

Magnetic resonance neurography in the management of peripheral trigeminal neuropathy: experience in a tertiary care centre

Brian Cox¹ · John R. Zuniga² · Neeraj Panchal³ · Jonathan Cheng⁴ · Avneesh Chhabra¹

Received: 10 July 2015 / Revised: 14 December 2015 / Accepted: 18 December 2015 / Published online: 21 January 2016
© European Society of Radiology 2016

Abstract

Objective This tertiary care experience examines the utility of magnetic resonance neurography (MRN) in the management of peripheral trigeminal neuropathies.

Materials and methods Seventeen patients with clinically suspected peripheral trigeminal neuropathies (inferior alveolar nerve and lingual nerve) were imaged uniformly with 1.5-T examinations. MRN results were correlated with clinical and surgical findings in operated patients and the impact on clinical management was assessed.

Results Clinical findings included pain (14/17), sensory changes (15/17), motor changes (2/17) and palpable masses (3/17). Inciting events included prior dental surgery (12/17), trauma (1/17) and idiopathic incidents (4/17). Non-affected side nerves and trigeminal nerves in the intracranial and skull base course were normal in all cases. Final diagnoses on affected sides were nerve inflammation (4/17), neuroma in continuity (2/17), LN transection (1/17), scar entrapment (3/17), infectious granuloma (1/17), low-grade injuries (3/17) and no abnormality (3/17). Associated submandibular gland and sublingual gland oedema-like changes were seen in 3/17 cases

because of parasympathetic effects. Moderate-to-excellent MRN-surgical correlation was seen in operated (8/17) patients, and neuroma and nerve transection were prospectively identified in all cases.

Conclusion MRN is useful for the diagnostic work-up of suspected peripheral trigeminal neuropathy patients with significant impact on clinical management and moderate-to-excellent correlation with intra-operative findings.

Key Points

- MRN substantially impacts diagnostic thinking and management in peripheral trigeminal neuropathy.
- MRN has moderate-to-excellent correlation with intra-operative findings.
- MRN should be considered in pre-surgical planning of peripheral trigeminal neuropathy subjects.

Keywords Trigeminal nerve · Inferior alveolar nerve · Lingual nerve · MRN · Neurography

Introduction

The peripheral trigeminal nerve distal to the skull base can be injured during infratemporal, dental and oral surgery procedures or facial fractures, with more common involvement of the inferior alveolar nerve (IAN) and lingual nerve (LN). Iatrogenic injuries may be related to traumatic anaesthetic injections, dental implant osteotomy or placement, and molar extraction (often the 3rd molar). Some studies have noted a complication rate as high as 13% [1–5]. Less commonly, these nerves can be affected by inflammatory disease or mass lesions [6]. Trigeminal nerve injuries have a profound effect on patients due to resulting functional issues such as drooling while eating or drinking, unintentional chewing of the tongue and lips, pain, heat and cold sensitivity, and difficulty speaking.

✉ Avneesh Chhabra
avneesh.chhabra@utsouthwestern.edu

¹ Department of Radiology, UT Southwestern Medical Center, 5323 Harry Hines Blvd, Dallas, TX 75390-9178, USA

² Department of Oral & Maxillofacial Surgery, Surgery, Neurology & Neurotherapeutics, UT Southwestern Medical Center, Dallas, TX, USA

³ Department of Oral Maxillofacial Surgery, University of Pennsylvania, Philadelphia, PA, USA

⁴ Department of Plastic Surgery, UT Southwestern Medical Center, Dallas, TX, USA

Table 1 The 1.5-T MR neurography protocol

Sequence	TR (ms)	TE (ms)	Slice (mm)	Matrix	FOV/other
Axial T2 SPAIR	5320	69	3.5	320 × 342	Corpus callosum to chin; Tau = 160 ms
Axial T1W	710	8.7	3.5	320 × 342	Corpus callosum to chin
Axial CISS 3D	5.32	2.66	0.8	256 × 256	Suprasellar area to C2 vertebral level
Axial DTI	7100	83	4	74 × 74	Skull base to chin; B values: 0, 800, 1000; directions = 12
Coronal 3D STIR SPACE	3000	78	1.5 iso	320 × 259	Corpus callosum to chin
Coronal 3D DW PSIF	12	3.25	0.9 iso	256 × 208	Corpus callosum to chin

MRN, magnetic resonance neurography; T, Tesla; Iso, isotropic; W, weighted; TR, repetition time; TE, echo time; C, cervical; SPAIR, spectral adiabatic inversion recovery; CISS, constructive interference in steady state; STIR, short tau inversion recovery; SPACE, single-slab 3D acquisition with variable excitation flip angle evolutions; DW, diffusion weighted; DTI, diffusion tensor imaging; PSIF, reversed steady state in free precession

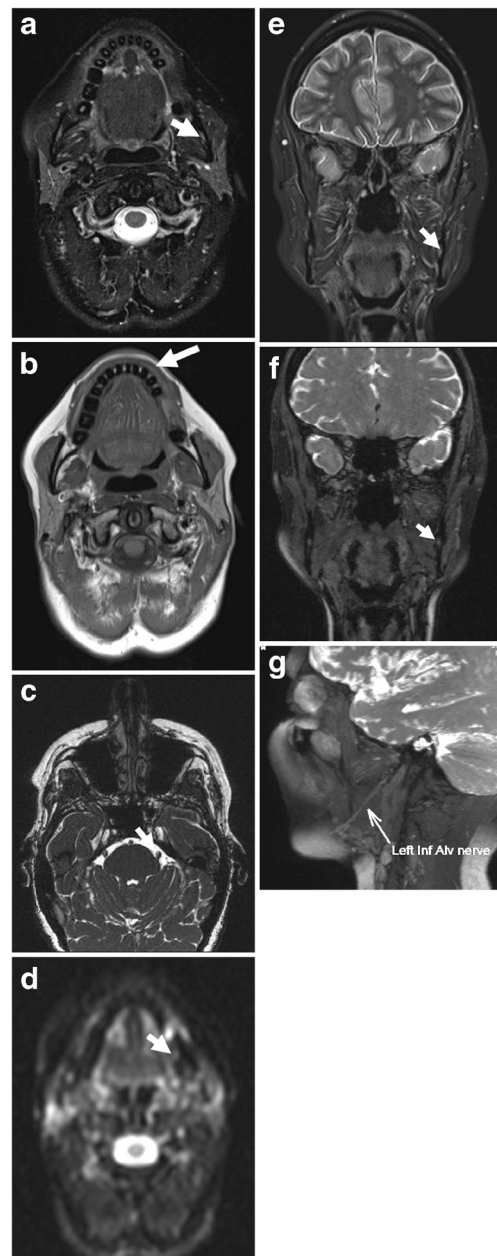


Fig. 1 a–g Peripheral trigeminal nerve MRN. **a** Axial T2 SPAIR, **b** axial T1W, **c** axial CISS-3D and **d** axial DTI images in the *top row* show the normal left inferior alveolar nerve and intracranial trigeminal nerve (*arrows*). **e** Coronal 3D STIR SPACE (non-vessel-suppressed) and **f** coronal 3D DW PSIF (vessel-suppressed nerve selective) imaging shows the left inferior alveolar nerve in the mandibular canal (*arrows*). **g** Sagittal oblique MIP reconstruction from 3D DW PSIF shows the entire course of the left inferior alveolar nerve (*arrow*)

The symptoms of IAN injury can include altered sensation including spontaneous or evoked paresthesia, dysesthesia, analgesia and anaesthesia [7]. Injury to the lingual nerve (LN) may in addition affect taste perception on the affected side of the tongue along with loss of fungiform papillae and parasympathetic changes of the ipsilateral salivary glands. The vast majority (about 90%) of these injuries are temporary in nature and resolve within 8 weeks. However, if the injury persists, it is

Table 2 Patient demographics and clinical findings

Patient	Age	Sex	Inciting event	Duration of symptoms (months)	Pain	Other sensory symptoms	Motor symptoms	Palpable mass
1	58	F	Surgery	48	Y	Y	N	Y
2	48	M	Surgery	1.5	N	Y	N	N
3	55	M	Surgery	36	Y	Y	N	N
4	69	F	Surgery	6	Y	Y	N	N
5	14	F	Surgery	2	N	Y	Y	N
6	46	F	Surgery	8	Y	N	N	N
7	27	F	None	3	Y	Y	N	N
8	61	M	None	2	N	Y	N	Y
9	26	F	Surgery	36	Y	Y	N	N
10	20	M	Surgery	48	Y	Y	Y	N
11	62	F	Surgery	2.5	Y	Y	N	N
12	57	M	None	204	Y	Y	N	N
13	38	M	Surgery	0.5	Y	Y	N	N
14	54	M	Surgery	7	Y	N	N	N
15	29	F	Surgery	8	Y	Y	N	Y
16	43	F	None	3	Y	Y	N	N
17	60	F	Surgery	38	Y	Y	N	N

deemed likely to be permanent [3]. Proper assessment and surgical planning and additionally the decision for surgery and when to employ trigeminal nerve microsurgery techniques warrant in-depth clinical assessment, since the timing of the intervention can impact outcome [1]. Pre-operative imaging of the nerve has previously focussed on identifying the expected location based on known anatomic landmarks and panoramic radiographs; however, these modalities poorly evaluate the nerve or perineural tissues [8]. Magnetic resonance neurography (MRN) is now available for high-resolution demonstration of the peripheral trigeminal nerve and its branches [9–12]. Prior work by Terumitsu et al. showed the importance of the T1-weighted MR sequence in patients with suspected IAN pathologies [13] and the authors showed good correlation of perineural scarring in the mandibular canal with surgery. With currently available 3D (dimensional), steady-state and diffusion-based techniques, better T2W evaluation of different branches of the peripheral trigeminal nerve is possible, which enhances the detection of the alterations in the endoneurial fluid and presence of intra-neural oedema and mass lesions [9, 12, 14, 15]. The purpose was to evaluate a consecutive series of patients suspected of having peripheral trigeminal neuropathy with MRN using a uniform imaging protocol and assess the correlation with surgical findings and the impact of imaging in the clinical management of such patients.

Material and methods

The study was a retrospective chart review and was performed in an HIPAA-compliant manner following

approval of the local IRB. A consecutive series of 17 patients suspected of peripheral trigeminal neuropathies referred from two surgeons (JRZ and JC) for pre-surgical evaluation were included. All imaging studies were uniformly performed using a multichannel head coil on a 1.5-T scanner (Siemens, Avanto, Erlangen, Germany) over a 20-month period (Table 1, Fig. 1). Most imaging studies were performed without intravenous contrast initially with a total imaging time of 45 min. One patient was called back for intravenous gadolinium examination following detection of a mass within the IAN and one had contrast examination during the same study. Patient demographics in terms of age (mean and SD) and sex and clinical findings including the inciting event, prior nerve surgery, duration of symptoms before MRN, pain, other sensory symptoms, motor symptoms and palpable mass were recorded. There were 17 patients including 10 females with age 43.4 ± 18.7 years (mean \pm SD) and 7 males with age 47.5 ± 14.2 years (mean \pm SD) and symptoms ranged from 2 weeks to 17 years (2.2 ± 4.0 years, mean \pm SD) (Table 2). Prior dental work artefact caused suboptimal visualisation of both IAN and LN in 1/17 and isolated lingual nerve in another 1/17 patients. Prior nerve surgery history was present in 2/17 patients; 1 had repair of the distal mental branch of the IAN and the other had prior lingual nerve repair for class 5 injury. Clinical findings included pain (14/17), other sensory changes (15/17), motor changes (2/17) and palpable mass (3/17). Inciting events included prior dental surgery (12/17), trauma (1/17) and idiopathic (4/17). During the image

Table 3 MRN findings and impact, surgical correlation and impact on management

Patient	Peripheral trigeminal branch affected IAN, LN	Signal change, caliber change	Mass lesion	Perineural fibrosis	Final Impression	Impact on clinical management	Surgical correlation	Duration of follow-up after imaging	Follow-up and clinical outcome
1	-	N	N	N	N	Normal	Substantial	-	Lost follow-up
2	LN	Y	Y	Y	N	Injury-transsection	Substantial	Excellent	Improved
3	IAN	N	Y	N	Y	Entrapment	Mild	-	Lost to follow-up
4	IAN	Y	Y	N	Y	Injury-low grade	Unchanged	Moderate	Improved
5	LN,IAN	Y	Y	N	N	Injury-low grade	Unchanged	Moderate	Improved
6	IAN	Y	Y	N	N	Inflammation	Mild	-	Conservative management, unchanged
7	IAN	Y	Y	N	N	Inflammation	Mild	-	Conservative management, unchanged
8	IAN	Y	Y	N	N	Infection/granuloma	Mild	Moderate	Improved
9	IAN, LN	Y	N	Y	Y	Neuroma in continuity	Substantial	Excellent	Unchanged
10	IAN	Y	N	N	N	Inflammation	Unchanged	Balloon rhizotomy	Improved
11	IAN	Y	Y	Y	Y	Entrapment	Substantial	Excellent	Improved
12	-	N	N	N	N	Normal	Unchanged	-	Conservative management, unchanged
13	IAN	Y	Y	N	Y	Entrapment	Substantial	Moderate	Post-operative
14	IAN	Y	Y	N	N	Inflammation	Mild	-	Conservative management, unchanged
15	LN	Y	Y	Y	Y	Neuroma in continuity	Substantial	Moderate	Surgical management, unchanged
16	IAN	N	N	N	N	Metal artifact, otherwise normal	Unchanged	-	Conservative management, unchanged
17	IAN	Y	Y	Y	Y	Injury-low grade	Mild	-	Conservative management, unchanged

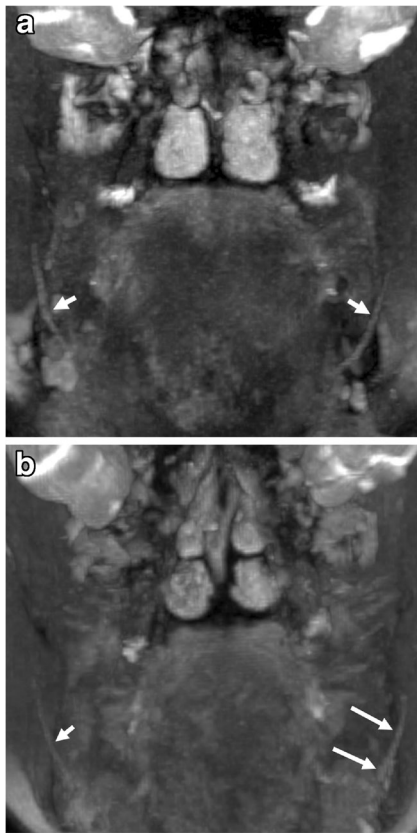


Fig. 2 a, b Coronal 3D DW PSIF MIP images showing: **a** Patient 1: Normal symmetric bilateral IANs (*small arrows*). **b** Patient 7: There is mild asymmetric thickening and hyperintensity of the left IAN (*long arrows*) distally along its course as compared to the right normal IAN (*small arrow*) suggesting inflammation

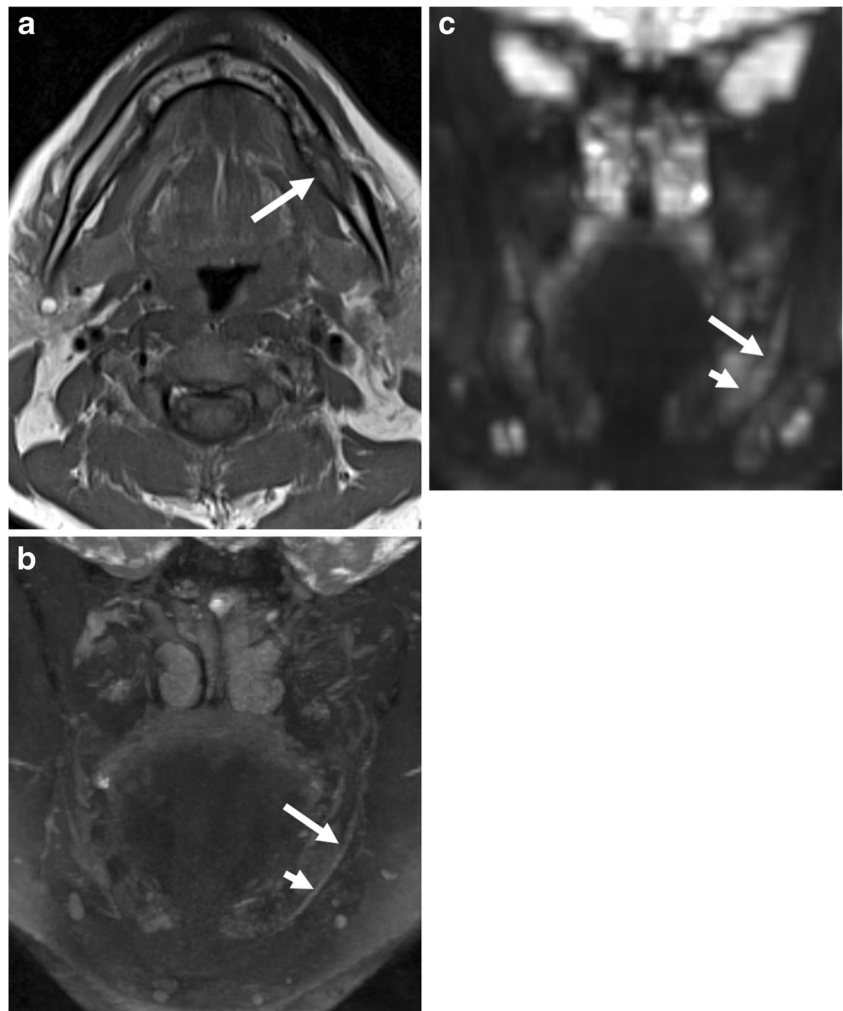
evaluation, from 3D isotropic MRN sequences, thick slab maximum intensity projections (MIPs) were obtained in nerve longitudinal planes (coronal and oblique sagittal) on an independent workstation (Aquarius, Tera Recon, Foster City, CA, USA). The MRN findings of nerve signal and calibre alteration were read as part of clinical care by two readers (attending: 19 years and multiple fellows: 5 years of radiology experience) in consensus in light of the clinical findings, but blinded to the side of abnormality, and no separate independent reads were performed. The final impression was generated in terms of normal, entrapment, injury or a mass lesion. Perineural fat planes were assessed for the presence of scarring or mass lesions. The CISS 3D sequence was employed in the protocol to exclude any intracranial neural pathology and the axial T1W and T2 SPAIR sequences were extended to the corpus callosum to the chin to exclude any intra-nuclear or adjacent intra-cranial pathology. The impact on the diagnosis and clinical management was assessed as none (no change in diagnosis, nerve involved or pre-MRN treatment strategy), mild (change in diagnosis, nerve or

alternative diagnosis but no change in treatment) and substantial (change in diagnosis or change in involved nerve with change in proposed treatment, such as change from proposed follow-up to immediate surgery or change from surgery to non-surgical management). Based on the MRN results, the surgeons offered non-operative treatment, operative treatment (for entrapment, mass and high-grade nerve injuries—neuroma in continuity and transection cases) and rhizotomy (long-standing low-grade injury cases). Surgical correlation of MRN findings was obtained in the operated cases and was classified as poor (no substantiation of MRN findings), moderate (partial correlation) or excellent (full substantiation of MRN findings) correlation. Follow-up clinical status after imaging and surgery was also recorded.

Results

On MRN, the nerve abnormalities were seen in the IAN (13/17), LN (2/17), and both IAN and LN (2/17) (Table 3). Ipsilateral signal changes were seen in 13/17, diffuse nerve thickenings in 12/17, focal mass-like nerve thickenings in 4/17 and perineural fibrosis in 7/17. Enhancement on contrast administration was seen in 1/17 patient with focal mass-like thickening in the proximal mandibular canal, which decreased slightly on follow-up MRN examination after 2 months. The contralateral nerves and trigeminal nerve in the intracranial and skull base course were normal in all cases. Associated submandibular gland and sublingual gland oedema-like changes were seen in 3/17 cases because of parasympathetic effects. Final diagnoses were nerve inflammation (4/17) (Fig. 2), scar entrapment (3/17) (Fig. 3), neuroma in continuity (2/17) and LN transection (1/17) (Figs. 4 and 5), infectious granuloma (1/17), low-grade injuries (3/17) and no abnormality (3/17) (Figs. 3 and 4). Six of 17 studies resulted in a substantial impact on management, 6/17 in a mild impact and 5/17 did not change management. Moderate-to-excellent MRN-surgical correlation was seen in operated (8/17) patients. Neuroma, nerve entrapment and nerve transection were prospectively identified in all cases on MRN with excellent correlation (Fig. 5). One patient had class 4 injury on surgery, which was overcalled on MRN as class 4/5 injury because of suboptimal identification of a small segment of the LN on MRN related to encasement in scarring. It was classified as moderate correlation. Other cases of low-grade injuries and entrapments were classified as moderate correlation, where the surgeon found more scarring than was seen on MRN and in one case, there was foreign material in the inferior

Fig. 3 a–c Left IAN entrapment: Patient 11. **a** Axial T1W image shows perineural fibrosis (*arrow*) along the course of the left IAN with obscuration of the nerve. **b** Coronal 3D DW PSIF MIP image shows the thickened and hyperintense left IAN (*small arrow*) with mild contour irregularity due to entrapment. **c** The respective abnormalities are nicely seen on the MIP image from DTI



alveolar nerve from a prior injury, which was not prospectively seen on MRN. Follow-up ranged from 1 week to 19 months and most cases improved following surgery or intervention (balloon rhizotomy), i.e. 8/9 cases with intervention.

Discussion

This study confirms that high-resolution MRN is very useful in the evaluation of peripheral trigeminal neuropathies. Pain and other sensory changes correctly point to the side of the abnormality; however such symptoms are not specific to the aetiology or location of the lesion and are noted in most cases. MRN correctly showed normal nerves on the asymptomatic side as intermediate signal without hyperintensity or caliber alterations, corroborating the excellent negative

predictive value of the examination. The intracranial segment and proximal trigeminal nerve at the base of the brain and in the infratemporal fossa were also normal in all cases, leading to good localisation of the lesion in the periphery, which has not been shown before. On the abnormal side, not only perineural scarring was identified on T1W images, as previously shown by Terumitsu et al. [13], but also nerve signal changes and calibre alterations were seen in most cases on high-resolution fat-suppressed fluid-sensitive 2D and 3D T2W images. For the three cases (one degraded by metal artefacts) where nerves were seen as normal, it may be hypothesised that the sensory nerve abnormality was below MRN resolution. However, a contribution of psychological and other multifactorial causes is not excluded. MRN did not find a surgical cause to address in those cases, which is also important for management purposes.

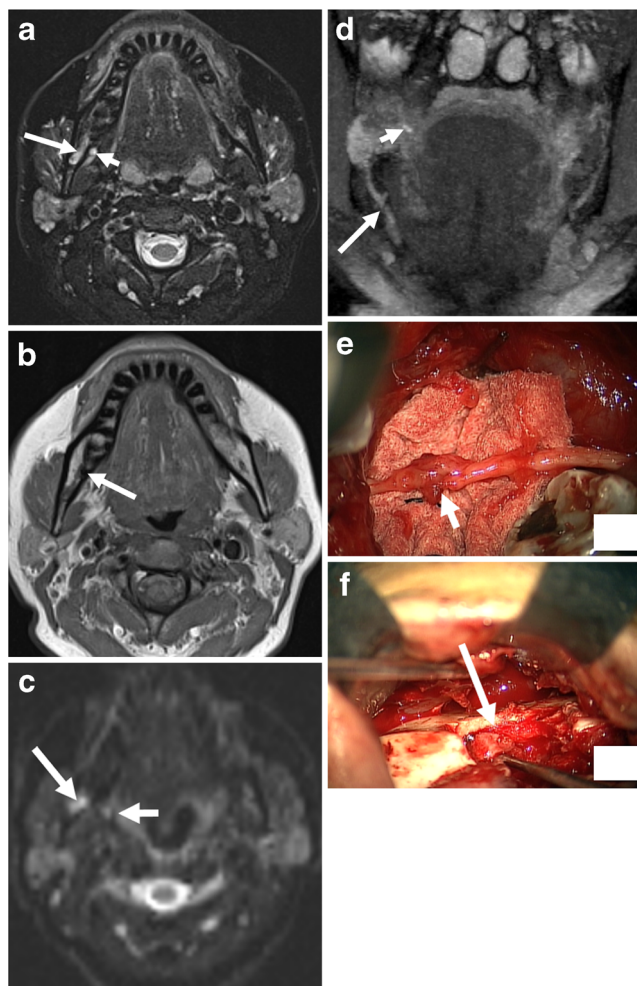


Fig. 4 a–f Patient 9. **a** Axial T2 SPAIR image shows thickened and hyperintense right IAN (*long arrow*) and LN with a small neuroma in continuity (*small arrow*). **b** Axial T1W image shows perineural fibrosis around the thickened IAN (*long arrow*). **c** Axial DTI shows good vascular signal suppression and confirms the above neural abnormalities (*arrows*). **d** 3D DW PSIF MIP image also shows a neuroma in continuity of the LN (*small arrow*) and abnormally thickened irregular IAN (*long arrow*). **e, f** Intraoperative pictures confirm the neuroma in continuity of the LN (*small arrow* in **e**) and entrapped thickened IAN with perineural fibrosis (*long arrow* in **f**)

We could produce excellent image quality on 1.5-T scanners using a head coil. In only two cases, the nerves were sub-optimally visualised because of dental hardware-related susceptibility artefacts. The isotropic 3D images could be easily reconstructed to produce long axis images of the peripheral trigeminal branches, which showed asymmetric signal and calibre alterations on the affected sides. The water-selective fat-suppressed 3D DW PSIF imaging sequence was ideal in demonstrating the IAN and LN selectively with excellent fat and vascular signal suppression [10, 12]. The neuroma in continuity (class 4 injury), scar entrapment and lingual nerve transection (class 5

injury) were correctly identified with moderate-to-excellent surgical correlation [16]. Use of T1W, T2W and DTI images in tandem aids in the evaluation of neural abnormalities, perineural fibrosis and the ancillary finding of salivary gland parasympathetic changes. The abnormality shows up as considerably bright signal on DTI and 3D STIR SPACE and 3D DWPSIF images as compared to 2D images. The reconstructions along the long axis of the nerve showed both calibre alterations and discontinuity for the surgeon's benefit in contemplating pre-operative planning [17–19].

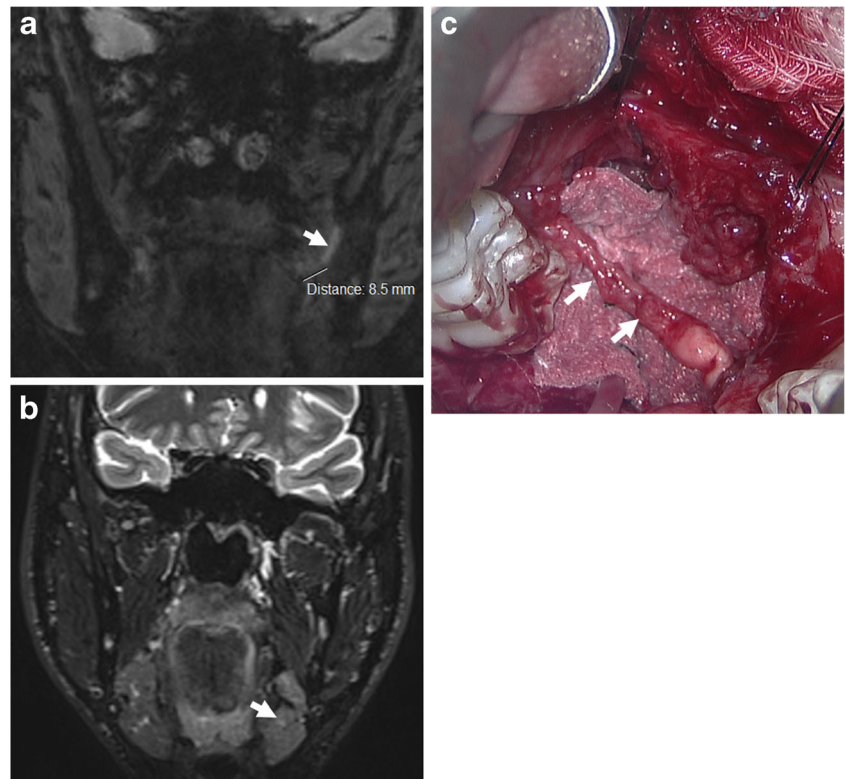
The impact on clinical management was important. Less than 1/3 of the cases (29%) did not have a change in clinical management and in about 35% of cases it changed substantially. Clinical findings thus need objective substantiation from high-resolution imaging, such as MRN [20, 21]. Additionally, pain can be present before and after nerve repair and does not point to resolution or improvement of the nerve injury [22]. This was also seen in one of our previously operated patients; MRN could find an unsuspected neuroma in continuity, which was resected with nerve repair. Currently, there is controversy regarding how to best treat these nerve injuries, with increasing evidence seeming to point towards better outcomes with nerve grafting as compared to the primary repair [3, 23]. However, no studies have reported the effects of the intervention on the remaining primary outcomes of pain, difficulty eating or speaking, or taste or quality of life. This study also did not assess the long-term outcome, although in the short term, most cases improved following surgery. However, that was not the primary objective of the study. Other limitations of the study include selection bias, as these cases came from surgeons and not primary physicians, and the small sample size.

In future, larger prospective studies can be performed in a single or multicentre trial to evaluate the patient outcomes and impact of MRN on management [24]. Further refinement of the techniques may help to image the sensory nerves in both the absence and presence of dental artefacts. Finally, we did not attempt to correlate the imaging findings with objective neurosensory testing [25], which, of note, is not universally performed in different centres managing peripheral trigeminal neuropathy.

Conclusion

To summarise, MRN is useful for the diagnostic work-up of suspected peripheral trigeminal neuropathy patients with significant impact on the clinical management and moderate-to-excellent correlation with intra-operative findings.

Fig. 5 a–c. **a** Patient 2: Coronal 3D DW PSIF image showing enlarged thickened and the discontinuous left lingual nerve (*arrow*) with the nerve gap measuring 8.5 mm. **b** Coronal 3D STIR SPACE image showing hyperintense left submandibular gland (*arrow*) due to parasympathetic effects. **c** Intraoperative picture showing the discontinuous nerve gap filled with scarring. Following neurolysis to refashion the nerve endings, the nerve gap measured 12 mm and was repaired with allograft



Acknowledgments The scientific guarantor of this publication is Avneesh Chhabra. The authors of this manuscript declare relationships with the following companies: Avneesh Chhabra serves as a consultant with Siemens for the MSK CAD group. He also receives royalties from the Jaypee, Wolters and Elsevier groups of publishers. The authors state that this work has not received any funding. One of the authors has significant statistical expertise. Institutional Review Board approval was obtained. Written informed consent was waived by the Institutional Review Board. Methodology: retrospective, diagnostic or prognostic study performed at one institution.

References

- Ziccardi V, Zuniga J (2007) Nerve injuries after third molar removal. *Oral Maxillofac Surg Clin N Am* 19:105–115
- Tay AB, Lai JB, Lye KW, Wong WY, Nadkarni NV, Li W, Bautista D (2015) Inferior alveolar nerve injury in trauma-induced mandible fractures. *J Oral Maxillofac Surg*
- Coulthard P, Kushnerev E, Yates JM, Walsh T, Patel N, Bailey E, Renton TF (2014) Interventions for iatrogenic inferior alveolar and lingual nerve injury. *Cochrane Database Syst Rev* 4, CD005293
- Tay AB, Zuniga JR (2007) Clinical characteristics of trigeminal nerve injury referrals to a university centre. *Int J Oral Maxillofac Surg* 36(10):922–927
- Ellies LG (1992) Altered sensation following mandibular implant surgery: a retrospective study. *J Prosthet Dent* 68:664–671
- Fujita H, Kokubun N, Sada T, Nagashima T, Komagamine T, Kawabe K, Hirata K (2015) Demyelinating hypertrophic inferior alveolar nerve mimicking a nerve tumor. *Intern Med* 54(9):1109–1111
- Alhassani A, AlGhamdi A (2010) Inferior alveolar nerve injury in implant dentistry: diagnosis, causes, prevention, and management. *J Oral Implantol* 36(5):401–407
- Liu W, Yin W, Zhang R, Li J, Zheng Y (2015) Diagnostic value of panoramic radiography in predicting inferior alveolar nerve injury after mandibular third molar extraction: a meta-analysis. *Aust Dent J*
- Cassetta M, Pranno N, Pompa V, Barchetti F, Pompa G (2014) High resolution 3-T MR imaging in the evaluation of the trigeminal nerve course. *Eur Rev Med Pharmacol Sci* 18(2):257–264
- Chhabra A, Subhawong TK, Bizzell C, Flammang A, Soldatos T (2011) 3T MR neurography using three-dimensional diffusion-weighted PSIF: technical issues and advantages. *Skelet Radiol* 40(10):1355–1360
- Vargas MI, Viallon M, Nguyen D, Beaulieu JY, Delavelle J, Becker M (2010) New approaches in imaging of the brachial plexus. *Eur J Radiol* 74(2):403–410
- Fujii H, Fujita A, Yang A, Kanazawa H, Buch K, Sakai O, Sugimoto H (2015) Visualization of the peripheral branches of the mandibular division of the trigeminal nerve on 3D double-echo steady-state with water excitation sequence. *AJNR Am J Neuroradiol*
- Terumitsu M, Seo K, Matsuzawa H, Yamazaki M, Kwee IL, Nakada T (2011) Morphologic evaluation of the inferior alveolar nerve in patients with sensory disorders by high-resolution 3D volume rendering magnetic resonance neurography on a 3.0-T system. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 111(1):95–102
- Chhabra A, Soldatos T, Subhawong TK, Machado AJ, Thawait SK, Wang KC, Padua A Jr, Flammang AJ, Williams EH, Carrino JA (2011) The application of three-dimensional diffusion-weighted

- PSIF technique in peripheral nerve imaging of the distal extremities. *J Magn Reson Imaging* 34(4):962–967
15. Chhabra A, Carrino J (2015) Current MR neurography techniques and whole-body MR neurography. *Semin Musculoskelet Radiol* 19(2):79–85
 16. Seddon HJ, Medawar PB, Smith H (1943) Rate of regeneration of peripheral nerves in man. *J Physiol* 102:191–215
 17. Kasper JM, Wadhwa V, Scott KM, Rozen S, Xi Y, Chhabra A (2015) SHINKEI—a novel 3D isotropic MR neurography technique: technical advantages over 3DIRTSE-based imaging. *Eur Radiol* 25(6):1672–1677
 18. Breitenseher JB, Kranz G, Hold A, Berzaczy D, Nemeč SF, Sycha T, Weber M, Prayer D, Kasparian G (2015) MR neurography of ulnar nerve at the cubital tunnel: a diffusion tensor imaging study. *Eur Radiol* 25(7):1911–1918
 19. Baumer P, Kele H, Kretschmer T, Koenig R, Pedro M, Bendszus M, Pham M (2014) Thoracic outlet syndrome in 3T MR neurography—fibrous bands causing discernible lesions of the lower brachial plexus. *Eur Radiol* 24(3):756–761
 20. Jengojan S, Kovar F, Breitenseher J, Weber M, Prayer D, Kasparian G (2015) Acute radial nerve entrapment at the spiral groove: detection by DTI-based neurography. *Eur Radiol* 25(6):1678–1683
 21. Schwarz D, Weiler M, Pham M, Heiland S, Bendszus M, Bäumer P (2015) Diagnostic signs of motor neuropathy in MR neurography: nerve lesions and muscle denervation. *Eur Radiol* 25(5):1497–1503
 22. Zuniga JR, Yates DM, Phillips CL (2014) The presence of neuropathic pain predicts postoperative neuropathic pain following trigeminal nerve repair. *J Oral Maxillofac Surg* 72(12):2422–2427
 23. Miloro M, Ruckman P 3rd, Kolokythas A (2015) Lingual nerve repair: to graft or not to graft? *J Oral Maxillofac Surg*
 24. Chhabra A, Belzberg AJ, Rosson GD, Thawait GK, Chalian M, Farahani SJ, Shores JT, Deune G, Hashemi S, Thawait SK, Subhawong TK, Carrino JA. Impact of high resolution 3 tesla MR neurography (MRN) on diagnostic thinking and therapeutic patient management. *Eur Radiol*. 2015 Sep 22. doi:10.1007/s00330-015-3958-y
 25. Zuniga JR (2015) Sensory outcomes after reconstruction of lingual and inferior alveolar nerve discontinuities using processed nerve allograft—a case series. *J Oral Maxillofac Surg* 73(4):734–744