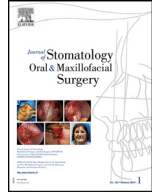




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## Review

# Inferior alveolar nerve repositioning surgical techniques and outcomes – a systematic review



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## ABSTRACT

Inferior alveolar nerve (IAN) lateralization (IANL) or transposition (IANT) are both techniques allowing for dental implant placement in posterior atrophic mandibles. The aim of this study was to systematically review the implant survival rate and the complications associated with IAN reposition techniques with simultaneous implant placement in atrophic posterior mandibles.

This systematic review was conducted following PRISMA guidelines (Preferred Reporting Items for Systematic review and Meta-Analysis). The review was designed to answer the following PICO question: Is IAN repositioning (I) a safe and efficient technique (O) to treat patient looking for fixed dental rehabilitation of an atrophic posterior mandible (P).

Thirty-three articles were reviewed, including a total of 899 patients, and approximately 950 IAN repositioning procedures. Dental implant survival rate ranged between 86.95% and 100% with a mean dental survival rate of 90.16%. Among the 269 patients who underwent IANT, there were 93% immediate neurosensory disturbance, and 15% persistent neurosensory disturbance. Among the 350 patients who underwent IANL, there were 93% immediate neurosensory disturbance, and 6% persistent neurosensory disturbance.

IANT and IANL are reliable techniques allowing safe dental implant placement in atrophic posterior mandible with high patient satisfaction. IANL seems to cause less persistent neurosensory disturbances compared to IANT. The level of evidence is poor due to the high number of bias present in the included studies. IAN neurosensory disturbance assessment should be better homogenized in order to increase comparability.

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## 1. Introduction

Dental rehabilitation of posterior atrophic mandibles is not an easy matter. Implant supported prostheses is the most popular option but may be challenging due to the proximity between the alveolar ridge and the inferior alveolar nerve (IAN). Through the past decades, different options with their own advantages and inconveniences have been described, such as short dental implants, bone augmentation procedures and IAN repositioning. Short (< 10 mm) or extra-short (< 6 mm) dental implants [1] may be used when the IAN canal is too close to the alveolar ridge to place a standard ( $\geq 10$  mm) dental implant. However, while some studies showed no difference in implant survival between short and standard implants [2], others found more long-term implant failure with short implant rehabilitations [3,4]. Furthermore, in cases of severe atrophy, the distance between the alveolar ridge and the IAN canal can be too short to place

the shortest dental implants, measuring 4 mm long. In order to increase the distance between the alveolar ridge and the IAN canal, surgical bone augmentation techniques have been developed [5–7]. Several techniques have been described such as alveolar distraction, bone grafting, and guided bone regeneration [8,9]. These techniques require several surgical steps, since bone healing takes time, thus lengthening the delay before obtaining the final prosthodontic reconstruction for the patient. Furthermore, the posterior mandible is a site of high resorption for bone grafts [10,11] which may lead to the impossibility of performing the initially planned implant rehabilitation.

Instead of increasing the distance between the alveolar ridge and the IAN canal, IAN repositioning techniques circumvent this limitation allowing standard dental implant placement. IAN repositioning was first described by Alling in 1977 [12] (IAN lateralization), and subsequently modified by Jensen and Nock in 1987 [13] (IAN transposition). Briefly, in IAN lateralization (IANL) the incisive nerve is preserved since the IAN is reflected laterally (lateralized) during implant placement and left to fall back into its canal at the end of the procedure; while in IAN transposition (IANT) the incisive nerve is sectioned

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since the IAN is completely transposed laterally starting from the mental foramen, thus generating a new posterior foramen. Both techniques require nerve manipulation, hence they are associated with postoperative neurosensory disturbances. However, the occurrence and persistence of such lesions are variable in the literature, with IANT being considered at higher risk than IANL [14,15]. Furthermore, the assessment of these disturbances can be performed in various manners [16], which may positively or negatively influence the collection of these disturbances. Other complications such as mandibular fractures have also been described [17,18]. These complications have to be balanced with the outcome in terms of implant survival in these complex cases of mandibular rehabilitations.

The aim of this study was to systematically review the outcome (implant survival) and the complications associated with IAN repositioning techniques with simultaneous implant placement in atrophic posterior mandibles.

## 2. Materials and methods

This systematic review was conducted following PRISMA guidelines (Preferred Reporting Items for Systematic review and Meta-Analysis) [19]. The review was designed to answer the following PICO question: Is IAN repositioning (I) a safe and efficient technique (O) to treat patient looking for fixed dental rehabilitation of an atrophic posterior mandible (P)?

The literature search was performed in the Pubmed (MEDLINE), Cochrane Library and clinicaltrials.gov databases. The search terms used were: (1) « inferior AND alveolar AND nerve AND lateralization » ; (2) « inferior AND alveolar AND nerve AND transposition » ; (3) « inferior AND alveolar AND nerve AND reposition » ; (4) « inferior AND alveolar AND nerve AND translocation ». There were no limits in the search, which was performed up to December 2022. References cited in the selected articles were also manually searched.

Studies focusing on any IAN repositioning technique were eligible. Clinical studies reporting data on IAN repositioning outcomes (dental implant survival rates) and/or intra- and postoperative complications (neurosensory disturbances and other complications) were included. Neurosensory disturbance evaluation was included only if the follow-up lasted until at least 6 months or until full recovery of the patients included. The following exclusion criteria were respected: studies on animals, finite elements analysis, letters to the editor, technical notes, review articles, case reports and case series with  $n < 5$ , publication language other than English, and unavailability of the full text.

After duplicate removal and initial screening based on title and abstract, the authors read the selected articles in full, applying the inclusion and exclusion criteria to determine final inclusion in the review. The following data was collected: study design, number of patients included, their demographic data (age, gender) and relevant health status (tobacco use, diabetes), surgical procedure performed, dental implant survival, occurrence and duration of neurosensory disturbances and the related-assessment technique used, occurrence of other complications, and length of follow-up. The study was considered retrospective if not otherwise stated.

Bias were assessed in each study and presented using the ROBVIS tool (visualization tool for risk of bias assessments in a systematic review) [20] (Fig. 2). The classification of the risk of potential bias for each study was based on Cochrane Risk of bias assessment, which include seven evidence-based domains : (1) random sequence generation, (2) allocation concealment, (3) blinding of participants and personnel, (4) blinding of outcome assessment, (5) incomplete outcome data, (6) selective reporting.

## 3. Results

### 3.1. Study selection

The database search yielded 475 results, while the manual search found 3 more articles, leading to a total of 478 results, which included 92 duplicates. Three hundred and one articles were excluded based on title and abstract. Eighty-five articles were identified as relevant after reading the title and/or abstract, among those, 6 could not be retrieved. The full text of these 79 papers was evaluated according to the inclusion and exclusion criteria. Among these articles, 44 did not fulfill one or more selection criteria or had an exclusion criterion. Two others articles were pilot studies of which the definitive study was already included in the review (Fig. 1). Thirty-three articles were finally included in the review.

### 3.2. Study characteristics

Among the included studies, there were 3 randomized controlled trials, 11 prospective cohort studies, and 19 retrospective studies. Study characteristics, patient and procedure related data are summarized in Table 1. All follow-up periods lasted at least six months except for one study [21], which was included since all patients had recovered from their neurosensory disturbance at the end of the 4 months follow-up.

### 3.3. Quality rating

The risk of bias is globally high. Only 3 studies used a randomization process with allocation concealment [22–24]. The participants and personnel were never blinded. Outcome assessment was blinded only in one study [24]. Data concerning the outcomes were mostly complete except in 4 studies [23,25–27] with several patients lost to follow-up. Selective reporting bias was considered low as implant survival is an objective data, while neurosensory disturbance assessment was mostly the main outcome of the included studies.

## 4. Synthesis of results

### 4.1. Patient characteristics

There was a total of 899 patients corresponding approximately to 950 IAN repositioning procedures in the included studies. Three studies only stated the number of patients included and not the number of procedures [21,28,29], which could be uni- or bilateral. Hence, the exact number of procedures performed could not be retrieved. The mean age of the included patients was 52.54 year-old, ranging from 19 [14] to 82 year-old [30]. Age-related data was not reported at all in three studies [21,25,28], and only as a range in four studies [14,22,31,32]. The mean male-female sex-ratio was 0.55, hence in favor of females at the exception of 3 studies, which included more males than females [22,33,34]. Gender-related data was not reported in four studies [21,23,25,28].

Data about significant comorbidities such as diabetes mellitus or smoking were mostly lacking, only a handful of studies mentioned the number of diabetic patient [14,15,24,28,33,35] or smokers [23,31,35–38] included. On another hand, diabetes was considered an exclusion criterion in 4 studies [14,24,33,35] and smoking in 2 studies [23,36].

The maximal distance between the alveolar ridge and the IAN considered to propose IAN repositioning varied from 5 mm [27,32,35,39] to 8 mm [21,22,29]. Twenty-four studies did not state specific measurement guidelines used to decide whether or not an IAN repositioning is necessary [14,15,18,23–26,28,33,34,36–38,40–50]. The mean distance between the alveolar ridge and the IAN in

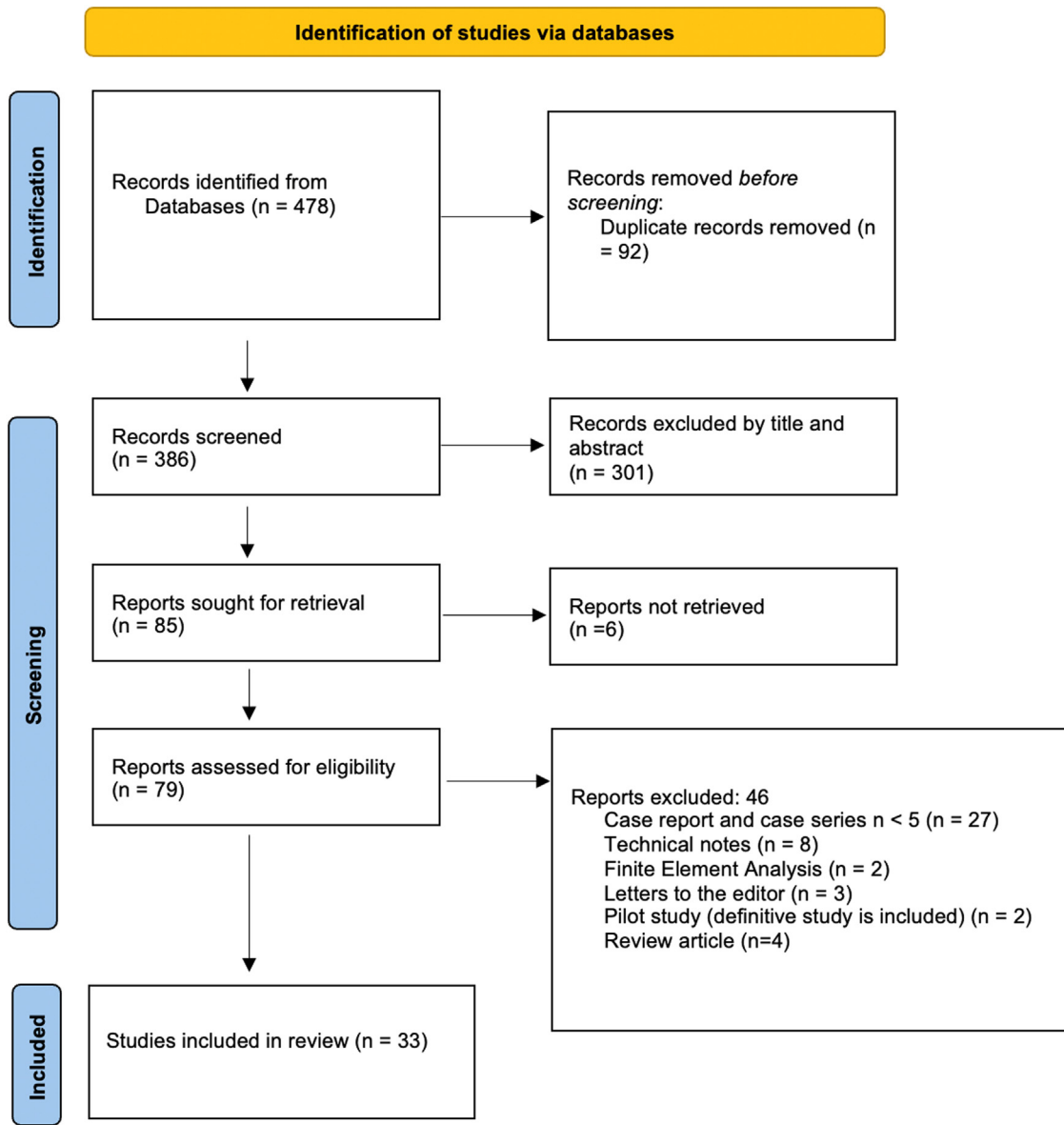


Fig. 1. Flowchart of the systematic review.

the case included varied from 0.93 mm [38] to 8.1 mm [15]. This data was not mentioned in 23 studies [21–25,27–36,39–41,43,43–45,50].

Follow-up ranged from 4 months to 84.5 months. In the study with only 4 months follow-up, the cessation of follow-up was due to patient complete nervous recovery [21]. All the other studies included had a minimal follow-up of 6 months.

#### 4.2. Type of interventions and techniques

The included studies could be divided into 3 groups: studies focusing on IANL ( $n = 14$ ), studies focusing on IANT ( $n = 13$ ), and studies focusing or comparing both techniques ( $n = 6$ ). One variant of IANT should be mentioned, the superiorization described by Kablan [51] where the nerve is not transposed through a lateral approach but a superior approach. This procedure was associated with autologous calvarial bone grafting and buccal fat pad free transfer for mucosal sealing.

Two types of devices were used to perform the osteotomy: piezo-electric device ( $n = 8$ ) [14,22,27,31,32,38,39,48], or burs ( $n = 13$ ) [21,23,24,26,29,30,33,34,40,44,45,47,51], both were used in 4 studies

[35,37,43,46]. The device used was not mentioned in 8 studies [15,25,28,36,41,42,49,50]. Dental implants were placed generally simultaneously except for a few patients in some studies [28,43,44,46] with a total of 2342 dental implants placed. There was no data about the time of implant placement in one study [41].

The bony window was put back into its original place in 6 studies [25,31,32,41,48,50], while it was grinded in particles and used as a source of autologous bone grafting in 10 studies [14,21–23,30,32,37,40,44]. Simultaneous bone grafting was performed in 13 studies: 1 autograft [14] (other than the bony window), 1 allograft [29], 5 xenografts [22,23,27,32,42], 3 synthetic calcium phosphate cement [21,24,46], 3 mix [37,43,51]. These grafts were associated with the bone of the bony window in particular form in 5 studies [14,21,22,32,37]. A resorbable collagen membrane was placed above the grafted material in 13 studies [22,27,29,31,32,35,37,39,41–43,47,48].

#### 4.3. Outcome – dental implant survival rate

Dental implant survival rate ranged between 86.95% [30] and 100% with a mean dental survival rate of 90.16% (Table 2). Four

Study	Risk of bias						Overall
	D1	D2	D3	D4	D5	D6	
Deryabin 2021	⊗	⊗	⊗	⊗	⊗	⊖	⊗
Garoushi 2021	⊕	⊕	⊗	⊖	⊕	⊖	⊗
Kablan 2020	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Al Almaie 2020	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Rathod 2019	⊗	⊗	⊗	⊗	⊕	⊖	⊗
De Campos 2019	⊕	⊕	⊗	⊖	⊗	⊖	⊗
Castellano-Navarro 2018	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Martinez Rodriguez 2018	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Sethi 2017	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Nishimaki 2016	⊗	⊗	⊗	⊗	⊗	⊖	⊗
Martinez Rodriguez 2016	⊗	⊗	⊗	⊗	⊕	⊖	⊗
De Vicente 2016	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Khojasteh 2016 a.	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Khojasteh 2016 b.	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Dursun 2016	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Barbu 2014	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Gasparini 2014	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Khajehahmadi 2013	⊕	⊖	⊗	⊕	⊕	⊖	⊗
Fernandez Diaz 2013	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Lorean 2013	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Hashemi 2010	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Chrcanovic 2009	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Hashemi 2006	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Ferrigno 2005	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Morrison 2002	⊗	⊗	⊗	⊗	⊗	⊖	⊗
Peleg 2002	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Hori 2001	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Nocini 1999	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Kan 1997	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Hirsh 1995	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Jensen 1994	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Rosenquist 1994	⊗	⊗	⊗	⊗	⊕	⊖	⊗
Friberg 1992	⊗	⊗	⊗	⊗	⊕	⊖	⊗

D1: Random sequence generation  
 D2: Allocation concealment  
 D3: Blinding of participants and personnel  
 D4: Blinding of outcome assessment  
 D5: Incomplete outcome data  
 D6: Selective reporting

Judgement  
 ⊗ High  
 ⊖ Unclear  
 ⊕ Low

Fig. 2. Risk of bias assessment using robvis tool.

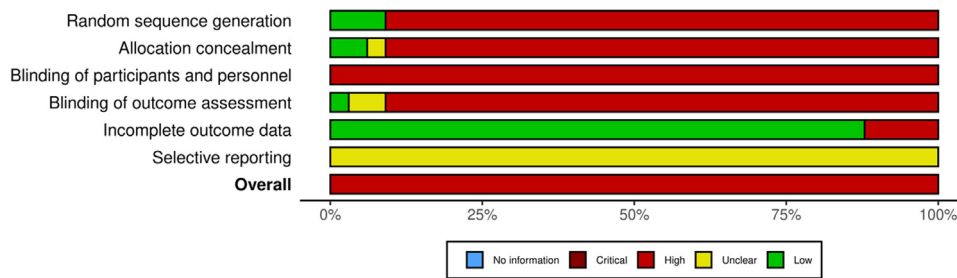


Fig. 2. Continued.

studies failed to report data about the number of implants placed [21,33,34,43] and 2 did not mention the survival rate [38,44]. It should be noted that only 8 studies [15,26,42–44,47,49,51], including 295 dental implants, had a follow-up of at least 3 years (one of these did not mention the number of dental implants placed [43]). Four studies [14,27,39,46], including 559 dental implants, had a follow-up of at least 5 years.

#### 4.4. Outcome - neurosensory disturbances

Among the 269 patients who underwent IANT, there were 93% immediate neurosensory disturbance, and 15% persistent neurosensory disturbance at the end of the follow-up (Table 3). Among the 350 patients who underwent IANL there were 93% immediate neurosensory disturbance, and 6% persistent neurosensory disturbance at the end of the follow-up. The end of the follow-up varied between studies, although there were full recovery already at 6 months in 9 studies [21,22,29,34,37,40,43,48,51], mostly IANL.

Seven studies could not be included in this aggregated result: 5 failed to detail immediate neurosensory disturbance [35,37,41,50,51], while 2 [14,36] detailed results in terms of procedure and not in terms of patients.

Neurosensory disturbance was evaluated using the following methods: questionnaire ( $n = 5$ ) [14,23,28,30,33], subjective clinical sensitivity tests (i.e. light touch test, 2-point discrimination test, heat and pain test) ( $n = 15$ ) [15,21,22,24,26,27,29,36,37,39,40,43–45,48], association of questionnaire with subjective clinical tests ( $n = 9$ ) [25,31,32,35,42,46,47,49,50], and objective sensitivity test (i.e. electrophysiological test) ( $n = 1$ ) [41]. Two-point discrimination tests were used with various threshold in the included studies, sensitivity being considered as normal when the two points were less than 8 mm [22] to less than 15 mm [31] apart. Nishioka et al. [52] thresholds were mostly used: normal sensitivity (< 14 mm), reduced sensitivity (14 – 20 mm), and absence of sensitivity (> 20 mm). When questionnaires were associated with subjective clinical testing, there was a discrepancy between what was reported in the questionnaire's answers and what was found using sensitivity testing. Electrophysiological test was used only in 1 study [41], and only at 18 postoperative months. These objective results were similar to those found using 2-point discrimination test but higher than those found using heat and pain test.

Three studies did not report neurosensibility evaluation data [34,38,51].

#### 4.5. Other complications

The 2 main complications were infections, with 7 infections [45,46] and 5 mandibular osteomyelitis [15,30,45,49], and mandibular fractures, with 6 corporeal fractures [14,23,28,47,49] and 3 crestal fractures [27]. Two intraoperative hemorrhage were also noted [45,49], one leading to an abortion of the planned implant placement and subsequent patient exclusion from the study [49].

## 5. Discussion

Rehabilitation of atrophic posterior mandible is challenging not only due to IAN position but also due to poor vascularization leading to longer healing time [53], and hence osseointegration. This review found a 90.16% dental implant survival rate following IAN repositioning. It should be noted that all of the included studies ranged between 93.60% and 100%, except two studies with a 88% [40] and 86.95% [30] survival rate. The survival rate seemed higher for IANL procedures (99%) than for IANT procedures (95%). This result is comparable with short dental implant survival rate (96% survival rate for  $\leq 6$  mm implants according to Ravida et al. [3]), and with dental implant survival rate in augmented bone (94.5% according to Chiapasco et al. [5], or 95.3% according to Nissan et al. [7]). Dursun et al. did not show any significant difference regarding marginal bone loss between standard implants placed in association with IAN repositioning and short implants [48]. However, when the distance between the alveolar ridge and the IAN is smaller than 5 mm, short implants cannot be used. Bone augmentation will require time for bone healing in a site known for its high bone resorption [10,11]. Furthermore, Khojasteh et al. showed higher implant success rate with IAN repositioning techniques than with cortical autogenous tenting technique [28]. It should be noted that most studies about IAN repositioning are primarily focused on neurosensory disturbance, hence the follow-up was often short to assess long-term survival of dental implants. However, studies were long enough to assess osseointegration. Since dental implants are inserted in strong cortical bone, often with a basilar anchorage, it could be inferred that most of the implants loss occurred in the early stages before osseointegration. Several factors are well known as possible causes of implant failure, notably smoking or diabetes. However, data about these comorbidities were often not disclosed in the included studies leading to a possible effect of these confounding factors.

The main morbidity following IAN repositioning was IAN neurosensory disturbances. Indeed, manipulation of the IAN [54,55] and old age [56–58] are known risk factors of neurosensory disturbances, well described in the orthognathic surgery literature. IAN repositioning is all about IAN manipulation, and edentulous patients tend to be older, which was confirmed in the patient included in the review (the mean age was 52.3 and the oldest patient was 82 year-old). The effect of gender is more subject to debate, most studies [54,58] found no differences between male and females, whereas in this review, hypoesthesia was more common in females. This may be related to the higher number of females included.

These neurosensory disturbances include not only negative symptoms, such as hypoesthesia or anesthesia, but also positive symptoms, such as paresthesia, dysesthesia, or hyperesthesia. These disturbances may last since nerve healing is a long and unpredictable process [59], depending on the initial lesion. Sunderland [60] classified nerve lesions in 5 stages. The first stage is neurapraxia, characterized by nerve conduction alteration without nerve fiber interruption, usually following nerve traction. A 10% to 17% traction of nerve fibers can already cause temporary conduction failure [61]. The second

**Table 1**  
Description of the included studies and patients.

Publication (first author, year)	Study Design	Patients included (n)	Procedures included (n)	Sex-ratio (M/F)	Mean age, range (years)	Diabetes (n)	Smokers (n)	Maximal alveolar ridge - IAN distance used to propose the procedure (mm)	Alveolar ridge - IAN mean distance and range (mm)	IAN repositioning performed
Deryabin, 2021	Retrospective	15	23	0.25	N/A, 19 - 68	0 (exclusion criterion)	N/A	N/A	4.3 (0.5 - 7)	IANL (n = 17) IANT (n = 6)
Garoushi, 2021	Randomized controlled trial	18	30	2	N/A, 24 - 53	N/A	N/A	8	N/A	IANL (n = 30)
Kablan, 2020	Retrospective	11	18	0.22	45, N/A	N/A	N/A	N/A	0 - 3	IAANT (n = 18)
Al-Almaie, 2020	Prospective	8	10	0.6	48, N/A	N/A	N/A	N/A	N/A	IAANT (n = 10)
Rathod, 2019	Prospective	10	N/A	N/A	N/A	N/A	N/A	8	N/A	IANL (n = N/A)
De Campos, 2019	Randomized controlled trial	34	34	N/A	49.77, N/A	N/A	0 (exclusion criterion)	N/A	N/A	IANL (n = 34)
Castellano-Navarro, 2019	Retrospective	123	139	0.36	55, N/A	N/A	0 (exclusion criterion)	N/A	N/A	IANL (n = 139)
Martinez Rodriguez, 2018	Prospective	40	48	0.66	57.1, N/A	N/A	N/A	5	N/A	IANL (n = 48)
Sethi, 2017	Retrospective	78	121	0.25	54.3, N/A	N/A	N/A	N/A	0 - 8	IANL (n = 105) IANT (n = 16)
Nishimaki, 2016	Retrospective	7	8	0.16	64, N/A	N/A	N/A	N/A	7.43 (1 - 10)	IAANT (n = 8)
Martinez Rodriguez, 2016	Prospective	27	27	0.588	57.74, N/A	N/A	N/A	5	N/A	IANL (n = 27)
De Vicente, 2016	Prospective	13	13	0.08	N/A, 45 - 68	N/A	0	7	N/A	IANL (n = 13)
Khojasteh, 2019 a.	Retrospective	14	23	0.55	53.93, N/A	0 (exclusion criterion)	0	5	N/A	IANL (n = 23)
Khojasteh, 2016 b.	Retrospective	69	N/A	N/A	N/A	0	N/A	N/A	N/A	IAANT (n = 69)
Dursun, 2016	Prospective	7	7	0.75	54.63, N/A	N/A	N/A	N/A	3 - 8	IANL (n = 7)
Barbu, 2014	Retrospective	7	11	N/A	43.29, N/A	N/A	0	N/A	0.93 (0.5 - 1.5)	IAANT (n = 11)
Gasparini, 2014	Retrospective	35	49	0.84	55.8, N/A	N/A	N/A	N/A	N/A	IANL (n = 49)
Khajehahmadi, 2013	Randomized controlled trial	21	28	0.9	49.5, N/A	0 (exclusion criterion)	N/A	N/A	N/A	IANL (n = 10) IANT (n = 11)
Fernandez Diaz, 2013	Prospective	15	19	0.06	N/A, 30 - 64	N/A	N/A	5	N/A	IANL (n = 19)
Lorean, 2013	Retrospective	57	79	0.239	47.38, N/A	N/A	3	N/A	3.88 (1 - 7)	IANL (n = 11) IANT (n = 68)
Hashemi, 2010	Prospective	87	110	1.175	39.3, N/A	0 (exclusion criterion)	N/A	N/A	N/A	IANL (n = 110)
Chrcanovic, 2009	Retrospective	15	18	0.5	46, N/A	N/A	N/A	N/A	N/A	IAANT (n = 18)
Hashemi, 2006	Retrospective	11	17	1.2	45.3, N/A	N/A	N/A	N/A	N/A	IANL (n = 17)
Ferrigno, 2005	Prospective	15	19	0.66	58.1, N/A	N/A	N/A	N/A	6.8 (6 - 8)	IAANT (n = 19)
Morrison, 2002	Retrospective	15	26	N/A	N/A	N/A	N/A	N/A	N/A	IAANT (n = 26)
Peleg, 2002	Retrospective	10	N/A	0.25	56, N/A	N/A	N/A	8	N/A	IANL (n = N/A)
Hori, 2001	Retrospective	6	8	1	37.83, N/A	N/A	N/A	N/A	N/A	IAANT (n = 8)
Nocini, 1999	Prospective	10	18	0.428	46, N/A	N/A	N/A	N/A	N/A	IAANT (n = 18)
Kan, 1997	Retrospective	15	21	0.363	64, N/A	N/A	N/A	N/A	6.8 (5 - 10)	IANL (n = 12) IANT (n = 9)
Hirsh, 1995	Retrospective	18	24	0.5	59.1, N/A	1	N/A	N/A	8.1 (6 - 10)	IAANT (n = 10) IANT (n = 14)
Jensen, 1994	Retrospective	6	10	0	54.8, N/A	N/A	N/A	N/A	N/A	IAANT (n = 10)
Rosenquist, 1994	Retrospective	72	100	0.56	58, N/A	N/A	N/A	N/A	N/A	IAANT (n = 100)
Friberg, 1992	Prospective	10	13	0.166	60, N/A	N/A	N/A	7	N/A	IAANT (n = 13)

IANL = Inferior Alveolar Nerve Lateralization; IAANT = Inferior Alveolar Nerve Transposition; N/A = Data Not available.

**Table 2**  
Description of the procedures performed and the dental implant survival outcome.

Publication (first author, year)	IAN repositioning performed	Associated procedures performed	Device used	Dental implant placed (n)	Dental implant survival rate (%)	Mean follow-up (months)	Complications
Deryabin, 2021	IANL (n = 17)	Particulate bone window	Piezoelectric	48	95.8	61.2	Mandibular fracture (n = 1)
Garoushi, 2021	IANT (n = 6)	± autograft					
	IANL (n = 30)	Xenograft + particulate bone window	Piezoelectric	43	100	6	N/A
		± collagene membrane					
Kablan, 2020	IANT (n = 18)	Allo/autograft mix	Bur	63	100	49.18	N/A
		+ free buccal fat pad graft					
Al-Almaie, 2020	IANT (n = 10)	± Xenograft + collagene membrane	N/A	20	100	47.1	N/A
De Campos, 2019	IANL (n = 34)	Xenograft (n = 19)	Bur	82	97.56	12	Mandibular fracture (n = 2)
		Particulate bone window (n = 15)					
Rathod, 2019	IANL (n = N/A)	BCP graft + particulate bone window	Bur	N/A	N/A	4	N/A
Castellano-Navarro, 2019	IANL (n = 139)	None	N/A	337	N/A	12	N/A
Martinez Rodriguez, 2018	IANL (n = 48)	Xenograft + collagene membrane	Piezoelectric	129	98.44	60	N/A
Sethi, 2017	IANL (n = 105)	β-TCP graft	Piezoelectric & Bur	308	97.8	84.5	Infections (n = 2)
	IANT (n = 16)						
Nishimaki, 2016	IANT (n = 8)	None	Bur	22		49	N/A
Martinez Rodriguez, 2016	IANL (n = 27)	Collagene membrane	Piezoelectric	74	98.6	60	Crestal fractures (n = 3)
De Vicente, 2016	IANL (n = 13)	Reposition of bone window + collagene membrane	Piezoelectric	27	100	12	N/A
Khojasteh, 2016 a.	IANL (n = 23)	± Collagene membrane + PRF	Both devices	51	N/A	12	N/A
Khojasteh, 2016 b.	IANT (n = 69)	None	N/A	184	98.74	18.51	Mandibular fracture (n = 1)
Dursun, 2016	IANL (n = 7)	Reposition of bone window + collagene membrane	Piezoelectric	25	100	12	N/A
Barbu, 2014	IANT (n = 11)	None	Piezoelectric	32	100	35.71	N/A
Gasparini, 2014	IANL (n = 49)	Auto/xenograft mix + collagene membrane	Piezoelectric & Bur	N/A	100	54.2	N/A
Khajehahmadi, 2013	IANL (n = 10)	β-TCP graft	Bur	65	100	34.2: 42 for IANT and 26.4 for IANL	N/A
	IANT (n = 11)						
Fernandez Diaz, 2013	ANL (n = 19)	Reposition of bone window OR Xenograft + Particulate bone window + collagene membrane	Piezoelectric	38	97.36	24	N/A
		Reposition of bone window OR Allo/Xenograft mix + Particulate bone window + collagene membrane + PRF	Piezoelectric & Bur	232	99.56	20.62	N/A
Lorean, 2013	IANL (n = 11)						
	IANT (n = 68)						
Hashemi, 2010	IANL (n = 110)	None	Bur	N/A	N/A	12	N/A
Chrcanovic, 2009	IANT (n = 18)	Particulate bone window	Bur	25	88	6	N/A
Hashemi, 2006	IANL (n = 17)	None	Bur	N/A	N/A	6	N/A
Ferrigno, 2005	IANT (n = 19)	Collagene membrane	Bur	46	95.7	49.1	Mandibular fracture (n = 1)
Morrison, 2002	IANT (n = 26)	Reposition of bone window	N/A	30	100	16	N/A
Peleg, 2002	IANL (n = N/A)	Allograft + collagene membrane	Bur	23	100	29.8	N/A
Hori, 2001	IANT (n = 8)	Particulate bone window	Bur	17	100	36	N/A
Nocini, 1999	IANT (n = 18)	Reposition of bone window + collagene membrane	N/A	N/A	N/A	N/A	N/A
Kan, 1997	IANL (n = 12)	None	N/A	64	93.8	41.3	Mandibular fracture (n = 1)
	IANT (n = 9)						Mandibular osteomyelitis (n = 1)
							Intraoperative bleeding (n = 1, patient excluded)
Hirsh, 1995	IANT (n = 10)	None	N/A	63	92.1	36	Mandibular osteomyelitis (n = 1)
	IANL (n = 14)						
Jensen, 1994	IANT (n = 10)	Reposition of bone window	N/A	21	100	23	N/A
Rosenquist, 1994	IANT (n = 100)	None	Bur	250	93.6	18	Infections (n = 5)
							Mandibular osteomyelitis (n = 2)
							Intraoperative bleeding (n = 1)
							Mandibular osteomyelitis (n = 1)
Friberg, 1992	IANT (n = 13)	Particulate bone window	Bur	23	86.95	10	

IANL = Inferior Alveolar Nerve Lateralization; IANT = Inferior Alveolar Nerve Transposition; BCP = Biphasic Calcium Phosphate; TCP = Tri-Calcium Phosphate; N/A = Data Not available.

**Table 3**  
Description of the neurosensory disturbance outcome.

Publication (first author, year)	Patients included (n)	IANR repositioning performed	Device used	NSD assessment method	Immediate NSD (n, % patients)	NSD at 2–3 months (n, % patients)	NSD at 6 months (n, % patients)	NSD at 12 months	Long-term NSD (min 18–24 months)	Mean follow-up (months)
Deryabin, 2021	15	IANL (n = 17) IANT (n = 6)	Piezoelectric	Q	15 (100%)	3 (20%)	N/A	2 (13.3%)	2 (13.3%), all IANT	61.2
Garoushi, 2021	18	IANL (n = 30)	Piezoelectric	LTT HPT 2PDT	18 (100%)	19 (63.3% sites)	0	N/A	N/A	6
Kablan, 2020	11	IANT (n = 18) IANT (n = 10)	Burr N/A	Q N/A	N/A 6 (75%)	N/A	0 Q: 3 (30%)	0 LT + PT + 2DT: 2 (20%) Q: 1 (10%)	0 N/A	49.18 47.1
De Campos, 2019	34	IANL (n = 34)	Burr	2PDT	34 (100%)	17 (50%)	7 (20.58%)	0	N/A	12
Rathod, 2019	10	IANL	Burr	LTT	10 (100%)	N/A	0*	N/A	N/A	4
Castellano-Navarro, 2019	123	IANL (n = 139)	N/A	LTT	132 sites (94.96% sites)	34 (85%)	26 sites (18.7% sites)	0	N/A	12
Martinez Rodriguez, 2018	40	IANL (n = 48)	Piezoelectric	2PDT	40 (100%)	28 (35.9%)	15 patients 37.5%	0	0	60
Sethi, 2017	78	IANL (n = 105) IANT (n = 16)	Piezoelectric & Burr	Q LTT HPT 2PDT	78 (100%)	10 (11.49%)	10 (11.49%)	Q: 3 (3.84%) 2 IANL / 1 IANT LTT, HPT, 2PDT: 0	N/A	84.5
Nishimaki, 2016	7	IANT (n = 8)	Burr	2PDT	7 (100%)	N/A	N/A	N/A	1 (16.6%)**	49
Martinez Rodriguez, 2016	27	IANL (n = 27)	Piezoelectric	LTT	27 (100%)	7 (25.9%)	3 (11.1%)	N/A	2 (7.4%)	18
De Vicente, 2016	13	IANL (n = 13)	Piezoelectric	2PDT	13 (100%)	2 (15.38%)	N/A	1 (6.66%)	N/A	12
Khojasteh, 2016 a.	14	IANL (n = 23)	Both devices	LTT HPT 2PDT	N/A	13	Q: 9 (64.28%) 2PDT: 3 (21.4%) LTT: 2 (14.28%)	Q: 2 (14.28%) 2PDT: 0 LTT: 1 (7.14%)	N/A	12
Khojasteh, 2016 b.	69	IANT (n = 69)	N/A	Q	69 (100%)	N/A	N/A	N/A	7 (10.14%)	18.51
Dursun, 2016	7	IANL (n = 7)	Piezoelectric	LTT HPT	2 (28%)	N/A	0	0	N/A	12
Barbu, 2014	7	IANT (n = 11)	Piezoelectric	2PDT	7 (100%)	N/A	N/A	N/A	0	35.71
Gasparini, 2014	35	IANL (n = 49)	Piezoelectric & Burr	N/A HPT	6 (17.1%)	6 (17.1%)	0	N/A	N/A	54.2
Khajehmadi, 2013	21	IANL (n = 10) IANT (n = 11)	Burr	2PDT	21 (100%)	2 (9.52%)	N/A	2 (9.52%) (1 IANT, 1 IANL)	N/A	34.2: 42 for IANT and 26.4 for IANL
Fernandez Diaz, 2013	15	IANL (n = 19)	Piezoelectric	Q	15 (100%)	3 (20%)	N/A	N/A	1 (6.66%)	24
Lorean, 2013	57	IANL (n = 11) IANT (n = 68) + collagen + PRF + reposition of bone window in onlay or particulate and mixed with allo/ xenograft	Piezoelectric & Burr	2PDT LTT HPT 2PDT	57 (100%)	4 (7%) (3 IANT, 1 IANL)	0	0	0	20.62
Hashemi, 2010	87	IANL (n = 110)	Burr	Q	110 sites (100%)	81 sites (5.45% sites)	3 sites 2.72%	3 sites (2.72% sites) 2 (2.29%)	N/A	12
Chrcanovic, 2009	15	IANT (n = 18)	Burr	HPT	18 sites (100%)	17 sites (94%)	0%	N/A	N/A	6

(continued on next page)

**Table 3** (Continued)

Publication (first author, year)	Patients included (n)	IAN repositioning performed	Device used	NSD assessment method	Immediate NSD (n,% patients)	NSD at 2–3 months (n,% patients)	NSD at 6 months	NSD at 12 months	Long-term NSD (min 18–24 months)	Mean follow-up (months)
Hashemi, 2006	11	IANL (n = 17)	Burr	N/A	11 (100%)	6 (54.5%)	0	N/A	N/A	6
Ferrigno, 2005	15	IANL (n = 19)	Burr	Q LTT HPT 2PDT	10 (66.66%)	N/A	4 patients 26.66%	2 patients 13.33%	1 patient (6.66%)	49.1
Morrison, 2002	15	IANL (n = 26)	N/A	Q LTT HPT 2PDT	15 (100%)	N/A	Q: 4 (26.66%) LT, 2PT, PT: 0	N/A	N/A	16
Peleg, 2002	10	IANL (n = N/A)	Burr	HPT	6 (60%)	0%	0	0	N/A	29.8
Hori, 2001	6	IANL (n = 8)	Burr	LTT HPT	6 (100%)	6 (100%)	6 (100%)	5 (83.3%)	3 (50%)	36
Nocini, 1999	10	IANL (n = 18)	N/A	HPT 2PDT EPST	N/A	N/A	N/A	N/A	HPT: 7 (70%) 2PDT: 9 (90%) EPST: 9 (90%)	12
Kan, 1997	15	IANL (n = 12) IANL (n = 9)	N/A	Q LTT 2PDT	15 (100%)	N/A	N/A	N/A	Q: 6 (37.5%) (2 IANL et 4 IANT) LTT, 2PDT: 10 (62.5%) (3 IANL et 7 IANT)	41.3
Hirsh, 1995	18	IANL (n = 10) IANL (n = 14)	N/A	LTT HPT 2PDT	18 (100%)	N/A	N/A	N/A	3 (16.66%) (2 IANT, 1 IANL)	36
Jensen, 1994	6	IANL (n = 10)	N/A	Q 2PDT	N/A	2PDT: 4 sites (40% sites)	2PDT: 2 sites (20% sites) Q: 0	2PDT: 1 site (10% sites) Q: 0	N/A	23
Rosenquist, 1994	72	IANL (n = 100)	Burr	2PDT	56 (79%)	N/A	23 (23%)	7 (7.7%)	3 (5%)	18
Friberg, 1992	10	IANL (n = 13)	Burr	Q	10 (100%)	N/A	2 (20%)	N/A	N/A	10

IANL = Inferior Alveolar Nerve Lateralization; IANT = Inferior Alveolar Nerve Transposition; NSD = Neuro-sensory disturbances; Q = Questionnaire; LT = Light Touch test; HPT = Heat & Pain Test; 2PD = 2-point discrimination test; EPST = Electrophysiological test; N/A = Data Not available.

\* this result was evaluated at 4 months, not at 6 months, all patients had recovered.

\*\* last follow-up between 12 and 105 months.

stage is axonotmesis with section of the nerve fiber but conservation of the connecting tissues, usually following compression trauma. Nerve recovery should occur within 3 months after axonotmesis. Following stages include neurotmesis with complete destruction of the nerve, hence recovery is then longer and often uncomplete. Hence, IAN manipulation should be careful and kept to a minimum. However, nerve trauma cannot be completely avoided, which is confirmed with immediate neurosensory disturbance occurrence in 93% of the cases, ranging from 60% to 100% of the patients. The significant morbidity was persistent neurosensory disturbances, caused by severe nerve trauma (neurotmesis), which must be avoided. IAN can be either lateralized or transposed, and even if IANT was described after IANL, IANL was more commonly performed (269 IANT versus 345 IANL in this review). In this review, there was no difference in terms of neurosensory disturbances (93% of the cases) between IANL and IANT immediately after surgery. However, at the end of follow-up, IANT was associated with twice more (15%) persistent neurosensory disturbance when compared to IANL (6%). Studies comparing IANL and IANT mostly found more neurosensory disturbances, and longer occurring disturbances in the IANT group [14,15,49], while 2 studies found similar results for both techniques [24,37] (Lorean et al. found complete recovery in both groups at 6 months). Conversely, one study found more neurosensory disturbances following IANL versus IANT based on a questionnaire assessment, whereas the clinical tests (light touch test, heat and pain test and two-point discrimination test) all demonstrated complete recovery [46]. IANT requires incisive nerve transection, leading to permanent loss of sensitivity of the teeth located anteriorly to the mental foramen. Thus, IANT should be considered only for patients with an edentulous or devitalized anterior sector. IANL seems a safer technique regarding long term neurological complications.

While IAN manipulation is the main cause of neurosensory disturbances, it may also occur due to nerve trauma during implant placement or due to direct contact between the IAN and sharp implant thread. The use of non-threaded implants has therefore been proposed [29]. On another hand, many authors advocate the interposition of a biologic barrier to avoid direct contact between the IAN and the implants, such as a collagen membrane [27,31,32,35,35,37,39,41–43,47,48], autogenous bone graft, xenograft or allograft [14,23,51]. This theory was based on an experimental dog model, which showed lower neurosensory disturbances when a collagen membrane was placed [62]. However, the use of such interposition has not shown any significant difference regarding the neurosensory outcome or the implant survival in recent clinical studies [22,23], suggesting that interposition was ineffective in neurosensory disturbance prevention.

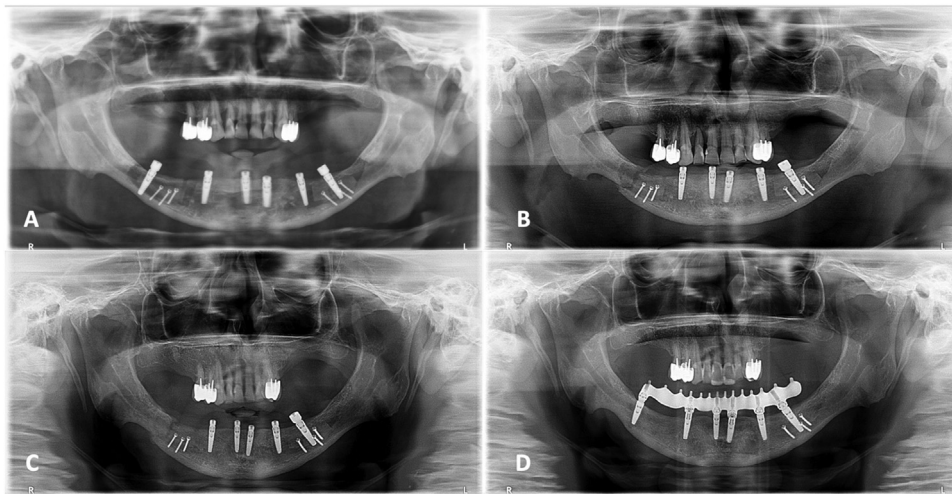
Lastly, nerve trauma may occur during the osteotomy. Osteotomies were performed either with a bur, or with a piezoelectric device, or both in the studies included. Most studies used the bur, which is not surprising since piezosurgery appeared more recently and its access is more limited. Moreover, two studies were conducted before invention of piezosurgery [30,45]. Piezosurgery effectively cut bone while preserving surrounding soft tissues. Piezosurgery has shown its superiority to burs in accuracy and soft tissue preservation, limiting postoperative morbidity in several mandibular surgeries: third molar removal [63], mandibular autograft harvesting [64], orthognathic surgery [65], sinus lift [66]. The study that compared burs versus piezosurgery found less neurosensory disturbances when using piezosurgery (10,5%) versus burs (25%), albeit this result was not statistically significant [43].

One of the main problem with neurosensory disturbance is the difficulty to assess it with reproducibility, hence to compare the result of several studies. This assessment can be performed using either objective means (e.g. electrophysiological assessment) or subjective means (e.g. sensory testing or patient reporting through questionnaires). Only one of the included studies [41] used an objective

assessment method, measuring the nerve conduction velocity (demyelinating injury assessment), and the amplitude of sensory action potential (axonal damage assessment). Most patients showed a slower of nerve conduction velocity with normal or reduced amplitude of sensory action potential, except four surgical sites where no action potential could be recorded [41]. The other studies used subjective assessment methods: clinical sensitivity examination (two-point discrimination test, light touch test, heat and pain test) in fifteen studies [15,21,22,24,26,27,29,36,37,39,40,43–45,48], self-reported questionnaires in five studies [14,23,28,30,33], and an association of both in nine studies [25,31,32,35,42,46,47,49,50]. Most studies used a mix of subjective tests, indeed, each clinical sensitivity examination test different nerve fibers. The light touch test and heat and pain test have the ability to selectively discriminate between large myelinated quick-adapting A $\alpha$  fibers, lightly myelinated A $\delta$  fibers (representing 90% of A axons) and unmyelinated C fibers. Whereas, the two-point discrimination test selects only large myelinated slow-adapting A $\alpha$  fibers (representing 10% of A axons) [67]. It is important to test several fibers since all fibers are not impacted the same way following a trauma: larger sensory axons mediating cutaneous epicritic sensitivity are less resistant to compressive and ischemic events than fibers standing for heat and pain sensitivity [41].

There is currently no gold standard in IAN injury assessment [16]. The objective evaluation could be considered the most accurate, but it may not reflect the patient experience. Indeed, to the patient, changes in sensitivity and their consequences on daily life matter most than testing estimates of residual nerve injury [68]. This was highlighted by the discrepancy between the objective and subjective results in the Nocini et al. study [41], where the outcome perceived by the patient was superior to the objective testing results regarding heat and pain sensitivity. Subjective testing can therefore be considered as a good assessment method, especially when clinical testing and self-report questionnaires are associated [16]. Questionnaires cannot avoid bias, however patient self-reporting has been shown to be quite reliable [69]. Given the same instructions by multiple examiners, patients provided identical responses when requested to describe alterations that occur spontaneously or were elicited by touch [70]. Hence, even if the assessment means used in the studies included vary, it can offer a reliable portrait of neurosensory disturbance occurrence. The method of evaluation is not the only variable, indeed the timing of the evaluation varies also greatly in the studies included. Concerning early neurosensory disturbances, some studies performed testing immediately after the termination of the local anesthesia effect, others waited for a week or even a month following the procedure. One study only performed one single evaluation a year after surgery [41], while another did not standardize the time of evaluation which ranged between 12 and 105 months [26]. Few long term data were available on neurosensory disturbances, given that only thirteen studies reported a follow-up of at least eighteen months [14,15,27,28,32,37–39,41,44,45,49,51]. However, it should be noted that some studies [21] stopped follow-up since nerve recovery was complete in 100% of the included patients. Comparability would be increased if a standardized method was used both in terms of tests used and their timing. Finally, it should be noted that many studies reported a high satisfaction of patients even in presence of residual neurosensory disturbances [25,47].

Few complications have been described outside nerve-related complications: infections, hemorrhage, and mandibular fracture. Significant intra-operative hemorrhage was described in 2 studies, which caused the cancelation of the procedure [45,49]. Infections have been reported in 7 cases [15,30,45,46,49]. Five of them were described as osteomyelitis [15,30,45,49]. Mandibular fractures were the most frequent of these serious complications (Fig. 3). They have been reported in 17 cases [14,17,18,23,28,47,71–78] (6 of these cases occurring in studies included in this review [14,23,28,47,49]). Fractures occurred between 10 days to 4 weeks following surgery, at the



**Fig. 3.** Example of a mandibular fracture after bilateral inferior alveolar nerve transposition. Immediate postoperative orthopantomogram (A); One month postoperative orthopantomogram showing a right mandibular fracture with loss of the distal implant (B); Two months postoperative orthopantomogram showing a bony callus after conservative management (C); Final orthopantomogram after secondary dental implant placement and final dental rehabilitation (D).

exception of a bilateral intraoperative fracture [17]. The treatment described was either conservative (soft diet with maxillomandibular fixation [72,75,78] or without [72]) or surgical (mini plates [73] or reconstruction plates [74–76]). The implants were systematically removed, except in one case [78]. When IAN reposition is indicated, the mandible is atrophic, hence prone to fracture. When the IAN is positioned lingually, removal of the buccal plate may significantly fragilize the mandible, causing these fractures [73,75]. Another factor which may explain these fractures is the bicortical anchorage. Indeed, several authors perform the bicortical anchorage to increase primary stability of the implants [79,80]. However, disruption of the inferior border further weaken an already atrophic mandible. This caused several authors to advocate inferior border preservation [23,74,75,77].

## Conclusion

IANL and IANT are reliable techniques allowing safe dental implant placement in atrophic posterior mandible with high patient satisfaction. IANL seems to cause less persistent neurosensory disturbances compared to IANT and should be favored. The level of evidence is poor due to the high number of bias present in the included studies. IAN neurosensory disturbance assessment should be better homogenized in terms of means and duration in order to increase comparability.

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## Declaration of Competing Interests

The authors declare that there are no conflict of interest.

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