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Systematic review of preoperative mandibular canal position as it relates to postoperative neurosensory disturbance following the sagittal split ramus osteotomy

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Abstract

The purpose of this study was to review the current literature for the relationship between the preoperative position of the mandibular canal on three-dimensional (3D) radiographic imaging and postoperative neurosensory disturbance (NSD) following a sagittal split ramus osteotomy (SSRO). A literature search was conducted using PubMed, EMBASE, and the Cochrane Database for articles published from 1 January 2000 through 31 December 2013. Studies that included preoperative 3D imaging and assessment of NSD after surgery were reviewed. Study sample characteristics and results were extracted. Of the 69 articles identified, seven met the inclusion and exclusion criteria. There was no standardization for measuring the canal position or for evaluating NSD. General consensus was that the less space between the mandibular canal and the outer border of the buccal cortex the more frequent the occurrence of NSD. Increased bone density also appeared to contribute to a higher incidence of NSD. Utilization of 3D images to locate and measure the position of the mandibular canal is not standardized. Advances in 3D imaging and evaluation tools allow for new methodologies to be developed. Early attempts are informative, but additional studies are needed to verify the relationship between the location of the nerve and NSD following surgery.

Keywords

mandibular canal; inferior alveolar canal; neurosensory disturbance; sagittal split ramus osteotomy; 3D imaging; CBCT; cone beam computed tomography

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Introduction

Recent reports suggest that up to 40% of patients who have a sagittal split ramus osteotomy (SSRO) experience persistent (longer than 6 months) neurosensory alteration^{1–3}.

Several authors have suggested that the anatomical position of the mandibular canal and surrounding bone quality before surgery may be related to the likelihood of nerve injury during an SSRO^{1,4–7}. Others have suggested that the placement of osteotomy cuts and/or fixation placement may be important contributors to the possibility of nerve injury^{3,8}. Two-dimensional (2D) cephalograms have been used routinely to address maxilla–mandible discrepancies at skeletal maturity and the stability of orthognathic surgery procedures. However, these methods are not sufficiently sensitive or discriminatory to quantify the position of the inferior alveolar canal within the mandible prior to surgery, or the surgical placement of osteotomy cuts or fixation^{3,9}.

The use of medical computed tomography (CT) or cone beam computed tomography (CBCT) and three-dimensional (3D) superimposition tools now allow 3D quantification as well as the assessment of surface adaptations using surface distances or shape correspondence not possible with 2D landmark linear or angular measures¹⁰. The purpose of this study was to review published reports using 3D volumes to assess the position of the mandibular canal preoperatively as it relates to neurosensory disturbances after SSRO surgery.

Methods

Eligibility criteria

Longitudinal studies that incorporated 3D imaging obtained before sagittal split osteotomy and post-surgery assessment of neurosensory disturbance (NSD) were investigated. Only articles written between 1 January 2000 and 31 December 2013 and in English were included.

Information sources and search

Relevant studies were located by searching the National Library of Medicine (PubMed), EMBASE, and the Cochrane Database. The related citations function in PubMed was used to identify additional articles. The search and study selection were carried out independently by two reviewers (JR and CP). The terms used in the search strategy were the following: (1) ‘sagittal split’, (2) ‘neurosensory disturbance’, (3) ‘mandibular canal’, and (4) ‘inferior alveolar nerve’. Searches were conducted by filtering studies identified through a combination of search terms 1 and 2 using search terms 3 and 4 separately. Titles and full text abstracts were initially reviewed for eligibility. The full-text of eligible studies was obtained for data extraction (Fig. 1)

Data collection process

The following information was extracted from each article: sample characteristics (sample size, gender, age, presenting skeletal disharmony), length of follow-up, measurement(s) obtained from 3D images, assessment of NSD, and results.

Results

Article selection

The initial search yielded 69 articles. Thirty-four of these were excluded as duplicate articles. A further 28 were excluded following screening of the titles and full-text abstracts because no 3D imaging (CT) was obtained preoperatively or there was no follow-up assessment of NSD. None of the articles attempted to quantify the postoperative location of the canal, osteotomy cuts, or fixation placement.

Study methods

While all studies examined the relationship between the position of the inferior alveolar nerve canal (IAN canal) before surgery and NSD following surgery, surgical techniques, CT and NSD measurements, and timing of neurosensory assessment varied. Six studies used spiral CT imaging taken with the occlusal plane perpendicular to the ground and with a slice thickness of 2 mm to evaluate the location of the IAN canal in relation to the surrounding bone, and one study used CBCT. The location on the mandible selected for measurement of the location of the IAN canal differed. The vast majority of the patients included in these reports were class III. Specifics for each study are outlined below. Table 1 summarizes the 3D measurements and NSD methods.

Yamamoto et al. (2002)⁴: Twenty patients with a mean age of 22.6 years (range [Au?1] 16–40 years) were evaluated. Sixteen of the 20 had a preoperative diagnosis of prognathism. The bone marrow space between the canal and external cortical bone was measured on 2-mm-thick CT slices taken from a base plane at the mandibular foramen to 22 mm below the base plane. The number of consecutive slices showing contact between the canal and cortical bone was recorded as the extent of the contact. The method of Epker was used by the surgeon to determine the bone incision line. Bicortical tandem screws or titanium miniplates were used to provide fixation. NSD was tested bilaterally more than 1 year after surgery using a quantitative algometer, a thermocryoesthesiometer, a two-point threshold discriminator, and a small paintbrush for light-touch discrimination. NSD was recorded as present if one or more of the four sensory tests was abnormal when compared to an area of the cheek unaffected by surgery.

Yoshioka et al. (2010)⁵: Twenty-eight patients with prognathism were assessed; the mean age was 25.8 years (range [Au?1] 18–49 years). Patients were excluded if there was significant mandibular asymmetry, i.e., if the discrepancy for the setback was >5 mm from left to right. The distance from the outer buccal cortical margin of the mandible to the buccal aspect of the IAN canal was measured at the mandibular second molar using software connected to the CT scanner. This distance was compared to measurements taken from 30 non-prognathic patients. The outcome of interest was the presence of contact between the

IAN canal and buccal cortex. The SSRO was performed using the Obwegeser–Dal Pont technique with semi-rigid fixation by titanium miniplate. NSD was measured 3 months after SSRO using a patient questionnaire based on a visual analog scale (VAS) and light touch, brush stroke direction, two-point discrimination, and temperature assessments conducted at six sites.

Yoshioka et al. (2011)⁶: Thirty-five consecutive patients with prognathism were evaluated; the mean age was 25 years (range [Au?1] 18–49 years). All third molars had been taken out at least 1 year previously. A CT scan was taken with bone–tissue windows using a 400 Hounsfield units (HU) window level and a 2000 HU window width. On the cross-sectional CT at the distal edge of the mandibular second molar, the number of HU in the bone as an indicator of bone density was measured using the CT scanner software. High HU values are an indicator of higher bone density. The same neurosensory tests as performed by Yoshioka et al. (2010)⁵ were done at 3 months postoperatively to measure NSD.

Yoshioka et al. (2012)⁷: This study included the same 35 consecutive prognathic patients as in Yoshioka et al. (2011)⁶; mean age was 24.6 years (range [Au?1] 18–49 years). The distance from the cortical margin to the canal⁵ and the HU value⁶ were reported as defined in the previous publications^{5,6}. The distance between the superior aspect of the IAN canal and the alveolar crest and the width of the buccal cortical bone distal to the second mandibular molar were also reported. NSD was measured using the same methods as in previous studies done by the author (VAS and neurosensory tests), but the neurosensory assessments were recorded at longer postoperative intervals of 6 and 12 months.

Yamauchi et al. (2012)¹: Thirty skeletal class III patients with a mean age of 22 years (range [Au?1] 16–39 years) were studied. All third molars were removed at least 4 months prior to surgery. The bone marrow space between the outer mandibular canal and lateral cortex of the ramus was measured approximately 10 mm inferior to the occlusal plane on cross-sectional CT images. The length between the retromolar and gonion points at the mandibular angle was measured on lateral cephalograms. The retromolar point was defined as the intersection of the tangents to the anterior margin of the mandibular vertical ramus and superior margin of the mandibular body. The Dal Pont surgical technique was used for the SSRO. Care was taken to ensure that the neurovascular bundle was not contained in the proximal segment after the split. Four- or six-hole miniplates and monocortical screws were used to obtain primary stability, followed by intermaxillary fixation (IMF) for approximately 4 days. NSD was assessed bilaterally using discrimination to touch with the sharp head of a mechanical probe at 1, 3, and 6 months postoperatively. No criteria specifying the presence/absence of NSD were given.

Kuroyanagi et al. (2013)¹¹: Fifty consecutive patients (48 with prognathism, two with retrognathism) were evaluated; patients were aged 17–44 years. All third molars had been taken out at least 1 year prior, and all patients underwent mandibular osteotomy alone. Distances between the mandibular notch and lingual as well as surgical space medial to the mandibular ramus (space enclosed by the mandible, maxilla, and zygomatic bone) were measured by two independent maxillofacial surgeons on CT images. Clinical sensory tests were done at 1 week, 6 months, and 1 year postoperatively using Semmes–Weinstein

pressure esthesiometer filaments. NSD was considered positive if the threshold value in one of nine regions was higher than normal (2.83).

Huang et al. (2013)¹²: One hundred forty-six patients with prognathism, mean age 23.47 years (range [Au?1] 18–39 years), were evaluated and underwent bimaxillary surgery including a bilateral sagittal split osteotomy setback. Preoperative CBCT images were used to measure the distance between the IAN and corresponding buccal cortical bone. The buccal cortical thickness (BCT) was measured as the shortest distance between the inner buccal surface of the mandibular canal and the outer surface of the buccal cortical bone. BCT was measured every 2 mm from the mandibular foramen to the furcation of the first mandibular molar. NSD was tested at 1 week, 6 weeks, and 1 year using light touch (Semmes–Weinstein monofilament) and pricking pain (dental explorer). NSD was considered positive if there was no response to either light touch or pain.

Major findings

Yamamoto et al. (2002)⁴: At the 1 year or longer postoperative assessment, the prevalence of NSD was 100% on sides where the canal came into contact with the external cortical plate. No NSD was observed on the 14 sides with a bone marrow space of 1.0 mm or more. NSD was significantly more likely if the width of the marrow space was 0.8 mm or less ($P < 0.002$). Separating the IAN from the external cortical bone without injuring the IAN canal is difficult with a small (<0.8 mm) or absent bone marrow space.

Yoshioka et al. (2010)⁵: No significant difference was found in the distance from the buccal aspect of the IAN canal to the outer buccal cortical margin of the mandible between patients with and without mandibular prognathism. The average preoperative distance from the IAN canal to the buccal cortical margin was significantly different for subjects with NSD and without NSD at 3 months post-surgery: the average preoperative mean distance was 4.53 ± 1.03 mm for subjects with NSD compared to 7.11 ± 1.10 mm preoperatively in subjects without NSD at 3 months. The shorter the distance from the buccal aspect of the IAN canal to the outer buccal cortical margin in the mandibular second molar region, the more likely a subject was to present with NSD. At 3 months postoperatively, a higher proportion of women (42.9%) had NSD than men (7.1%) ($P = 0.04$).

Yoshioka et al. (2011)⁶: The difference in the preoperative average HU of mandibular bone was significantly different between men and women ($P < 0.05$). Eighteen of the 35 surgery subjects presented with NSD at 3 months postoperatively, with a significantly higher rate of NSD in women ($P = 0.04$). In relation to bone density, the greater the number of HU in the mandibular bone at the distal edge of the second mandibular molar, the more likely NSD was observed postoperatively ($P < 0.001$). In subjects with unilateral NSD, the number of HU on the affected side was significantly higher than on the unaffected side ($P < 0.01$) suggesting that high bone density might require more pressure for the osteotomy split and thereby increase the likelihood of damage to the nerve.

Yoshioka et al. (2012)⁷: Females had a significantly higher rate of NSD after SSRO at 6 months ($P = 0.043$) and 12 months ($P = 0.047$) than males [Au?2]. The shorter the distance from the buccal aspect of the IAN canal to the outer buccal cortical margin, the more likely

NSD occurrence was at both 6 months ($P < 0.01$) and 12 months ($P < 0.01$). Resolution of NSD between 3 and 12 months was more likely if the preoperative distance was greater than 6 mm compared with distances less than 6 mm. Bone quality (measured in HU) impacted healing as well. Subjects with values less than 300 HU were more likely to experience resolution of NSD between 3 months and 12 months ($P < 0.0001$) compared to those with values greater than 300 HU.

Even though the samples were the same or overlapped, the three articles by Yoshioka et al.⁵⁻⁷ were included because the CT measurements and timing of assessment differed.

Yamauchi et al. (2012)¹: Although no criteria for the presence of NSD were given, the overall occurrence of NSD was reported as 25% at 1 month, 15% at 3 months, and 11.7% at 6 months. A decreased frequency of NSD was correlated with an increased bone marrow space. At 1 month postoperatively, the incidence of NSD in those with a marrow space of 2–3 mm was 5.9%, significantly less than the 57.1% of patients experiencing NSD with a preoperative marrow space of ≥ 1 mm ($P = 0.002$). Patients with a longer distance from the retromolar to gonion points and a small bone marrow space were significantly more likely to present with NSD at 6 months than those with a shorter distance and larger marrow space ($P = 0.006$).

Kuroyanagi et al. (2013)¹¹: Lower lip hypoesthesia was seen in 33% of operated sides at 1 week postoperatively, and 11% at 6 months. Only 2% of operated sides showed NSD at 1 year following surgery. The surgical space on the medial side of the mandibular ramus was significantly different between patients with and without NSD at 1 week ($P = 0.006$) and 6 months ($P = 0.001$). A distance of less than 1.5 mm between the buccal aspect of the mandibular canal and the buccal cortex, and a wide surgical space of 195 mm² or more on the medial side of the ramus, were associated with a statistically significant higher risk of NSD following surgery ($P < 0.001$).

Huang et al. (2013)¹²: Numbness of the lower lip was found in 32.5% of operated sides at 1 week postoperatively. Decreased buccal cortical thickness was identified throughout the length of the mandibular canal in those experiencing NSD compared with those having normal sensation. Thickness of the buccal cortex was an average of 5.67 ± 0.77 mm in the NSD group, which was thinner than in the non-NSD group, mean 5.96 ± 0.75 mm. For both men and women, the buccal cortex was thinner in those who experienced NSD, although the location from the mandibular foramen of the statistically significant differences in thickness differed for men and women.

Discussion

The overall quality of life improves substantially for the vast majority of patients who have mandibular corrective jaw surgery¹³⁻¹⁵. However, NSD constitutes a notable morbidity for a minority of patients. Virtually all patients who have a mandibular osteotomy experience a neurosensory alteration in the short-term after surgery, and the timeline for resolution likely depends on any number of factors including the type of skeletal deformity as it relates to regional anatomy, osteotomy technique and tools, the amount and direction of surgical

movement as it relates to nerve position and tension, the amount of required surgical manipulation of the neurovascular bundle intraoperatively, the experience of the operator, the type and location of fixation, patient age, and the time allowed for return of sensation. In the studies reviewed, 2%¹¹ to 17% of sides operated⁷ were reported as experiencing NSD at 1 year. However, previous publications have discussed the variability in the reporting of the percentage of NSD depending on the method of assessment³. Patient self-report findings indicate that more than 60% of patients report NSD 6 months after surgery¹⁶ and the alteration can persist for up to 2 years in more than 10% of the patients^{17–19}. Currently, there is no generally accepted, standard method of assessing sensory disturbances in the distribution of the IAN following mandibular osteotomy or on the sites to be assessed, which makes the comparison of findings from published reports difficult^{3,20}. A summary of the neurosensory methods employed in the reviewed articles is described in Table 1.

The reports summarized in this review sought to clarify the risk of NSD by focusing on the preoperative IAN canal position^{1,4–7}. The position of the canal is particularly relevant to postoperative NSD following SSRO because the canal position impacts and is impacted by osteotomy design and fixation techniques. Novel technologies and software to evaluate the canal are emerging with the availability and utility of modern medical CT and CBCT data. Nevertheless, omitted from any of the studies was the surgeon's operative assessment of the neurovascular bundle during the procedure. Fridrich et al. in 1995 proposed a five-point ordinal rating scale for surgeons to use in the operating room that could be incorporated easily in studies as a possible confounder. The rating scale ranges from grade 1, 'nerve encased within the bony canal and not visualized in the distal segment', to grade 5, 'nerve transected'²¹.

The optimal utilization of 3D innovative techniques continues to be elucidated and is not well standardized. To date, measurements of the IAN canal in relation to the lateral border of the mandible have consistently been done using cross-sections of CT (spiral or cone beam) images. However, within these studies there remains notable variability in the methodology for obtaining these measurements. In some reports the location of the canal was only measured at one location (i.e., the mandibular second molar)^{5–7}; while in others it was measured at "whichever slice showed the canal closest to the cortical plate"⁴. Additionally, the cross-sectional images that were examined were not standardized to be sliced perpendicular to the ramus, thus creating the potential for a larger measurement than the actual distance.

There is currently insufficient evidence with respect to the measurement on the image that best predicts the likelihood of NSD for routine use in treatment planning or for setting appropriate patient expectations with respect to NSD. Surgical technique may be altered on a case-to-case basis to reflect the surgeon's subjective concern relative to the preoperative location of the canal if a preoperative CT or CBCT is taken.

Another challenge of particular interest for SSRO is that no studies have used 3D imaging to examine the location of the canal after healing has occurred. The unique problem following this technique is that the neurovascular bundle is typically released from the osseous canal during the procedure and assumes a new position between the proximal and distal segments

along the osteotomy. This complicates the task of identifying the true neurovascular bundle versus the osseous canal. Assessing the effects of fixation and segment adaptation as they relate to the nerve itself and NSD outcomes requires further work to clarify how the anatomy of the subject relates to the image data in this circumstance.

Even so, early attempts to find associations are informative. Presurgery, an increased distance between the canal and cortical bone is associated with a lower incidence of postoperative NSD^{1,4,5}, while greater bone density is associated with a higher incidence of postoperative NSD⁶. No human data are currently available on the impact of osteotomy or fixation placement on the incidence of NSD. However, from a short post-surgery assessment comparing monocortical and bicortical fixation in a monkey model, there is an indication that IAN function was better after plate fixation than after screw fixation²².

With advances in imaging techniques and more robust tools for dealing with 3D images, new methods and standards for evaluating the position of the mandibular canal in relation to the surrounding anatomy are needed. In addition, the current studies almost exclusively enrolled prognathic patients. Since the amount and direction of surgical movement as it relates to nerve position and tension may also affect the occurrence and persistence of NSD, additional studies on patients with other presenting characteristics, retrognathia/asymmetry, as well as studies with long-term (12 months) follow-up are needed to more accurately correlate the preoperative and postoperative position of the IAN canal with persistent postoperative NSD.

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Fig. 1.
Flow diagram summarizing the literature search.

Table 1

Techniques used for canal measurement and testing for neurosensory disturbance.

Article	Preoperative IAN canal measurement	Tests, timing, patients, sites, and criteria for NSD
Yamamoto et al. ⁴	Cross-sectional slices: counted number of consecutive slices showing contact between the canal and cortical bone	<p>Tests: Quantitative algometer, a thermocryesthesiometer, a two-point threshold discriminator, light-touch discrimination</p> <p>Timing: >1 year postoperative</p> <p>Patients: 16 prognathic, 3 cleft lip and palate, 1 micrognathia</p> <p>Sites: Unaffected cheek, lower lip, chin</p> <p>Criteria: One or more tests showed abnormalities</p>
Yoshioka et al. ⁵	Cross-sectional slice: at mandibular second molar, distance between outer buccal cortical margin to buccal aspect of IAN canal	<p>Tests: Patient questionnaire (visual analog scale); light touch, brush stroke direction, two-point discrimination, and temperature</p> <p>Timing: 3 months postoperative</p> <p>Patients: 28 prognathic patients</p> <p>Sites: Upper right, lower right, upper left, and lower left</p> <p>Criteria: Questionnaire score >20, positive two-point discrimination, and positive temperature test results</p>
Yoshioka et al. ⁶	Cross-sectional slice: at the distal edge of mandibular second molar; the number of HU in the bone	<p>Tests: Same as above</p> <p>Timing: Same as above</p> <p>Patients: 35 prognathic patients</p> <p>Sites: Same as above</p>
Yoshioka et al. ⁷	Same as Yoshioka (above); distance between superior aspect of canal and alveolar crest. Width of buccal cortical bone at distal of second mandibular molar	Same as Yoshioka (above) but data obtained at 6 and 12 months postoperative
Yamauchi et al. ¹	Cross-sectional slice: 10 mm inferior to the occlusal plane. Bone marrow space measured between outer mandibular canal and lateral cortex of the ramus	<p>Tests: Discrimination to touch (sharp head of a mechanical probe)</p> <p>Timing: 1, 3, and 6 months postoperative</p> <p>Patients: 30 skeletal class III patients</p> <p>Sites: Not specified</p> <p>Criteria: Not given</p>
Kuroyanagi et al. ¹¹	Distances between the mandibular notch and lingual, as well as surgical space medial to the mandibular ramus (space enclosed by the mandible, maxilla, and zygomatic bone) were measured by two independent maxillofacial surgeons on CT images	<p>Tests: light touch (Semmes–Weinstein pressure esthesiometer filaments)</p> <p>Timing: 1 week, 6 months, and 1 year postoperative</p> <p>Patients: 48 skeletal class III, 2 skeletal class II</p> <p>Sites: Lower lip and chin</p> <p>Criteria: Threshold value in one or more of nine regions higher than normal (2.83)</p>
Huang et al. ¹²	Distance between IAN and corresponding buccal cortical bone. The buccal cortical thickness was measured as the shortest distance between inner buccal surface of the mandibular canal and the outer surface of the buccal cortical bone. Buccal cortical thickness was measured every 2 mm from the mandibular foramen to the furcation of the first mandibular molar	<p>Tests: Light touch (Semmes–Weinstein monofilament) and pricking pain (dental explorer)</p> <p>Timing: 1 week, 6 weeks, and 1 year postoperative</p>

Article	Preoperative IAN canal measurement	Tests, timing, patients, sites, and criteria for NSD
		Patients: 146 prognathic patients Sites: Lower lip and chin – four zones Criteria: No response to either light touch or pain

IAN, inferior alveolar nerve; NSD, neurosensory disturbance; HU, Hounsfield units; CT, computed tomography.