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Review

Evidence-based outcomes following inferior alveolar and lingual nerve injury and repair: a systematic review

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SUMMARY **The inferior alveolar nerve (IAN) and lingual (LN) are susceptible to iatrogenic surgical damage. Systematically review recent clinical evidence regarding IAN/LN repair methods and to develop updated guidelines for managing injury. Recent publications on IAN/LN microsurgical repair from Medline, Embase and Cochrane Library databases were screened by title/abstract. Main texts were appraised for exclusion criteria: no treatment performed or results provided, poor/lacking procedural description, cohort <3 patients. Of 366 retrieved papers, 27 were suitable for final analysis. Treatment type for injured IANs/LNs depended on injury type, injury timing, neurosensory disturbances and intra-operative findings. Best functional nerve recovery occurred after direct apposition and suturing if nerve ending gaps were <10 mm; larger gaps required nerve grafting (sural/greater auricular nerve). Timing of microneurosurgical repair after injury remains debated. Most authors recommend surgery when neurosensory deficit shows no improvement 90 days post-diagnosis. Nerve transection diagnosed intra-operatively should be repaired *in situ*; minor nerve injury repair can be delayed. No consensus exists regarding optimal methods and timing for IAN/LN repair. We suggest a schematic guideline for treating IAN/LN injury, based on the most current evidence. We acknowledge that additional RCTs are required to provide definitive confirmation of optimal treatment approaches.**

KEYWORDS: **nerve injury, nerve repair, lingual nerve, inferior alveolar nerve, cranial nerve injury, trigeminal neuropathy**

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Background

The inferior alveolar nerve (IAN) supplies the chin, lower lip, vestibular gingivae, molars, premolars and alveolus. The lingual nerve (LN) supplies the oral gingivae, surface mucosa of the anterior two-thirds of the tongue and sublingual gland (1). Nerves can be severed, stretched or crushed during surgery or trauma (2, 3). The IAN and LN can be damaged during many diverse interventions such as dentoalveolar, implant, orthognathic and benign and malignant tumour surgeries, endodontic therapy, facial trauma repair and local anaesthetic injection. Neurosensory deficiency resulting from these procedures is a rare complication; however, due to the frequency of these treatments, a small but significant number of patients are affected by this issue. Peripheral nerve injury can manifest itself as loss of sensation of a particular area, painful sensation, altered taste and even distorted speech (4). No matter what the aetiology, IAN/LN neurosensory deficits are very significant to patients, underscoring the importance of developing updated management protocols to treat altered sensation due to IAN/LN injury.

This review assesses the most current findings regarding clinical outcomes of different treatment interventions to repair or enhance the recovery of iatrogenic injuries/trauma to the IAN and LN.

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Evidence-based outcomes were compared between the different causative factors of injury, times until repair and reconstruction types. There are still relatively few robust studies investigating traditional repair methods, either by comparing different traditional methods (e.g., suturing) with new technologies or by comparing surgery with continuous patient review. Additionally, we wanted to determine whether there had been any recent developments using biomaterials, scaffolds, conduits, antiscarring agents or other therapeutic interventions that could influence the management of these unfortunate patients. There currently exists no conventional protocol for managing IAN and LN neurosensory deficiency in regards to optimal methods and the timing for surgical repair. Therefore, another goal of this retrospective study was to develop a schematic flowchart that details recommended sequential steps for managing IAN and LN injury. Here, we propose a schematic guideline for treating IAN/LN injury, by merging the most current findings with historical approaches. We appreciate that differences certainly exist in treating IAN versus LN injuries and acknowledge that additional RCT evidence is required to further optimise treatment protocols when these nerves become damaged.

Methods

An electronic database search was performed as per Cochrane review (Coulthard *et al.*) (5) using MEDLINE via OVID (1950–Dec 2013), EMBASE via OVID (1950–Dec 2013) and CENTRAL via the Cochrane Library. The following search strategy was used: ('inferior dental nerve*' or 'inferior alveolar nerve*' or 'mandibular nerve*' or 'trigeminal nerve*' or 'lingual nerve*' or 'lingual dental nerve*') AND ('sensory disturbance' or 'taste disorder*' or 'neurosensory deficit*' or 'somatosensory disorder*' or 'altered sensation*' or 'hyperalgesia' or 'hypaesthesia' or 'paresthesia' or 'hypesthesia' or 'paraesthesia' or 'inju*' or 'damage*' or 'contus*' or 'section*' or 'trauma*' or 'lesion*' or 'morbid*') AND ('local anaesthe* or anesthe*' or 'tumor or 'third molar extraction*' or 'dentoalveolar surgery' or 'sagittal split ramus osteotomy' or 'orthognathic surgery' or 'implant surgery' or 'implant treatment' or 'endodontic therapy' or 'endodontic treatment' or 'endodontic surgery') AND ('repair*' or 'surg*' or 'anastamos*' or 'graft*' or 'medical*' or 'analgesi*' or 'antidepressant*' or 'anti-depressant*' or 'antiepileptic*' or 'anti-epileptic*').

Titles and abstracts obtained using this search strategy were scrutinised, and all relevant articles and abstract were retrieved, and their main text was critically analysed for relevance. Reference lists in all relevant articles were manually screened in case they included additional relevant citations that were missed by our electronic search. The full-text versions of any thus-identified citations were analysed and included in the study compilation if deemed relevant.

The initial inclusion criterion was reporting outcomes of IAN- or LN-injury treatment. No restrictions on language, publication date or publication status were applied. All studies on IAN- and/or LN-injury patients were initially included, regardless of age, gender, sample size or treatment method.

Studies on subjects with microneurosurgical reconstruction of IAN and LN injury were selected. Reports including alternative treatments for neurosensory disturbance due to IAN and LN damage were also selected. Studies were selected if the reason for IAN and LN neurosensory disturbance was oral and maxillofacial surgery or facial trauma. In most studies, quantitative trauma evaluation relied on response to gentle (blunt) touch, pin prick (sharp) touch and two-point discrimination thresholds. For paraesthesia and dysesthesia, most authors use linear analogue scales 0–10 to assess the degree of sensory abnormality. However, this is not the only measure of patients' difficulties (6). Several analyses used objective assessments such as the Oral Impact on Daily Performance (OIDP) scale, which assesses the impact of the surgical intervention on an individual's daily life, for example eating and speaking (7). All included studies had clearly described intervention, patient pre- and postoperative examinations, follow-up, inclusion and exclusion criteria, reasons for withdrawals, and why intervention was performed. Studies with no presented statistics were also included. Studies were excluded if no treatment was performed, for lack procedural description, or if no information about patient follow-up or outcomes was provided.

In our analysis, we focused on outcomes based on three variables: (i) causative factors; (ii) time to repair and (iii) repair method. The primary outcome measure was functional sensory recovery (FSR). Secondary outcome measures were difficulty eating and speaking and altered thermo- and mechanosensation or taste. Data from all included studies are collated in Table 1.

Results

After electronic title/abstract screening, 366 articles were initially obtained (Fig. 1). After duplicates and irrelevant papers were removed, 62 papers were tentatively included, and their full-text versions were scrutinised for reporting clinical outcomes following IAN/LN microneurosurgery repair after injury. After full-text screening, 27 of these 62 articles were included in this review (Table 1) and 35 articles were excluded because no microsurgery was performed, lack of adequate procedural description or no follow-up information. The earliest included paper was published in 1984, and the most recent included article was from 2012.

Causative factors

Most of the studies included in this analysis used mixed aetiologies to retain higher numbers in their statistical analysis. When reviewing the studies, it is apparent that the predominant cause of IAN and LN injury is third-molar extraction, but these studies also include a diverse array of other aetiologies including sagittal split ramus osteotomy (SSRO), mandibular fracture, anaesthesia injection, dental implants and tumour excision. We wanted to determine whether there were different recovery rates based on the injury aetiology. In a study of 186 IAN injury patients, Bagheri *et al.* (8) found no relationship between the cause of injury and FSR. It is difficult to judge whether this result is confirmed in the literature, because there are only a few studies reporting results based on the aetiology. Those studies included in the analysis that report by aetiology are described below.

Third-molar extraction. Yamauchi *et al.* (9) evaluated three LN-injury patients injured during third-molar extraction and treated with tension-free anastomosis. In that study, all the patients had some improvement, although some were still considered sensory impaired. In addition, there was still some taste impairment at the 1- to 2-year follow-up. Rutner *et al.* (10) studied the long-term outcome of LN-injury repair. Nineteen of the 20 patients included in the study had been injured by third-molar extraction. In this study, 90% of patients reported subjective improvement, with 50% rating the improvement as moderate or significant, and 85% showed neurosensory improvement. The assessments included statistically significant increases in response to hot/cold, cotton wisp, vibration, directional stroke, pin pricks, two-point discrimination and light touch.

In a comparison of patient satisfaction and objective neurosensory testing, 19 patients were treated for LN and IAN injury from third-molar extraction. Of those, 84·2% of patients experienced an improvement in neurosensory status, and this change was associated with improved pronunciation. Patient satisfaction was inversely associated with discomfort eating (11). In another study of patient satisfaction following third-molar-injured LN and IAN repair, no objective FSR was reported; however, >50% of the 63 patients reported good to excellent satisfaction with surgery. They observed that taste impairment was more common in LN injuries, and only 35% of patients improved taste sensation following surgery. Taste sensation was also significantly different between good and poor satisfaction groups (12). In a study of 53 patients undergoing LN repair for third-molar injuries, no objective FSR was reported; however, high levels of patient satisfaction were reported with the outcome. Patients showed significantly improved gustatory response. Significant improvements in touch/motion paraesthesia, light touch, pin prick measures, reduced two-point discrimination and accidental biting were reported (13). Farole and Jamal (14) performed a study on third-molar extraction LN and IAN injuries repaired with a NeuraGen®* bioabsorbable collagen nerve cuff. In that study, they showed some success, with eight of nine patients showing some to good improvement. Hillerup (15) studied IAN injuries, including those from third-molar extractions. Interestingly, of the patients who opted out of surgery, only those with third-molar injuries spontaneously recovered, whereas injuries from local anaesthetic injections, implant surgery and endodontic therapy did not.

SSRO. Bagheri *et al.* (16) studied IAN, LN and buccal nerve damage resulting from SSROs in 54 patients. Of

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Table 1. Results of search of included articles with title, authors, publication year and brief description of each study's findings

Year	Author(s)	Title	Intervention (patient numbers)	Aetiology (patient numbers)	IAN/LN (number of nerves), gap length	Time between damage and surgery	Follow-up	Outcomes
2012	Fagin *et al.* (47)	What factors are associated with functional sensory recovery (FSR) following LN repair	Primary anastomosis (38), neurolysis and decompression (17)	Not provided	LN (55), median 12·1 mm	Mean 140 days	Mean 250 days	74·5% achieved FSR post-operatively
2012	Renton and Yilmaz (6)	Managing iatrogenic trigeminal nerve injury: a case series and review of the literature	Reassurance and counselling (114), reassurance and counselling and patient discharged (9), CBT (17), exploration, decompression, and anastomosis (24), neuroma excision (10), medication (12), topical lidocaine patches (15), alternative (3)	Third-molar extraction, local anaesthetic injection, implant treatment, endodontic treatment and others	IAN (123), LN (93)	Median 6 months (IAN), 5·5 months (LN)	Not provided	Significant decreases in the neuropathic area, reduced pain, and improved mechanosensory and subjective function in 15 IAN and 18 LN-injury patients after surgical treatment

Table 1. (continued)

Year	Author(s)	Title	Intervention (patient numbers)	Aetiology (patient numbers)	IAN/LN (number of nerves), gap length	Time between damage and surgery	Follow-up	Outcomes
2012, 2011*	Bagheri *et al.* (8) (Bagheri and Meyer) (48) Both studies are stating same results	Microsurgical repair of the inferior alveolar nerve: Success rate and factors that adversely affect outcome	External decompression (20), internal neurolysis (60), neuroma excision (17), neurorrhapy (18), autogenous nerve graft (71)	Third-molar removal (70), SSRO (31), mandibular fracture (21), implant placement (15), endodontic treatment (14), resection of pathology (9), anaesthetic injection/gunshot/biopsy/pre-prosthetic surgery (26)	IAN (186)	Mean 10·7 months	12 months	Acceptable level of neurosensory function in 152 repairs (81·7%); 18·3% – no or worse results
2011	Kim *et al.* (30)	Effective end-to-end repair of IAN defect using nerve sliding technique	End-to-end direct closure with incisive nerve transection (3)	Not provided	IAN (3), 10 mm	Not provided	Not provided	No post-operative neurological problems
2010	Jones (27)	The use of vein grafts in the repair of the IAN following surgery	Vein grafting (posterior facial vein/external jugular vein) (5)	Third-molar extraction (3), Tumour removal (1), SSRO (1)	IAN (5)	0–18 months	18 months	2 patients – sensory recovery after 3 months; Two patients – sensory recovery after 12–18 months; One patient – no recovery
2010	Bagheri *et al.* (19)	Retrospective review of microsurgical repair of 222 LN injuries	Excision of neuroma with neurorrhaphy (154), external decompression and neurolysis (29), autogenous nerve graft (19), neurorrhaphy (15), external decompression (5)	Third-molar surgery (191), SSRO (14), Local anaesthetic (12), gunshot wound (2), second molar extraction (1), tumour surgery (1), mandible fracture (1)	LN (222)	Mean 8·5 months	≥1 year	Useful sensory recovery to complete return of sensation 90·5%

Table 1. (continued)

Year	Author(s)	Title	Intervention (patient numbers)	Aetiology (patient numbers)	IAN/LN (number of nerves), gap length	Time between damage and surgery	Follow-up	Outcomes
2010	Bagheri *et al.* (16)	Microsurgical repair of the peripheral trigeminal nerve after mandibular SSRO	Nerve graft for IAN (sural/greater auricular) (22), internal neurolysis (12), excisional neuroma with/without neurorrhaphy (14), external decompression (6)	SSRO (54)	IAN (39), LN (14), Long buccal nerve (1)	Mean 9·4 months	≥12 months	Complete return of sensation – 50%; useful sensory function – 35%; no or inadequate recovery – 15%
2009	Bagheri *et al.* (18)	Microsurgical repair of peripheral trigeminal nerve from maxillofacial trauma	Nerve graft (10), external decompression/internal neurolysis (20)	Mandibular angle fracture (IAN 21), mandibular parasymphysis fracture (12), zygomaticomaxillary complex (7), mandibular body fracture (2)	IAN (21), LN (1), Mental nerve (12), Infraorbital nerve (7), Long buccal nerve (1)	Mean 12·5 months	≥12 months	Full recovery or useful sensory function – 86%; no or inadequate recovery – 14%
2009	Ziccardi *et al.* (21)	Comparison of lingual and inferior alveolar nerve microsurgery outcomes	External neurolysis (29), external neurolysis only (4), internal and external neurolysis (6), microsurgical repair including neuroma excision (19)	Extraction (17), root canal treatment (4), implant placement (3), needle stick injury (1), apicoectomy (1), removal of lesion (1), BSSO (1), operculectomy (1)	IAN (15), LN (14)	Mean 234·10 days (IAN), Mean 137·80 (LN)	Not provided	Statistically significant improvement in sensory recovery for those patients who underwent microsurgery for both LN and IAN injuries. Suggested that patients will experience better results if microsurgery is performed before 6 months following injury

Table 1. (continued)

Year	Author(s)	Title	Intervention (patient numbers)	Aetiology (patient numbers)	IAN/LN (number of nerves), gap length	Time between damage and surgery	Follow-up	Outcomes
2008	Hillerup (15)	Iatrogenic injury to the IAN: aetiology, signs and symptoms and observation on recovery	Direct anastomosis (1), decompression (3)	Third-molar surgery (36), Local anaesthetic (5), implant surgery (5), endodontic therapy (4), unknown (2)	IAN (52)	3, 6 and 12 months	Mean 9 months	Two patients with significant sensory recovery; one with recovery of pain perception; one with no neurosensory function
2008	Farole and Jamal (14)	A bioabsorbable collagen nerve cuff for repair of LN and IAN injuries: a case series	External neurolysis, neurorrhaphy excision of neuroma and NeuraGen® nerve guide (9)	Third-molar extraction (8)	IAN (3), LN (6), 15 mm	3–7 months	1·0–2·5 years	4 nerves – good improvement; 4 nerves – some improvement; 1 – no improvement
2008	Tay *et al.* (17)	Immediate repair of transected IAN in SSRO	Transposition, neurorrhaphy (2), transposition, neurorrhaphy, and spot fascicular repair (1)	SSRO (3)	IAN (3)	0	≥1 year	All three patients reported good/excellent improvement in sensory recovery
2007	Susarla *et al.* (20)	Does early repair of LN injuries improve FSR	Direct suture (49), exploration and decompression (15)	Not provided	LN (64)	Mean 153·2 days	Mean 214·4 days	FSR achieved in 52 patients
2006	Yamauchi *et al.* (9)	Experiences in LN repair surgery	Tension-free primary anastomosis (3)	Third-molar surgery (3)	LN (3)	1 day to 4 months	12–24 months	Some improvements

Table 1. (continued)

Year	Author(s)	Title	Intervention (patient numbers)	Aetiology (patient numbers)	IAN/LN (number of nerves), gap length	Time between damage and surgery	Follow-up	Outcomes
2006	Strauss *et al.* (49)	Outcome assessment of IAN microsurgery: a retrospective review	External neurolysis (5), external and internal neurolysis (11), primary microsurgical repair and external neurolysis (12)	Third-molar extraction (12), endodontic treatment (5), implant placement (4), mandible fracture (2) and other causes (5)	IAN (28)	Mean 6·6 months	Mean 9·5 months	92·9% statistically significant neurosensory improvement
2006	Ka *et al.* (50)	Treatment results of acupuncture in inferior alveolar and lingual nerves sensory paralysis after oral surgery	Needles only (A), A with moxibustion, electrical needle stimulation (ESA) using LEP 4000 OhmPulser Ra direct current 6V, 5–100 Hz, and ESA+A; exercise therapy	Third-molar extraction (32), orthognathic surgery (11)	43 patients	No information	No information	Acupuncture is useful in treating sensory paralysis in young patients
2005	Rutner *et al.* (10)	Long-term outcome assessment for LN microsurgery	Microrepair and excision of neuroma (13), external and internal neurolysis (6), external neurolysis (1)	Third-molar surgery (19), Local anaesthetic (1)	LN (20)	Mean 8 months	3·5–14 months	90% of patients reported subjective improvement
2005	Susarla *et al.* (11)	Comparison of patient satisfaction and objective assessment of neurosensory function after trigeminal nerve repair	Exploration w/direct suture repair (14), autologous graft (1), entubulisation (1), neurolysis (3)	Third-molar extraction	IAN (2), LN (17) (6·0–20·0 mm)	Mean 4·5 ± 2·3 (1·4–11·2) months	1 year	The majority of patients (84·2%) experienced improvement in neurosensory status

Table 1. (continued)

Year	Author(s)	Title	Intervention (patient numbers)	Aetiology (patient numbers)	IAN/LN (number of nerves), gap length	Time between damage and surgery	Follow-up	Outcomes
2003	Lam *et al.* (12)	Patient satisfaction after trigeminal nerve repair	Direct suture repair (32), neuroma present (31)	Third-molar extraction	IAN (10), LN (36) 14·3 ± 7·3 mm	Mean 6·8 ± 11·5 months	1 year	>50% reported a satisfaction level of good to excellent
2002	Pogrel (25)	The results of microsurgery of IAN and LN	Decompression (5), excision and anastomosis (26), excision and graft (20)	Not provided	IAN (17), LN (34)	96 h to 9 months	≥1 year	Good improvement (10); some improvement (18); no improvement (22); worse (1)
2001	Pitta *et al.* (29)	Use of Gore-Tex® tubing as a conduit for IAN and LN repair: experience with six cases	Entubulisation using Gore-Tex®	Third-molar surgery (4), endodontic treatment (1), Apicoectomy (1)	IAN (3), LN (3)	Mean 20 months	12–31 months	Two patients reported decreased subjective pain; Two reported return of some sensation to sharp stimulus
2001	Pogrel and Maghen (28)	Autogenous vein grafts for IAN and LN reconstruction	Autogenous vein graft (long saphenous vein graft for LN and facial vein graft for IAN)	Third-molar surgery (14), SSRO (1), endodontic treatment (1)	IAN (6), LN (10), 2–14 mm	4–10 months	Mean 22 months	4 patients – good return of sensation; 5 – some return of sensation; 7 – no return of sensation
2000	Robinson *et al.* (13)	Prospective, quantitative study on the clinical outcome of LN repair	Neuroma excision and anastomosis (53)	Third-molar surgery (53)	LN (53), 4–14 mm	Mean 15 months	1, 4, 12+ months	0–51% responded to most of all light touch stimuli; 34–77% to pinprick stimuli
1998	Pogrel *et al.* (26)	Gore-Tex® as a conduit for repair of LN and IAN continuity defect: a preliminary report	Exploration, neuroma excision and entubulisation with Gore-Tex® tube (5)	Third-molar surgery (4), mandible fracture (1)	IAN (2), LN (5), 5–15 mm	4–30 months	3 years	Two of seven nerves had some return of sensation (defects were 3 mm or smaller)

Table 1. (continued)

Year	Author(s)	Title	Intervention (patient numbers)	Aetiology (patient numbers)	IAN/LN (number of nerves), gap length	Time between damage and surgery	Follow-up	Outcomes
1997	Cornelius *et al.* (22)	Microneural reconstruction after iatrogenic lesions of the lingual nerve and the inferior alveolar nerve. Critical evaluation	LN: direct suturing (39), suturing + sural nerve grafting (23); IAN: direct suturing (11) suturing + sural nerve grafting (10); MN: direct suturing (11)	No information	IAN (21), LN (62), MN (11)	None	14 months	Direct suturing of LN 69% of the patients exhibited protective sensation and 41% regained discriminative function (DF). LN grafting protective function (PF) in 39% and DF in 17%. IAN suturing: 91% PF; 18% DF; IAN grafting: 60% PF, 0% DF
1985	Mozsary and Syers (23)	Microsurgical correction of the injured IAN	Decompression (12), anastomosis (11)	Third-molar surgery (17), Apical surgery (2), Local anaesthetic (4)	IAN (23), 10–15 mm	No information	≥1 year	Full recovery – 20 patient;, partial recovery – 2; no recovery – 1
1984	Mozsary and Middleton (24)	Microsurgical reconstruction of the LN	Exploration, neuroma excision and anastomosis (18)	Tooth extraction (10), Local anaesthetic (3), SSRO (1), other causes (4)	LN (18)	1 month to 2 years	1 year	12 patients – return of sensation; 6 – partial return

*Indicates publication of same results in alternative publication.

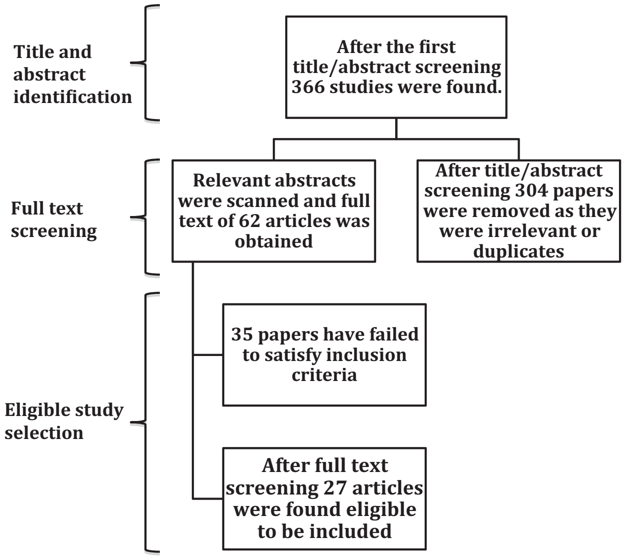

Fig. 1. Three-step search strategy. Title and abstract identification, full-text screening and eligible study selection

the 30 patients who underwent surgery, 85·2% experienced useful sensory recovery or complete return of sensation. The patient subset that refused surgery showed no improvement at 8 weeks. Better outcomes were observed prior to neuroma formation (e.g. earlier repair) and with reduced age. Another study of immediate IAN repair during SSRO demonstrated that immediate repair resulted in good to excellent improvement in sensory function, with no functional problems (drooling, lip biting and speech difficulties) apparent at the 1-year follow-up (17).

Implants. Dental implants can injure the IAN, largely through crush trauma. There are limited studies including implants, and few conclusions are drawn. In a study performed by Renton and Yilmaz (6), they noted that if implants are not removed within 30 h, then no sensory recovery was achieved.

Maxillofacial trauma. One study focused on nerve injuries resulting from maxillofacial trauma, including injuries to the LN and IAN along with the mental nerve, infraorbital nerve and long buccal nerve. In this study, FSR was achieved in 86% of the 30 patients (18).

Time to repair

The time to repair following IAN and LN injury is a controversial topic, and the results are mixed. In one retrospective study of 216 patients with IAN and LN repair, they evaluated 33 surgically treated patients. They reported significant improvements in subjective and mechanosensory function. Better outcomes for LN surgery occurred within 2–3 weeks of injury; however, surgery resolved symptoms up to 2 years after the injury occurred. The authors concluded that the recommended time for exploratory surgery was within 3–6 months of injury (6). In Bagheri *et al.* (8), 81·7% of the 152 IAN injury patients had acceptable FSR within 1 year of surgery. There was a negative correlation between FSR and time to repair, with an 11% decrease in sensory improvement per month of delayed surgery. In a study of 222 LN repairs, they observed that shorter time to repair improved outcomes. Injuries >9 months showed a significantly higher risk of non-improvement. Overall, they observed a 5·8% decrease in the odds of improvement for each month repair was delayed (19). A study of LN-injury repair timing in 64 patients showed that patients undergoing surgery within 90 days had 93% FSR versus 62·9% for those treated after 90 days. Early repair was statistically associated with FSR (hazard ratio 2·3, $P = 0{\cdot}02$) (20).

Ziccardi *et al.* (21) evaluated outcomes in IAN and LN microsurgery in 29 patients. The authors observed significant improvement in two-point discrimination and tactile detection if the surgery was performed within 6 months of the injury. Cornelius *et al.* (22) performed a study of 92 patients undergoing IAN, LN and mental nerve microsurgery. For LN-injury patients treated with direct suturing, improved satisfaction and taste perception were associated with shorter time to repair. Mozsary *et al.* (23) evaluated IAN microsurgery in 23 patients. They observed that all the patients receiving treatment within 1 year recovered fully, whereas patients treated after 1 year only showed a 57·1% full recovery rate. In a study of LN repair performed by the same group, those patients treated within 6 months achieved FSR (24).

In a study of 51 LN and IAN microsurgeries, there was some to good improvement in 88·9% of patients treated within 10 weeks compared with 47·6% in patients treated ≥4 months after the injury. However, these data were not statistically significant (25). The maxillofacial trauma study, described above, showed reduced improvement if surgery was delayed >9 months (18). In Lam *et al.* (12), there was a trend towards improved outcomes with reduced time to repair; however, it was not statistically significant. In a study of Gore-Tex tubing as a nerve conduit for IAN and LN repair, only two of the seven injuries repaired had some return of sensation. The authors attributed the poor FSR to a number of factors, including the fact that only one repair occurred within the 3- to 6-month ideal repair window (26).

Robinson *et al.* (13) achieved significant improvement in a number of sensory function categories including mechanosensation, gustatory and functional outcomes (e.g. speech and tongue biting); however, they saw no correlation between time to repair and procedure success.

Reconstructive methods

There are a number of methods to repair nerve injury. Unfortunately, there is no way to effectively image nerves externally; thus, exploratory surgery is needed, and the treatment decision must occur while the patient is on the operating table. As a result, most studies include mixed results regarding the repair method. However, a number of observations could be pulled from those studies included in the analysis.

External decompression. Bagheri *et al.* (8) observed an 85% FSR rate in those patients treated with external decompression (17 of 20 patients). Additionally, in Mozsary *et al.* (23), decompression-treated IAN patients recovered faster than those treated with anastomosis, with sensation beginning to return within 3 weeks and complete recovery in 2–3 months.

Direct suture/neurorrhaphy. Bagheri *et al.* (8) observed an 88·9% FSR rate in those patients treated with neurorrhaphy (16 of 18 total patients). In Tay *et al.* (17), all three patients were treated with transposition neurorrhaphy, with or without spot fascicular repair, and they achieved 100% FSR. The Robinson *et al.* (13) study used neuroma excision and anastomosis exclusively and showed statistically significant improvement in all sensation measures. In the Cornelius *et al.* (22) study, direct LN suturing restored protective sensation in 69% of patients and discriminative function in 41%, and IAN suturing restored protective function in 91% of patients and discriminatory function in 18%. In Mozsary *et al.* (23), IAN patients treated with anastomosis recovered slower than those treated with decompression, and some did not achieve full recovery within the follow-up time. In Mozsary *et al.* (24), of the 18 LN patients treated with anastomosis, 12 fully recovered and six partially recovered. In contrast, Susarla *et al.* (20) observed that LN neurorrhaphy was associated with neuroma formation, and the patients were 60% less likely to achieve FSR within 1 year compared with decompression treatment. In Yamauchi *et al.* (9), three LN nerves were repaired with primary anastomosis. All patients showed some improvement; however, the patients still exhibited limited sensory and taste impairment.

IAN reconstruction with autogenous grafts. Autogenous grafts can be divided into two categories: nerve grafts and vein grafts. For the nerve grafts, Bagheri *et al.* (8) observed an 87·3% FSR rate (62 of 71 patients) for patients receiving great auricular or sural nerve grafts. The authors noted that great auricular nerve grafts are preferred; however, a sural nerve graft is recommended in the gap is >2 cm. Bagheri *et al.* (16) observed that greater auricular nerve grafts achieved FSR in all three patients receiving this treatment. In Cornelius *et al.* (22), sural nerve grafting restored protective sensation in 60% of patients but no discriminatory function. In regards to vein grafts, Jones *et al.* (2010) used using posterior facial or external jugular veins to repair IAN injury in five patients. Of those, two patients had FSR within 3 months and two had FSR within 18 months (27). Pogrel and Maghen (28) used facial vein grafts to repair IAN injuries in 16 patients. They evaluated sensation using light touch, two-point discrimination and temperature testing. Four of the patients had good return of sensation, five had some sensation return, and seven had no change. Of the three patients whose nerve gap was <5 mm, two achieved good recovery, and one, some recovery. In the 13 patients with nerve gaps >5 mm, only one achieved good recovery, and two, some recovery.

LN reconstruction with autogenous grafts. Generally, grafting is unnecessary for LN repair because the nerve path is tortuous enough to mobilise without tension (19); however, it is occasionally used. In Bagheri *et al.* (16), one patient required a great auricular nerve graft and achieved FSR. In Cornelius *et al.* (22), sural nerve grafting restored protective sensation in 39% of patients and discriminatory function in 17%. In regards to vein grafting, Pogrel and Maghen (28) used long saphenous vein grafts to treat LN injuries in ten patients. Of the three patients with gaps <5 mm, one achieved good recovery and two achieved some recovery. No recovery was achieved in the seven patients with >5 mm gaps (28).

Sleeves. In Bagheri *et al.* (8), the two patients treated with polyglycolic acid sleeves achieved FSR, and the 12 patients treated with absorbable collagen sleeves achieved 83·3% FSR. As mentioned above, Farole *et al.* (14) had some success using the Neurogen® nerve cuff to repair IAN and LN injuries, with four patients showing good improvement and four patients showing some improvement. Gore-Tex®† tubing has been proposed to be a potential nerve conduit. Pitta *et al.* (29) performed a study evaluating its effectiveness. Of the six patients (three LN, three IAN), only two reported reductions in subjective pain, and two reported some return of sharp stimulus sensation. The author could not recommend the use of Gore-Tex as a nerve conduit. Pogrel *et al.* (26) also evaluated Gore-Tex® tubing, and only those defects that were 3 mm or smaller showed some recovery.

IAN reconstruction using nerve sliding. Kim *et al.* (30) introduced a new technique to treat large IAN nerve gaps without grafting. In their method, the 'incisive nerve is intentionally transected from 5 mm anterior to the mental foramen so that a sufficient posterior movability of the distal stump of IAN can be obtained'. Three patients underwent this procedure. While no FSR data were presented, the authors did note that the technique was well tolerated, and the patients did not present with neurological problems relating to the incisive nerve transection (30).

Conclusion

There are a number of potential aetiologies for IAN and LN injury. Neurosensory deficiency in the oral and maxillofacial region is a rare complication of dental procedures such as third-molar extraction, local anaesthetic injection, dental implant placement and root canals. Kim *et al.* (31) stated that following third-molar extraction, IAN injury has an incidence of 0·4–5·5%, and LN injury ranges from 0·06–10%. Similarly, Guerrero *et al.* (32) described the ranges of permanent IAN and LN sensory disturbance after third-molar extraction to be 0·4–13·4% and 0 to 11%, respectively. Local anaesthetic injection-induced IAN or LN damage is rare, and IAN/LN dysfunction spontaneously reverts in 85–94% of patients (33). Hillerup *et al.* (34) concluded that neurotoxicity is the main cause of local anaesthetic-induced injury. Dental implants can cause numbness and unpleasant sensations (35). Tay and Zuniga (36) reported that implant surgery is the fourth most common aetiology of trigeminal nerve injury, accounting for 11% of all cases. The rate of altered sensation caused by implant treatment reportedly ranges between 0% and 43·5% (37), and the incidence of permanent sensory deficit ranges between 0% and 13% (38). Root canal therapy can also cause neurosensory disturbance indirectly due to overfilling the root canals of lower jaw premolars and molars or directly by endodontic instrument-induced nerve damage (39). Altered sensation caused by endodontic therapy is a rare complication, with an incidence of 0·96% (40). Mandibular surgery, such as SSRO, can cause IAN and LN injury (41). Kuroyanagi *et al.* (42) reported that IAN sensory deficit incidence after SSRO varies between 9% and 84·6%. Additionally, lower lip hypoesthesia incidence in affected SSRO patients was 30% at 1 week and 11% at 3 months following surgery. Similarly, maxillofacial trauma can result in post-traumatic neurosensory deficits (43). Thurmuller *et al.* (44) reported that between 8% and 66·7% of patients with mandible fractures complained of altered sensation. In addition to the injury itself, serious IAN sensory disturbances significantly decrease patient quality of life. Consequently, Bagheri *et al.* (18) developed an algorithm for evaluating and treating patients with maxillofacial trauma-related nerve injuries (modified in Fig. 2).

Tumour-associated nerve compression and damage can occur during resection in areas supplied by the IAN and LN, such as the tongue, chin and lower lip, which cause post-operative neurosensory deficits (45). Chow and Teh (46) reported 10 cases of mandible resection involving the IAN, and all patients experienced neurosensory deficiency. However, in contrast to other forms of injury, most patients adapted to tumour-related neurosensory deficit and described minimal effect on their social life and functional outcomes.

Altered sensation following IAN and LN injury is a diagnostic and management challenge for dental clinicians who treat these patients. Correct diagnosis,

†Gore Company, Flagstaff, AZ, USA.

management and appropriate intervention timing are essential for optimising treatment and prognosis following neurosensory deficiency (6, 8, 16, 19, 27, 30, 47, 48). Altered sensation associated with trigeminal nerve branch injury is often easily diagnosed; however, the symptoms are frequently far less definitive and can cause significant difficulties in providing the correct advice to patients (14, 17, 41, 42). In this study, there were different cases reported with significant symptom overlap and divergent means used to assess these symptoms. Subsequently, it was a difficult task to quantitatively compare symptoms from different studies to provide consistent reporting and arrive at treatment consensus. There were multiple sensory tests used in the included studies and little test standardisation to distinguish and quantify the symptoms related to touch, cold and hot sensation and pain (9, 20, 49). However, a few conclusions could be drawn.

When looking at the microsurgical success based on aetiology, it is apparent that the overall FSR rates are fairly equivalent across the various causes of injury. This is consistent with the observations from Bagheri *et al.* (8) that found no relationship between injury aetiology and FSR. When reviewing the studies in depth, those patients that did not respond were largely those with more severe injuries, who had longer time to repair, and older patients. The only exception is dental implants, in which implant removal is required within 30 h of placement to avoid permanent damage (6). In regards to the secondary outcomes, there were a number of notable features. Consistent with the overall FSR, the individual thermo- and mechanosensation markers showed improvement following microsurgery. In third-molar extraction injury repair, neurosensory improvement was concurrent with factors such as hot/cold, light touch, pin prick, and directional detection and improvement in two-point discrimination (10, 13). However, this did not hold true for taste. Third-molar extraction LN injury was associated with taste impairments (9, 12, 13), and reduction in taste impairment was frequently poor (9, 12). In Robinson *et al.* (13), the authors hypothesised that this may be related to poor regeneration of small diameter nerves, such as gustatory fibres. In regards to difficulty eating and speaking, one-third of molar extraction injury study demonstrated that the change in neurostatus was associated

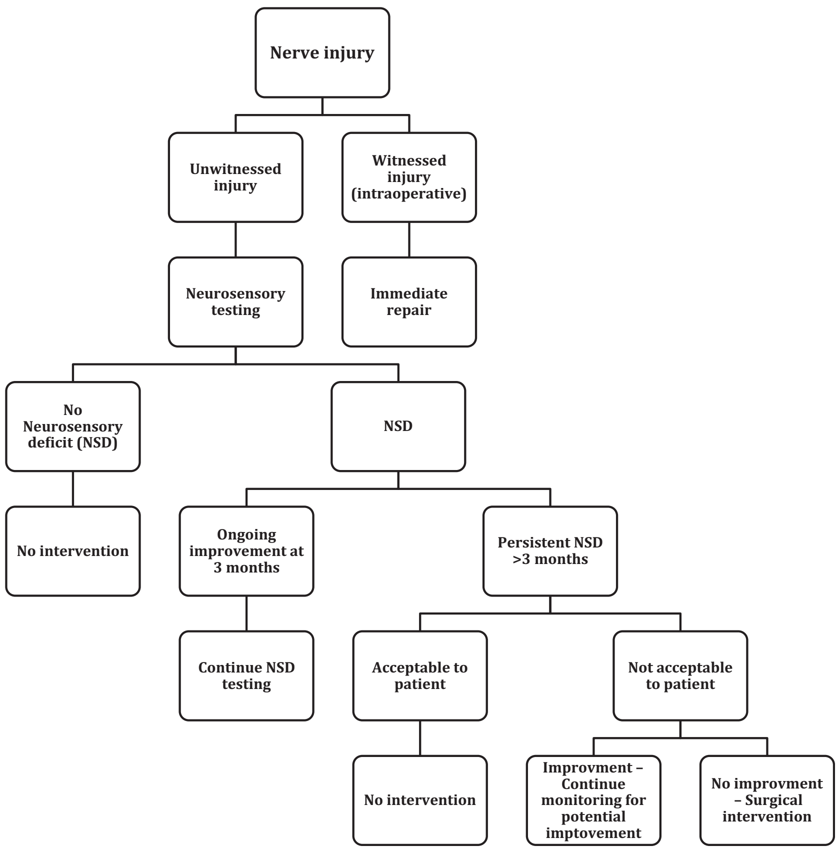

Fig. 2. Algorithm for managing patients with inferior alveolar and lingual nerve injury (updated and modified from Bagheri *et al.*, 2009).

with improved pronunciation, which in turn, led to improved patient satisfaction (11). In Tay *et al.* (17), immediate repair of IAN during SSRO corrected all functional issues, including speech problems, within the first year.

Time to repair played a significant role in overall surgical outcome, although the exact timing is still variable. Susarla *et al.* (20) stated that patients with LN repair within 90 days of injury had FSR within 1 year after repair in 93% of cases. Pogrel stated that microsurgical repair within 10 weeks of injury showed better results for FSR of both the IAN and LN (25, 26, 28). Jones (27) stated that 3 months after injury is the optimal time for nerve repair unless it is known that the injury has occurred at the time of surgery, in which case immediate nerve reconstruction provides better recovery results. Ziccardi *et al.* (21) observed improved treatment of diverse iatrogenic IAN and LN injury if intervention began within 6 months of damage. Two of the larger studies calculated that the odds of FSR decreased between 5·8 and 11% for each month of delay [Bagheri *et al.* (8), Bagheri *et al.* (19)]. When looking at mechanosensation (21), Susarla *et al.* (20) saw significant improvement in two-point discrimination and tactile detection when surgery was performed within 6 months. All these results are in contrast with Robinson *et al.* (13). In that study, they observed no correlation between time to repair and procedure success. In addition, they saw significant improvement in a number of our secondary outcome measures, including taste, mechanosensation and speech function. Despite this contradiction, the overwhelming evidence supports earlier intervention. However, it should be noted that increased time to repair does not necessarily preclude sensory recovery. Many studies had fairly high FSR rates, even in patients who delayed surgery and patients undergoing surgery rarely experienced worsening symptoms (8, 10, 18–20). Thus, patients who were referred late may still have a chance for sensory recovery.

When reviewing repair methods, the literature supports using external decompression or direct suturing of injured nerve ends whenever possible (8, 13, 23, 24). In cases with neuroma excision followed by direct suturing, FSR was slightly decreased or delayed, but this is still the best method overall (20, 24). Where direct suturing without tension is not possible, nerve grafting should be considered (11, 12, 49). There are four types of nerve autografts and allografts: nerve grafts from the sural or great auricular nerves, vein grafts, denatured striated muscle grafts and allografts (Gore-Tex®, resorbable tubes, etc.) (14, 16, 18, 19, 26, 27, 29). Nerve grafts are ideal; however, they can cause sensory defects in the donor site (8). The results from vein grafts and poly glycolic acid and collagen sleeves seem to work best in IAN injuries, which are protected by the mandible, and for shorter gaps (3–5 mm) (8, 14, 22, 27, 28). However, Gore-Tex tubing was ineffective in two independent studies (26, 29). When dealing with the IAN, Kim *et al.* (30) suggested direct end-to-end closure with incisive nerve transection. Using this direct suturing method, three nerves with ≈10 mm gaps were successfully repaired without nerve grafting. Further investigations of this method should be undertaken to obtain more detailed and conclusive results. After thoroughly assessing all the current literature, we revised the suggested treatment guidelines for persistent IAN and LN dysfunction that results from iatrogenic or traumatic injury (Fig. 2). Currently, there is no clear consensus regarding the optimal timing after injury and repair method for IAN and LN treatment. Suggested times to allow spontaneous healing between injury and before surgical intervention vary from 70 days (25, 26, 28) and 90 days (20) to within 6 months (21). Although no sound consensus has been achieved yet, the cumulative data nonetheless strongly suggest that 90 days post-injury should be considered as indicative for surgery if altered sensation remains, particularly if it has not shown recent improvement. If ongoing improvement is apparent, then it might be prudent to delay surgery for up to 6 months while closely following patient symptoms. With respect to the best interventional approach for both IAN and LN repair, direct suturing, if possible with minimal tension, demonstrates the best results for nerve regeneration and FSR. If direct closure is not possible, then grafting would be the treatment of choice. While we acknowledge our need for well-designed RCTs to solidify a consensus on optimal treatment regimens, we have thoroughly scrutinised the currently available literature to develop our revised algorithm of recommended treatment approaches for persistent IAN/LN dysfunction after iatrogenic or traumatic injury.

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Conflict of interest

The authors have no conflict of interest to declare.

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