 [4.8%]). Less frequent cause-and-effect relationships with IAN injury were associated with local anesthetic injections, biopsies, gunshot wounds, and preprosthetic surgery (mandibular vestibuloplasty or alveolar ridge augmentation).

Table 4. DESCRIPTIVE STATISTICS: ETIOLOGIC VARIABLES

<table>
<thead>
<tr>
<th>Cause</th>
<th>No. of Injured IANs</th>
<th>% of Total (186 Injured IANs)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third molar removal</td>
<td>70</td>
<td>37.6%</td>
<td>NS</td>
</tr>
<tr>
<td>Mandibular SSRO</td>
<td>31</td>
<td>16.7%</td>
<td>NS</td>
</tr>
<tr>
<td>Mandibular fracture</td>
<td>21</td>
<td>11.3%</td>
<td>NS</td>
</tr>
<tr>
<td>Dental implant placement</td>
<td>15</td>
<td>8.1%</td>
<td>NS</td>
</tr>
<tr>
<td>Endodontic treatment</td>
<td>14</td>
<td>7.5%</td>
<td>NS</td>
</tr>
<tr>
<td>Resection of pathology</td>
<td>9</td>
<td>4.8%</td>
<td>NS</td>
</tr>
<tr>
<td>Other causes*</td>
<td>26</td>
<td>14.0%</td>
<td>NS</td>
</tr>
</tbody>
</table>

Abbreviation: NS, not statistically significant (P ≥ .05).

*Local anesthetic injections, biopsies, gunshot wounds, and preprosthetic surgery (mandibular vestibuloplasty or alveolar ridge augmentation).


Operative variables are summarized in Table 5. The most common intraoperative finding was a compression injury (n = 59 [31.7%]), followed by neuroma formation (n = 43 [23.1%]), total nerve discontinuity (n = 46 [24.7%]), and partial nerve severance (n = 38 [20.4%]) (Fig 3). In our study population FSR was achieved in 88.9% of patients with neurorrhaphy (16 of 18), 87.3% of those undergoing IAN reconstruction with an autogenous nerve graft (62 of 71), 85% of those who had an external decompression (62 of 71), 87.3% of those who had internal neurolysis (45 of 60), and 70.6% of those who had excision of an exophytic neuroma only (12 of 17). The differences in success rates of achieving FSR among the various operative findings and the microsurgical operations performed to repair those findings, however, were not statistically significant (P = .20).

Table 5. DESCRIPTIVE STATISTICS: OPERATIVE VARIABLES

<table>
<thead>
<tr>
<th>Method of repair</th>
<th>No. of Injured IANs</th>
<th>% of Total (186 Injured IANs)</th>
<th>Success Rate</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>59</td>
<td>31.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neuroma</td>
<td>43</td>
<td>23.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial severance</td>
<td>38</td>
<td>20.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete discontinuity</td>
<td>46</td>
<td>24.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Method of repair</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External decompression</td>
<td>20</td>
<td>10.8</td>
<td>17/20 (85%)</td>
<td>NS</td>
</tr>
<tr>
<td>Internal neurolysis</td>
<td>60</td>
<td>32.3</td>
<td>45/60 (75%)</td>
<td>NS</td>
</tr>
<tr>
<td>Neuroma excision</td>
<td>17</td>
<td>9.0</td>
<td>12/17 (70.6%)</td>
<td>NS</td>
</tr>
<tr>
<td>Neurorrhaphy</td>
<td>18</td>
<td>9.7</td>
<td>16/18 (88.9%)</td>
<td>NS</td>
</tr>
<tr>
<td>Autogenous nerve graft</td>
<td>71</td>
<td>38.2</td>
<td>62/71 (87.3%)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Abbreviation: NS, not statistically significant (P ≥ .05).


Discussion

The purpose of this investigation was to report the success rate of achieving FSR and which variables might affect outcome in the largest standardized patient group to date with IAN injuries that had undergone microsurgical repair. The results of the study, conducted as a retrospective chart review that was subjected to data analysis, showed that a significant majority of patients (81.7%) achieved FSR at their last postoperative visit at 12 months or more after surgery, defined by the MRCS as ranging from S3 (USF) to S4 (CSR) (Table 2). An analysis of outcome variables showed that an increasing length of time from IAN injury to its surgical repair and increasing age of the patient had negative effects on the likelihood of regaining FSR. No other factor (pain alone as the chief complaint, cause of injury, operative finding of the extent of nerve injury, or type of operation performed to repair the IAN) had a significant effect on outcome.

Selection of patients for surgical repair of their IAN injuries was based on findings from the history and examination.30 Indications for surgical intervention, as developed by consensus of clinicians involved in
the care of nerve-injured patients and adopted by the Clinical Interest Group on Maxillofacial Nerve Disorders, American Association of Oral and Maxillofacial Surgeons, included an open (observed by the surgeon) nerve injury showing partial or complete severance or a closed (unobserved) nerve injury with persistent significant/unacceptable (to the patient) diminished sensation or complete loss of sensation, interference with orofacial functions (eating, drinking, oral hygiene, speech, washing, shaving, and so on), and/or unremitting pain that was temporarily relieved by local anesthetic block of the suspected nerve.

As in our previous studies, we have continued to use standardized methods of evaluating neurosensory function (NST) and of grading the final outcome of nerve recovery after surgical repair (MRCS). NST has been evaluated and accepted by many clinicians working in the area of peripheral trigeminal nerve injury as the most accurate and reliable method of semiojective examination of sensory nerve function. The MRCS was originally developed by clinicians working with patients who were recovering from peripheral nerve injuries of the upper extremity and hand. Advocacy for application of the objective MRCS to peripheral trigeminal nerve injuries originated with Dodson and Kaban, and the scale was first used in clinical studies by Susarla et al. Adherence in the future to these standardized and reproducible methods of evaluating sensory dysfunction and grading recovery after microneurosurgery will assist in overcoming obstacles to comparison of results of past and future studies from multiple centers.

In clinical practice the most frequent oral surgical operation is estimated to be removal of teeth. The variability of the anatomic relationship between the roots of mandibular third molars (M3s) and the inferior alveolar canal (IAC) poses unique risks for IAN injury during the removal of M3s. In our study a plurality of injuries (37.6%) occurred in third molar patients. Many of these patients, going back to the mid 1980s, had a periapical film as their only pre-extraction imaging study. Thereafter panoramic radiographs began to be used more frequently to ascertain nerve injury risk factors associated with M3 root position vis-à-vis the IAC. Most recently, advanced imaging modalities (ie, computed tomography scans) have assisted oral and maxillofacial surgeons in assessing the true relationship between M3 roots and the IAC. With the increased information and accuracy from new technology, it is hoped that the incidence of IAN injury associated with removal of M3s will decline.

Other risks of IAN injury are associated with procedures or conditions that routinely disrupt the IAN canal and its contents. Mandibular SSRO and mandibular fractures accounted for approximately 16.7% and 11.3%, respectively, of the IAN injuries in our series. Interestingly, when compared with the series of

FIGURE 3. A, Transcutaneous submandibular exposure of IAN, depicting neuroma in continuity. B, The neuroma has been excised; the distal and proximal nerve stumps have been debrided and prepared for approximation. C, Reconstruction of an IAN gap with an autogenous SN graft. The arrows indicate sutured anastomoses of the IAN with the graft. Bagheri et al. Microsurgical repair of IAN. J Oral Maxillofac Surg 2012.
Pogrel\textsuperscript{19} or Strauss et al.\textsuperscript{20} IAN injury caused by dental procedures (local anesthetic injection, dental implant placement, endodontic therapy) in our series was less frequent whereas the number of IAN injuries associated with SSRO or mandibular trauma was much higher. This may be because of the nature of our referral base, which included a number of otolaryngologists and plastic surgeons, who referred many of the patients with maxillofacial trauma- or craniomaxillofacial surgery-related IAN injuries. In addition, the incidence of partial or complete nerve severances encountered in our series was higher than that of Strauss et al. Our higher incidence of more severe IAN injuries is probably because of the greater degree of nerve trauma that often occurs from maxillofacial trauma or during the SSRO as compared with dentoalveolar procedures.

In our series, 62 patients (33.3%) complained of numbness whereas 91 (48.9%) complained of numbness with pain and 33 (17.7%) complained of pain without concurrent numbness. Although there was some variability in outcomes among those patients who complained only of numbness (55 of 62 achieved FSR [85.5%]), those who had numbness and pain (76 of 91 achieved FSR [83.5%]), and those who had pain only (23 of 33 achieved FSR [69.7%]), these differences were not significant ($P = .14$), possibly because of the small sample size of pain-only patients. Nevertheless, the presence of pain did not affect the likelihood of achieving FSR after repair in a statistically significant manner, a finding also noted by Pogrel.\textsuperscript{19} These results are somewhat at odds with the findings of Gregg,\textsuperscript{37} who reported a lower rate of successful outcomes in nerve operations for painful conditions. In our patients, if pain was not a major complaint before nerve repair, there was little or no likelihood that neuropathic pain would develop postoperatively. This information can be of some reassurance to patients during the preoperative informed consent discussion before microneurosurgery.

In our study population, all patients were operated on under general endotracheal anesthesia in a hospital operating theater. Adequate magnification of the operative field was attained with either surgical loupes ($3.5 \times$ to $5.0 \times$) or the operating microscope. In general, the suspected location of the site of injury dictated the surgical approach. IAN injuries in the mandibular molar region or further posterior ($n = 171$) were exposed through a transcutaneous submandibular incision. Only injuries anterior to the first molar area or in which adequate visualization and sufficient exposure of the IAC for all surgical manipulations on the IAN were deemed possible by the surgeon were accessed transorally ($n = 15$). In some patients their desire to avoid a surgical scar, no matter how inconspicuous, might have influenced the surgeon’s choice of approach. Because the goal of the surgery is a successful outcome of nerve repair, an approach that compromises the surgeon’s ability to achieve that goal must be made clear to the patient as part of the preoperative informed consent process. However, all transcutaneous incisions were carefully placed in natural skin creases, skin closure was performed under magnification, incision margins were injected before closure with dilute triamcinolone in African Americans or those with a history of hypertrophic scar or keloid formation, incisions were supported with adhesive strips, and skin care was prescribed. Only 3 patients (3 of 171 incisions, all in female patients, none of whom was African American) required subsequent scar revisions, which successfully performed by 1 of the authors (R.A.M.).

The microneurosurgical repair of an IAN involves a progressive series of surgical steps (nerve exposure and external decompression, excision of neuroma, internal neurolysis [Fig 4], and preparation of the
nerve stumps to perform neurorrhaphy, if there is a discontinuity defect, performed in order and completed one after the other. The operation can be terminated at any of these steps, if the repair is deemed satisfactory by the surgeon. The type of nerve repair that was performed in any given study patient was dependent on the operative findings, once the IAN was adequately exposed, and the surgeon’s judgment. The most common operative finding was a compression injury (n = 59 [31.7%]). The surgical findings in IAN injuries differed from those in our previous study evaluating outcomes of LN repair, where the most commonly encountered injury was neuroma in continuity. As the first step in IAN repair, all nerves were decompressed by lateral unroofing and enlarging of the IAC diameter. Nerve compression was most often observed to be the result of narrowing of the IAC due to excessive osseous proliferation that occurred in response to the original injury at the site of trauma (third molar removal, mandibular fracture through the IAC, SSRO, drilling for implant placement) to the wall of the IAC. In some patients removal of perineural scar tissue and foreign material (internal fixation screws, root canal filling material, missile fragments, and so on) that were impinging on the IAN was necessary as well. It should be emphasized that the bone removed in the exposure of the IAC was not replaced. Theoretically, replacement of an overlying bone segment after completion of the nerve repair might seem to provide protection from formation of secondary neuromas or adhesions. However, bone replaced over the repair site converts the IAC to a “closed box” analogous to a closed head injury, where increasing pressure caused by postoperative edema of the nerve could lead to compression of its blood supply, ischemia, and necrosis. This mechanism is likely the cause of some of the IAN injuries occurring during the SSRO. The next most common intraoperative finding in the IAN was neuroma formation (n = 43 [32.1%]). In most of these cases this was an exophytic or adhesive neuroma, and the conducting portion of the nerve remained continuous after excision of the neuroma. In most such patients the outcome of neuroma excision was good relief of pain and restoration of FSR. After decompression, the epineurium was opened axially over the area of injury, and the internal structure of the nerve was inspected for further damage (ie, loss of continuity of individual fascicles or interfascicular scarring), which was repaired by internal neurolysis for scar tissue removal. Individual fascicles that had lost continuity were not sutured but were merely replaced into good alignment. The epineurium was closed with No. 8-0 or 10-0 monofilament ophthalmic sutures after internal neurolysis. Farole and Jamal presented a series of 6 lingual and 3 IAN injuries that were repaired with neurorrhaphy and placement of an absorbable collagen (CGN) sleeve. In theory, the nerve sleeve should enhance the healing across a neurorrhaphy by prevention of axonal leakage and lateral neuroma formation, blocking the ingrowth of scar tissue, localization of nerve growth factors, and creation of a conduit to guide axonal sprouts in the case of a nerve gap. They reported that 4 patients had “good improvement” (of sensation) whereas 4 had “some improvement” and 1 had “no improvement.” Unfortunately, they failed to include a control group, making it difficult to draw firm conclusions regarding the cost- or risk-benefit ratio of using absorbable nerve sleeves in peripheral nerve repairs. In our study population there were 14 nerve repairs in which absorbable polyglycolic acid nerve sleeves (Neurotube; Synovis Life Technologies, St Paul, MN) (n = 2, internal neurolyses in both) or CGN nerve sleeves (NeuraGen; Integra Life Sciences, Plainsboro, NJ) (n = 12, comprising 4 neuroma excisions, 3 internal neurolyses, 3 neurorrhaphies, and 2 autogenous nerve grafts) were placed. All patients with polyglycolic acid sleeves (2 of 2 [100%]) and 10 patients with CGN sleeves (10 of 12 [83.3%]) regained FSR. However, conclusions based on these incomplete data are not presented for these patients at this time, because they are part of a larger controlled study to address this question, the complete results of which will be reported in a separate article.

There were 38 partial and 46 complete nerve discontinuity defects, all of which required reconstruction of nerve continuity with either neurorrhaphy or autogenous nerve graft. The sine qua non of successful repair of a peripheral “nerve gap” is approximation of the nerve stumps without tension. After preparation of the IAN by excision of stump neuromas and scar tissue to expose viable fascicles suitable for optimal nerve reapproximation and suturing, the proximal and distal stumps often cannot be brought together without tension unless a complete IAN lateralization anteriorly to the mental foramen and posteriorly to the mandibular foramen is performed. Sometimes, the terminal incisive branch of the IAN must be severed at its junction with the mental nerve as well to allow adequate lateralization and mobilization of the IAN. This additional manipulation and trauma to the IAN may compromise its ability to heal, and the patient whose incisive nerve was transected will have permanent numbness of the mandibular labial gingiva and the incisor and canine teeth. One of the authors (R.A.M.) has reoperated on 2 patients for removal of pain-producing proximal stump neuromas of the incisive nerve that developed after incisive nerve transection for mobilization of the IAN. The deleterious effects of tension on a nerve repair site have been well documented, so the inability to...
perform a primary tension-free repair indicated the need for reconstruction of the nerve gap with an autogenous nerve graft. In this study only 18 neurorhaphies were performed whereas 71 IANs required reconstruction with an autogenous nerve graft. This is in sharp contrast to our previous report on LN injuries, in which the surgeon was usually able to close a nerve gap without tension by simply mobilizing and advancing the proximal and distal nerve limbs. The LN’s tortuous course in the floor of the mouth and its location totally within soft tissue undeniably enhance the ability of the surgeon to resolve the LN gap without resorting to a nerve graft.

The 2 most common nerves used for grafting the IAN have been the sural nerve (SN) and the great auricular nerve (GAN) (Fig 5). In this series the autogenous nerve graft was always harvested after exposure of the IAN so that the desired length of the graft could be accurately determined beforehand. The GAN was used most frequently because it was easily accessible without the necessity of repositioning and repreparing the patient (when the IAN was approached in a transcutaneous manner). In those instances where there was a discrepancy between the diameter of the IAN and the GAN, a cable graft was placed. Although the GAN generally has a smaller diameter than the SN, it has a greater density of axons per square millimeter, probably a more important factor in restoration of nerve function. The SN was harvested when the nerve gap was greater than 2.0 cm, there was a need for a nerve-sharing procedure because of the unsuitability or absence of a viable IAN proximal limb, or the patient objected to an additional surgical scar in the neck.

Early in our experience, an attempt was made to re-anastomose the proximal and distal limbs of the GAN after graft harvesting, often resulting in tension across the suture line. Because of persistent donor-site pain, 3 painful GAN donor sites were re-explored. In each of these, the nerve stumps were seen to have pulled apart with the development of a proximal stump neuroma. Excision of the neuroma relieved

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**Figure 5.** A, Exposure of SN (upper arrow) in lower extremity for harvesting of autogenous nerve graft for reconstruction of IAN gap. The short saphenous vein (lower arrow) is an important adjacent anatomic landmark. B, Resulting area of anesthesia in lateral aspect of foot from SN graft. C, Exposure of greater auricular nerve in neck.

persistent post-harvest neck pain in each of the 3 patients. As a result of this experience, the management of the proximal stump of the donor nerve was altered. The proximal stump of the donor GAN or SN was henceforth sutured into adjacent muscle (the GAN to the sternocleidomastoid and the SN to the gastrocnemius), the so-called nerve “redirection procedure.” No further re-explorations of donor nerve sites for pain relief were required in our study population. Loss of sensation in the distribution of the GAN is generally well tolerated or unnoticed. Indeed, several male patients expressed a desire to undergo ear piercing after losing ear lobe sensation after harvesting of a GAN graft. Permanent loss of sensation in the heel or lateral surface of the foot may pose a problem for athletes or others whose livelihood depends on good position sense in the foot (Fig 5B). The patient requires an informed discussion about the risks or problems involved in autogenous nerve graft reconstruction, including those with the donor site, so that he or she can make an appropriate decision on whether to proceed and which graft donor site to select.

In our study population FSR was achieved in 88.9% of patients who underwent a neurorrhaphy (16 of 18), 87.3% of those who had IAN reconstruction with an autogenous nerve graft (62 of 71), 85% of those who had an external decompression (17 of 20), 75% of those who had internal neurolysis (45 of 60), and 70.6% of those who had excision of an exophytic neuroma only (12 of 17) (Table 5). It would seem that the prospect of a favorable outcome from nerve graft reconstruction of a nerve gap is equally as good as, if not better than, that with the other surgical alternatives. Regarding the less favorable outcomes after excision of an exophytic neuroma without further repair or an internal neurolysis, this is probably a reflection of the surgeon’s inability at the time of the operation to correctly judge the need for further surgery based on the clinical appearance of the nerve under the microscope. When an anatomic discontinuity of the nerve does not exist, it is often difficult to determine whether there might be further damage not readily observed that could cause a “physiologic discontinuity” (ie, lack of conductivity) of the nerve. The ability to correctly judge the status of an injured nerve improves with increasing experience.

To eliminate some of the objections with or risks of autogenous nerve grafts, reconstruction of the nerve gap may be possible with allografts or nerve conduits. To bypass the need for adjunctive immunosuppressive therapy, itself a great risk to patients, allografts can be treated to remove antigenic factors. For example, allogeneic nerve grafts (AxoGen, Alachua, FL) composed of decellularized and cleansed extracellular matrix from human cadaveric peripheral nerves are processed to be nonimmunogenic and inert when transplanted into another person. These were not used in this series. However, outcomes data on patients who we have treated with allogeneic grafts are included in another study that will be reported in the future.

There are many factors believed to affect the results of peripheral nerve repair by microneurosurgery. These include the time between injury and repair, the type and extent of injury, the vascularity of the injury site, the experience and technical skill of the surgeon and thence the quality of the repair, the harvesting and preparation of the graft, the tension (if any) across the repair, and the age and general health of the patient. Many of these factors are related to nerve healing, poorly understood at present, and beyond the surgeon’s control. The time between injury and repair and patient age are shown by our study, however, to be strongly related to outcome of repair of the IAN and deserve careful consideration by clinicians responsible for their management.

The timing of IAN repair is controversial, and making the decision whether to observe or treat is critical. The decision to proceed to surgery requires a standardized evaluation of the subjective and objective clinical findings reflecting the extent of the nerve injury. Robinson et al reported that there was no association between delayed nerve repair and neurosensory outcome. However, in our study patients who had undergone surgery early after their nerve injury had a statistically significantly greater likelihood of achieving FSR compared with patients who underwent later repair. The mean time from injury to microsurgical repair in our patients was 10.7 months (range, 0-72 months). With increasing duration from time of injury to IAN repair, the likelihood of restoring FSR (ranging from USF to CSR) decreased (odds ratio, 0.898; P < .001). The chances of achieving FSR exhibited a linear decline of 11% with each month of time between injury and repair, with a threshold drop of achieving FSR beginning at 12 months. Receiver operator characteristic analysis showed that a patient who waited for a longer duration from nerve injury until its repair had a significantly greater risk of an unsatisfactory outcome. As reported by Susarla et al, the time interval from nerve injury to its repair was statistically insignificant; however, all their patients underwent surgical repair within 1 year. Many of the patients in these studies, including our series, were not seen initially for evaluation by a microsurgeon for several months or longer after their injury, whether because of delay of referral by the surgeon who performed the original surgical procedure associated with the nerve injury or because of reluctance of the patient to follow the surgeon’s recommendation for referral. The results of
this study should urge clinicians who initially see patients with nerve injuries to refer them promptly to those specialists who are experienced in their management. Seddon’s comment more than 60 years ago, “If a purely expectant policy is pursued, the most favorable time for operative intervention will be always missed,” continues to guide today’s clinicians faced with the care of these challenging injuries.

Sunderland compared the recovery rate after peripheral nerve suture in persons aged 11 to 42 years, and he observed no differences because of patient age. However, this was a relatively young patient population compared with the age range (15-75 years) of our series. In our present study and others, we found that there was a significant negative relationship between increasing patient age and outcomes. These results are supported by a recent discussion of age as a significant factor in the prognosis for recovery of injured nerves due to changes in electrophysiology and axonal transport.

Our study was subject to certain biases and confounders of which we are aware. The retrospective nature of the study introduced selection bias, and the heterogeneity of the IAN injury etiology (third molar extraction, SSRO, dental implant, endodontic procedure, tumor removal, mandibular fracture, and so on) mixed together dissimilar patient populations with varying mindsets and expectations from treatment for and recovery from different types of injuries. The operations used to treat these nerve injuries also varied and were entirely dependent on the clinical status of the nerve at microsurgical exposure and the clinical judgment of the surgeon. Lack of a control group (no operation or a sham operation) always compromises the conclusions of a clinical study, but it is deemed unethical to withhold, by random selection, treatment of known benefit.

Our study has shown that microsurgical repair of the injured IAN results in FSR for a significant majority (81.7%) of a selected group of patients with unacceptable neurosensory dysfunction. Therefore surgical repair of the injured IAN is a recommended treatment option for patients with observed nerve injury or persistent, unacceptable sensory dysfunction in an unobserved injury. Although our data compare favorably with previously reported series of microsurgical repairs of injured IANs, they are derived from a much larger cohort of patients, making it possible to identify some of the variables that influence outcome. The ability to achieve FSR in our patients was significantly adversely affected by increasing patient age and lengthened duration between injury and microsurgical repair. Repair should be conducted as soon as indicated after nerve injury, because there appears to be a significant reduction in the likelihood of a successful outcome after 12 months. Patient age greater than 50 years was associated with poorer outcomes. Our future studies now in progress aim to determine the effects of using nerve sleeves to entubulate nerve repairs or placing processed cadaveric nerve allografts to reconstruct nerve gaps on the success rate of achieving FSR after microsurgical repair of peripheral trigeminal nerve injuries.

We advocate the use of standardized NST in evaluating peripheral trigeminal nerve injuries and the MRCS in grading the final outcome of treatment, whether surgical or nonsurgical. We hope that, going forward, all clinicians who care for peripheral nerve injuries will use these evaluation methods so that data from various studies can be meaningfully compared and analyzed.

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