RESEARCH ARTICLE

3.0 Tesla MRI in the early evaluation of inferior alveolar nerve neurological complications after mandibular third molar extraction: a prospective study

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Objectives: To evaluate the use of 3.0 T MRI in the prognosis of inferior alveolar nerve (IAN) sensory disorders after mandibular third molar extraction, in the early post-operative period.

Methods: 343 IANs were examined before and 3 days after surgery. Two radiologists evaluated the course of the nerve and the relative signal intensity (RSI). Cohen's kappa coefficient (κ) and intraclass correlation coefficient (ICC) were used to evaluate the interobserver ($\kappa = 0.891$) and intra-observer variability (ICC = 0.927; 0.914, respectively). The IANs were divided into four groups on the basis of neurosensory disorders recovery time. ANOVA was used to evaluate the differences among the RSIs of the four groups, and multiple comparisons were performed with Tukey's range test.

Results: No differences in the course of IANs were found before and after surgery. In 280 IANs, no iatrogenic paraesthesia was found (Group A). 63 IANs showed a neurosensory impairment. 38 IANs showed recovery of post-operative paraesthesia at 3-month follow-up (Group B). 16 IANs showed a full recovery of iatrogenic paraesthesia at 6-month follow-up (Group C). Seven IANs displayed a full recovery at 12-month follow-up and two IANs showed persistence of neurosensory disorders at 18-month follow-up (Group D). The one-way ANOVA results indicated statistically significant difference among all groups ($p < 0.05$), except between Groups C and D ($p = 0.504$).

Conclusions: The early evaluation of RSI values represents a valid tool to determine the prognosis of IAN sensory disorders after mandibular third molar extraction.

Dentomaxillofacial Radiology (2014) **43**, 20140152. doi: [10.1259/dmfr.20140152](https://doi.org/10.1259/dmfr.20140152)

Cite this article as: Cassetta M, Pranno N, Barchetti F, Sorrentino V, Lo Mele L. 3.0 Tesla MRI in the early evaluation of inferior alveolar nerve neurological complications after mandibular third molar extraction: a prospective study. *Dentomaxillofac Radiol* 2014; **43**: 20140152.

Keywords: magnetic resonance imaging; third molar; inferior alveolar nerve; oral surgery; trigeminal nerve injuries

Introduction

The inferior alveolar nerve (IAN), a branch of the mandibular nerve, is at risk of injury that may occur in tumours, trauma and several orofacial surgical procedures such as extraction of the mandibular third molar,¹ orthognathic surgery of the mandible,² root canal

treatment,³ block anaesthesia and dental implant surgery.^{4,5} The damage of the IAN may result in neurosensory impairment ranging from complete anaesthesia to more common partial loss of sensitivity. The percentage of neurosensory impairment related to IAN injuries during the extraction of the third molar is around 4% (0.4–8.4%).^{1–7} The neurosensory impairment can be owing to iatrogenic resections of the IAN or the compression

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Received 14 May 2014; revised 17 June 2014; accepted 18 June 2014

of this nerve caused by the presence of inflammatory tissue or oedema.

MRI has been widely used in the study of temporomandibular joint and in the field of oral and maxillofacial surgery.^{8–13} Currently, there are no studies using MRI in the evaluation of early neurological complications resulting from the extraction of the mandibular third molar.

The purpose of this study was to evaluate, in the early post-operative period, the use of 3.0 T MRI in the prognosis of IAN sensory disorders after mandibular third molar extraction, assessing the IAN course and the signal intensity (SI).

Methods and materials

Patient population

A prospective study was carried out between January 2008 and April 2012. The inclusion criteria were an indication for mandibular third molar extraction and one of the following radiographic findings detected on panoramic radiography (Ortophos XG plus[®]; Sirona,

Bensheim, Germany): the lower third molar root apexes reached the upper cortical boundary of the mandibular canal, the lower third molar root apexes were superimposed by the mandibular canal or one of the lower third molar root apexes reached over the inferior cortical line of the mandibular canal wall.

Patients with IAN sensory disorders, expansile lesions of the jaw or previous mandible fractures were excluded from the study.

A total of 196 patients were included (112 males and 84 females; mean age, 23 years; range, 19–32 years).

Patients were informed of the study protocol and signed an informed consent form. The study was approved by the local ethics committee (Umberto I General Hospital of Rome, Rome, Italy) and conducted in accordance with the Helsinki Declaration of 1975 as revised in 2000.

MRI acquisition protocol

All patients underwent a MRI examination before the third molar surgery and 3 days after the extraction. MR was performed using a 3.0 T superconducting magnet (Discovery MR750; GE Healthcare, Milwaukee, WI) equipped with an eight-channel neurovascular

Figure 1 T_2 weighted three-dimensional (3D) fast imaging employing steady-state acquisition (a–c) and T_1 weighted 3D fast spoiled gradient recalled echo (d–f) images showing the procedure to obtain an optimal plane to display the inferior alveolar nerve. In multiplanar reformation technique, the reference axes were centred in the proper axial images at the level of the mandibular third molar with an axis oriented parallel and the other perpendicular to the alveolar bone to achieve a parasagittal plane to correctly depict the course of the inferior alveolar nerve. A, anterior; F, foot; H, head; L, left; P, posterior; R, right.

phased-array coil (GE Healthcare). The standardized imaging protocol included T_2 weighted three-dimensional fast imaging employing steady-state acquisition (3D FIESTA) and T_1 weighted fast spoiled gradient recalled echo (3D SPGR) sequences. Imaging parameters of 3D FIESTA sequence were repetition time = 4.6 ms; echo time = 2.2 ms; slice thickness = 0.6 mm; field of view = 20×20 cm; number of excitations = 1; matrix = 512×512 pixels. Imaging parameters of 3D SPGR sequence were repetition time = 8 ms; echo time = 3 ms; slice thickness = 0.6 mm; field of view = 15×21 cm; number of excitations = 2; matrix = 512×512 pixels.

Axial acquisition was obtained for both sequences.

MRI post-processing and image interpretation

Two experts in oral radiology (Reader A with 30 years' experience and Reader B with 7 years' experience) evaluated the images independently and were blinded to clinical symptoms during three reading sessions. The images were evaluated on an offline dedicated workstation (AW VolumeShare2™; GE Healthcare). Optimal planes, including the course of IAN, were determined by using multiplanar reformation and the imager's standard reformation software (Figure 1).

In the first reading session, the IAN course in pre- and post-surgery images was assessed and compared.

During the second reading session, the SI in the post-surgery sites was evaluated. The measurements were made on 3D FIESTA coronal reconstructed images. Different sizes of regions of interest (ROIs) had been tested to measure the T_2 signal before starting the study. An area of 15 mm^2 was found to be appropriate for this study because it was the largest area that could be consistently used throughout the study without including volume averaging artefacts from structures outside the post-surgery site. The ROIs were placed in the surgical sites, including the IAN, and in the masseter muscle (Figure 2). The relative SI (RSI) of the post-surgical site was referenced to the SI of the ROI in the masseter muscle ($\text{RSI of post-surgical site} = \text{SI of ROI in surgical site} / \text{SI of the ROI in the masseter muscle}$).

In the last reading session, performed after 1 month to avoid recall bias, the specialists reassessed the RSIs to calculate the intra-observer variability.

Clinical evaluation

All patients, before and 3 days after the extraction of the third molar, were tested in the mental nerve area using the quantitative sensory testing, which is standard clinical evaluation for all types of sensitivities, as described by Said-Yekta *et al.*¹⁴

The quantitative sensory testing was repeated after 1, 3, 6, 12 and 18 months in patients with post-operative paraesthesia, to evaluate the progressive reduction, the persistence or the recovery of the neurosensory disorders.

The IANs were divided into four groups. Group A included those with no iatrogenic neurosensory disorders. Group B included IANs with recovery of post-operative

Figure 2 A T_2 weighted three-dimensional fast imaging employing steady-state acquisition reconstructed coronal image of a 30-year-old patient presenting dysaesthesia in the right side of the mental area after bilateral third molar extraction and recovery at 3-month follow-up. To obtain the relative signal intensity (RSI), a region of interest of 15 mm^2 was placed in the post-surgical site, including the inferior alveolar nerve, and in the masseter muscle. A higher RSI value in the mandibular side with dysesthesia (1.531) than that of the contralateral side without inferior alveolar nerve sensory impairment (0.536) was found. Avg, average; max, maximum; min, minimum; SD, standard deviation.

paraesthesia at 3-month follow-up. Group C included IANs with recovery of post-extraction paraesthesia at 6-month follow-up. Group D included IANs with recovery of post-extraction paraesthesia at 12-month follow-up or without any recovery of neurosensory disorders.

Statistical analysis

Descriptive statistics, including mean values and standard deviation, were used.

RSI values of the four groups were illustrated using box plots.

Cohen's kappa coefficient (κ) was used to evaluate the interobserver variability. Intraclass correlation coefficient was used to assess the intra-observer variability.

One-way ANOVA was used to evaluate the differences among the RSIs of the four groups and multiple comparisons were performed with Tukey's range test.

Data were evaluated using the statistical analysis software SPSS® v. 17.0 (IBM Corporation, Armonk, NY). In all analyses, a $p \leq 0.05$ was considered as an indicator for statistical significance.

Results

147 patients underwent bilateral mandibular third molar surgical removal, whereas 49 patients received unilateral mandibular third molar extraction, for a total of 343 IANs evaluated.

In all IANs, no differences in the course were found before and after surgery (Figure 3).

Figure 3 T_2 weighted three-dimensional (3D) fast imaging employing steady-state and T_1 weighted 3D fast spoiled gradient recalled echo reconstructed parasagittal images of a 27-year-old patient with neurosensory impairment, showing the course of the inferior alveolar nerve (black arrowheads) before (a, c) and 3 days after (b, d) the right third molar extraction. The relationship between the inferior alveolar nerve and third molar roots is well depicted (black arrows). No differences in morphological appearance were found before and after surgery. A, anterior; F, foot; H, head; L, left; P, posterior; R, right.

In 280 IANs, no iatrogenic paraesthesia was found (Group A).
63 out of 343 IANs showed a neurosensory impairment in the mental nerve area with reduction of the protopathic, epicritic and pain sensibility documented by quantitative sensory testing. In 38 out of the 63 IANs, a recovery of post-operative paraesthesia within the third month of follow-up (Group B) was recorded:

26 IANs showed a complete recovery of sensitivity at the first month of the follow-up, whereas 12 had a reduction of the hyposensitivity area at the first month and a full recovery of sensitivity at the third month of the follow-up. 16 out of the 63 IANs with post-extraction paraesthesia (Group C) showed a full recovery of iatrogenic paraesthesia at the sixth month of follow-up. 7 out of the 63 IANs with post-operative paraesthesia

Table 1 Descriptive statistics of the relative signal intensity values in the different groups according to Reader A

Reader A	n	Mean	Std. deviation	Std. error	95% confidence interval for mean			
					Lower bound	Upper bound	Minimum	Maximum
Group A	280	0.755950	0.1634187	0.0097661	0.736725	0.775175	0.4380	1.5600
Group B	38	0.872447	0.3181061	0.0516036	0.767888	0.977006	0.4870	1.8930
Group C	16	1.949625	0.0953253	0.0238313	1.898830	2.000420	1.7350	2.1430
Group D	9	2.041222	0.1394093	0.0464698	1.934063	2.148382	1.8200	2.2560
Total	343	0.858262	0.3670536	0.0198190	0.819280	0.897245	0.4380	2.2560

Std., standard.

Table 2 Descriptive statistics of the relative signal intensity values in the different groups according to Reader B

Reader B	n	Mean	Std. deviation	Std. error	95% confidence interval for mean			
					Lower bound	Upper bound	Minimum	Maximum
Group A	280	0.779611	0.1382233	0.0082604	0.763350	0.795871	0.5170	1.4960
Group B	38	0.842217	0.3278901	0.0633054	0.807512	0.916354	0.4360	1.7990
Group C	16	1.899117	0.0911254	0.0338765	1.758230	2.015810	1.8120	2.0930
Group D	9	2.065231	0.1421356	0.0522115	1.884122	2.200125	1.7880	2.0210
Total	343	0.877577	0.3530562	0.0190632	0.840081	0.915073	0.4870	2.3170

Std., standard.

displayed a full recovery within the 12th month of follow-up and 2 IANs showed persistence of neurosensory disorders at the 18th month of follow-up (Group D).

In the assessment of RSI values in the post-surgical sites, the interobserver agreement (k) was 0.891.

The intraobserver variability (intraclass correlation coefficient) was 0.927 for Reader A and 0.914 for Reader B.

The RSI values in post-extraction sites found by Reader A and Reader B are summarized in Tables 1 and 2.

Given the excellent interobserver and intra-observer agreement, the mean measurements of RSI values in post-extraction sites provided by the two readers were used to perform ANOVA test and Tukey's range test (Figure 4).

The one-way ANOVA results (Table 3) for the evaluation of RSIs among the four groups indicated statistically significant difference between Groups A and B ($p = 0.02$); Groups A and C ($p < 0.001$); Groups A and D ($p < 0.001$); Groups B and C ($p < 0.001$); and Groups B and D ($p < 0.001$). No statistically significant interaction was observed between Groups C and D ($p = 0.631$).

Figure 4 Box plot showing median, quartile and extreme values of relative signal intensity (RSI) means in post-operative sites. Boxes include 50% of values; the horizontal lines inside the boxes indicate the medians, and the vertical lines extend to 1.5 of the interquartile range. Circles and stars denote outliers.

Discussion

Lower third molar removal is one of the most frequent oral surgical procedures.¹ Most of the common post-operative complications are mild and reversible, although IAN damage is one of the most serious consequences. Post-operative complications such as swelling, trismus and pain are easy to manage, but the functional loss of sensory innervations of the lower lip may cause traumatic injuries and fibromas, scar tissue and mucocele formation on the mucosa.

The cited frequency of IAN post-operative paraesthesia ranges between 0.4% and 8.4%, whereas permanent risk is usually <1%.¹⁻⁷ Damage to the IAN has been related to deep impactions, horizontal angulations, less experienced surgeons and the close anatomic relationship between the third molar root and the mandibular canal.¹⁵⁻¹⁸

IAN injury can result from a number of different actions: a direct action such as the use of elevators or burs, if the drilling reaches the nerve, and an indirect action owing to the compression of the IAN from haemorrhage and/or inflammation.

CBCT,^{19,20} CT and panoramic radiography are traditionally used in oral and maxillofacial surgery;^{21,22} during the post-operative period, these imaging methods can delineate deformity of the mandibular canal bone structure, but the morphologic changes of the IAN cannot be evaluated. Several studies demonstrated that MRI can provide highly detailed anatomical information with excellent discrimination of the soft tissues, avoiding patient's exposure to X-rays. The main advantage of a high magnetic field system (3.0 T) is the higher signal-to-noise ratio, which provides significantly superior spatial resolution compared with standard magnetic field strength of 1.5-T.²³

Routine conventional MRI techniques to depict peripheral nerves have mainly consisted of two-dimensional MRI with relatively thick slice, using maximum intensity projection.²⁴⁻²⁶ By contrast, 3D sequences, such as T_1 weighted fast SPGR,^{27,28} are more accurate for depicting fine nervous structures such as IAN. T_2 weighted 3D fast imaging employing steady-state acquisition has been widely used in the evaluation of the cranial nerves.²⁹⁻³³

In 3D-FIESTA sequence, the IAN shows a low SI, whereas the jaw bone shows a higher SI. In SPGR sequence, which is a fat-saturated T_1 weighted sequence providing a high contrast between the bone tissue and

Table 3 One-way ANOVA and Tukey's range test used to evaluate the differences among the relative signal intensity (RSI) values of the four groups

RSI values (I)	RSI values (J)	Mean difference (I – J)	Standard error	Significance	95% confidence interval	
					Lower bound	Upper bound
Group A	Group B	−0.1164974 ^a	0.0318230	0.002	−0.198659	−0.034336
	Group C	−1.1936750 ^a	0.0473157	0.000	−1.315836	−1.071514
	Group D	−1.2852722 ^a	0.0623372	0.000	−1.446216	−1.124329
Group B	Group A	−0.1164974 ^a	0.0318230	0.002	0.034336	0.198659
	Group C	−1.0771776 ^a	0.0548585	0.000	−1.218812	−0.935543
	Group D	−1.1687749 ^a	0.0682393	0.000	−1.344956	−0.992593
Group C	Group A	1.1936750 ^a	0.0473157	0.000	1.071514	1.315836
	Group B	1.0771776 ^a	0.0548585	0.000	0.935543	1.218812
	Group D	−0.0915972	0.0766986	0.631	−0.289619	0.106425
Group D	Group A	1.2852722 ^a	0.0623372	0.000	1.124329	1.446216
	Group B	1.1687749 ^a	0.0682393	0.000	0.992593	1.344956
	Group C	0.0915972	0.0766986	0.631	−0.106425	0.289619

^a*p* < 0.05 statistically significant.

I and J indicate the RSI values of different groups compared using ANOVA.

the IAN, the bone is displayed as a very low SI structure, whereas the IAN is depicted as a high SI structure.

The studies on the evaluation of the course and injury of the IAN are few, and no studies in the early MRI evaluation of IAN sensory disorders after the extraction of the mandibular third molar have been reported.^{27,28,34}

The aim of the present study was to evaluate the use of 3.0 T MRI in the prognosis of sensory disorders after mandibular third molar extraction in the early post-operative period. A large number of patients who underwent mandibular third molar removal were studied, a total of 343 IANs were evaluated.

In all cases, no differences in the IAN course was observed at 3-day follow-up, even in the two patients without recovery of neurosensory impairment within 18-month follow-up. These findings suggest that the evaluation of the IAN course, using a 3.0 T magnet, in the early post-operative period, is not useful in the sensory disorders prognosis.

The high interobserver and intra-observer agreement found for the measurement of RSIs in post-surgical sites indicate a high degree of reproducibility and reliability of this quantitative approach used to assess IAN neurosensory impairment following third mandibular extraction.

A statistically significant difference in RSI values was observed between patients with and without post-extraction paraesthesia.

Moreover, a statistically significant difference in RSI values was found among patients who experienced different neurosensory disorder recovery time.

The highest RSIs found in patients with post-operative paraesthesia could be due to both a direct trauma causing injury of the IAN bundle and indirect damage of IAN owing to compression from haemorrhage and/or inflammation.

These results show that the RSI values allow discrimination of a neurosensory impairment that will recover within 3 months after surgery from a neurosensory deficit, that will recover within 6–12 months or that will not recover.

However, it is not possible to provide an early prognostic evaluation between a neurosensory impairment that will recover within 6–12 months and a permanent neurosensory deficit.

In conclusion, the evaluation of IAN course in the early post-operative period, using a 3.0 T magnet, is not useful for the prognosis of sensory disorders. Nevertheless, the early evaluation of RSI values can be considered as a reliable tool to assess the prognosis of sensory disorders. However, further studies in which the described promising results are reproduced on a wider series of patients are required before the measurement of RSI values can be used in clinical practice to evaluate the prognosis of patients with paraesthesia after mandibular third molar extraction.

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