

Risk factors of neurosensory disturbance after sagittal split ramus osteotomy

*Komachi Hase¹, Tomokazu Motohashi², Toshihiko Takenobu² and Masahiro Nakajima³

¹Graduate School of Dentistry (Second Department of Oral and Maxillofacial Surgery) and ²Second Department of Oral and Maxillofacial Surgery, Osaka Dental University, 8-1 Kuzuhahanazono-cho, Hirakata-shi, Osaka 573-1121, Japan and

³Department of Oral and Maxillofacial Surgery, Osaka Dental University, Osaka Dental University Hospital, 1-5-17 Ohtemae, Chuo-ku, Osaka 570-0008, Japan

*E-mail: hase-k@cc.osaka-dent.ac.jp

In this study, we investigated the factors affecting postoperative neurosensory disturbance (NSD) in patients who underwent sagittal split ramus osteotomy (SSRO). The subjects were 92 patients with 184 sides who underwent SSRO in our department from February 2021 to January 2022. NSD was evaluated preoperatively and 1, 3, 6, 12 months postoperatively using subjective and objective assessments. We examined whether each data obtained from medical records and preoperative CT images would affect NSD. Gender, age at surgery, Total surgical time for SSRO, and amount of blood loss were not factors associated with NSD. Factors that influence postoperative NSD include the direction of mandibular bone movement, the presence of inferior alveolar nerve exposure, the thickness of the mandibular bone, the distance from the maxillary tuberosity to the mandible, and the distance from the mandibular canal to the outer cortical bone. (J Osaka Dent Univ 2024; 58: 139-151)

Key words: Sagittal split ramus osteotomy; SSRO; Neurosensory disturbance; NSD; Inferior alveolar nerve; IAN

INTRODUCTION

Sagittal split ramus osteotomy (SSRO), performed by Trauner and Obwegeser in 1957, is now the most commonly used surgical technique in orthognathic surgery. Surgical complications during and after SSRO include bleeding, bad split, soft tissue damage, tooth damage, neurosensory disturbance, postoperative infection, condylar resorption, or malocclusion caused by relapse.¹⁻⁵ Among them, neurosensory disturbance (NSD) is considered to be the most common surgical complication, and it has been reported that the majority of patients undergoing SSRO complain of NSD immediately after surgery.^{2, 6, 8-11} It is generally reversible, with most symptoms resolving within 6 months of surgery. However, there are reports that 10.5% to 15% of patients have residual NSD even one year after surgery.^{6, 7, 10, 12} Residual postoperative NSD is a factor that greatly influences patient satisfaction with

surgery in SSRO.

NSD is said to be mainly caused by direct intraoperative injury to the inferior alveolar nerve (IAN), but other factors such as the patient's gender, age, surgeon's technique, surgical technique, or amount of bone movement are also thought to be involved, and there are several reports evaluating the causes of direct and indirect injury risk to the IAN.^{2, 7, 11, 13, 15-18}

If we can identify the factors that cause the development and persistence of NSD, it is thought that predicting them before surgery and using them for appropriate informed consent of patients will improve patient satisfaction with surgery. In this study, we investigated the sequelae and recovery time of NSD after SSRO using medical records and CT images.

MATERIALS AND METHODS

The subjects were 92 patients with 184 sides (27

males, 65 females) who underwent bilateral SSRO from February 2021 to January 2022 at the 2nd Department of Oral Surgery, Osaka Dental University Hospital. The surgical procedure was isolated SSRO in 43 cases and two jaw surgery (Le Fort osteotomy/ anterior alveolar osteotomy + SSRO) in 49 cases. The surgery was performed by four persons with more than 15 years of experience according to the original Obwegeser method.²¹ In all cases, cortical bone osteotomy was performed with a tungsten carbide rod and bone splitting was performed with an osteotome and mallet. The fragment has miniplate fixation. The direction of distal segment motion was setback (SB) on the 139 side and advancement (AD) on the 45 side. Intermaxillary fixation was applied for 1 week from the first postoperative day, followed by intermaxillary anchorage. Patients who developed postoperative NSD were instructed to take mecobalamin tablets at a dose of 1500 μ g/day for up to 6 months until NSD recovered.

The gender, age, operative time, amount of blood loss, surgeon, presence or absence of the IAN exposure, and direction of distal segment movement were assessed from medical records.

Mandibular anatomy was assessed from preoperative CT images obtained with SOMATOM Scope (Siemens Healthineers, Erlangen, Germany). Axial images were acquired parallel to the occlusal plane with a tube voltage of 130 kV. The tube current was automatically optimized for the object thickness (maximum, 120 mA), 0.75 mm slice thickness, and 200 \times 200 mm field of view.

In the axial plane, the height of 5 mm above the lingula mandibulae corresponding to the medial osteotomy line was designated as A, the lingula mandibulae height was designated as B, and the lowest point of the lingula mandibulae was designated as C (Fig. 1-1).

On plane A, (1) the thickness of the marrow space was measured. Three points were established on plane B: a (anterior ramus margin), b (posterior ramus margin), and c (medial oblique line margin). Then, (2) the distance between a-b (anteroposterior length of the lateral ramus), (3) the

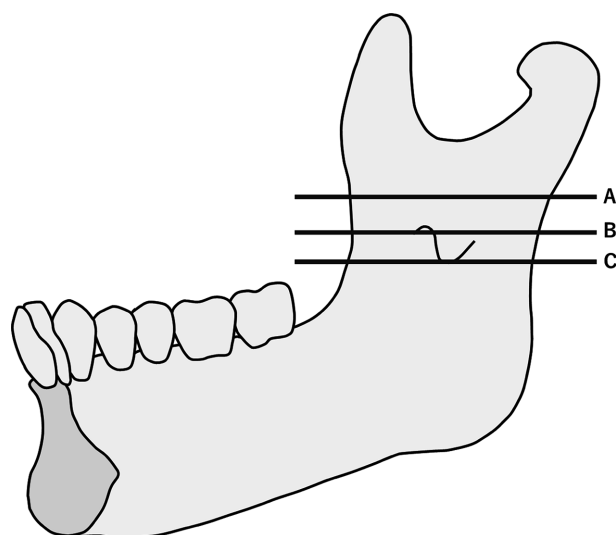


Fig. 1-1 Measurement site and items.

A: Measure (1) at this height. (5 mm above the lingula mandibulae/height of the medial osteotomy line)

B: Measure (2)(3)(4) at this height. (lingula mandibulae height)

C: Measure (6)(7) at this height. (The lowest point of the lingula mandibulae)

distance between a-c (thickness of the anterior ramus), (4) the distance between b-c (anteroposterior length of the medial ramus), and (5) c to the maximum bulging of the maxillary tuberosity were measured. In plane C, (6) the thickness of the mandible and (7) the distance from the mandibular canal to the outer cortical bone were measured. Regarding (5), only isolated SSRO ($n = 43$ cases, 86 sides) was measured because in cases of maxillary surgery, there is a difference from the preoperative CT due to movement of the maxilla (Fig. 1-2).

Then, in the sagittal plane, the distance from the most distal point of the mandibular lingula to the root apex of the proximal root of the first molar (if the first molar is missing, the distance to the distal suprabulge area of the second premolar crown is measured) was measured and divided into 8 equal parts. Each block was divided into 8 equal parts as (8)-(15) from the mesial side, and the shortest distance from the mandibular canal to the outer cortical bone in each region was measured (Fig. 2).

Sensory impairment was evaluated preoperatively, 1 month postoperatively, 3 months postoperatively, 6 months postoperatively, and 12 months postoperatively using subjective and objective as-

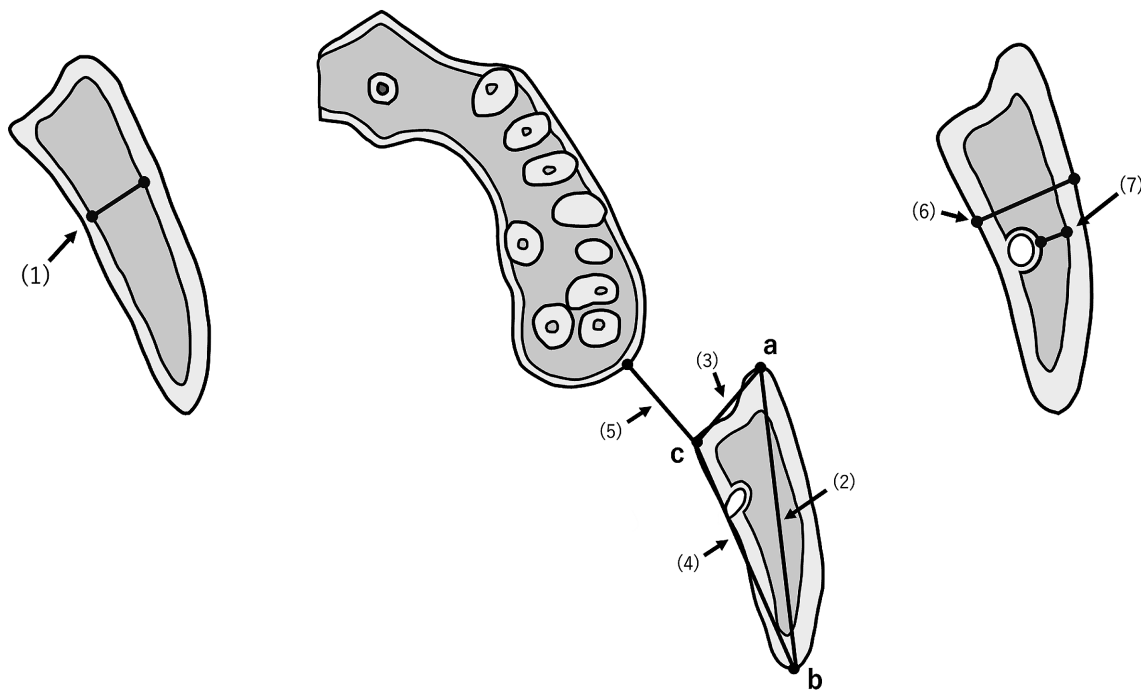


Fig. 1-2 Measurement site and items.

- (1) Thickness of the bone marrow space
- (2) a-b (Anteroposterior length of the lateral ramus)
- (3) a-c (Thickness of anterior ramus)
- (4) b-c (Anteroposterior length of the medial ramus)
- (5) Shortest distance from the maxillary tuberosity to the mandible
- (6) Thickness of the mandible
- (7) Distance from the mandibular canal to the outer cortical bone

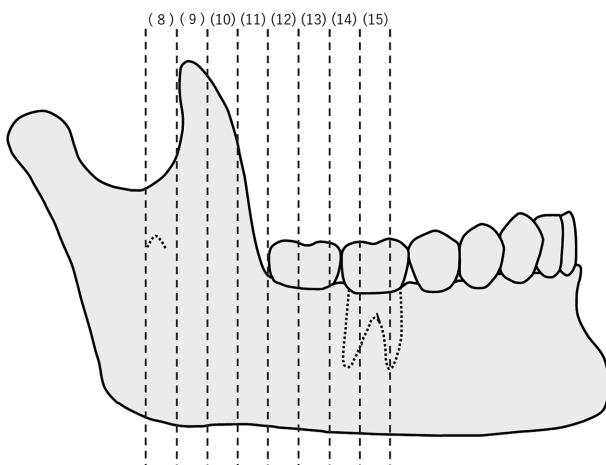


Fig. 2 Distance from the most distal point of the mandibular lingula to the root apex of the proximal root of the first molar was measured and divided into 8 equal parts. Set each block as (8), (9), (10), (11), (12), (13), (14), (15).

sessments. The evaluation was performed according to the "Implementation guidelines for Precision Tactile Function Test" of the Japanese Society of Orofacial Pain and the "Lip and tongue sensory abnormality protocol description requirements" of the Japanese Society of Oro-Facial Neuronal Function.

Subjective evaluation was performed on the left and right sides using the Visual Analog Scale (VAS). Objective evaluation was performed using the SW test, which measures 4 points on the left and right side as specified in the protocol using Semmes-Weinstein monofilament (0.008 to 2.0 g) (Fig. 3). If the thickest filament of 4.31 (2.0 g) could not be detected, it was classified as "unable to judge".

Patients whose subjective evaluation (VAS) and objective evaluation (SW test) both recovered to the same level as before surgery were designated as the recovery group (RG), and regardless of the

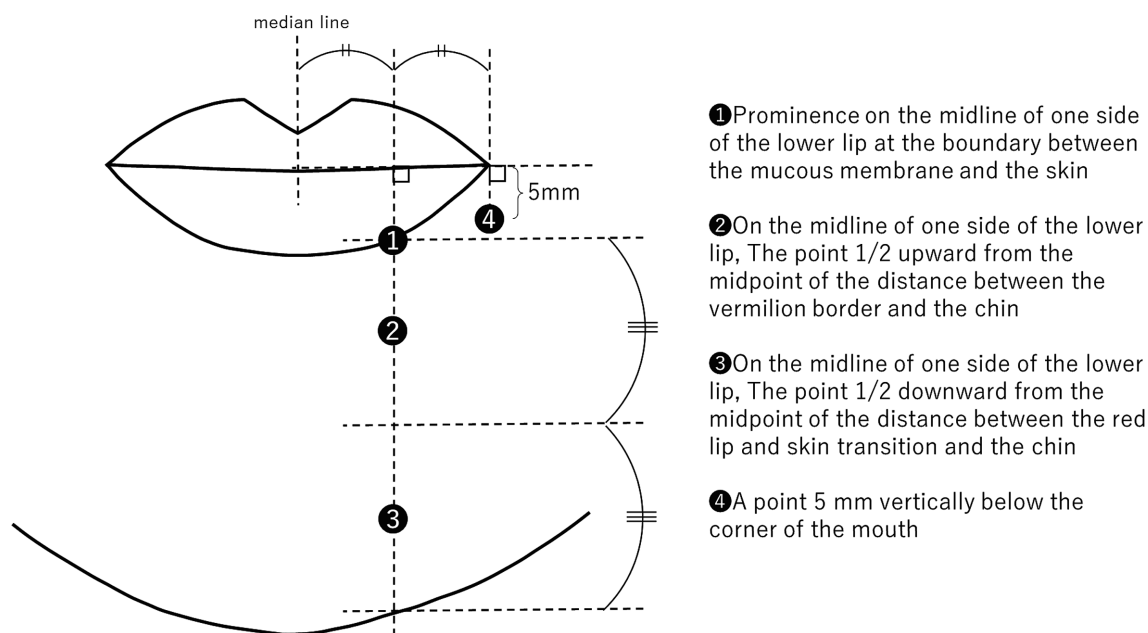


Fig. 3 Areas of the lower lip and chin to be examined.

SW test results, those whose VAS values did not recover to the preoperative level were designated as the non-recovery group (NRG). Furthermore, among the NRGs, those whose SW test, which is an objective assessment, had recovered to the same level as before surgery were referred to as the SW recovery group (SW-RG), and those who had not recovered to the same level as before surgery were referred to as the SW non-recovery group (SW-NRG).

Comparison of RG and NRG in terms of gender, presence or absence of the IAN exposure, and direction of distal segment movement (SB or AD) was examined using a χ^2 test. Comparisons between SW-RG and SW-NRG with respect to the presence or absence of the IAN exposure and direction of distal segment movement were examined using a χ^2 test.

Comparisons between RG and NRG and between RG and SW-RG and SW-NRG in terms of measured distance of each CT, age at surgery, surgery time, and amount of blood loss were examined using the Mann-Whitney U test. A p value of less than 0.05 was considered statistically significant.

This study was approved by the ethics committee

of Osaka Dental University (Approval No.111161)

RESULTS

Relationships of NSD with age, surgical time, amount of bleeding, gender, and surgeon

The number of sides in RG increased progressively after surgery: 50 (27.17%), 76 (41.30%), 96 (52.17%), and 130 (70.65%) 1, 3, 6, and 12 months after surgery, respectively. NRG consisted of 54 sides (27.17%) 12 months after surgery, with 33 sides being SW-RG and 21 sides being SW-NRG (Fig. 4).

The mean age at surgery was 27.74 years (16-

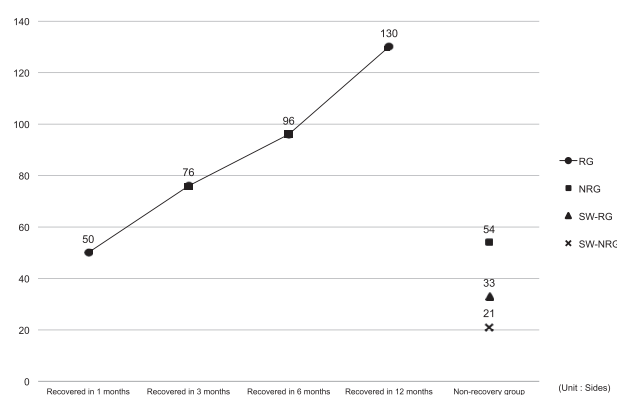


Fig. 4 Changes in NSD over time.

58 years) in all patients and was 26.00 ± 7.75 and 28.00 ± 8.44 years in NRG and RG, respectively. The mean surgical time was 139.19 minutes (103-211 minutes) in all patients and was 134.50 ± 22.23 and 135.00 ± 16.05 minutes in NRG and RG, respectively. The mean amount of blood loss was 95.60 mL (50-858 mL) in all patients and was 51.50 ± 104.46 mL and 50.00 ± 112.67 mL in NRG and RG, respectively. No significant difference was observed in the age, surgical time or amount of blood loss between RG and NRG.

According to gender, NRG consisted of 17 (31.48%) of the 54 sides in males and 37 (28.46%) of the 130 sides in females.

According to the surgeon, NRG consisted of 21 (43.75%) of the 48 sides operated on by A, 11 (22.45%) of the 49 sides operated on by B, 8

(18.18%) of the 44 sides operated on by C, and 14 (32.56%) of the 43 sides operated on by D. No significant difference was observed in the incidence of NSD according to gender or surgeon (Figs. 5 and 6).

Relationship between the direction of distal segment movement and NSD

The direction of movement was SB in 139 sides and AD in 45 sides. In NRG, it was SB in 33 sides (23.74%) and AD in 21 sides (46.67%), and NSD was associated significantly more frequently with AD than with SB ($p = 0.0033$). In SW-NRG, SB showed 13 sides (39.39%), and AD showed 8 sides (38.10%), and no significant difference was observed in the direction of movement between SW-RG and SW-NRG. According to gender, SB was observed in 46, and AD was observed in 8, of the 54 sides in males. In NRG of males, SB showed 11 sides (23.91%), and AD showed 6 sides (75.00%). In males, NSD was associated significantly more frequently with AD than with SB ($p = 0.0086$). Concerning males in SW-NRG, SB showed 6 sides (54.55%), and AD showed 2 sides (33.33%). No significant difference was observed in the direction of movement between SW-RG and SW-NRG in males. In females, SB was observed in 93, and AD was observed in 37, of the 130 sides. Concerning females in NRG, SB showed 22 sides (23.66%), and AD showed 15 sides (40.54%). No significant difference was observed in the incidence of NSD between AD and SB. In females in SW-NRG, SB showed 7 sides (31.82%), and AD showed 6 sides (40.00%). No significant difference was observed in the direction of movement between SW-RG and SW-NRG in females. No significant gender difference was observed in the frequency of RG and NRG or SW-RG and SW-NRG according to the direction of movement. (Figs. 7, 8).

Relationship between nerve exposure and NSD

The IAN was exposed in 35 sides and not exposed in 149 sides. In NRG, the IAN was exposed in 19 sides (54.29%) and not exposed in 35 sides (23.49%). In NRG, the IAN was exposed signifi-

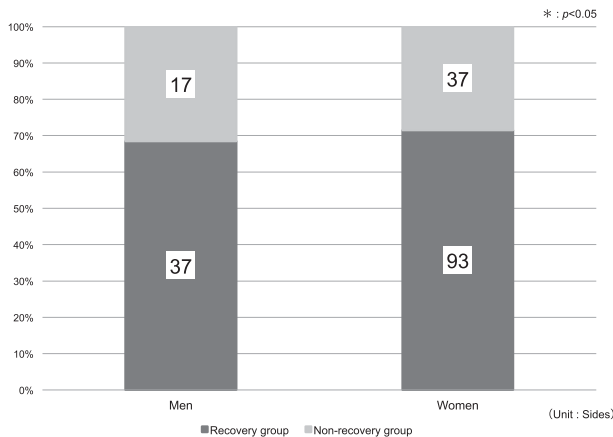


Fig. 5 The relationship between NSD recovery and gender.

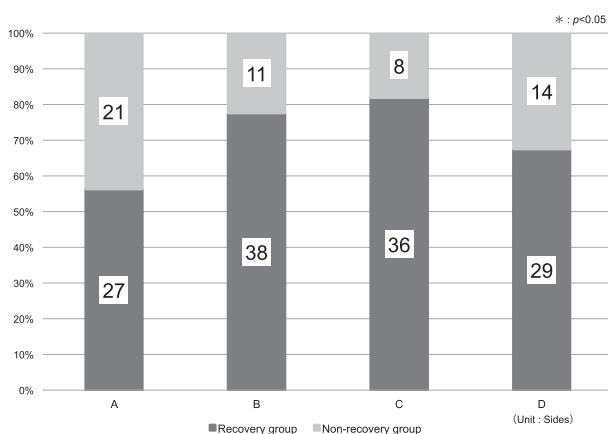


Fig. 6 The relationship between NSD recovery and surgeon.

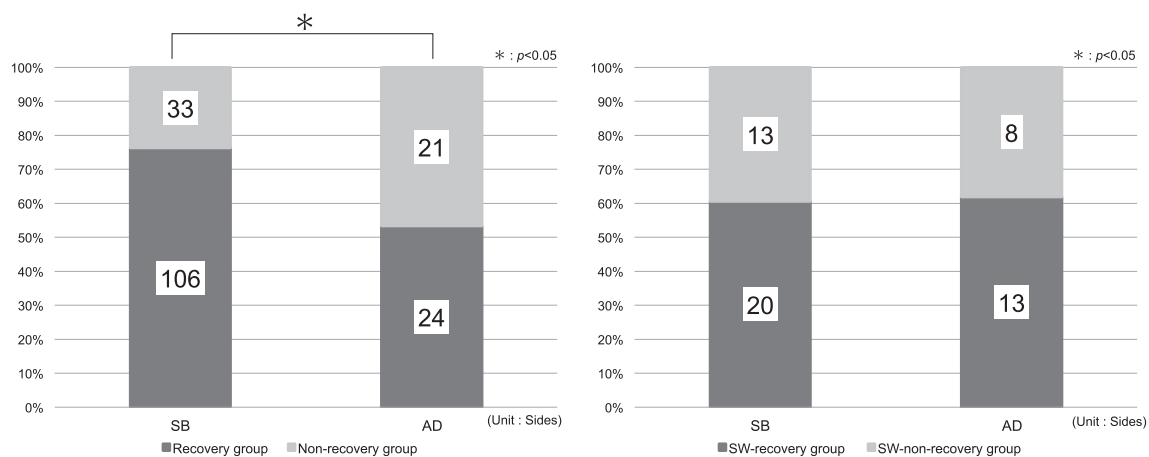


Fig. 7 The relationship between direction of movement and NSD recovery (Comparison of SW-test only and SW-test + VAS).

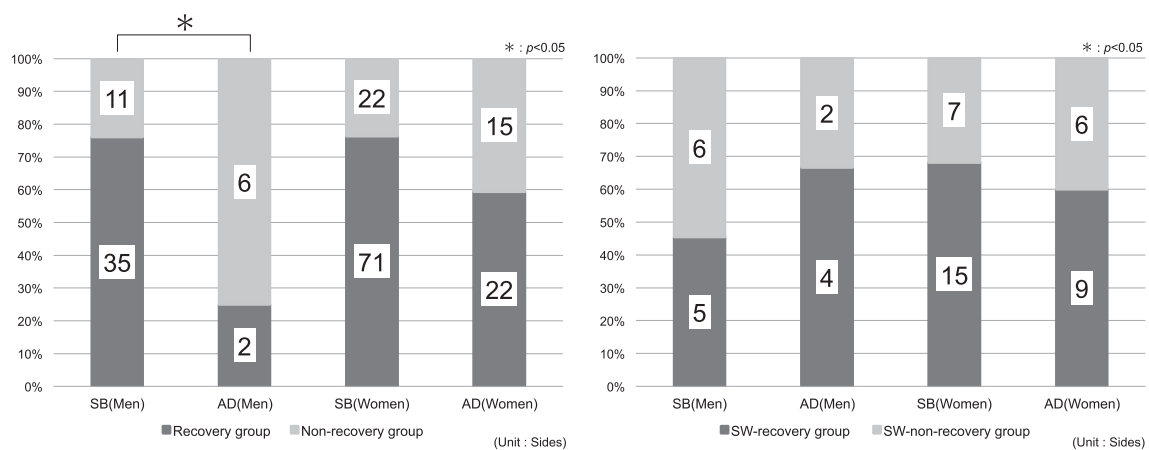


Fig. 8 Relationship between direction of movement and NSD recovery by gender.

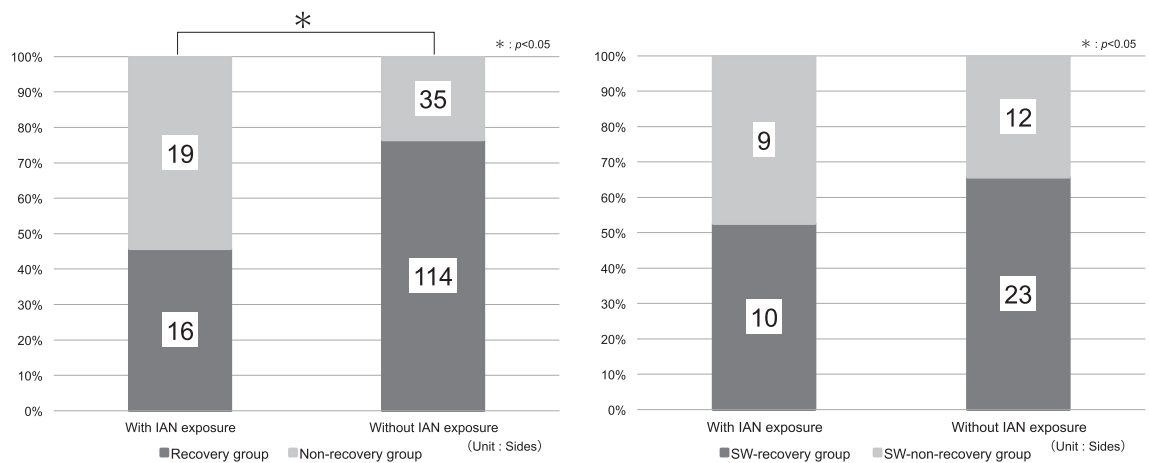


Fig. 9 Relationship between NSD recovery and IAN exposure.

cantly more frequently than not exposed ($p = 0.0003$). In SW-NRG, the IAN was exposed in 9 sides (47.37%) and not exposed in 12 sides (34.29%). No significant difference was observed in the frequency of the IAN exposure between SW-RG and SW-NRG (Fig. 9).

Relationships of NSD with various distances measured on CT

The thickness of cancellous bone at a height of 5 mm from the lingula mandibulae (1) was 2.56 ± 1.16 mm in NRG and 3.06 ± 1.54 mm in RG, being significantly thinner in NRG than in RG ($p = 0.0154$). The anteroposterior length of the lateral ramus at the height of the lingula mandibulae (2) was 31.13 ± 2.42 mm in NRG and 31.84 ± 2.80 mm in RG, being significantly shorter in NRG than in RG ($p = 0.0396$). The thickness of the anterior ramus at the height of the lingula mandibulae (3) was 7.55 ± 1.71 mm in NRG and 8.23 ± 1.95 mm in RG, being significantly thinner in NRG than in RG ($p = 0.0120$). The distance from the edge of the medial oblique line to the maximum bulge of the maxillary tuberosity at the height of the lingula mandibulae (5) was 12.27 ± 2.05 mm in NRG and 10.92 ± 2.20 mm in RG, being significantly longer in NRG than in RG ($p = 0.0065$). The thickness of the mandibular ramus at the height of the lower margin of the lingula mandibulae (6) was 9.23 ± 1.70 mm in NRG and 10.00 ± 1.37 mm in RG, being significantly thinner in NRG than in RG ($p = 0.0004$). The distance from the mandibular canal to the outer cortical bone at the height of the lower margin of the lingula mandibulae (7) was 1.51 ± 1.02 mm in NRG and 2.77 ± 1.34 mm in RG, being significantly shorter in NRG than in RG ($p = 1.6928 \times 10^{-7}$). The distance from the mandibular canal wall to the outer cortical bone was significantly shorter in NRG than in RG in all coronal planes (8)-(15) (Table 1-1). In comparison of RG with SW-RG and SW-NRG, (1) was 2.60 ± 1.16 mm in SW-RG, being significantly thinner than in RG ($p = 0.0313$), but was 2.24 ± 1.15 mm in SW-NRG, showing no significant difference compared with RG. (2) was 31.27 ± 2.52 mm in SW-RG and did not differ significantly compared with RG

Table 1-1 Median in recovery group and non-recovery group per distance measured from preoperative CT scans

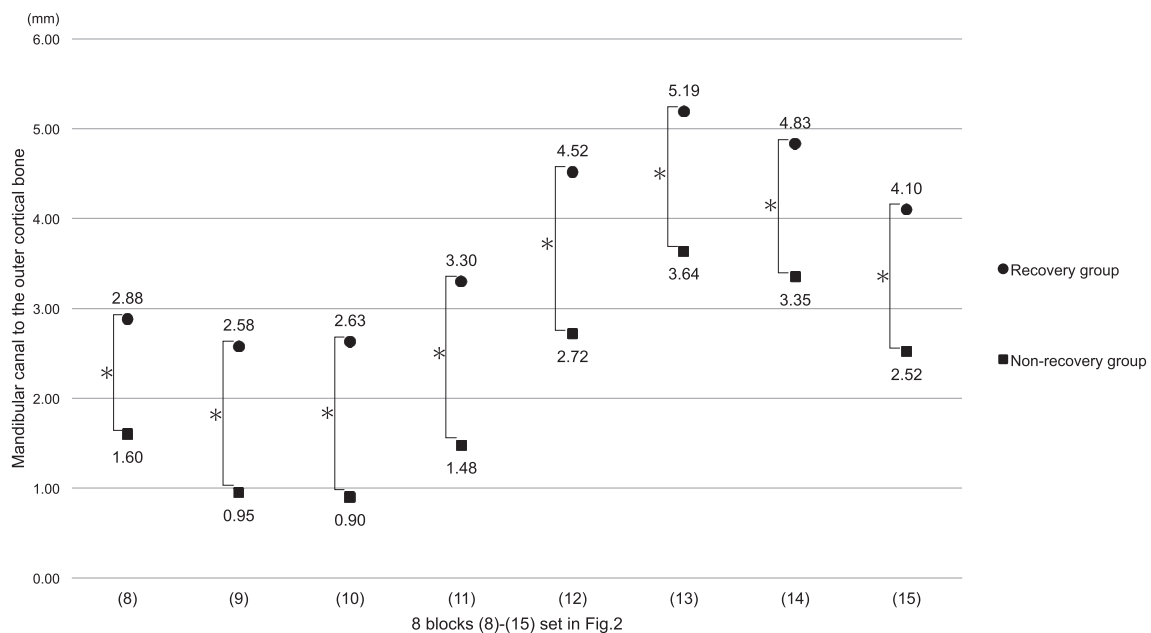
Variable	Recovery group ($n = 130$ sides) mean, SD	Non-recovery group ($n = 54$ sides) mean, SD
*: $p < 0.05$		
(1)Thickness of the bone marrow space(mm)*	3.06, 1.54	2.56, 1.16
(2)Points a-b(mm)*	31.84, 2.80	31.13, 2.42
(3)Points a-c(mm)*	8.23, 1.95	7.55, 1.71
(4)Points b-c(mm)	26.77, 3.19	26.25, 2.71
(5)Maxillary tuberosity to the mandible(mm)*	10.92, 2.20 ($n = 61$ sides)	12.27, 2.05 ($n = 25$ sides)
(6)Thickness of the mandible(mm)*	10.00, 1.37	9.23, 1.70
(7)distance from the mandibular canal to the outer cortical bone(mm)*	2.77, 1.34	1.51, 1.02
(8)(mm)*	2.88, 1.32	1.60, 1.04
(9)(mm)*	2.58, 1.32	0.95, 0.96
(10)(mm)*	2.63, 1.37	0.90, 1.09
(11)(mm)*	3.30, 1.55	1.48, 1.65
(12)(mm)*	4.52, 1.77	2.72, 1.93
(13)(mm)*	5.19, 1.57	3.64, 1.56
(14)(mm)*	4.83, 1.41	3.35, 1.30
(15)(mm)*	4.10, 1.55	2.52, 1.36

but was 31.13 ± 2.10 mm in SW-NRG, being significantly longer than in RG ($p = 0.0172$). (3) was 7.55 ± 1.84 mm in SW-RG and did not differ significantly compared with RG but was 7.58 ± 1.47 mm in SW-NRG, being significantly shorter than in RG ($p = 0.0362$). (5) was 13.19 ± 1.86 mm in SW-RG, being significantly longer than in RG ($p = 0.0065$), but was 11.64 ± 2.29 mm in SW-NRG and did not differ significantly compared with RG. (6) and (7) were significantly shorter in SW-RG and SW-NRG than in RG (Table 1-2). No significant difference was observed in any of the distances (1)-(15) between SW-NRG and SW-RG.

The distance from the mandibular canal to the outer cortical bone was significantly shorter in NRG than in RG in all coronal planes (8)-(15) (Table1-1). It showed no significant difference between SW-NRG and SW-RG but was significantly shorter in SW-RG and SW-NRG than in RG in all coronal planes (8)-(15) (Table1-2). In NRG, it was less than 2 mm in the mandibular ramus in planes (8)-(11), but less than 4 mm in the mandibular body in

Table 1-2 Median in recovery group and non-recovery group per distance measured from preoperative CT scans

	Recovery group (<i>n</i> = 130 sides) mean, SD	Non-recovery group (<i>n</i> = 55 sides)	
		SW-recovery group (<i>n</i> = 33 sides) mean, SD	SW-non-recovery group (<i>n</i> = 21 sides) mean, SD
(1)Thickness of the bone marrow space(mm)	3.06, 1.54	2.60, 1.16*	2.24, 1.15
(2)Points a-b(mm)	31.84, 2.80	31.27, 2.52	31.13, 2.10*
(3)Points a-c(mm)	8.23, 1.95	7.55, 1.84	7.58, 1.47*
(4)Points b-c(mm)	26.77, 3.19	26.33, 2.52	25.61, 2.98
(5)Maxillary tuberosity to the mandible(mm)	10.92, 2.20 (<i>n</i> = 61 sides)	13.19, 1.86* (<i>n</i> = 14 sides)	11.64, 2.29 (<i>n</i> = 11 sides)
(6)Thickness of the mandible(mm)	10.00, 1.37	9.42, 1.62*	9.05, 1.74*
(7)distance from the mandibular canal to the outer cortical bone(mm)	2.77, 1.34	1.70, 1.14*	1.35, 0.66*
(8)(mm)	2.88, 1.32	1.68, 1.16*	1.29, 0.72*
(9)(mm)	2.58, 1.32	1.03, 1.09*	0.79, 0.59*
(10)(mm)	2.63, 1.37	1.09, 1.07*	0.69, 1.11*
(11)(mm)	3.30, 1.55	1.60, 1.70*	1.47, 1.58*
(12)(mm)	4.52, 1.77	2.90, 2.07*	2.59, 1.69*
(13)(mm)	5.19, 1.57	3.70, 1.74*	3.34, 1.19*
(14)(mm)	4.83, 1.41	3.43, 1.42*	3.35, 1.09*
(15)(mm)	4.10, 1.55	2.52, 1.36*	2.65, 1.35*

*: $p < 0.05$ **Fig. 10-1** Relationship between the presence or absence of NSD recovery and the distance from the mandibular canal to the outer cortical bone in (8)-(15).

planes (12)-(15) (Figs. 10-1, 10-2). The distance from the mandibular canal to the outer cortical bone was significantly shorter in those with the IAN exposure than in those without the IAN exposure in all

coronal planes (8)-(15). In those with the IAN exposure, it was less than 1.5 mm in planes (8)-(11) in the mandibular ramus and less than 4 mm in planes (12)-(15) in the mandibular body (Fig. 11).

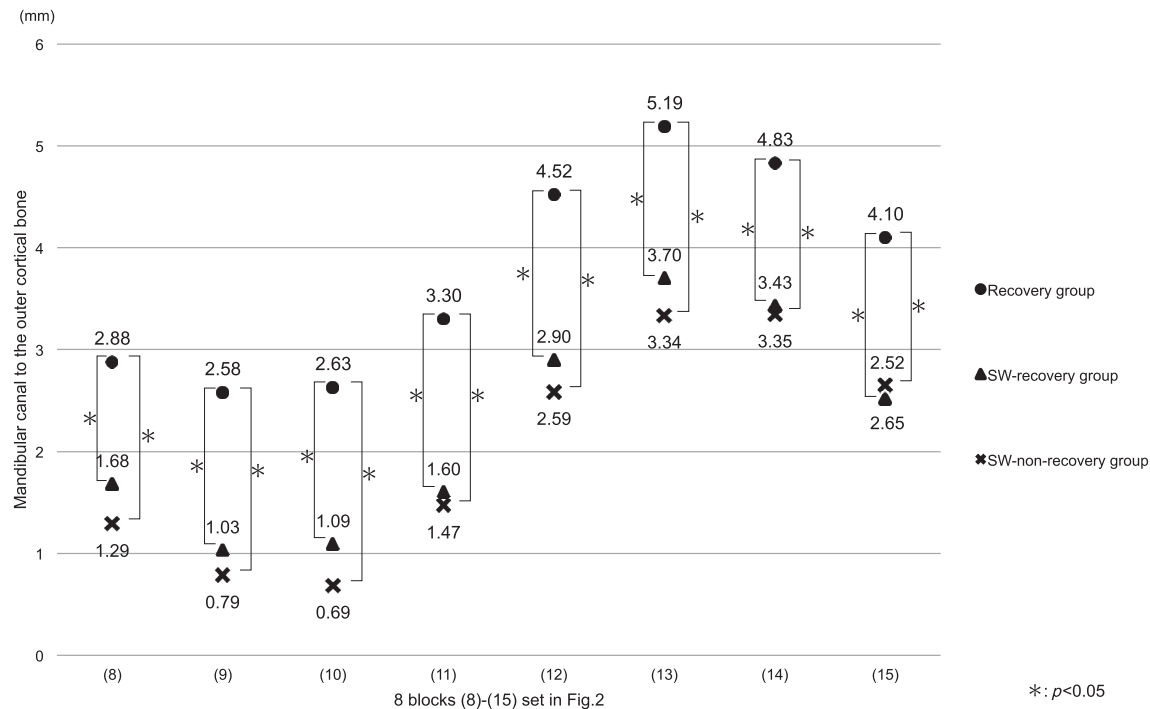


Fig. 10-2 Relationship between the presence or absence of NSD recovery and the distance from the mandibular canal to the outer cortical bone in (8)-(15).

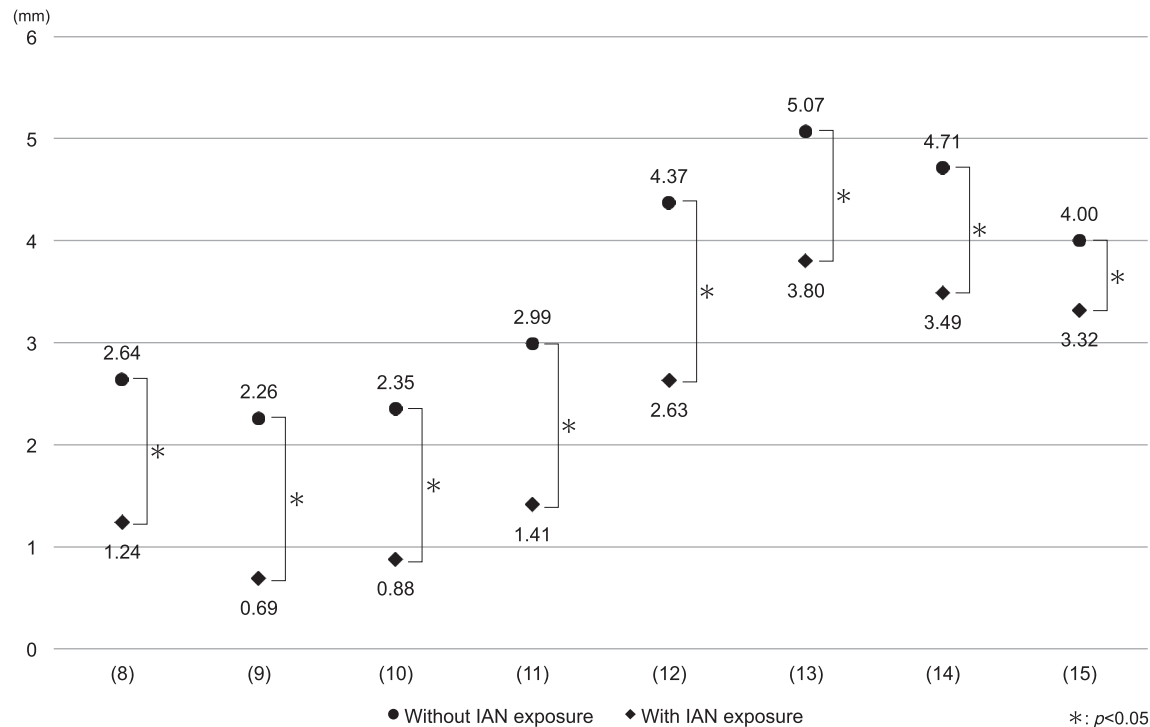


Fig. 11 Relationship between the presence or absence of IAN exposure and the distance from the mandibular canal to the outer cortical bone in (8)-(15).

DISCUSSION

SSRO is a surgical procedure designed to restore occlusion by bone splitting along the outer cortical bone and repositioning distal bone fragments. NSD, which is one of the postoperative complications of SSRO, is considered to be caused by direct damage to the IAN during bone splitting using an osteotome or making screw holes or by intraoperative or postoperative traction or compression of the IAN.^{11, 13, 15-18}

Since bone splitting is performed by inserting osteotomes along the outer cortical bone, if the width of the bone-marrow space between the mandibular canal and outer cortical bone is short, the risk of damaging the IAN during osteotome insertion is increased. There have been various reports on the relationship between the occurrence of NSD and the width of the bone-marrow space between the mandibular canal and the outer cortical bone.^{18-20, 24-30} Leena Ylikontiola *et al.*²⁴ reported that NSD occurs when the width of the bone-marrow space between the mandibular canal and the outer cortical bone at the level of third molar is ≤ 2 mm. Yoshida *et al.*¹⁸ observed that severe neurological impairment persisted even 1 year after surgery when the shortest distance from the mandibular canal wall to the outer cortical bone in the segment from the second molar to the mandibular foramen was ≤ 0.4 mm. In this study, the relationship between the distance from the mandibular canal wall to the outer cortical bone and NSD was evaluated by measuring the distance in 8 blocks with equal thickness from the distal margin of the lingula mandibulae to the proximal root apex of the first molar (8)-(15). As a result, NRG consisted of sides in whom the distance was < 2 mm in the mandibular ramus and < 4 mm in the mandibular body.

When the relationship between the distance from the mandibular canal wall to the outer cortical bone in the coronal plane and exposure of the IAN was evaluated, the IAN was exposed when the distance was < 1.5 mm in the mandibular ramus and < 4 mm in the mandibular body. During surgery, the IAN is often exposed in the mandibular ramus and less

frequently in the mandibular body, but as the mandibular body is likely to be thinner in patients with a thin mandibular ramus, the thickness in the IAN exposure group is considered to be less than that in the no IAN expose group. Therefore, nerve exposure is considered to be related to the distance between the mandibular ramus and the mandibular canal. Also, as the percentage of patients with the IAN exposure was significantly higher in NRG, the IAN exposure was considered to be a factor that significantly affects the persistence of NSD.

Teerijoki-Oksa *et al.*¹³ observed disturbance of the intraneural action potential during the inner detachment and eversion procedure by orthodromic sensory nerve action potential (SNAP) analysis and reported the possibility the IAN injury. Usually, in SSRO, osteotomy is performed by inserting the retractor after detaching the inner periosteum to the posterior margin of the mandibular ramus. If the anteroposterior length of the lateral ramus is short, the distance from the internal oblique line of the mandible to the mandibular foramen is also proportionally short. Therefore, ablation around the mandibular foramen must be performed blindly without sufficiently detaching the periosteum, which is considered to increase the risk of the IAN injury during detachment of inner soft tissue. Conversely, if the anteroposterior length of the lateral ramus is long, the distance from the internal oblique line of the mandible to the mandibular foramen is also long, allowing sufficient securing of the space for detachment of inner soft tissue. This provides a satisfactory surgical field of view and permits protective surgical manipulations. Similarly, in the splitting procedure, if the anteroposterior length of the lateral ramus is long, the distance from the anterior margin of the mandibular ramus to the mandibular canal wall is proportionally long, which provides a sufficient space for the bone splitting procedure using an osteotome. This also leads to securing of a sufficient field of vision for splitting and makes it possible to perform bone splitting while visually identifying the mandibular canal, permitting protective bone splitting. This is considered to reduce the risk of the IAN injury during bone splitting.

Likontiola *et al.*¹⁴ reported that NSD is induced by manipulating the retractor with the IAN exposed on the inner side of the mandibular ramus. Also, according to the report by Kuroyanagi *et al.*²⁰ the area of the space on the medial side of the ramus is significantly larger ($207.4 \pm 43.6 \text{ mm}^2 > 166.1 \pm 58.5 \text{ mm}^2$), and the distance from the maxillary tuberosity to the mandible was longer ($11.8 \pm 1.9 \text{ mm} > 10.4 \pm 3.2 \text{ mm}$), in patients who showed no improvement in NSD 6 months after surgery compared with those who showed improvements.

The distance from the maxillary tuberosity to the mandible was significantly longer in NRG than in RG. If the distance from the maxillary tuberosity to the mandible is long, the space for the manipulation is secured, and reflection of the inner mucosa and periosteum is facilitated, but this may induce excessive detachment. Excessive extension is considered to further stretch and stress the IAN. In this study, we omitted 3-dimensional measurements and did not perform detailed evaluation of the inner manipulation space. However, since a significant difference was observed in the distance from the maxillary tuberosity to the mandible between the group that showed recovery from NSD by 12 months after surgery and the group that did not, examination of this distance is considered useful for the prediction of postoperative residual of NSD. Also, as the distance from the maxillary tuberosity to the mandible was significantly longer in SW-RG than in RG, extension of the IAN was considered more likely to affect subjective than objective evaluation of postoperative NSD.

The direction of movement of the mandibular bone was significantly more often anterior than posterior in those who residual of NSD. However, according to the SW-test, which is a method for objective evaluation, no significant difference was observed in recovery from NSD between those with anterior movement and those with posterior movement. The mandibular ramus is reported to be thicker in patients with anterior movement than in those with posterior movement,³¹ and direct nerve damage is considered less likely to be caused by the splitting manipulation in those with anterior

movement than in those with posterior movement. For this reason, nerve extension by anterior movement of distal bone fragment rather than direct nerve damage during the splitting manipulation is considered to be related to NSD in patients with anterior movement. However, this tendency was observed only in males. Probably because no difference was caused by the direction of movement of the mandible in females, in whom the mandible is thinner than in males,³¹ and the bone splitting procedure exerts a greater effect on the IAN. From these observations, the direction of movement of the mandible is considered to have affected the development of NSD in patients with a thick mandible, in whom direct nerve damage is less likely to be caused by the splitting procedure.

The above observations suggest that the residual NSD after SSRO is related to the distance from the mandibular canal to the outer cortical bone in the part affected by the bone splitting procedure, the exposure of the inferior alveolar bone, the direction of movement of the mandible, the distance from the maxillary tuberosity to the mandible (space for detachment of the periosteum on the inner side of the mandibular ramus), and the anteroposterior length of the lateral ramus. The distance from the mandibular canal to the outer cortical bone in the area affected by the bone splitting procedure, the exposure of the inferior alveolar bone, and the anteroposterior length of the lateral ramus influenced both subjective and objective evaluations, and extension of the IAN associated with movement of the mandible is considered to affect the occurrence of NSD in patients with a thick mandible, in whom direct nerve damage by the splitting procedure is less likely to occur. Subjectively, the occurrence of NSD was affected by the distance from the maxillary tuberosity to the mandible.

Prediction of exposure of the IAN by morphometry of the mandible on preoperative CT may help predict the occurrence and prognosis of postoperative NSD and improve preoperative satisfaction of patients with jaw deformity.

The authors have no conflicts of interest directly relevant to

the content of this article.

REFERENCES

- Kim SG, Park SS. Incidence of complications and problems related to orthognathic surgery. *J Oral Maxillofac Surg* 2007; **65**: 2438-2444.
- Panula K, Finne K, Oikarinen K. Incidence of complications and problems related to orthognathic surgery: a review of 655 patients. *J Oral Maxillofac Surg* 2001; **59**: 1128-1136.
- Lanigan DT, Hey J, West RA. Hemorrhage following mandibular osteotomies: A report of 21 cases. *J Oral Maxillofac Surg* 1991; **49**: 713-724.
- Martis C, Karabouta I. Infection after orthognathic surgery, with and without preventive antibiotics. *Int J Oral Surg* 1984; **13**: 490-494.
- Al-Bishri A, Rosenquist J, Sunzel B. On neurosensory disturbance after sagittal split osteotomy. *J Oral Maxillofac Surg* 2004; **62**: 1472-1476.
- Yoshida T, Nagamine T, Kobayashi T, Michimi N, Nakajima T, Sasakura H, Hanada K. Impairment of the inferior alveolar nerve after sagittal split osteotomy. *J Craniomaxillofac Surg* 1989; **17**: 271-277.
- Mensink G, Zweers A, Wolterbeek R, Dicker GG, Groot RH, van Merkesteyn RJ. Neurosensory disturbances one year after bilateral sagittal split osteotomy of the mandibula performed with separators: a multi-centre prospective study. *J Craniomaxillofac Surg* 2012; **40**: 763-767.
- Westermarck A, Bystedt H, von Konow L. Inferior alveolar nerve function after mandibular osteotomies. *Br J Oral Maxillofac Surg* 1998; **36**: 425-428.
- Upton LG, Rajvanakam M, Hayward JR. Evaluation of the regenerative capacity of the inferior alveolar nerve following surgical trauma. *J Oral Maxillofac Surg* 1987; **45**: 212-216.
- Colella G, Cannavale R, Vicidomini A, Lanza A. Neurosensory disturbance of the inferior alveolar nerve after bilateral sagittal split osteotomy: a systematic review. *J Oral Maxillofac Surg* 2007; **65**: 1707-1715.
- Thygesen TH, Bardow A, Helleberg M, Norholt SE, Jensen J, Svensson P. Risk factors affecting somatosensory function after sagittal split osteotomy. *J Oral Maxillofac Surg* 2008; **66**: 469-474.
- Schlund M, Grall P, Ferri J, Nicot R. Effect of modified bilateral sagittal split osteotomy on inferior alveolar nerve neurosensory disturbance. *Br J Oral Maxillofac Surg* 2022; **60**: 1086-1091.
- Teerijoki-Oksa T, Jääskeläinen SK, Forssell K, Forssell H, Vähätalo K, Tammissalo T, Virtanen A. Risk factors of nerve injury during mandibular sagittal split osteotomy. *Int J Oral Maxillofac Surg* 2002; **31**: 33-39.
- Ylikontiola L, Kinnunen J, Oikarinen K. Factors affecting neurosensory disturbance after mandibular bilateral sagittal split osteotomy. *J Oral Maxillofac Surg* 2000; **58**: 1234-1240.
- Becelli R, Renzi G, Carboni A, Cerulli G, Gasparini G. Inferior alveolar nerve impairment after mandibular sagittal split osteotomy: an analysis of spontaneous recovery patterns observed in 60 patients. *J Craniofac Surg* 2002; **13**: 315-320.
- Choi BK, Lee W, Lo LJ, Yang EJ. Is injury to the inferior alveolar nerve still common during orthognathic surgery? Manual twist technique for sagittal split ramus osteotomy. *Br J Oral Maxillofac Surg* 2018; **56**: 946-951.
- Zaytoun HS Jr, Phillips C, Terry BC. Long-term neurosensory deficits following transoral vertical ramus and sagittal split osteotomies for mandibular prognathism. *J Oral Maxillofac Surg* 1986; **44**: 193-196.
- Yoshida T, Nagamine T, Kobayashi T, Michimi N, Nakajima T, Sasakura H, Hanada K. Impairment of the inferior alveolar nerve after sagittal split osteotomy. *J Craniomaxillofac Surg* 1989; **17**: 271-277.
- Yamamoto R, Nakamura A, Ohno K, Michi KI. Relationship of the mandibular canal to the lateral cortex of the mandibular ramus as a factor in the development of neurosensory disturbance after bilateral sagittal split osteotomy. *J Oral Maxillofac Surg* 2002; **60**: 490-495.
- Kuroyanagi N, Miyachi H, Ochiai S, Kamiya N, Kanazawa T, Nagao T, Shimozato K. Prediction of neurosensory alterations after sagittal split ramus osteotomy. *Int J Oral Maxillofac Surg* 2013; **42**: 814-822.
- Dal P. Retromolar osteotomy for the correction of prognathism. *J Oral Surg* 1961; **19**: 42-47.
- Japanese Society of Orofacial Pain. Implementation guidelines for Precision Tactile Function Test (2018). <https://joro-facialpain.sakura.ne.jp/wordpress/wp-content/uploads/2018/03/0938e434c250813e8ffbe2937a6d15e7.pdf>.: accessed on December 17 2020. (Japanese)
- Japanese Society of Oro-Facial Neuronal Function. Lip and tongue sensory abnormality protocol description requirements. *Bulletin of the Japanese Society of Oro-Facial Neuronal Function* 2007; **11**: 21-22. (Japanese)
- Ylikontiola L, Moberg K, Huuononen S, Soikkonen K, Oikarinen K. Comparison of three radiographic methods used to locate the mandibular canal in the buccolingual direction before bilateral sagittal split osteotomy. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2002; **93**: 736-742.
- Huang CS, Syu JJ, Ko EW, Chen YR. Quantitative evaluation of cortical bone thickness in mandibular prognathic patients with neurosensory disturbance after bilateral sagittal split osteotomy. *J Oral Maxillofac Surg* 2013; **71**: 2153.e1-10.
- Yoshioka I, Tanaka T, Habu M, Oda M, Kodama M, Kito S, Seta Y, Tominaga K, Sakoda S, Morimoto Y. Effect of bone quality and position of the inferior alveolar nerve canal in continuous, long-term, neurosensory disturbance after sagittal split ramus osteotomy. *J Craniomaxillofac Surg* 2012; **40**: e178-83.
- Yamauchi K, Takahashi T, Kaneuji T, Nogami S, Yamamoto N, Miyamoto I, Yamashita Y. Risk Factors for neurosensory disturbance after bilateral sagittal split osteotomy based on position of mandibular canal and morphology of mandibular angle. *J Oral Maxillofac Surg* 2012; **70**: 401-406.
- Aizenbud D, Ciceu C, Hazan-Molina H, Abu-El-Naaj I. Relationship between inferior alveolar nerve imaging and neurosensory impairment following bilateral sagittal split osteotomy in skeletal class III cases with mandibular prognathism. *Int J Oral Maxillofac Surg* 2012; **41**: 461-468.
- Böckmann R, Meyns J, Dik E, Kessler P. The modifications of the sagittal ramus split osteotomy: a literature review. *Plast Reconstr Surg Glob Open* 2015; **2**: e271.
- Noleto JW, Marchiori E, Da Silveira HM. Evaluation of mandibular ramus morphology using computed tomography in patients with mandibular prognathism and retrognathia: relevance to the sagittal split ramus osteotomy. *J Oral Maxillofac Surg* 2010; **68**: 1788-1794.
- Golavskiy PI, Pytkov AI, Gorodkov ZE. Morphometric fea-

tures of the condylar process of the mandible. *Stomatologija*
2023; **102**: 60-65. (Mosk)