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Original Article

Risk factors for inferior alveolar nerve injury associated with implant surgery: An observational study

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KEYWORDS
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Abstract *Background/purpose:* Inferior alveolar nerve (IAN) injury is the most serious complication associated with dental implant surgery, posing difficulties in treatment and potential for permanent disabilities. This study aimed to identify patient-related risk factors for IAN injury during implant placement and to investigate sensory disturbances depending on whether the implant was removed.
Materials and methods: Twenty-eight patients with implant-related IAN injury were included. To determine risk factors, patient demographics and radiographic images were analyzed. Sensory functions were evaluated and compared based on whether the implant was removed.
Results: IAN injury occurred more frequently in women (60.7%), with a mean age of 62.9 years. The distance from the alveolar crest to the IAN was 9.8 ± 3.0 mm, with 40.9% patients having a residual alveolar bone of 10 mm or more. The mean bone density was measured at 586.2 ± 392.5 HU, which is below the normal range for the mandible. Notably, 31.8% of the patients were found to have D4 bone. Compared to patients who did not have implants removed, those who did showed better sensory function, except pressure perception, although these differences were not statistically significant.
Conclusion: Older women with lower bone density were at an increased risk of IAN injury, and IAN injury occurred even in cases with sufficient alveolar ridge. The removal of implants related to the injury alone does not markedly influence the extent of sensory disturbances during follow-up period, suggesting that other aspects such as the timing of removal and severity of injury could be crucial.

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Introduction

Inferior alveolar nerve (IAN) injury is the most serious complication associated with dental implant surgery. It can sometimes be transient and manageable, but often it is permanent. Libersa et al.[1] reported definitive injuries in 75% of patients with neurosensory disturbance following implant surgery. In the study by Renton et al.,[2] permanent IAN neuropathy following implant treatment was observed in 27 of 30 patients, and over 50% of patients complained of constant pain and/or discomfort. Dannan et al.[3] reported a transient trigeminal nerve damage rate of 3.0% following dental implant surgery, and 1.7% of the patients exhibited persistent neuropathy. Despite various efforts to manage IAN injury, such as pharmacological management, physical therapy, implant removal, internal/external decompression, and microsurgery, in many cases, neither patients nor practitioners are satisfied with the treatment outcomes. Patients who underwent implant treatment to improve mastication, pronunciation, and esthetics find it difficult to accept the symptoms and discomfort associated with damage to the IAN. Therefore, practitioners need to take precautions not only during the surgical process, but also in the pre-surgical phase, including meticulous diagnosis and identification of risk factors, to prevent accidental nerve injury during implant surgery.

The purpose of this study stems from the absence of previous research elucidating specific factors contributing to the potential injury of the IAN during implant surgery. While previous studies have extensively explored iatrogenic factors leading to nerve damage during implant procedures, there has been limited analysis of patient-related factors. Therefore, this study aimed to retrospectively analyze patients with IAN injury related to implant surgery to identify patient-related factors that influence IAN injury during implant placement, and additionally, to investigate the extent of sensory disturbances depending on whether the implant was removed.

Materials and methods

This study was conducted in accordance with the principles of the Helsinki Declaration. All included patients provided their informed consent prior to the study. The study protocol was approved by the Institutional Review Board of Seoul National University Dental Hospital (Approval No.: ERI24005).

Study sample

To recruit patients to be included in this study, a total of 72 consecutive patients with neurosensory disturbance who visited the Department of Oral and Maxillofacial Surgery at Seoul National University Dental Hospital from October 2020 to September 2023 were retrospectively analyzed. Patients meeting the following criteria were included in the study: 1) IAN injury after dental implant surgery; 2) no sensory disturbances in the corresponding area before implant surgery; 3) patients who underwent sensory function test; 4) unilateral IAN injury. The following exclusion criteria were applied to the study: 1) nerve damage resulting from procedures other than dental implant surgery (41 patients); 2) lingual nerve damage (1 patient); 3) patients who did not undergo sensory function test (1 patient); 4) bilateral nerve injuries (1 patient). Patient demographics including age, sex, initial symptoms, implant placement site, duration from implant placement to the first visit, and fixture presence at the time of the visit, and the symptoms related to nerve injury were examined.

Radiographic evaluation

To assess whether there was approximation, partial intrusion, or complete penetration of the implant into the nerve, the proximity of the implant to the IAN was examined using computed tomography (CT) images obtained at the first visit (Fig. 1). To determine possible risk factors for IAN injury, the following measurements were made using CT images by a single examiner (Fig. 2):

1) The distance from the alveolar crest to the superior aspect of the IAN, the distance from the inferior aspect of the IAN to the mandibular inferior border, the total mandibular height, and the vertical height of the IAN were evaluated on the coronal view of the CT images at the injured site.
2) Cortical thickness at the alveolar crest was measured on the coronal view of the CT images at the injured site.
3) Radiodensity of the mandible around the dental implant or the site where the implant was removed was measured in Hounsfield units (HU).

Sensory function test

The sensory function test was conducted through contact threshold, directional discrimination, two-point discrimination (2PD), pressure perception (PP) and cold perception tests (Fig. 3).[4] The contact threshold test was performed using a Von Frey hair kit to assess the mechanical sensitivity of the skin. The directional discrimination test was performed on the center of the area that showed the highest measurements in the contact threshold test using the smallest hair capable of eliciting sensation in that area. The hair was moved 1 cm up, down, left, and right, and the ability to perceive the direction of movement was evaluated. The procedure was repeated 20 times, and the number of correct identifications was converted into a percentage. In the 2PD test, the ability to discern the

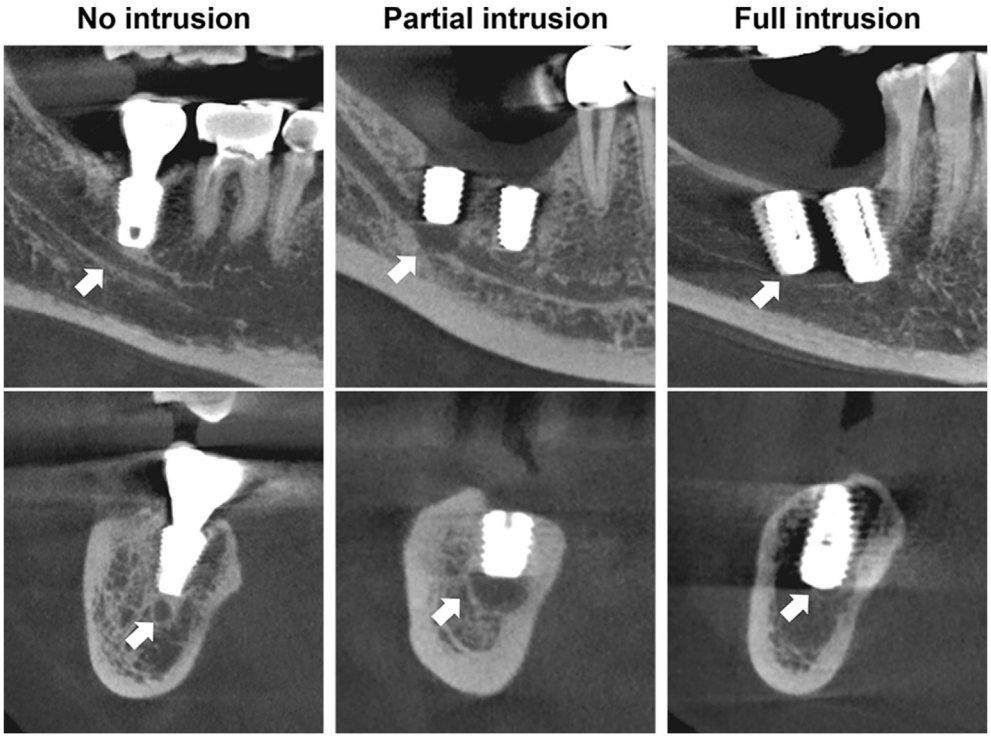

Figure 1 Proximity of the implant fixture to inferior alveolar nerve (arrow).

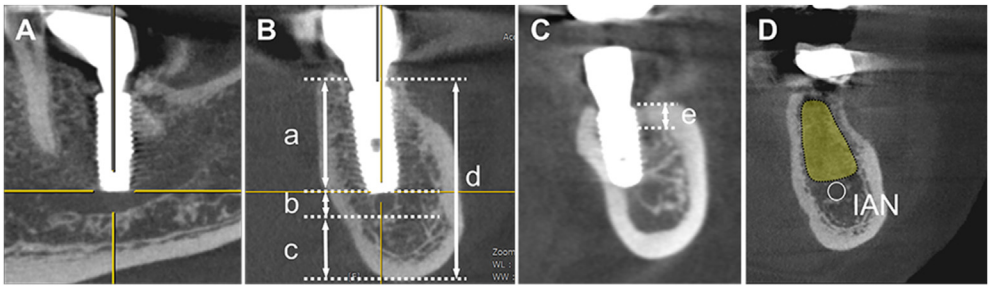

Figure 2 Radiographic measurements (A) Setting up the evaluation computed tomography view parallel to the long axis and passing through the center of the implant (B, C) Linear measurements for the mandible. The measurements are as follows: (a) distance from the alveolar crest to the superior aspect of the inferior alveolar nerve (IAN); (b) vertical height of the IAN; (c) distance from the inferior aspect of the IAN to the mandibular inferior border; (d) total mandibular height; (e) cortical thickness (D) Measurement of bone density. The bone marrow area superior to the IAN was designated as the region of interest, and the bone density within this selected area was measured in Hounsfield units.

distance between two points was assessed. Using a divider, the distance between the points was increased gradually, and the distance at which the patient recognized them as two separate points was recorded. The PP test was performed to evaluate the patient's ability to perceive pressure applied to the skin. Pressure was applied using a pressure gauge, and the pressure at which sharp pain was experienced was recorded. Both the 2PD and PP tests were conducted in the area where sensory loss was most pronounced, as was the directional discrimination test. The cold perception test measured the patient's ability to detect temperature changes. Cotton swabs, either soaked with ethanol stored in the refrigerator or not, were brought into contact with the normal and affected sides to assess the ability to perceive temperature changes.

Statistical analysis

The sample size calculation was conducted using G*Power version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Based on the previous study assessing sensory disturbances due to the inferior alveolar nerve injury, the effect size of 0.5 obtained.[5] A minimum of 28 patients were required to detect differences between the injured and normal sides, with 80% power and an α value of 0.05.

Statistical analyses were performed using SPSS Statistics version 25.0 (IBM Corporation, Armonk, NY, USA). To determine whether the data followed a normal distribution, the Kolmogorov—Smirnov test was performed. Descriptive statistics were described as the mean values

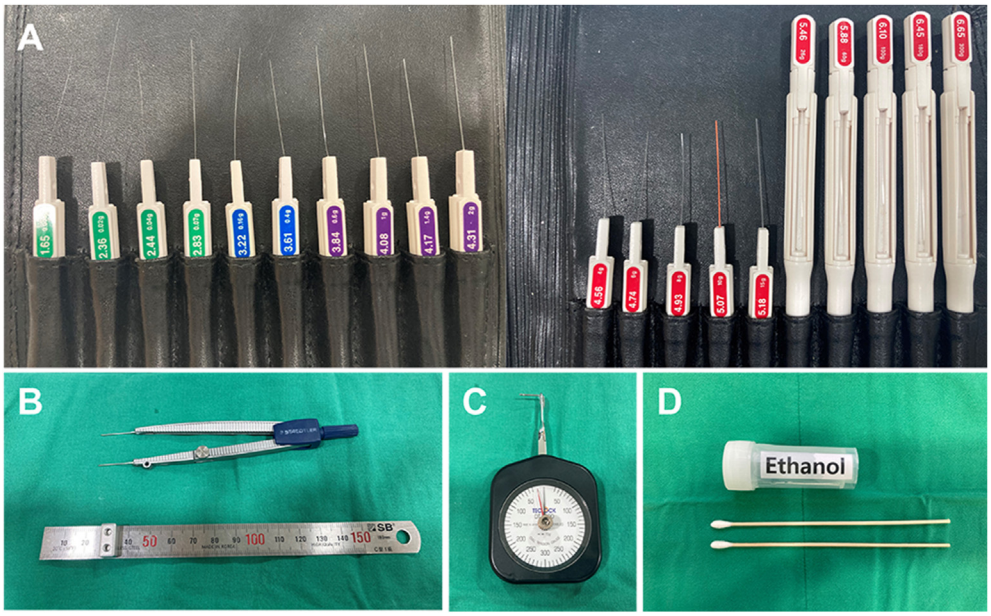

Figure 3 Instruments for sensory function test (A) Von Frey hair kit for contact threshold test (B) Divider and ruler for two-point discrimination test (C) Pressure gauge for pressure perception test (D) Ethanol and cotton swabs for cold perception test.

with standard deviation for continuous data and proportions for categorical data. The Wilcoxon signed rank test was used to compare differences within groups. To compare two independent groups, the Mann–Whitney U test and Fisher's exact test were conducted. The reported *P*-values were two-sided, and the level of significance was set at $P < 0.05$.

Results

Characteristics of the patients and implant surgeries associated with IAN injury

A total of 28 patients (male:female = 11:17; mean age, 62.9 ± 10.3 years; age range, 42–81 years) who met the inclusion and exclusion criteria were recruited. The mean duration from implant placement to the first visit to our hospital was 6.9 ± 7.8 months, ranging from 0.1 to 32.7 months. The implant placement sites associated with sensory impairment were predominantly located in the second molar region, accounting for over half at 64.3% (18 patients), followed by the first molar region at 32.1% (9 patients). Only one patient experienced nerve damage after implant placement in the canine region, and notably, this patient was edentulous. The incidence was 39.3% on the left side, and 60.7% on the right side. Thirteen patients (46.4%) visited with implants in place, while 15 patients (53.6%) had their implants removed for decompression before visiting. Regarding the symptoms after injury, anesthesia was reported by 14 patients (50.0%), dysesthesia by 10 patients (35.7%), allodynia by 9 patients (32.1%), hypoesthesia by 6 patients (21.4%), and paresthesia by 5 patients (17.9.7%). Eleven patients had two or more symptoms.

Radiographic evaluation

Among the 28 patients included in this study, radiographic analysis was conducted on 22 patients who had undergone CT scans after IAN injury, while the 6 patients without CT data due to patient's refusal were excluded. The mean mandibular body height at the implant placement site was 22.4 ± 3.9 mm, where the distance from the alveolar crest to the superior aspect of the IAN, the distance from the inferior aspect of the IAN to the mandibular inferior border, and the height of the IAN were 9.8 ± 3.0 mm, 9.9 ± 2.7 mm, and 2.7 ± 0.8 mm, respectively (Table 1). Of the 22 patients, the distance from the alveolar crest to the superior aspect of the IAN was more than 10 mm in 9 patients (40.9%), and more than 8.0 mm in 15 patients (68.2%). In terms of the relative vertical position of the IAN, the distance from the inferior border of the mandible

Table 1 Radiographic measurements.

Variable	Mean ± SD
Mandibular body height (mm)	22.4 ± 3.9
Distance from the alveolar crest to the superior aspect of the IAN (mm)	9.8 ± 3.0
Distance from the mandibular inferior border to the inferior aspect of the IAN (mm)	9.9 ± 2.7
Height of IAN (mm)	2.7 ± 0.8
Cortical bone thickness at the alveolar crest (mm)	1.2 ± 0.6
Bone density (HU)	586.2 ± 392.5

Abbreviations: SD, standard deviation; IAN, inferior alveolar nerve.

to the IAN and the percentage of this distance in relation to the total mandibular body height were 12.5 ± 2.7 mm and 56.3 ± 10.0%, respectively. The cortical bone thickness at the alveolar crest was 1.2 ± 0.6 mm, with a range of 0.4–3.3 mm. With respect to the bone quality around the implant fixture, the mean bone density value was 586.2 ± 392.5, with a range of −439.9 to 1180.1. Based on the classification of bone mineral density using HU value, there were no patients exhibiting D1 density, whereas D2 and D3 densities were observed in 36.4% and 31.8% of the 22 patients, respectively. Patients with bone below D4 density accounted for 31.8%.

Sensory function test

For the 13 patients with implants in place, the injured side exhibited significantly worse results compared to the normal side in the contact threshold (normal, 0.01 ± 0.02 g; injured, 0.33 ± 1.05 g; $P = 0.039$), directional discrimination (normal, 86.92 ± 22.04%; injured, 47.69 ± 37.45%; $P = 0.005$), and 2PD tests (normal, 8.38 ± 5.63 mm; injured, 14.62 ± 8.80 mm; $P = 0.011$) (Table 2). However, no significant difference was observed in the PP test (normal, 71.15 ± 58.8 g; injured, 70.85 ± 60.26 g; $P = 0.529$). In the cold perception test, nine patients reported an abnormal cold sensation on the injured side, whereas four patients reported a normal cold sensation. When the proximity and extent of invasion of the implant to the IAN were evaluated using CT images, seven patients (53.8%) exhibited partial intrusion, two patients (15.4%) showed full intrusion, and two patients (15.4%) were in proximity to the IAN without intrusion. Two patients (15.4%) did not undergo CT imaging. The results of the sensory function test based on the invasion of implant fixture to the IAN are described in Table 3.

In 15 patients where the implant fixture was removed, the majority, consisting of nine patients (60.0%), underwent fixture removal within one week. Two patients (13.3%) had removal within one month, one patient (6.7%) within three months, and two patients (13.3%) within nine months. Removal date for one patient was unknown. The mean period from the injury to removal of the implant was 30.6 ± 67.0 days. In the sensory function test, there are statistically significant differences in the contact threshold (normal, 0.008 g; injured, 0.49 ± 1.54 g; $P = 0.042$), directional discrimination (normal, 80.33 ± 27.74%; injured, 45.00 ± 33.11%; $P = 0.001$) and 2PD tests (normal, 8.37 ± 3.39 mm; injured, 16.10 ± 7.45 mm; $P = 0.004$) between normal and injured sides, whereas no significant difference was found in the PP test (normal, 64.33 ± 36.20 g; injured, 89.67 ± 84.36 g; $P = 0.182$). Regarding the cold perception test, 13 patients had abnormal cold sensation, whereas 2 patients reported normal cold perception. When comparing sensory function based on removal timing, patients who had removal within one week (9 patients) exhibited a contact threshold of

Table 2 Sensory function test results for patients with fixture-presence and fixture-removal patients at initial visit.

	Fixture-presence			Fixture-removal		
	Normal	Injured	*P*-value[a]	Normal	Injured	*P*-value[a]
Contact threshold (g)	0.01 ± 0.02	0.33 ± 1.10	0.039	0.008	0.49 ± 1.54	0.042
Direction discrimination (%)	86.92 ± 22.04	47.69 ± 37.45	0.003	80.33 ± 27.74	45.0 ± 33.11	0.001
2PD (mm)	8.38 ± 5.63	14.62 ± 8.80	0.011	8.37 ± 3.39	16.10 ± 7.45	0.004
PP (g)	71.15 ± 58.81	70.85 ± 60.26	0.529	64.33 ± 36.20	89.67 ± 84.36	0.182

Note: Data are presented as mean ± standard deviation.
Abbreviations: 2PD, two-point discrimination; PP, pressure perception.
[a] *P*-value indicates differences between normal and injured sides using Wilcoxon signed rank test.

Table 3 Sensory function tests based on the degree of inferior alveolar nerve intrusion by the implant. The list below exclusively targets patients who had their implants in place and whose degree of intrusion could be determined via computed tomography imaging.

	Degree of intrusion	Contact threshold (g)		Direction discrimination (%)		2PD (mm)		PP (g)		Cold perception
		Normal	Injured	Normal	Injured	Normal	Injured	Normal	Injured	Injured
1	Partial	0.008	0.020	100	50	4	25	40	36	Abnormal
2	Partial	0.008	0.008	100	70	9	25	90	70	Abnormal
3	Partial	0.008	0.008	100	15	11	15	50	70	Abnormal
4	Full	0.008	0.008	95	95	3	3	40	10	Normal
5	Partial	0.008	0.008	100	75	10	25	30	30	Normal
6	No	0.008	0.008	90	90	9	8	60	55	Abnormal
7	Partial	0.02	4.000	100	0	8	25	90	200	Abnormal
8	Partial	0.07	0.160	95	10	5	5	250	130	Normal
9	No	0.008	0.020	75	10	6	11	60	170	Abnormal
10	Full	0.008	0.008	100	100	5	7	30	20	Abnormal
11	Partial	0.008	0.020	95	65	25	25	55	70	Abnormal

Abbreviations: 2PD, two-point discrimination; PP, pressure perception.

0.80 ± 1.96 g, directional discrimination of 47.22 ± 39.38%, 2PD of 18.89 ± 6.97 mm, and PP of 96.11 ± 87.53 g. Conversely, patients with removal timing of more than one week (5 patients) showed a contact threshold of 0.008 g, directional discrimination of 47.00 ± 22.25%, 2PD of 10.30 ± 5.81 mm, and PP of 46.00 ± 26.08 g. No statistically significant differences were found according to the timing of removal (contact threshold, $P = 0.190$; directional discrimination, $P = 0.999$; 2PD, $P = 0.060$; PP, $P = 0.190$). The average time to undergo sensory function tests was 95.8 days after nerve injury for patients who had removal within one week and 204.6 days after nerve injury for patients with removal timing of more than one week ($P = 0.112$).

For patients with implants in place, the average time to undergo sensory function tests was 222.7 days after nerve injury. Considering this period, to evaluate the prognosis of sensory function based on implant removal, we compared the sensory function test results of patients who underwent additional sensory function tests six months after implant removal (7 patients) with the results of patients who still had implants. Six months after implant removal, sensory function tests showed an average of 0.013 ± 0.012 g in contact threshold, 75.71 ± 34.81% in directional discrimination, 11.29 ± 7.16 mm in 2PD, and 92.14 ± 0.48 g in pressure perception test, with 42.9% of patients having normal cold perception (Fig. 4). Compared to patients who did not have their implants removed, those who did showed better sensory function except PP tests, although these differences were not statistically significant (contact threshold, $P = 0.311$; directional discrimination, $P = 0.115$; 2PD, $P = 0.485$; PP, $P = 0.351$).

Discussion

This study aimed to help dental practitioners understand the characteristics of patients who experienced IAN injury during dental implant surgery. By identifying possible risk factors, the goal was to provide key considerations for preoperative assessments and actual surgical procedures to ensure safe and successful implant treatment.

In the present study, there were 17 females and 11 males with a mean age of 62.9 years. This higher incidence in older female aligns with previous studies. Chaushu et al.[6] found that 75% of patients with altered sensation after mandibular implant placement were women. In the retrospective study, Paasky et al.[7] reported that out of 38 patients who suffered IAN injury during implant surgery, 29 were women, indicating that women are more susceptible to iatrogenic IAN injury than men. This high incidence in women is not clearly understood, but may be explained by women's smaller mandibles, menopause, and subsequent changes in bone metabolism due to hormonal changes.[6,7] Older female patients frequently develop osteoporosis, which can cause excessive resorption of the alveolar ridge after tooth extraction. Additionally, low bone density prevents the mandibular canal from appearing clearly on radiographic images, which may cause misjudgment of the

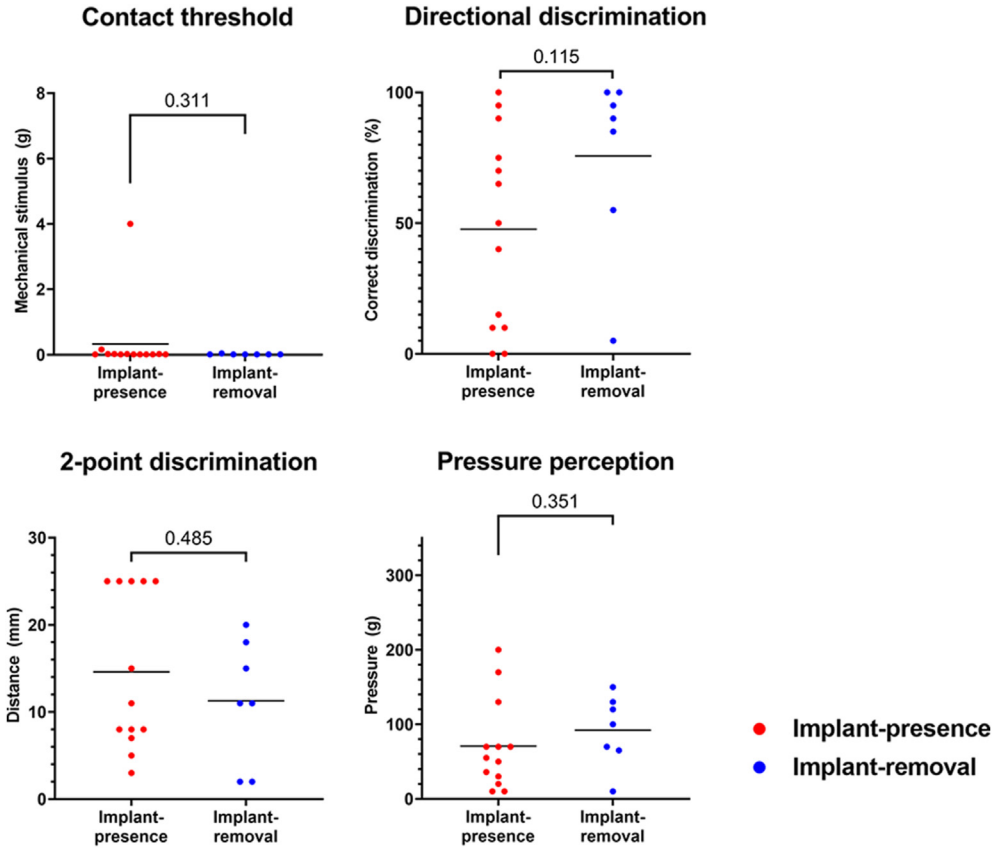

Figure 4 Comparison of sensory function according to whether the implants were removed.

location of the IAN. In fact, in previous studies on the etiological factors of IAN injury during implant surgery, inaccurate recognition of the IAN was reported to be the most frequent cause of IAN injury.[7,8] In our study, most patients had implants placed in the molar region, and the mean HU value of the surrounding bone was 586.2, which was lower than the general HU value for the mandibular molar region (797.0 ± 135.1).[9] These findings suggest that it may have been difficult to identify the location of the IAN and that the implant fixture could have easily encroached on the mandibular canal.

Several anatomical parameters are suggested as risk factors for IAN injury. In routine radiological examination, patients with a relatively high position of the IAN are frequently found. They exhibit a great distance from the mandibular inferior border to the IAN and have the IAN at or above the middle of the entire mandibular height. Compared to recent studies reporting a distance of approximately 7.0 mm,[10,11] the mean distance from the mandibular inferior border to the IAN in the present study was 10.0 mm. However, other studies have reported distances of 9 mm—10 mm between the mandibular inferior border and the IAN; thus it would be difficult to draw conclusions.[12,13] Along with bone density, cortical bone thickness may be related to slippage during implant drilling or placement. The average cortical thickness of the patients in this study was 1.2 mm, slightly lower than the average cortical thicknesses of 1.4—1.5 mm reported by previous studies;[14—16] however, it was not a clinically significant difference.

A notable finding in the present study is that the distance from the alveolar crest to the IAN averaged 9.8 mm, with 65% of patients having a bone height of 9 mm or more. This residual bone height does not necessarily indicate a high risk of nerve injury, suggesting that precise treatment planning prior to surgery may often have been neglected. Clinicians may have relied solely on panoramic images, which are quick and easy to obtain, to assess the alveolar crest-to-nerve distance. Panoramic images may not accurately measure the distance from the alveolar crest to the IAN, especially when the magnification of the panoramic image is not considered during implant surgery, increasing the risk of IAN injury. Moreover, panoramic images may not provide accurate assessment of cortical bone thickness or bone quality, increasing the risk of iatrogenic damage. To prevent such occurrences, preoperative CT imaging to precisely measure the distance to the nerve, bone quality, and cortical bone thickness is crucial. Furthermore, in some patients where highly resorbed residual bone was observed, the appropriate use of short implants, which have recently been reported to achieve successful treatment outcome, could have prevented nerve injury.[17,18]

Decompression for nerve injury has been reported to as a successful treatment method for resolving neurosensory dysfunction. As expected, this study also showed that patients who had their implants removed showed better sensory function; however, no statistically significant difference was found compared to patients with implants in place. Additionally, no significant differences in the degree of sensory impairment were observed depending on the extent of IAN invasion. The findings can be explained by the following reasons. First, patients who had their implants removed may have suffered more severe nerve damage than those who retained their implants. When the implant merely contacts or slightly compresses the IAN canal, it is often observed without removal. On the other hand, in cases where the degree of nerve invasion and resulting symptoms are severe, immediate removal is common. This may cause a difference in the degree of nerve damage between the two patient groups, which could affect the recovery of nerve function. Furthermore, not only the degree of nerve invasion by the fixture but also the damage caused by implant drilling significantly affects the prognosis of nerve injury, and this is often limited in evaluation by imaging studies alone. Additionally, the subjectivity of the sensory function test performed in the present study imposed limitations on achieving an objective assessment. Considering the decline in tactile sensory function with aging reported in the study by Decorps et al.[19] and the fact that a significant portion of the study sample in our study was elderly, it becomes challenging to rely on nerve mapping results. Regarding the effect of removal timing on the sensory recovery, several researchers recommend immediate removal or within a few days for optimal neural healing. In this study, no significant differences were found in sensory function test results based on the timing of implant removal. However, due to the small sample size and the varying intervals between implant removal and the subsequent sensory function test, as well as the differences in the severity of injuries among patients, definitive conclusions could not be drawn.[20,21]

The limitations of this study include the relatively small sample size and exclusion of some patients from radiological assessment for anatomical risk factors due to the absence of CT scans. Additionally, all patients included in this study visited our hospital for further evaluation and management after experiencing nerve injury. These aspects posed challenges in comparing various factors that may influence nerve function recovery and prognosis, as well as in collecting detailed information on the perioperative conditions and intraoperative events. Lastly, although the incidence is very low, IAN can be damaged by the injection needle during nerve block anesthesia. Although non-implant surgery-related IAN injuries have been excluded in this study, needle injuries are very difficult to distinguish, so it is still possible that the injection needle could have caused IAN injury before the implant surgery. Therefore, future research should involve a larger number of patients and comprehensively consider detailed perioperative factors to evaluate the risk factors and prognosis of nerve injury.

In conclusion, older women with lower bone density were at an increased risk of IAN, and IAN injury occurred even in cases with sufficient alveolar ridge. This underscores the importance of conducting a thorough preoperative examination of the position of the IAN and the quantity and quality of residual alveolar bone to determine the appropriate implant length. Lastly, the removal of implants related to the IAN injury alone does not markedly influence the extent of

sensory disturbances during the follow-up period, suggesting that other aspects such as the timing of removal and the severity of injury could be crucial.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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