

Inferior Alveolar Nerve Injury after Mandibular Third Molar Extraction: a Literature Review

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ABSTRACT

Objectives: The purpose of this study was to systematically review the comprehensive overview of literature data about injury to the inferior alveolar nerve after lower third molar extraction to discover the prevalence of injury, the risk factors, recovery rates, and alternative methods of treatment.

Material and Methods: Literature was selected through a search of PubMed electronic databases. Articles from January 2009 to June 2014 were searched. English language articles with a minimum of 6 months patient follow-up and injury analysis by patient's reporting, radiographic, and neurosensory testing were selected.

Results: In total, 84 literature sources were reviewed, and 14 of the most relevant articles that are suitable to the criteria were selected. Articles were analyzed on men and women. The influence of lower third molar extraction (especially impacted) on the inferior alveolar nerve was clearly seen.

Conclusions: The incidence of injury to the inferior alveolar nerve after lower third molar extraction was about 0.35 - 8.4%. The injury of the inferior alveolar nerve can be predicted by various radiological signs. There are few risk factors that may increase the risk of injury to the nerve such as patients over the age of 24 years old, with horizontal impactions, and extraction by trainee surgeons. Recovery is preferable and permanent injury is very rare.

Keywords: fifth cranial nerve injury; inferior alveolar nerve; mandible; paresthesia; third molar; tooth extraction.

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INTRODUCTION

Extraction of impacted or erupted mandibular third molars (M3s) is one of the most frequently performed dentoalveolar surgical procedures [1]. There are well-established indications [2] for removal of impacted M3s, and the controversies about prophylactic removal of asymptomatic M3s are based on evaluating the costs and risks of removal against the consequences of non-removal. The reasons for prophylactic surgery include the need to minimize the risk of disease (cysts and tumours), the reduction of the risk of mandibular angle fracture, increased difficulty of surgery with age, non-restorable caries or periodontal disease, and that M3s may be of less importance for mastication [2]. Within 4 - 8 weeks after surgery, 96% of inferior alveolar nerve (IAN) injuries recover [3], and the recovery rates are not influenced by gender and only slightly by age [4]. Some injuries may be permanent, lasting longer than 6 months, and with varying outcomes ranging from mild hypoesthesia to complete anaesthesia and neuropathic responses resulting in chronic pain [5]. The M3 is close to important structures such as the IAN, lingual nerve, and adjacent second molar. The lower it is, the more difficult it is to extract and more complications may occur during operation or postoperatively. Among them, injury of the IAN is of most concern for surgeons. Sometimes it is unavoidable and is most likely to lead to legal disputes between doctors and patients [6,7]. The risk of IAN injury (IANI) complication depends mainly on the position of the impacted tooth in relation to the mandibular canal (MC) before surgery. The IAN travels within the MC in the mandible, and is thus supported by the alveolus and the neurovascular bundle. Anatomically, the inferior alveolar vein is the most superior structure in the canal. When rotary instruments penetrate the canal, the bleeding will alert the surgeon that the superior aspect of the bony canal has been breached and the vein is injured. Nonsurgical removal of the M3 is unlikely to cause any damage to the nerve unless excessive force has been used. The radiographic position of the M3 in relationship to the MC has been shown to be useful in assessing the risk of damage to the IAN following extraction [8-10]. If the IAN is injured, unless it is displaced by bony fragments from the roof of the MC or displaced into the socket, it will remain within the canal and regenerate. The IAN neuropathy related to M3 surgery with a reported incidence of 1 - 20% temporary and 0 - 2% permanent [11]. IANI, and a subsequent sensory disturbance, may occur after direct or indirect trauma

during M3 removal [12]. For example, it may result from compression of the nerve by root elevators and lead to blunt nerve trauma or elevated roots. The IAN may be damaged by rotating instruments used for the surgical procedure or after IAN regional anaesthetic block injections [13]. Clinical observation of the neurovascular bundle during surgery may notify the surgeon about an increased risk of postoperative IANI. Tay and Go [14] found that if an intact IAN bundle is observed during M3 surgery, this indicates an intimate relationship with the M3 and has a 20% risk of postoperative paresthesia, and with a 70% chance of recovery within one year. Damage to the nerve is also more likely when the tooth is completely impacted in the bone and/or the apices of the tooth extend into or below the level of the neurovascular bundle. IAN paresthesia occurs widely from 0.35% to 8.4% [15-17]. Consequently, the purpose of this study was to systematically review the comprehensive overview of literature data about injury to the inferior alveolar nerve after mandibular third molar extraction to find out the prevalence of injury, the risk factors, recovery rates, and alternative methods of treatment.

MATERIAL AND METHODS

Protocol and registration

The review is registered in an international prospective register of systematic reviews 'PROSPERO' [18]. Registration number: CRD42014014231.

Types of publication

The review included studies on humans published in the English language. Letters, editorials, PhD theses, literature reviews, and abstracts were excluded.

Types of studies

The review included any published observational studies (cross-sectional surveys and case-control studies) and case series. Single case reports were excluded.

Information sources

The information source was the MEDLINE (PubMed) database.

Population

Studies of adult patients with performed M3 extractions were selected. Treatment had to be completed on healthy people without systemic diseases and immunological disorders.

Inferior alveolar nerve injury (IANI) definition

Injury to the IAN means any sensory impairment of the nerve that occurs after surgical M3 extraction.

Literature search strategy

According to the PRISMA guidelines [19], an electronic search was conducted using MEDLINE (PubMed) to locate articles concerning IANI after M3 extraction. The keywords used for the search were: "INFERIOR ALVEOLAR NERVE INJURY THIRD MOLAR", "INFERIOR ALVEOLAR NERVE THIRD MOLAR", "INFERIOR ALVEOLAR NERVE DAMAGE THIRD MOLAR", "INFERIOR ALVEOLAR NERVE PARESTHESIA THIRD MOLAR", "INFERIOR ALVEOLAR NERVE DYSESTHESIA

THIRD MOLAR", "PERMANENT INFERIOR ALVEOLAR NERVE INJURIES THIRD MOLAR". The search was restricted to English language articles published from January 2009 to June 2014. The search results revealed a high number of articles (1,251); however, a significance number of the shown articles were not related to the topic and were excluded according the exclusion criteria. Selection and filtration were done in order to know which articles were more suitable for the research. In the beginning, the titles of the article were read, and if the title fit the general idea of the research, the abstract of the article was read. After the abstract reading and after ensuring that the article provided the necessary information for the research, the entire article was read. The bibliographies of the selected articles were also manually searched. Figure 1 illustrates the flow diagram of the comprehensive literature review.

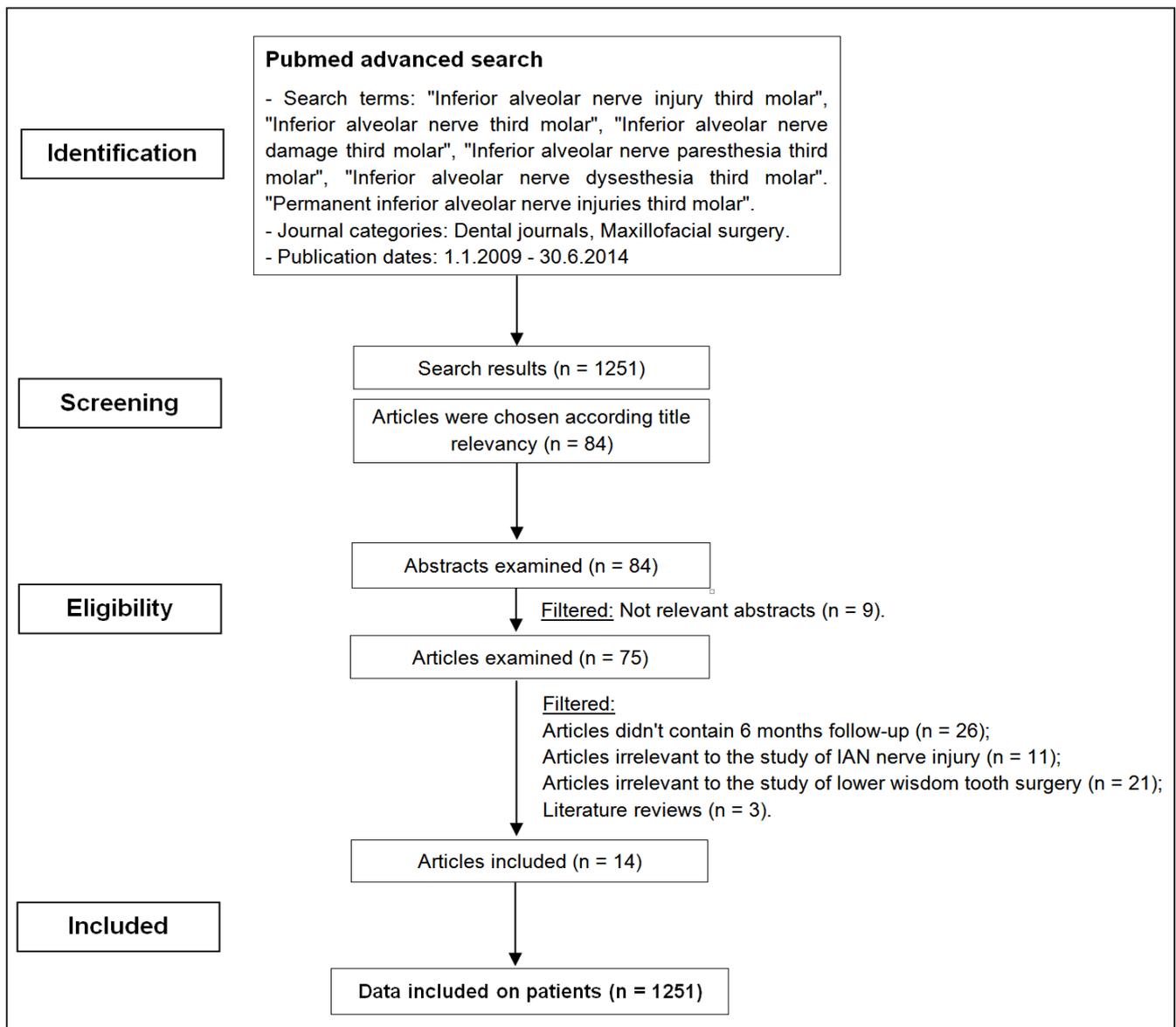


Figure 1. Flow diagram of studies selection according PRISMA guidelines.

Inclusion and exclusion criteria

Inclusion criteria for the selection

- English language;
- Studies performed on humans who had no systemic diseases and immunological disorders;
- Articles must be limited to lower wisdom tooth surgery/alternative methods for surgery and IANI;
- Minimum follow-up of 6 months postoperation.

Exclusion criteria for the selection

- Unhealthy people with systemic diseases and immunological disorders;
- Patient follow-up shorter than 6 months;
- Articles irrelevant to the study of lower wisdom tooth surgery/alternative methods for surgery and IANI;
- Articles irrelevant according to the types of publications' exclusion.

Article review and data extraction

The search delivered 1,251 search results, from which 84 abstracts were reviewed (Figure 1). A total of 84 articles were ultimately reviewed in full. Preliminary exclusion was made by the title and its relevancy and later by abstract relevancy; finally, articles that did not meet the inclusion and exclusion criteria were filtered as follows:

- Articles didn't contain minimum follow-up of 6 months (n = 26);
- Articles irrelevant to the study of IANI (n = 11);
- Articles irrelevant to the study of lower wisdom surgery (n = 21);

- Literature reviews (n = 3);
- The data were included on 22,791 patients.
- In the present article, it will discuss the following IANI aspects:
 - Risk factors;
 - Radiographic techniques before M3 extraction;
 - Alternative methods of M3 extraction;
 - Recovery of IANI.

Risk of bias across studies

The risk of bias (e.g., lack of information, surgeries performed by single operator, postoperative neurosensory examination performed by single examiner, postoperative neurosensory testing not performed, specific age group, sex scission, and low objectives number) that can affect the cumulative evidence was assessed across the studies. The risks were indicated.

The Cochrane Collaboration's tool for assessing the risk of bias [20] was used to assess bias across the studies that can affect cumulative evidence.

RESULTS

A total of 14 studies were included in this review: 5 studies were related to risk factors associated with injury to the IAN, 5 studies were related to the influence of radiographic techniques before M3 extraction, 3 studies were related to alternative methods of M3 extraction, and 1 study was related to the recovery of IANI (Table 1).

Table 1. Description of studies included in the review

Study	Year of publication	Diagnostic evidence	Follow-up	Number of patients treated
Studies regarding risk factors associated with IANI				
Xu et al. [22]	2013	Patient's reporting + Neurosensory testing	6 months	318
Kim et al. [23]	2012	Patient's reporting + Neurosensory testing + Radiographic	2 years	12,842
Jerjes et al. [47]	2010	Patient's reporting	2 years	3236
Kjolle et al. [48]	2013	Patient's reporting + Neurosensory testing	5 years	884
Guerrouani et al. [49]	2013	Patient's reporting	6 months	2112
Studies regarding the influence of radiographic techniques before M3 extraction				
Smith [21]	2013	Patient's reporting + Neurosensory testing	2 years	1000
Neves et al. [33]	2012	Patient's reporting + Neurosensory testing	6 months	33
Nakayama et al. [35]	2009	Patient's reporting	Over 6 months	1539
Hasegawa et al. [36]	2013	Patient's reporting + Neurosensory testing	6 months	295
Ghaeminia et al. [43]	2009	Patient's reporting + Neurosensory testing	6 months	40
Studies regarding alternative methods of mandibular M3 extraction				
Landi et al. [50]	2010	Patient's reporting + Radiographic	2 years	9
Wang et al. [52]	2012	Patient's reporting+ Radiographic	-	40
Dolanmaz et al. [56]	2009	Patient's reporting + Radiographic	4 years	43
Study regarding recovery of IANI				
Bhat et al. [43]	2012	Patient's reporting + Neurosensory testing	6 months	400

IANI = inferior alveolar nerve injury; M3 = third molar.

Study characteristics

All 14 articles finally selected for the review were performed on humans and published in the English language with a description of their study, the methods used, the number of patients, as well as the preoperative and postoperative examination techniques. All studies published were in 2009 - 2013 years and included a various number of patients, from 9 (lowest) to 12,842 (highest) (Table 1) to ensure statistical validity.

All authors except one conducted a postoperative follow-up of a minimum of 6 months. The one exceptional study [13] was an alternative method for conventional surgical extraction (orthodontic technique), which included a preoperative follow-up until the tooth reached a safe position for extraction.

Preoperative radiographs were assessed before the M3 extraction in all studies, and it can be clearly seen that panoramic radiograph is the preoperative radiograph of choice (Table 2).

The main postoperative evaluation methods were: two-point discrimination, pin-prick, light touch, and with a light touch test in the top (Table 3).

Reliability of studies

The number of patients treated (Figure 2), the preoperative radiographs used (Table 2), the neurosensory evaluation methods used (Table 3), the follow-up period (Figure 3), and the bias within studies (Table 4) highly affects the reliability of a study. A comparison between the studies was completed.

Risk of bias within studies

Only 5 of the 14 studies fulfilled the expected markers of validity. The risk of bias that was indicated within other studies and presented as a lack of information value was grouped as followed: treatment performed by a single operator, post-treatment neurosensory testing performed by a single examiner,

postoperative neurosensory testing not performed, specific age group treated, sex scission, and low objectives number (Table 4).

Anatomic relationship and incidence of IAN neurosensory impairment

Neurosensory impairment is a common complication of extraction of impacted M3s, and the incidence ranges from 0.35% to 8.4% [15-17,21]. In 2013, Smith [21] presented a clinical study on 1,000 patients, removing 1,589 impacted M3 teeth. Of the 1,589 M3 teeth extracted, 466 (29%) demonstrated a distant relationship of their apices to the MC, 869 (55%) were close to the canal, and only 254 (16%) were deemed to be intimate to the canal by radiographic evidences (Table 5). In postoperation, 39 patients (3.9%) reported neurosensory disturbance over the distribution of the IAN nerve in 40 extractions. Seven patients (0.7%) sustained permanent sensory loss. The incidence of IAN neurosensory deficit was highest with horizontal impaction (4.7%) and lowest when the teeth were vertically impacted (0.9%).

Table 2. Preoperative radiographs used in the studies

Author	Preoperative radiograph used
Smith [21]	OPG
Xu et al. [22]	OPG + CBCT
Kim et al. [24]	OPG
Neves et al. [33]	MDCT
Nakayama et al. [35]	OPG + CT
Hesagawa et al. [36]	OPG + CT
Ghaminia et al. [43]	OPG + CT
Bhat and Cariappa [44]	Not indicated
Jerjes et al. [47]	OPG
Kjolle et al. [48]	OPG
Guerruani et al. [49]	OPG
Landi et al. [50]	OPG + CT + Periapical
Wang et al. [52]	OPG + CT
Dolanmaz et al. [56]	OPG

OPG = orthopantomography; CT = computed tomography; CBCT = cone-beam computed tomography; MDCT = multi-detector computed tomography.

Table 3. Postoperative neurosensory evaluation methods used

	Pin-prick	2-point discrimination	Sharp blunt discrimination	Light touch/contact detection	Thermal testing	Brush stroke direction
Smith [21]	+	+		+		
Kim et al. [24]	+	+		+		
Neves et al. [33]			+	+		
Hasegawa et al. [36]	+			+		
Ghaeminia et al. [43]				+		
Bhat et al. [44]	+	+		+	+	+
Kjolle et al. [48]		+	+	+		

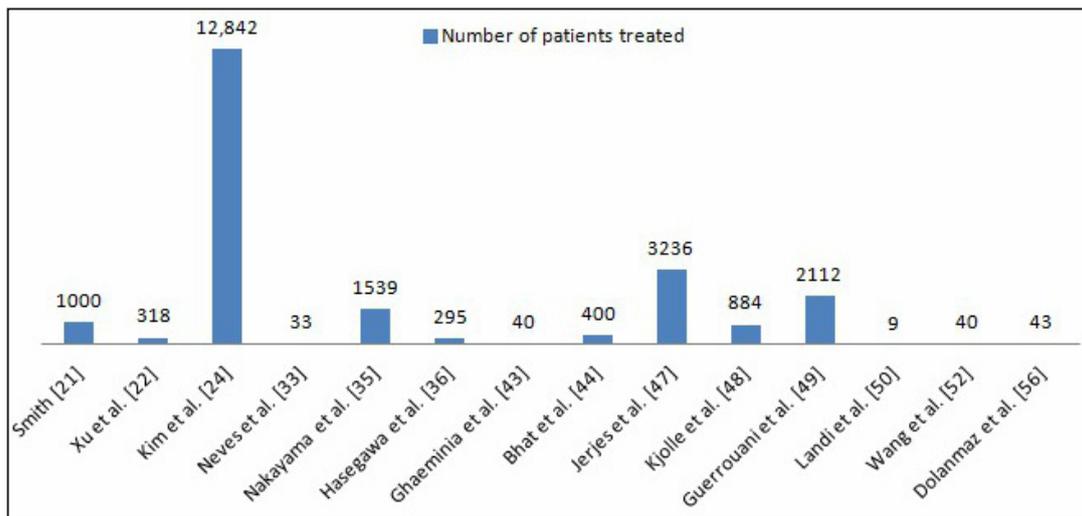


Figure 2. Number of patients treated.

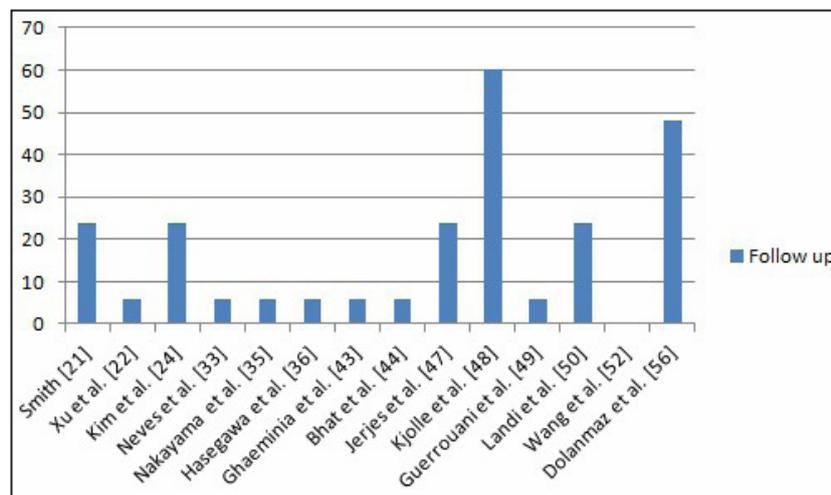


Figure 3. Postoperative follow-up period (months).

Table 4. Assessment of the risk of bias

	Treatment performed by single operator	Post-treatment neurosensory testing (NST) performed by single examiner	Post-treatment NST not performed	Specific age group treated	Sex scission	Low objectives number
Smith [21]	+	+	-	-	-	-
Nakayama et al. [35]			+			
Ghaemnia et al. [43]	-	+	-	-	-	-
Bhat and Cariappa [44]	+	+	-	-	-	-
Jerjes et al. [47]			+			
Guerrouani et al. [49]			+			
Landi et al. [50]		-	+	-	-	+(n = 9)
Wang et al. [52]	+	-	+	+(20 - 30)	+(Females only)	-
Dolanmaz et al. [56]			+			

Table 5. Proximity of the root’s apices to the mandibular canal (MC)

Proximity to the MC	Description
Distant from the canal	There is a radiologic separation of > 1 mm between the tips of the roots of the third molar and the MC.
Close to the canal	There is unchanged superimposition of the root apices over the MC.
Intimate to the canal	The tips of the roots are considered to be intimate to the MC when ≥ 1 of the following 3 criteria are met: 1. Diversion of the MC; 2. Darkening of the root; 3. Deflected root apices.

However, the difference between each type of impaction is not statistically significant ($P > 0.01$). The overall incidence of IAN nerve damage was 2.5% per tooth removal. The lowest incidences were seen when the nerve was either “distant” (0.8%) or “close” (0.9%), and highest when the nerve was classed as “intimate” (11%). The difference between the “distant” and “intimate” groups was statistically significant ($P < 0.01$). The difference between the “close” and “intimate” groups was also statistically different ($P < 0.01$). Yet, this study has limitations because the preoperative radiologic assessment, as well as the postoperative neurologic testing, was performed by the same clinician, thereby potentially introducing bias to the results.

In addition, Xu et al. [22] studied 537 impacted M3s in 318 consecutive patients. Most of them were mesioangular and vertical impactions. Horizontal impacted teeth were in the minority. A total of 272 were above the MC, 86 on the buccal side, 172 on the lingual side, and the canal was between the roots in 7 teeth. By the results shown (Table 6), we can see that the highest IANI rates are when the roots’ tips are buccally to the MC.

Risk factors of IAN impairment

Radiological factors

Orthopantomography

Orthopantomography (panoramic radiography) is the radiologic investigation of choice before M3 surgery. The criteria for injury are identifiable on this radiograph, but like other conventional radiographs, it is unable to give complete information in 3 dimensions [23]. In a study performed by Kim et al. [24], on a total of 12,842 patients who underwent extraction of the M3, univariate logistic regression analysis showed that the significant risk factors for neurosensory deficits according to the panoramic radiograph were the deflection of the root, narrowing of the root, diversion of the canal, and narrowing of the canal ($P < 0.5$). In contrast, a multivariate logistic regression analysis revealed that the significant risk factors were a darkening of the root, deflection of the root, narrowing of the root, dark and bifid apices of the root, and narrowing of the MC.

The narrowing of the root was the most significant type of superimposition, followed by dark and bifid apices of the root. However, the presence or absence of these radiographic signs does not always determine the possibility IANI, indicating that the panoramic radiograph does not have high diagnostic accuracy in the assessment of risk in surgical extractions of lower M3s [25,26].

Computed tomography (CT)

When the radiological marker on the panoramic radiograph indicates there is a close relationship between the M3 and the MC, additional investigation using computed tomography (CT) may be recommended to verify the relationship in a three-dimensional view [27-29]. The drawbacks of CT are the higher radiation dose and increased financial costs compared with panoramic imaging. Cone beam computed tomography (CBCT) has been introduced to improve conventional CT because it reduces the radiation dose, offers high spatial resolution, and decreases costs [30]. CBCT provides better image quality of teeth and their surrounding structures compared with conventional CT [31,32]. By the results in a study comprised by Neves et al. [33], in all 14 cases where IAN was exposed during surgery, the preoperative assessment by multi-detector computed tomography (MDCT) images classified the relationship between the roots of the M3s and the MC as at-risk (the tooth roots invade and restrict the MC space). There was a statistically significant relationship between IAN exposure and the relationship between the roots of the M3s and the MC ($P = 0.015$). MDCT is considered one of the most valuable imaging modalities for preoperative procedures because it allows the acquisition of fast, reliable, and reproducible images. Each slice can be viewed individually in the 3 planes (axial, coronal, and sagittal), and the overlapping of surrounding anatomical structures can be eliminated. Other advantages, such as the possibility of three-dimensional reconstruction of the evaluated structure and optimal contrast resolution, allow differentiation between tissues so that the obtained information is utilized more efficiently compared with conventional

Table 6. Inferior alveolar nerve (IAN) injury and recovery according to anatomic relationship of the roots’ tips in relation to the mandibular canal (MC)

Position of the roots in relation the MC	Above the canal	Buccal side	Lingual side	Canal between the roots
IAN injury incidence	9/272 (3.3%)	16/86 (18.6%)	8/172 (4.6%)	0/7 (0%)
P value	0.006	< 0.0001	0.32	-
IAN recovery	23 healed within a week, and 10 healed within 6 months. No permanent injury.			

radiographic techniques [34]. Nakayama et al. [35] performed extractions of 1,853 M3 teeth in 1,539 patients in their study. Among them, dental CT was performed on 53 M3s in 47 patients because their M3s were determined to be extremely close to the IAN on panoramic radiograph. The M3s were judged to make contact with the MC on dental three-dimensional images in 35 cases (66%). IANI occurred in 8 cases (15%). The mental region skin sensation of 4 cases returned within 3 months. However, in the other 4 cases, symptoms of IANI continued over 6 months. When the relation between dental CT image and IANI was investigated, all 8 cases of IANI were those in which the contact of the M3 with the MC was seen on dental three-dimensional CT images. No IANI occurred in cases without contact between the molar and the canal. Hasegawa et al. [36] published a study in 2013 in which 440 M3s were removed. Of the 440 teeth, according to CT scanning, 146 (33.2%) IANs were in the buccal position, 195 (44.3%) were in the inferior position, 95 (21.6%) were lingual, and 4 (0.9%) were in the inter-radicular position. The ratio of IANI in the extraction group with a lingual position between the roots was significantly higher ($P < 0.05$) than that in the group with other positions. Through the logistic regression model and forward stepwise algorithms, they determined that the close relationship of the roots to the IAN on CT examination is a significant variable in predicting an injury after M3 extraction ($P < 0.000$).

Surgeon experience

The prevalence of IANI is also dependent on the surgeon experience and the methods used. The results

published by Hasegawa et al. [36] have shown that IANI developed in 3 of 71 (4.2%) teeth in patients treated by the surgeons with 1 - 4 years of experience, in 14 of 175 (8%) teeth in the group treated by surgeons with 5 - 9 years of experience, and 11 of 194 (5.7%) teeth in the group of patients treated by surgeons with more than 10 years of experience. The incidence of IANI after extraction by surgeons with 5 - 9 years of experience was the highest in the 3 groups. However, there was no significant difference in the incidence based on surgeon seniority ($P > 0.01$).

Additional factors

The additional factors implicated in IANI include the age of the patient and the local blood supply. The reasons for this might be that the healing ability decreases with an increasing age and that more bone is usually removed owing to completely formed roots or increased bone mineralization [37]. Accordingly, Blondeau and Daniel [38] recommended that prophylactic M3 extraction should be avoided in patients aged 24 years or older because of a high possibility of complications such as permanent neurosensory deficits, infection, and alveolitis.

Evaluation of sensory impairment after extraction

In order to evaluate nerve dysfunction, it is important to use objective testing rather than to simply ask a patient to subjectively report neuropathic changes. Neurosensory disorders can be measured through various test levels (Table 7).

A study performed by Ghaeminia et al. [43] included extraction of 53 M3s from 40 patients with an increased risk of IANI. Neurosensory disturbances of

Table 7. Neurosensory evaluation tests

	Level A tests		Level B test	Level C tests		
Assessment	This test is used to determine the response of the slowly adapting larger myelinated fibers (A-a)		Assesses the quickly adapting large myelinated (A-a) fibers	These tests assess the small myelinated A-d and C fibers		
Test name	Two-point discrimination test [39,40]	Brush stroke direction [39,40]	Contact detection/light touch [39]	Thermal testing [40]	Sharp blunt discrimination [41]	Pin prick test [42]
Description	Two pointed, but not sharp, tips of a calliper touch the skin simultaneously with light pressure while the patient's eyes are closed. The separation of the two points are gradually reduced from 20 mm at the chin and 10 mm at the lips to the moment where the patient can feel one point only. The minimum separation at which two points can be report is recorded.	The sensory modalities for these receptors are vibration, touch and flutter. Moving stimuli is delivered with a soft brush at a fairly constant velocity (2 - 3 cm/s). Ten, two interval forced choice trials are then delivered to verify that the direction of motion is identified correctly.	The contact detection threshold, the minimum force of contact against the skin that is felt, is measured with the use of a monofilament mounted onto end of a plastic handle.	Perception of warmth is attributed to the integrity of A-d fibers and cold to C fibers. Two small glass tubes containing water at 50°C (warm) and 15°C (cold) were used. The report of each stimulus i.e. cold versus hot is record.	This is done by touching the test area randomly with a sharp or a blunt head of the mechanical probe. A rubber stopper is centred at the end of the dental probe so that when the tip is pressed to the skin, a constant degree of skin indentation was cause.	Consisted of repeating ten touches with an explorer tip on the chin skin and perform how many times the patient accused the contact.

the lip and chin were assessed by measuring the function of the IAN with light touch sensation. The contralateral halves of the lip and chin were taken as a control site. The area with impaired sensation was drawn on the skin and recorded photographically. The patients with altered sensation returned 3 and 6 months postoperatively and their recovery pattern was noted. Neurosensory disturbances of the lip and chin were assessed by measuring the function of the IAN with light touch sensation. Based on the neurosensory testing, temporary IANI occurred in 5 patients (9%). Altered sensations lasting longer than 6 months were scored as permanent IANI (3 patients [6%]). In this study, a bias exists because the neurosensory testing of all patients was carried out by only one investigator, which may influence the results' reliability. In addition, in a study conducted by Bhat and Cariappa [44] a total of 400 M3s were extracted. Out of 400, only one patient presented with IANI (0.25%). Levels A and B tests (two-point discrimination, brush-stroke direction, and contact detection) were altered. In these tests, the IAN did not show any signs of recovery by 6 months. Level C tests (pin-prick test and sharp blunt detection) showed that the nerve had recovered completely by 2 months, which may highly doubt the reliability of level A and B tests, although limitation in this study exists because all cases were examined by one examiner preoperatively and postoperatively.

Recovery rates of the IAN after injury

In most cases, IAN paresthesia is temporary and recovers within 6 months [45], and the risk of permanent injury, in which sensory impairment lasts longer than 6 months, is less than 1% [46]. A study published in 2010 by Jerjes et al. [47] included 3,236 patients who underwent surgical removal of impacted M3s. Over three-quarters (2531/3236, 78.2%) of the teeth were close to the MC (< 2 mm), when assessed on the two-dimensional orthopantomograph. After one month, 48 patients experienced IAN paresthesia. The prevalence of paresthesia at 6 months had only slightly reduced to 45. At 18 to 24 months postoperatively, 20 patients still exhibited IAN paresthesia. In addition, in a study published in 2013 by Kjolle et al. [48], of the total 1,220 M3s removed from 864 patients, 10 reported hypesthesia, anaesthesia, paresthesia, or dysesthesia postoperatively. After 3 - 4 months, the patients aged 29 years or younger had recovered fully. Three of the 8 patients older than 30 years had also full subjective recovery of the IAN after 1 - 17 months. The results showed that after 6 months, recovery seemed to be slight, and confirmed that permanent IAN dysfunction

is more frequent after M3 removal in patients older than 30 years ($P < 0.007$).

Methods of treatment

Surgical extraction

Surgical treatment for an impacted M3 is the conventional and most popular method used. The surgical treatment contains few stages of treatment: anaesthesia (local/general), flap elevation, if necessary root sectioning and bone removal, elevation/luxation of the tooth, later socket irrigation, and a suture to close the wound. A study published in 2013 by Guerrouani et al. [49] included surgical extraction of 7,659 M3s for 2,112 patients. All surgeries were carried out with the same surgical technique: sulcular incision and flap raising of the first or second molar with subsequent discharge. Bone removal, dental cutting, and separation (cracking) were carried out using a single bur in tungsten carbide; the sutures used were Vicryl Rapide 3/0. A sensory labiomenal dysesthesia (anaesthesia, hypoesthesia, or paresthesia) was reported in 9 cases (0.4%), always in relation with the hemilateral tooth section. Partial regression was experienced by the patient after 3 months in 6 cases, while in 3 other cases, it did not seem to improve during the same period. Methods of surgical treatment are wide and every surgeon uses different methods (e.g. anaesthesia, flaps, bone-removal, tooth-sectioning, different approaches, and sutures) according to his experience and results.

Novel surgical technique

Landi et al. [50] used a new surgical approach that was proposed and accepted by the patients. This approach consisted of the surgical removal of the mesial portion of the anatomic crown to create adequate space for mesial M3 migration. After the migration of the M3 had taken place, the extraction could then be accomplished in a second surgical session minimizing neurological risks. This technique has been also described in another article [51]. Nine consecutive patients required the extraction of 10 horizontally or mesioangular impacted M3s. In all cases, the M3 was in contact with the IAN with a high risk of nerve injury. In all cases, healing was uneventful. Three to 4 months after the surgery, all M3s moved forward and reached the distal aspect of the second molars. In 8 cases, radiographic evidence demonstrated clearance between the roots and the IAN so that a risk-free extraction could be scheduled. In 2 cases, the degree of migration was judged

Table 8. Comparison between orthodontic and surgical extraction methods

	Group 1 (orthodontic method)	Group 2 (surgical method)
Number of patients	20	20
Number of IANI cases	0	5
Patients' complaint	No complaints	Transient lower lip numb
Swelling	Minimal	Different degrees of swelling
Postoperative medications	-	Application of steroids and nerve nutrition medications; Intravenous antibiotics for at least 3 days
Recovery	-	1 week postoperation

IANI = inferior alveolar nerve injury.

inadequate to extract the teeth safely; therefore, a second surgical section was required to gain further space for mesial migration. This study does have limitations because the number of patients is relatively low (n = 9), which may affect the reliability of the study and introduce bias to the results.

Orthodontic extraction technique

Since there are patients who are at a high risk for operation, occurrence of IANI is relatively high, and the orthodontic extraction technique is recommended to the patients to reduce the postoperative complications. This technique needs an orthodontist to design and put a special bar on the tooth to control the direction of traction. It also needs a long time of traction from 6 to 12 months, especially for medially inclined and horizontal teeth to be away from the IAN. Patients also need frequent follow-ups to unite, reshape, and reactivate the cantilever every 4 to 6 weeks before the tooth is ready to be extracted. Of the 2 methods of this technique, one uses orthodontic brackets and hooks on the maxillary molars. The other method includes placing bone mini screws between them [52]. A study published in 2012 by Wang et al. [52] included 40 patients who were divided into 2 groups. In one group, 20 patients agreed to the orthodontic extraction technique, and in the second group, the other 20 did not want this technique and had the tooth removed directly because of various reasons including treatment time, etc. Postoperative results were compared between the 2 groups, and it can be clearly seen that the orthodontic extraction technique is very efficient (P < 0.01) although time consuming (Table 8). The results in this study contain a bias, which is that the treatment was performed only on females, on a specific age group of 20 - 30 years old, and in addition, the extractions in the second group were done by the same surgeon.

Table 9. Total amount of movement of root remnants along time

Time	Range of movement (mm)	Mean amount of movement (mm)	P value
6 months	2 - 4.8	3.4	< 0.01
12 months	0.1 - 0.9	3.8	
24 months	0 - 0.3	4	

Coronectomy technique

Another alternative found to overcome the risk of IANI is intentional coronectomy. Clinicians [53-55] use coronectomy to protect the IAN for mesioangular and vertical bony impacted M3s. The disadvantage of a coronectomy is the possible need for a second operation to remove the root, a late infection of the retained roots, and a high complication rate of unsatisfactory healing [54-56]. But it could be an optimal solution for tooth ankyloses, where the orthodontic extraction technique is ineffective [55]. Not all M3 teeth are suitable for coronectomy. Teeth with acute infection and mobile teeth should be excluded because root remnants of those teeth may act like foreign bodies. In addition, teeth that are horizontally impacted along the course of the MC may be unsuitable because the sectioning of a tooth could endanger the nerve [56]. Dolanmaz et al. [57] used coronectomy in 43 patients who needed removal of their M3, and whose root apices were very close to the MC. In total, 47 teeth underwent coronectomy, and the total amount of movement of the root remnants is presented (Table 9). All patients were invited to return for appointments at 6, 12, and 24 months for clinical and radiographic assessment of the retained root fragments. The root remnants were clinically examined for infection and the amount of movement was measured. None of the patients reported any problems associated with the root fragments. In all cases, the radiographs revealed that the root fragments showed various amounts of movement farther away

from the MC. None of the retained roots required a second operation.

DISCUSSION

The purpose of this review was to discover the relation between extractions of the mandibular wisdom tooth to the injury of the IAN, as well as to find out the prevalence of injury, the risk factors, recovery rates, and alternative methods of treatment.

The mandibular nerve is the third and the most inferior branch of the trigeminal nerve or the fifth cranial nerve. The lower branch is called the mandibular nerve. The nerve enters the mandible through the mandibular foramen on the medial surface of the ascending mandibular ramus. After passing through the mandibular foramen, the nerve is called the IAN. In the molar region, the IAN divides into the mental and mandibular incisal nerves [57].

IANI is a characteristic complication following the removal of an impacted M3 [58-60]. Although the incidence of such a complication is relatively low, its frequency increases as the roots of the impacted tooth move closer to the IAN [60]. To reduce the neurological risks, several strategies may be used. Wang et al. [51], in their study, used the orthodontic extraction technique, and through their results, it is clearly seen that this method is preferable over the surgical method in reducing the risk of paresthesia, yet it is time consuming and expensive and may not be tolerable for the patient. Dolanmaz et al. [56], in their study, used coronectomy in patients whose root apices were very close to the MC. By the results published, in all cases, the radiographs revealed that the root fragments showed various amounts of movement farther away from the MC, and none of the retained roots required a second operation, which significantly proves the efficiency of this technique. The novel approach presented by Landy et al. [50] aims to provide adequate space distal to the second molar to allow spontaneous M3 eruption to move the roots away from the neurovascular bundle. This novel technique aims to exploit this potential eruption by providing space distal to the second molar by removing a portion of the M3 crown. The amount of sectioning should take into account several factors: 1) tooth position and angulations; 2) the degree of mesial shift desired to move the roots away from the nerve; and 3) pulp chamber anatomy. Although a generous sectioning is desirable, every effort should be made, at least during the first odontectomy, to not interfere with tooth vitality. In the case of accidental pulp exposure, a pulpotomy may

be performed to minimize the risk of postoperative pain and discomfort. Evidence suggests that in young adults, 26% to 35% of unerupted mandibular M3s may change position over time and reach the occlusal plane [61,62]. Predicting IANI before surgical intervention is a common desire for the surgeon and the patient. Panoramic radiography is the supplementary examination initially requested to assess impacted M3s and estimate the risk of damage to the IAN. When specific signs are detected, CT is recommended for three-dimensional evaluation [63] to assess the relationship of the M3s with anatomical structures, especially the MC, and provide a higher operative safety [64-66].

The risk factors of postoperative IANI include the surgeon's experience, the age and sex of the patient, the degree of operative tissue damage, surgical instruments, and postoperative oedema. The most important factor, however, is the anatomical relation between the impacted M3 and the MC [47,67,68]. By the results shown by Kim et al. [23], age, impaction depth, and the 5 radiographic superimposition signs: darkening of the roots, deflection of the roots, narrowing of the roots, dark and bifid apex of the roots, and narrowing of the canal were significantly associated with neurosensory deficits of the IAN after M3 extraction. The number of subjects in this study was significantly big (12,842 patients), increasing the reliability of their results. In contrast, some authors [50,52,56] didn't perform neurosensory testing in order to evaluate IANI, only the X-ray examination, while other authors [35,47,49] didn't perform any examination at all, rather than simply asking the patients about their sensory feelings, which may bring uncertainty to the reliability of their results.

The age and gender of the patients should be taken into account because it is well documented for all types of nerve injuries that both factors are at higher risk of neurosensory deficits [37,69-71]. The surgeons have to make a preliminary neurosensory examination of IAN function before M3 extraction in order to determine whether there is pre-existing altered sensation [71].

In most cases, complete recovery of IANI occurs 6 to 8 weeks after the trauma, although it may take up to 24 months. If paraesthesia is not completely resolved within about 2 months, the probability of a permanent deficit increases significantly [72]. In accordance with the findings of the study published by Kim et al. [23], IANI after M3 extraction is usually not permanent but continues for a few months and shows spontaneous recovery in the first 6 months.

CONCLUSIONS

Inferior alveolar nerve paresthesia occurs widely from 0.35% to 8.4%. Although these figures are relatively low, they are still of great significance for both patients and clinicians. Sometimes the injuries are unavoidable and may have legal disputes between doctors and patients. All patients must be warned of the risks of mandibular third molar surgery, including possible damage to the inferior alveolar nerve, and informed consent must be obtained before the procedure. With regard to the inferior alveolar nerve, the factors associated with a significantly higher incidence of paresthesia includes patients over the age of 24 years old, with horizontal impactions,

close radiographic proximity to the mandibular canal, and treatment by inexperienced surgeons. In order to reduce the neurological risks, alternative strategies might be used like coronectomy and orthodontic extraction techniques.

It has been found that injury to the inferior alveolar nerve is usually not permanent and has a good likelihood of regenerating over time, and most of the injuries are healed after 6 months.

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