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Evaluation of risk of injury to the inferior alveolar nerve with classical sagittal split osteotomy technique and proposed alternative surgical techniques using computer-assisted surgery

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Abstract. Neurosensory disturbance after sagittal split osteotomy is a common complication. This study evaluated the course of the mandibular canal at three positions using computed tomography (CT), assessed the risk of injury to the inferior alveolar nerve in classical sagittal split osteotomy, based on the proximity of the mandibular canal to the external cortical bone, and proposed alternative surgical techniques using computer-assisted surgery. CT data from 102 mandibular rami were evaluated. At each position, the distance between the mandibular canal and the inner surface of the cortical bone was measured; if less than 1 mm or if the canal contacted the external cortical bone it was registered as a possible neurosensory compromising proximity. The course of each mandibular canal was allocated to a neurosensory risk or a non-neurosensory risk group. The mandibular canal was in contact with, or within 1 mm of, the lingual cortex in most positions along its course. Neurosensory compromising proximity of the mandibular canal was observed in about 60% of sagittal split ramus osteotomy sites examined. For this group, modified classic osteotomy or complete individualized osteotomy is proposed, depending on the position at which the mandibular canal was at risk; they may be accomplished with computer-assisted navigation.

Keywords: neurosensory; deficiency; ramus osteotomy; computer-assisted surgery; intraoperative navigation.

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Sagittal split ramus osteotomy (SSRO) of the mandibular ramus was reported to have been introduced in 1942[23]. The credit for improving this osteotomy goes to Trauner & Obwegeser[15,16] who, in 1957, described their modified sagittal split osteotomy. Since 1957, SSRO has become a standard procedure in the treatment of mandibular deformity[1,3,5,6,22]. SSRO has become a versatile technique to advance and set back the mandible[23]. General acceptability of this technique by maxillofacial surgeons has led to various modifications by many clinicians[1,3,5,6,9]. These modifications have made the technique easier and more predictable[1,3,5,6,9].

Despite its versatility and the numerous advantages of SSRO, neurosensory disturbances after the operation are common[2,11,21], because it is performed in close proximity to the inferior alveolar nerve (IAN)[21–23]. Neurosensory disturbance is reported to develop in the lower lip and mental skin of 30–40% of patients after such surgery[17,18]. Factors

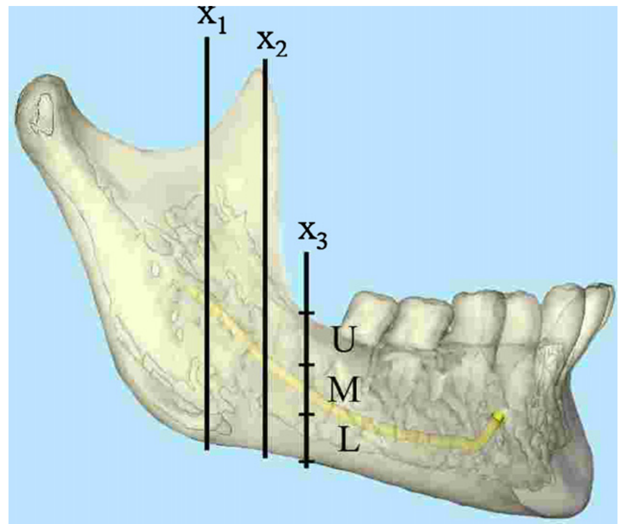

Fig. 1. X1, coronal CT slice 3 mm anterior of the mandibular foramen. X2, coronal CT slice at the transition of the ramus to the mandibular body. X3, coronal CT slice in the middle of the distance of the position X2 to distal of tooth 7.

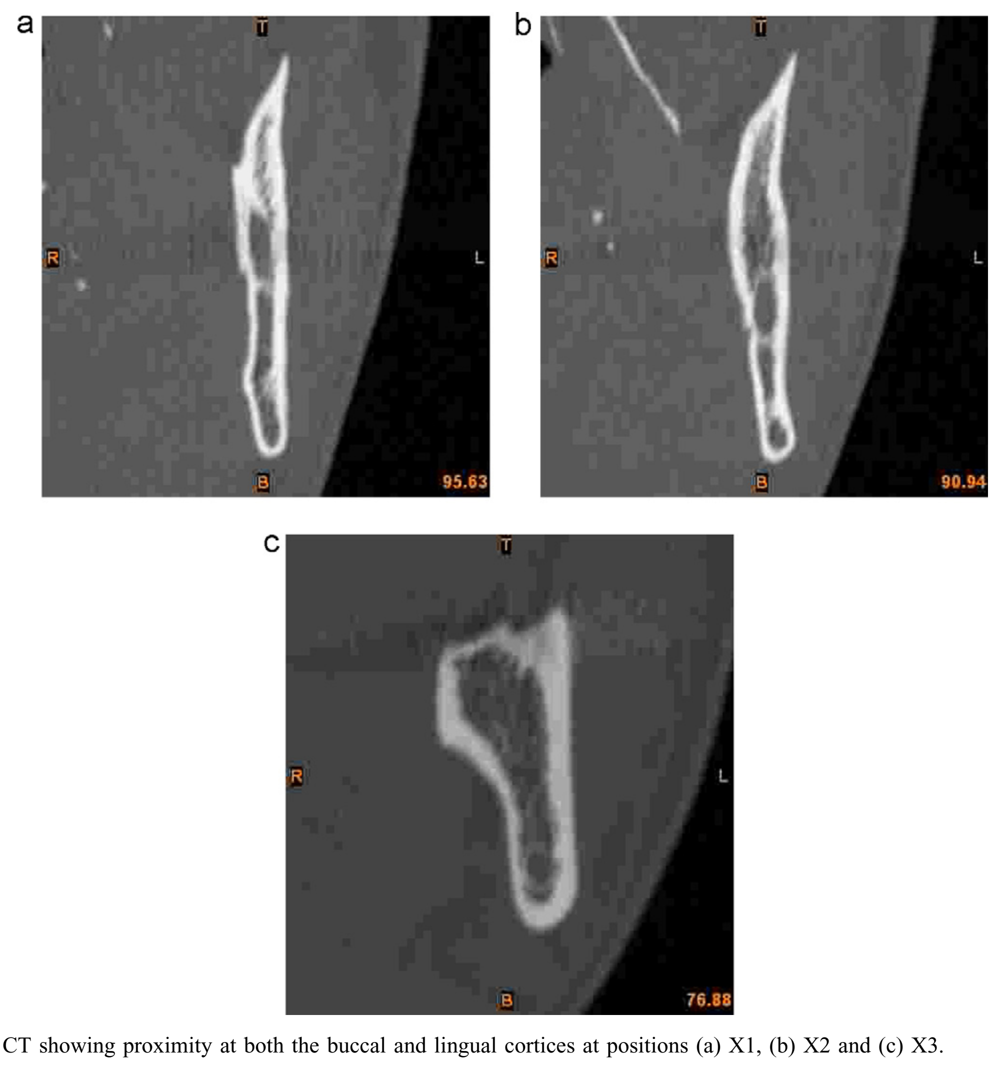

Fig. 2. Coronal CT showing proximity at both the buccal and lingual cortices at positions (a) X1, (b) X2 and (c) X3.

that influence neurosensory disturbance after SSRO include: age of patient, intraoperative magnitude of mandibular movement, degree of manipulation of the IAN and the width of marrow space between the mandibular canal and the external cortical bone[21–23].

Yamamoto et al.[21] showed that neurosensory disturbance was significantly more likely to be present 1 year after surgery when the width of the marrow space between the mandibular canal and the external cortical bone was 0.8 mm or less. It has been reported that separating the IAN from the external cortical bone without injuring the IAN canal is difficult when a marrow space is absent[21]. It has been suggested that the width of the marrow should be considered when planning the treatment of patients undergoing SSRO, and in some cases, the surgeon should select a procedure other than SSRO to avoid nerve injury[21].

Computer-assisted surgery technology has been employed in several surgical fields such as neurosurgery, endoscopy, arthroscopy, and bone surgery[10,12,20]. Reducing the risk of damage to anatomical structures such as nerves, vessels and neighbouring structures is one of the desired outcomes of preoperative computer-aided planning[10,19]. Tools for surgical guidance aim to transfer preoperative planning based on volumetric patient data (computed tomography (CT) or cone-beam CT (CBCT)) to the intra-operative site[10,19]. Computer-assisted navigation allows for real-time imaging of the surgical drill as an overlay graphic on CT and live intra-operative video images and has been reported to be suitable for routine clinical applications[20].

The aim of this study is to evaluate the course of the mandibular canal using CT, to assess the risk of injury to the IAN in classical sagittal split osteotomy based on the proximity of the mandibular canal to the external cortical bone, and to propose alternative surgical techniques using computer-assisted intra-operative navigation.

Materials and methods

CT data (right mandible:left mandible = 52:50) preoperatively acquired for navigated bimaxillary osteotomy in 52 patients (31 male, 21 female) were retrospectively evaluated to determine the course of the mandibular canal. At each CT slice (positions X1, X2, X3) the distance between the mandibular canal and the inner surface of the cortical bone was measured and registered as a possible neurosensory compromising proximity if it was less than 1 mm or if the mandibular canal came into contact with the external cortical bone (Fig. 1). At position X3 the location (upper, middle, lower third) of the canal was investigated (Fig. 1).

Images were acquired using different CT scans. Bone reconstruction mode was used. The data acquisition protocol was optimized for navigation purposes, with a gantry tilt of 0°. The CT scans were taken parallel to the Frankfort plane at 0.5 mm intervals, with a slice thickness of 0.5 mm. Voxel size was

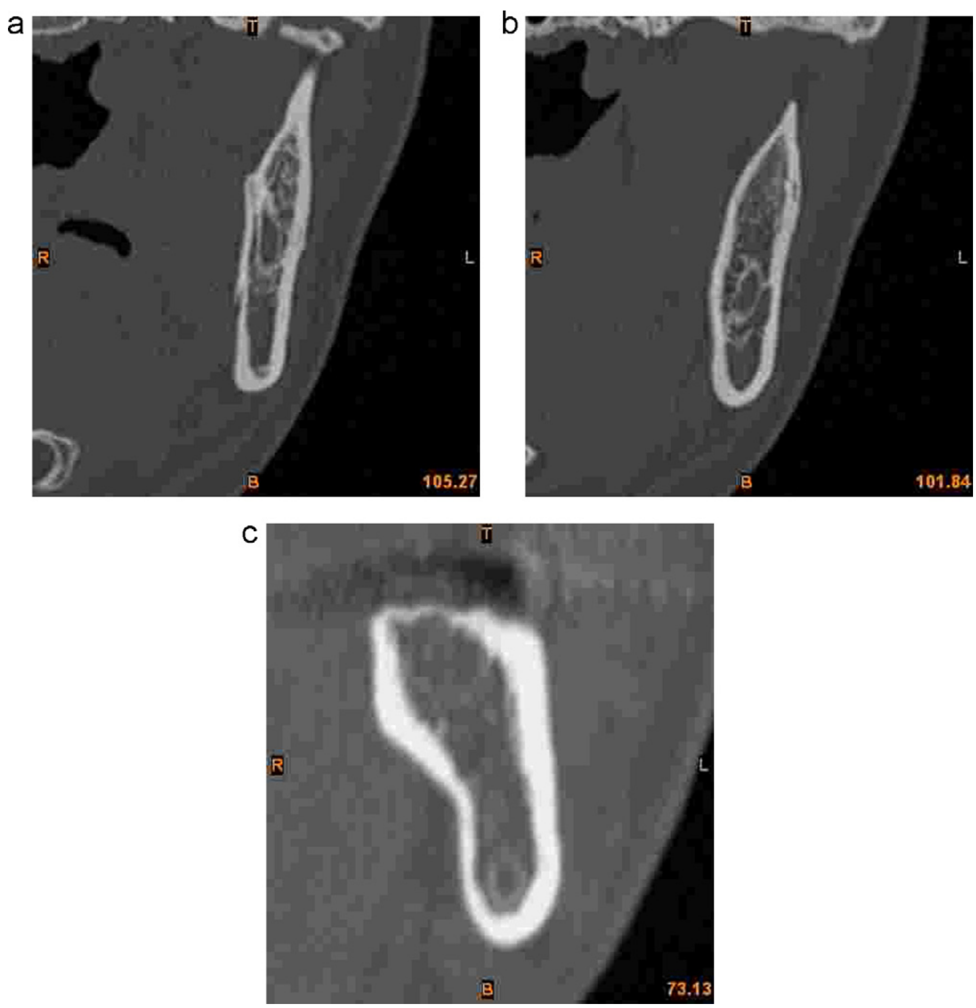

Fig. 3. Coronal CT showing no proximity at both the buccal and lingual cortices at positions (a) X1, (b) X2 and (c) X3.

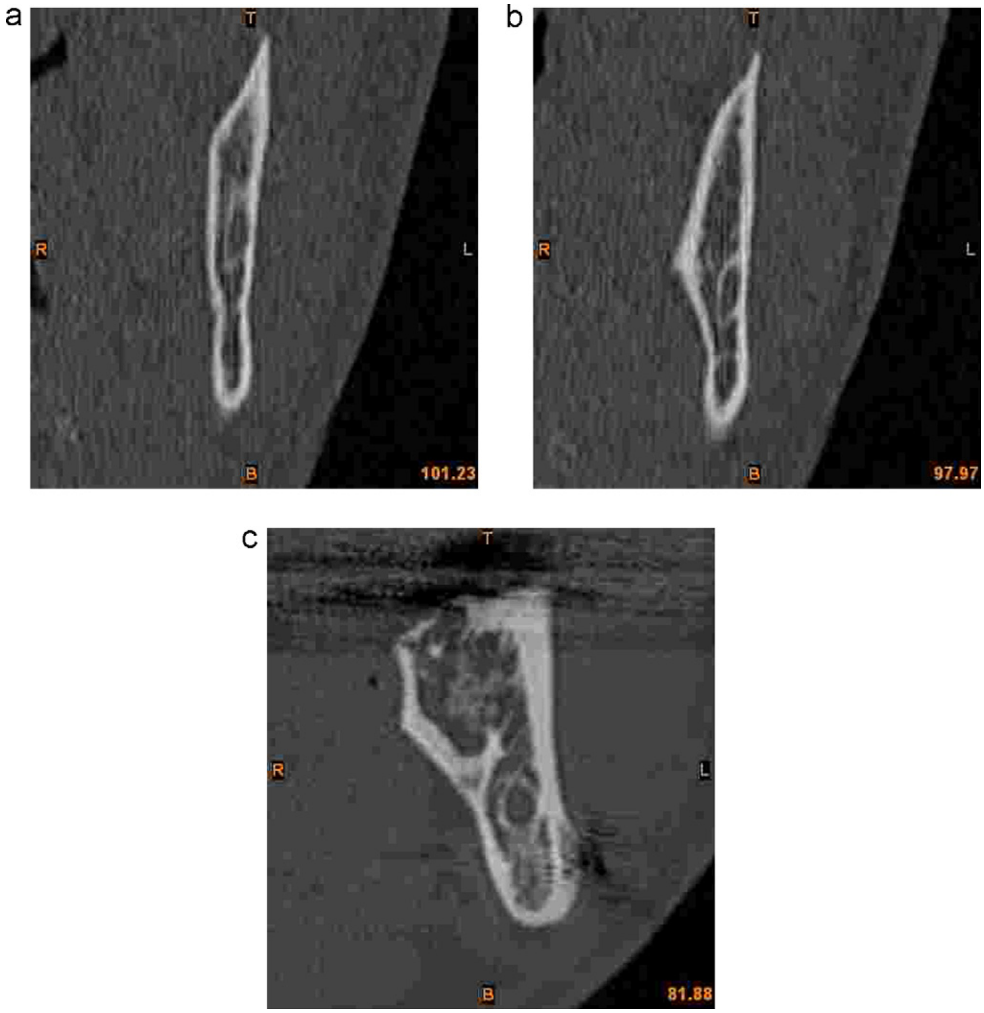

Fig. 4. Coronal CT showing proximity only at the buccal cortex at positions (a) X1, (b) X2 and (c) X3.

0.17 mm × 0.17 mm × 0.75 mm on a 1024 × 1024 matrix, with a field of view of 175 mm × 175 mm. Volume images were transferred to the Surgicase CMF® software (Materialise N.V., Leuven, Belgium) using the standard DICOM protocol.

The following definitions were used. Neurosensory compromising proximity was recorded if the distance between the mandibular canal and the inner surface of the cortical bone was less than 1 mm or there was contact between the mandibular canal and the inner buccal cortical bone. Proximity at the lingual cortex was not considered a neurosensory compromising proximity. Thin mandible (Tn) was recorded for proximity at both the buccal and lingual cortices (neurosensory compromising proximity) (Fig. 2a–c). Thick mandible (Tk) was recorded for no proximity at both the buccal and lingual cortices (no neurosensory compromising proximity) (Fig. 3a–c). Buccal proximity (Bn) was recorded for proximity only at the buccal cortex with nerve at risk of injury (neurosensory compromising proximity) (Fig. 4a–c). Lingual proximity (Ln) was recorded for proximity only at the lingual cortex (no neurosensory compromising proximity) (Fig. 5a–c). Based on the above, only Tn and Bn were considered as neurosensory compromising proximities.

Each mandibular canal was allocated to one of four neurosensory risk groups in relation to the classic procedure of the SSRO as follows: Group A (no risk group), mandibular canal (at positions X1, X2 and X3) with no proximities at positions X1, X2, and X3; Group B, proximity at 1 position; Group C, proximities at 2 positions; Group D, proximities at all positions (X1, X2 and X3).

Using virtual surgical planning, alternative surgical pathways (osteotomies) were tested. The virtual surgical planning was carried out using a commercial software package (Surgicase CMF 5.0, Materialise N.V., Leuven, Belgium). Based on CT scans, virtual models of the mandible were generated: In a threshold based segmentation process (160–3071 HU) the bony structures were identified and a 3D reconstruction was carried out. To visualize the alveolar nerve the course of channel was highlighted and then also reconstructed with an automatic algorithm. The osteotomy wizard module was applied to generate the virtual osteotomy. Based on the acquired data, different surgical pathways were tested virtually to avoid osteotomy lines in close proximity to the nerve, to optimize the overlap of bone of the two parts of the mandible and to guarantee stable fixation for healing of the bone for the correction of a mandibular pro- or retrognathism.

The data were analysed using SPSS for Windows (12.0 version, Chicago, IL). Data are presented in descriptive statistics.

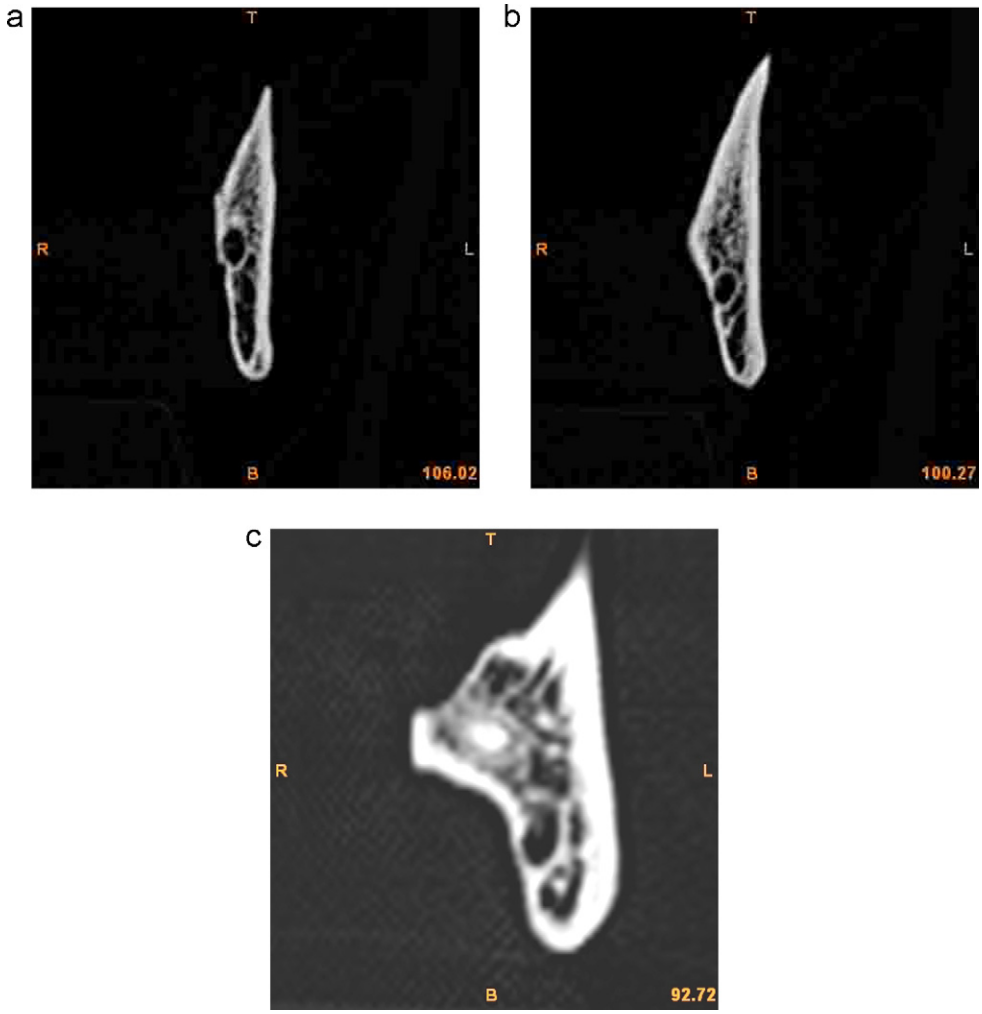

Fig. 5. Coronal CT showing proximity only at the lingual cortex at positions (a) X1, (b) X2 and (c) X3.

Results

Hundred and two mandibular canals from 62 males and 40 females were included in the analysis. Two females had only one canal visible, hence 102 canals were analysed. Table 1 shows the frequency of Bn, Ln, Tk and Tn at positions XI, X2 and X3. The mandibular canal was mostly in contact with or within 1 mm of the lingual cortex in all the positions (Table 1). At position X1, neurosensory compromising proximity was seen in 43% of cases (Bn, Tn); and in 58% and 24% of cases at positions X2 and X3, respectively (Table 1).

The location of the canal at position X3 was found to be at the middle portion in 61% ($n = 62$) of cases, followed by the lower portion in 38% ($n = 39$) of cases and the upper portion in only 1 case. A third molar was present in 34% ($n = 35$) of cases and absent in 66% ($n = 67$) of cases.

Forty (39%) mandibular canals showed no compromising neurosensory proximity at all positions (Group A). Sixteen (16%) canals showed compromising proximity in 1 position only (Group B), 27 (27%) in 2 positions (Group C), and 19 (19%) in all positions (Group D). Table 2 shows the sex distribution of the four neurosensory risk groups. There was no significant difference in the positional distribution of neurosensory proximity between male and female mandibular canals ($P = 0.594$).

The combination LnLnLn (55%) was seen most often in Group A, LnBnTk (38%) in Group B, TnTnLn (41%) in Group C, and TnBnBn (63%) in Group D (Table 3).

Based on categorization into the four neurosensory groups, classical SSRO can only be applied in 39% (Group A only) of all mandibular ramus surgery without risking neurosensory deficiency. In 61% (Groups B, C, and D) osteotomy of the mandibular ramus needs to be individualized to prevent a neurosensory deficiency.

Based on the virtual surgical planning, two fundamental types of individualized osteotomies can be hypothesized, which could be adapted, depending on the shape

Table 1. Proximities of mandibular canal to the buccal and lingual cortices at positions X1, X2 and X3.

Proximity	Position number (%)		
	X1	X2	X3
Bn	2 (2.0)	30 (29.4)	17 (16.7)
Ln	54 (52.9)	32 (31.4)	45 (44.1)
Tk	4 (3.9)	11 (10.8)	33 (32.4)
Tn	42 (41.2)	29 (28.4)	7 (6.9)
Total	102 (100)	102 (100)	102 (100)

Table 2. Sex distribution of the four neurosensory risk groups.

Sex	Neurosensory risk groups				
	A	B	C	D	Total
Male	24	8	19	11	62
Female	16	8	8	8	40
Total	40	16	27	19	102

$P = 0.594$.

Table 3. The distribution of the neurosensory compromising proximity in the four neurosensory risk groups.

Position			Number (%)
X1	X2	X3	
Group A			
Ln	Ln	Ln	22 (55)
Ln	Tk	Tk	6 (15)
Ln	Tk	Ln	1(2.5)
Ln	Ln	Tk	8 (20)
Tk	Tk	Tk	3 (7.5)
Total			40 (100)
Group B			
Ln	Bn	Tk	6 (37.5)
Ln	Bn	Ln	2 (12.5)
Ln	Tn	Kn	1 (6.25)
Ln	Tn	Ln	4 (25)
Tk	Bn	Ln	1(6.25)
Tn	Ln	Ln	2 (12.5)
Total			16 (100)
Group C			
Bn	Tk	Bn	1 (3.7)
Ln	Tn	Bn	2 (7.4)
Ln	Tn	Tn	2 (7.4)
Tn	Tn	Tk	5 (18.5)
Tn	Tn	Ln	11 (40.8)
Tn	Bn	Tk	4 (14.8)
Tn	Bn	Ln	2 (7.4)
Total			27 (100)
Group D			
Bn	Bn	Bn	1 (5.3)
Tn	Tn	Tn	3 (15.7)
Tn	Bn	Bn	12 (63.2)
Tn	Tn	Bn	1 (5.3)
Tn	Bn	Tn	2 (10.5)
Total			19

of the mandible and planned movement of the bone fragments.

The first is modified classic osteotomy (MCO). MCO is designed to perform a ramus osteotomy for Group B with one proximity at position X2 or X3 and Group C with two proximities at positions X2 and X3 (Fig. 6). MCO is a combination of computer-assisted osteotomy of the buccal cortical bone and classical osteotomy of the other parts of the ramus followed by a splitting between the cortical and the marrow of the ramus. Osteotomy of the outer cortical plate is to prevent damage of the nerve at position X2; the inner cortical plate above the lingula can then be performed traditionally. Through careful preparation of the medial part of the ramus, the entrance of the nerve into the ramus is visible, and damage to the nerve is prevented.

The second is complete individualized osteotomy (CIO). CIO is the basic design of ramus osteotomy for Groups B, C and D with one proximity at position X1. This type of osteotomy requires a fully navigated milling of the ramus. CIO is a bevelled osteotomy of the ramus to allow a maximum overlap of bone (Fig. 7).

Discussion

Several anatomic landmarks have been proposed in the literature to guide surgeons in locating and avoiding IAN during ramus osteotomy[4,8]. Although, techniques such as conventional radiographs, topography and the use of human dry skull have been used to locate the IAN, recent evidence suggests that CT scanning, especially the 3D variant, provides the best technique for assessing the location of the IAN[24]. Owing to the variety in anatomic structures, the importance of preoperative 3D CT scans to identify the location of the IAN and the position of antilingula has been recently stressed[24].

The present study considered the relationship of the mandibular canal at three positions between the lingula and distal surface of the second lower molar in relation to the inner buccal cortex of the mandibular ramus as a possible neurosensory compromising factor. This factor may be responsible for the traction on the IAN inside the ramus of the mandible during surgery or the injury to the nerve when the ramus of the mandible is split with subsequent paresthesia/anaesthesia on the distribution mental nerve.

The present study showed that the mandibular canal was in close proximity to the inner lingual cortex in all positions. Neurosensory compromising proximity (contact or proximity to the inner buccal cortex) was present in 43%, 58% and 24% of cases at positions X1, X2 and X3, respectively. It has been reported that contact between the mandibular canal and the external cortical bone is a risk factor for the development of neurosensory disturbance after SSRO[7,13,21]. Yamamoto et al.[21] reported that neurosensory disturbance was significantly more likely to be present 1 year after surgery, when the width of the marrow space between the mandibular canal and the external cortical bone was 0.8 mm or less, and neurosensory disturbance remained on all sides of the mandible in which a marrow space was absent. Separating the IAN from the external cortical bone without injuring the IAN is difficult when a marrow space is absent[21]. At position X3, it was found that the canal was mostly located (61%) in the middle portion and in 38% of cases in the lower portion, and rarely in the upper portion. This provides a useful practical guide during the split distal to the second molar position.

In the present study, only about 40% of the SSRO sites showed that the IAN was not in proximity to the inner buccal cortex of the mandibular. This indicates that the

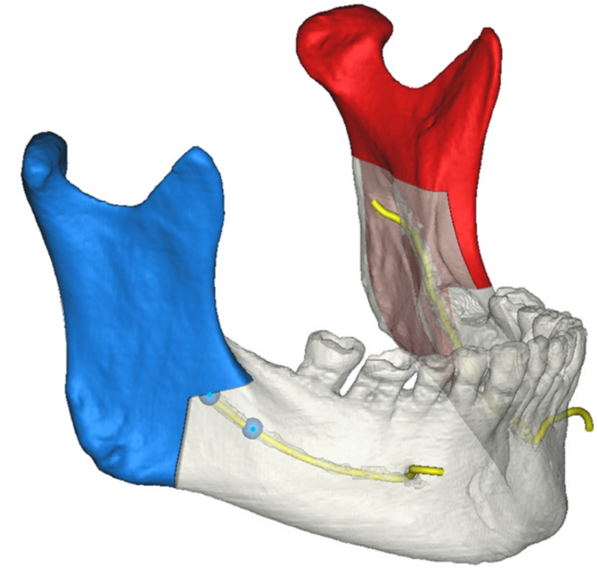

Fig. 6. Buccal (blue) and lingual (red) segments of mandible in MCO. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

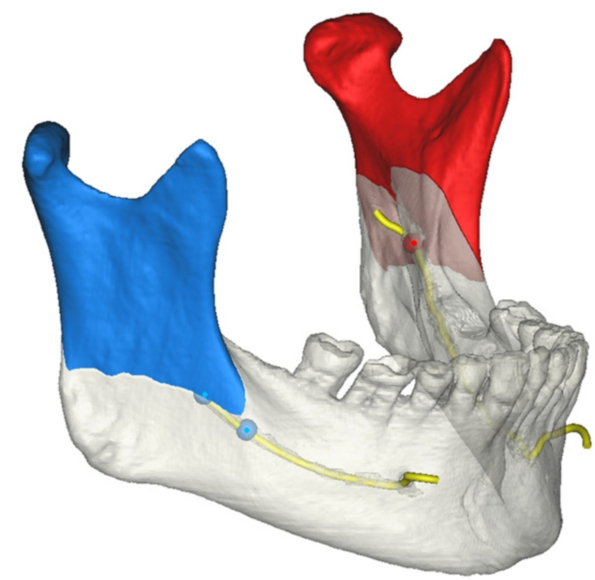

Fig. 7. Buccal (blue) and lingual (red) segments of mandible in CIO. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

possibility of nerve injury based only on nerve proximity to the buccal plate may be a reality in about 60% of SSROs. In the authors' opinion this provides a basis for preoperative CT scanning assessment and individualized osteotomy for patients undergoing sagittal ramus osteotomy. A case for individualized sagittal split osteotomy is also supported by recent findings by Yu & Wong[24]. Yu & Wong[24] evaluated SSROs using 3D CT scans, and found that anatomy related to SSROs is influenced by the gender and age group of the patients. The dimension of the female mandible at SSRO was found to be smaller than that of males, and the mean thickness of the mandible at this site was slightly less in the 30–40 year age group. It was also found that the mean bone thickness from mandibular canal to buccal plate at the second molar region was smaller in females than in males. Yamamoto et al.[21] suggested that the relationship between the mandibular canal and external cortical bone should be a consideration when planning the treatment of patients undergoing SSRO, and in some cases, the surgeon should select a procedure other than classical SSRO.

The present study considered the relationship of the mandibular canal at three positions between the lingula and distal surface of the second lower molar in relation to the inner buccal cortex of the mandibular ramus as a possible neurosensory compromising factor. Several other factors have been reported to be responsible for neurosensory disturbance after SSRO, including medial periosteal dissection, injury to the nerve when the screw holes are drilled, compression of the nerve by rigid fixation, overstretching of the nerve bundle by traction, and magnitude of mandibular movement[14,15,21,23]. Attention must be paid to these factors during sagittal ramus osteotomy to minimize the incidence of neurosensory disturbance.

For those in the risk groups (Groups B, C and D), the authors suggest two individualized osteotomies: MCO and CIO. There is the possibility to adapt the individualized osteotomies (MCO, CIO) depending on the shape of the mandible and the planned movement of the bone fragments to correct mandibular prognathism or mandibular retrognathism.

Other alternative surgical procedures for the correction of mandibular deformities apart from SSRO include inverted L-ramus osteotomy (ILRO), and intraoral vertical ramus osteotomy (IVRO)[14]. ILRO and IVRO are unsuitable for mandibular advancement surgery when the bone contact area between proximal and distal segments is considered. The alternative surgical techniques for ramus osteotomy proposed in the present study (MCO, CIO) can be used for mandibular set back and advancement. By using computer navigated system, an individualized surgical treatment plan can be performed with respect to the anatomical variations of the ramus resulting in less uncontrolled separation of the ramus and avoiding IAN injury. These techniques require meticulous preoperative planning with the aid of CT scans. Preoperative planning is transferred to the intra-operative site with the aid of computer-assisted navigation which allows for real-time imaging of the surgical drill as an overlay graphic on CT and live intra-operative video images.

The proposed individualized osteotomies are the fundamental types, but there may be a need to modify them according to the virtual planning to account for movement of the bony structures enabling the best result for bone healing. One major drawback of the proposed individualized osteotomy is the cost implication and exposure to radiation due to CT acquisition but it is thought that once this technique gains popularity the cost of CT acquisition will be minimized.

In conclusion, the present study showed that neurosensory compromising proximity of the mandibular canal was observed in about 61% of SSRO sites examined. The proposed MCO and CIO procedures may be an alternative to SSRO depending on the site at which the IAN may be at risk. These procedures may be accomplished with the aid of computer-assisted navigation.

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Competing interests

None declared.

Ethical approval

Not required.

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