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ORIGINAL ARTICLE

Evaluation of an innovative computer-assisted sagittal split ramus osteotomy to reduce neurosensory alterations following orthognathic surgery: a pilot study

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Abstract

Background Sagittal split ramus osteotomy (SSRO) can be associated with postoperative neurosensory disturbances. This study aimed to evaluate the effectiveness of computer-assisted SSRO in reducing the incidence and severity of neurosensory alterations, using a surgical guide fabricated by computer-aided design and rapid prototyping (to guide bone cutting lateral to the inferior alveolar nerve).

Methods A prospective double-blind, randomized controlled, clinical trial of computer-assisted SSRO vs conventional SSRO (assigned in a split-mouth design) in eight patients, mean age 23 (range 18–30) years, who participated in one session preoperatively and three sessions at 1 week and 1, 3 and 6 months postoperatively. At each session, subjective oral sensation was scored and quantitative sensory tests were performed. Neurosensory changes were compared between the two sides.

Results The results showed that on the computer-assisted SSRO sides, patients had lower postoperative abnormal thresholds for the Semmes–Weinstein monofilaments on lower lip and chin ($p < 0.05$ at 3 months) and for the two-point discrimination on lower lip ($p < 0.05$ at 1 week) and chin ($p < 0.05$ at 6 months), with fewer abnormal self-reported changes in lower lip sensation ($p < 0.05$ at 1 week) after surgery.

Conclusions These findings imply that computer-assisted SSRO is associated with better levels of neurosensory function after surgery.

Keywords computer-assisted; sagittal split ramus osteotomy; inferior alveolar nerve; surgical guide; neurosensory disturbances

Introduction

Mandibular sagittal split ramus osteotomy (SSRO) is a versatile technique used in the surgical correction of dentofacial deformities. This technique was first introduced by Trauner and Obwegeser and later modified by Dal Pont (1–3). It has certain merits, such as providing a wide area of contact of the split bone surfaces, allowing for the anterior and posterior movements of the mandible, thus being useful for patients with mandibular prognathism, mandibular retrognathism and those with facial asymmetry.

Despite being a safe procedure, SSRO can be associated with postsurgical neurosensory disturbance in the lower lip and chin area, due to a functional deficit of the inferior alveolar nerve (IAN) (4–8). Although these sensory changes tend to be reversible in most cases, long-term follow-up has shown an incidence of sensory disturbance 1 or 2 years after surgery, in the range 0–94%, depending on the sensibility of the testing method and the follow-up period (9).

Several factors have been implicated in the aetiology of IAN functional damage during surgery (9–12): it can occur due to direct laceration of the IAN during drilling or sawing cortical bone, during the lingual osteotomy cut and the anterior vertical cut in the buccal cortex (13), or during splitting through the bone cut on the upper surface of the external oblique ridge with the osteotome. The lateral course of the mandibular canal in the ascending ramus and mandibular second molar (14–16), its proximity to the buccal plate and the thickness of the ramus (17) were also found to increase the possibility of neurosensory disturbances after SSRO. Some authors have suggested that soft tissue dissection on the medial aspect of the mandibular ramus may compress the IAN bundle on the lingula and under the dissecting instrument, causing nerve tear at this stage of the operation (5). Moreover, fixation method was shown to have an effect on IAN damage when it causes compression against the nerve (18).

In our study we aimed to investigate the effectiveness of computer-assisted surgical guide for SSRO in reducing the incidence and severity of IAN injury following surgery, by directing the surgical cutting plane to be positioned lateral to the IAN within the ramus and posterior body of the mandible.

Materials and methods

This study was a prospective double-blind, randomized, controlled, clinical trial, conducted at the Department of Oral and Maxillofacial Surgery, Jordan University Hospital, Amman, Jordan. Consecutive Jordanian patients scheduled for bilateral SSRO with no concomitant surgical procedures on the mandible were asked to participate. Six women and two men, mean age 23 (range 18–30) years, agreed to participate and were included in the study. Four patients had a diagnosis of mandibular prognathism, and the remaining four had mandibular retrognathism.

All patients completed presurgical orthodontic treatment and were categorized as ASA 1 (normal healthy patient) or ASA 2 (patient with mild systemic disease), according to the American Society of Anesthesiologists (19). Exclusion criteria for patients were as follows: those with a history of trauma and nerve injuries to the jaws, or other neurosensory disturbances of the IAN, were not included in the study. The patient assessment procedure involved a comprehensive clinical examination by a maxillofacial surgeon and an orthodontist, study models, radiographic examination (panoramic X-ray, lateral cephalogram) and an explanation of what orthognathic surgery involved with the aid of information literature and explanatory photos.

A member of the research team explained details of the study. The study protocol was approved by the Faculty of Academic Research at the University of Jordan (No. 23/2011-2012) and followed the guidelines of the Helsinki II Declaration.

Before being enrolled in the study, patients were given consecutive numbers and assignment of the patients' mandibular sides (right or left) to undergo computer-assisted SSRO was done sequentially. Patients and the examiner who assessed neurosensory alteration were blinded to the assignment; on the other hand, the performing surgeon could not be blinded, which was a limitiation in the design of this study. All neurosensory assessments were performed by one examiner who was not the surgeon. The other side of the mandible underwent conventional SSRO (control side). All osteotomies were performed by one senior surgeon (first author). Written informed consent was obtained from all patients.

A dual CT scan (Siemens SOMATOM Sensation 16 CT scanner) was performed for all patients. The first scan was taken of the patient while biting on a piece of folded gauze to separate the two jaws and obtain sharper images of the dental occlusal surface. A second scan was taken of the patient's study cast to remove the scattering effect of metal restorations and show the soft tissue contour. The image acquisition parameters were: tube voltage 120 KV; effective tube current 70 mA; CT matrix size 512 × 512; and slice increment 0.5 mm.

The DICOM images were imported into the surgical planning software (Solid Planner, Solid Models Co.), where a thresholding process was carried out on the first scan to exclude soft tissues and to further segment the mandible alone before a 3D reconstruction was calculated (Figure 1).

The two scans were then superimposed, employing teeth as the common structures, thereby accurately relating the

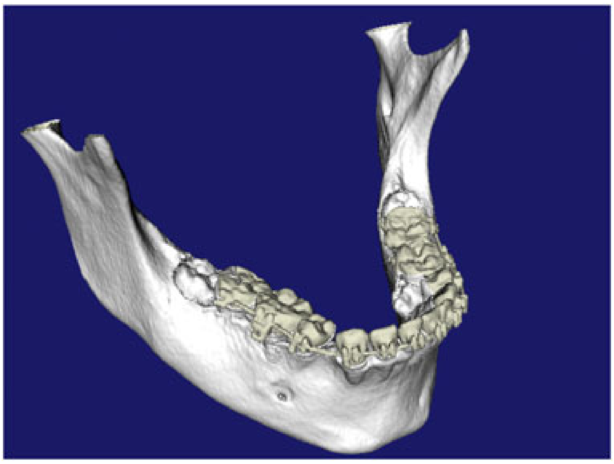

Figure 1. 3D reconstruction of the mandible following the thresholding process that was carried out on the first CT scan to exclude soft tissues and segment the lower jaw

dental cast to the jawbone. The intrabone course of the IAN was identified bilaterally. Two virtual guiding markers were then placed at two different levels lateral to the IAN within the ramus and posterior body of the mandible (Figures 2, 3). The final reconstructed image of the lower jaw with the hollowed-out guiding markers was then printed out on a 3D printer (ZCorp Z310), using rapid prototyping. An acrylic resin splint was then constructed on the jaw model, with a two-sided stainless steel custom-made surgical guide (fabricated using computer-aided design; blades 1 mm apart) attached to it, to direct the surgical cutting plane lateral to the IAN intrabone course (Figure 4). The guide had two rods that were fitted to the two hollow guiding markers within the jaw model. A second two-sided stainless steel guide was planned and constructed to guide the surgical cut on the body of the mandible if the first cutting plane was not lateral to the route of the IAN within the body of the mandible.

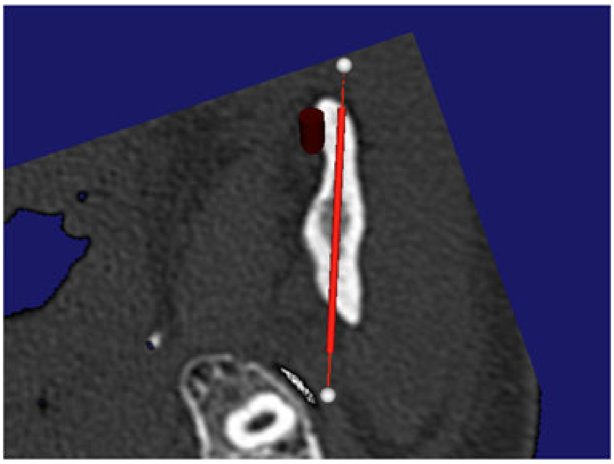

Figure 2. The marker represents a virtual sagittal ramus osteotomy cut positioned lateral to the IAN

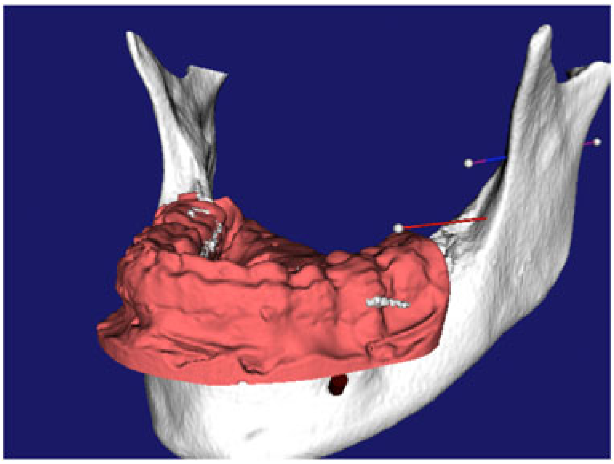

Figure 3. Three components are gathered: accurately superimposed study model (red) to bone (white), using common structures (teeth) and markers placed at two different levels following tracing of the inferior alveolar nerve. The virtually planned model is ready

Figure 4. Final acrylic splint with surgical guide on the rapid prototyped base

Operation methods

The SSRO technique used was the Obwegeser–Dal Pont technique (1–3); a standard soft tissue dissection was performed with minimal distraction of the soft tissues in the ramus (9). The CAD guide was fitted well into the lower dentition and wired to the fixed orthodontic appliance, using holes within the splint. A reciprocating saw was used to perform the SSRO, directed by the CAD guide on the tested side (Figures 5, 6), while a conventional SSRO (CL) was performed on the control side after identification of the intrabone course of the IAN on the two-dimensional (2D) CT scan. Intraoperative changes in nerve position and continuity were assessed and recorded bilaterally. A semi-rigid fixation was accomplished using a titanium miniplate at the anterior mandibular ramus.

Quantitative neurosensory testing

All patients participated in five sessions: at baseline (before surgery), at 1 week and 1, 3, and 6 months after surgery, during which their somatosensory function was assessed on four cutaneous points, using a grid in the lower lip and symphyseal region bilaterally with sensory thresholds for three tests:

1. Tactile threshold, using a Semmes–Weinstein (SW) monofilament aesthesiometer (Stoelting Co., Wood Dale, IL, USA), in which postoperative change in sensory function of the lower lip (at the vermilion border) and chin was evaluated as an increase in the size of the filament registered by the patient. The filaments were applied perpendicular to the skin until the filament was detected, starting with the least-stiff filament (1.65), as described by Teerijoki-Oksa *et al.* (20).
2. Two-point discrimination was performed using pairs of needles with decreasing inter-needle distance, starting from 20 mm distance.

Figure 5. Custom-made splint with surgical guide is fitted to the lower jaw to direct the reciprocating saw blade to perform the virtually planned sagittal ramus osteotomy

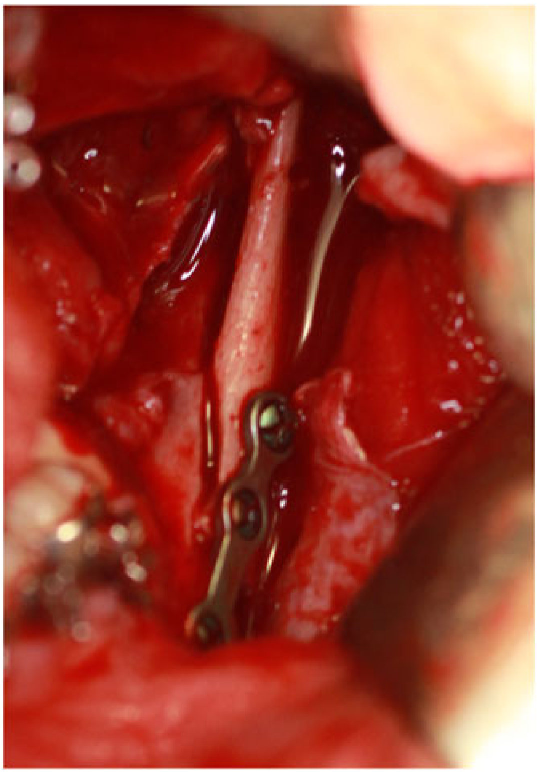

Figure 6. Fixation using a titanium miniplate at the anterior mandibular ramus

3. Direction of brush stroke. Two brush strokes were performed bilaterally, first directed from the base of the chin to the lip and then in the reverse direction. Responses were reported as either correct or incorrect.

Subjective neurosensory testing

Patients were asked to rate changes in sensory function in the lower lip and chin bilaterally and to quantify these changes on a visual analogue scale (VAS), a tool that was employed in previous studies for self-evaluation of neurosensory changes (21–23). Patients were carefully instructed on the use of the VAS, where 0 was defined as the ‘most imaginable change’ and 100 was defined as ‘no changes at all’.

Data analysis

The differences between the computer-assisted SSRO side and the control side measurements in tactile threshold and brush stroke direction were analysed by χ^2 test, and differences in the two-point discrimination and VAS were analysed by a two-sample *t*-test at 1 week and 1, 3 and 6 months after surgery; $p < 0.05$ was considered significant. The statistical analysis was performed using the statistical software SPSS v 15 (SPSS, Chicago, IL, USA).

Results

During surgery, intraoperative parameters related to the IAN were assessed by the surgeon, as shown in Table 1. These involved changes in nerve position and continuity following the surgical procedure. The IAN was partially exposed in only one of the eight computer-assisted SSRO sides, which did not require free dissection. For the CL sides, complete exposure of the IAN during surgery was required for one side and active free-dissection of the IAN was needed to release visible adherences to the proximal segment during SSRO in three sides.

Somatosensory function

The lower lip and chin sensation was impaired following the surgical procedure, mainly on CL sides as demonstrated by the increased tactile thresholds, the two-point discrimination mean thresholds, brush stroke direction test results and patients’ subjective evaluation of their reduced sensory function following surgery.

Patients were classified according to their SW monofilaments tactile thresholds, in the manner described by Kobayashai *et al.* (24). The control differential threshold levels for the SW tester on the lower lip and chin was determined preoperatively in our sample, using a fibre that was detectable at both points. The control level was found to be in the range 1.65–2.83, and no difference was detected between the right and left sides of the lower lip and chin. The tactile threshold was therefore considered abnormal at >2.83. At 1 week after surgery, 83% of the CL sides had abnormal tactile thresholds (> 2.83) at the lower lip and chin, compared to 67% of abnormal thresholds in the computer-assisted SSRO sides; this

Table 1. Intraoperative parameters assessed by the surgeon during sagittal split ramus osteotomy in the computer-assisted SSRO group ($n = 8$) and the CL group ($n = 8$)

Parameter	Computer-assisted SSRO	CL group	p
Partial exposure of the alveolar nerve (yes/no)	1/8	4/8	0.106
Complete exposure of the alveolar nerve (yes/no)	0/8	1/8	0.302
Adherence of alveolar nerve to the anterior bone segment (yes/no)	0/8	1/8	0.302
Free dissection of the alveolar nerve performed (yes/no)	0/8	3/8	0.055
Transsection of the alveolar nerve (yes/no)	0/8	0/8	–

Level of statistical significant difference was obtained by the χ^2 test; $p < 0.05$.

difference was significant at the lower lip at 6 months and chin at 3 months after surgery ($p < 0.05$). At 6 months after surgery, abnormal thresholds were observed in 50% of computer-assisted SSRO sides, with no rate improvement for the CL sides (Figure 7).

For the two-point discrimination, a significant difference was found between the computer-assisted SSRO and CL sides for the lower lip and chin 1 week after surgery ($p < 0.05$), with lower mean values observed at computer-assisted SSRO sides throughout the postoperative period of 6 months (Figure 8). Patients' subjective evaluation of their neurosensory disturbances was significantly different between the computer-assisted SSRO and the CL sides at 1 week after surgery ($p < 0.05$), with better values reported on the computer-assisted SSRO sides. Patients reported improvement of their lower lip and chin sensation in the postoperative period, with higher mean values reported at the computer-assisted SSRO sides compared to CL sides at 1, 3 and 6 months after surgery (Figure 9).

On the brush stroke direction test, the computer-assisted SSRO sides showed 100% normal response at 1, 3 and 6 months after surgery, while 33% of CL sides' responses remained abnormal at 6 months after surgery (Figure 9). Furthermore, in order to examine the effect of the side of the mandible on neurosensory disturbances after SSRO, as suggested by Hanzelka *et al.* (25), the two sides of the lower lip and chin were compared in terms of their tactile thresholds, the two-point discrimination mean thresholds, brush stroke direction test results and patients' subjective evaluations of reduced sensory function following surgery. No significant difference was found between the two sides during the 6 month follow-up period.

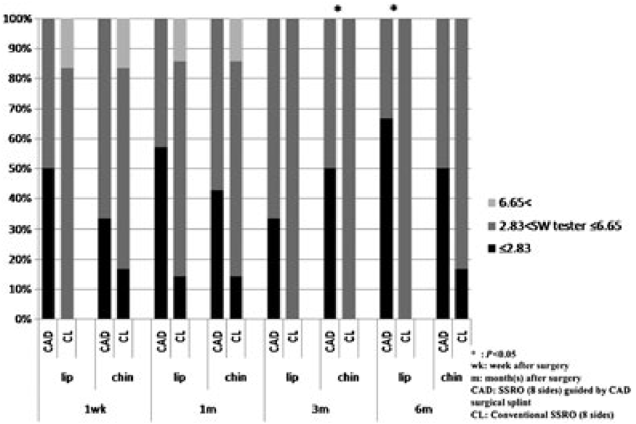

Figure 7. Incidence of lower lip and chin sensory disturbances based on the threshold to Semmes–Weinstein monofilament tester

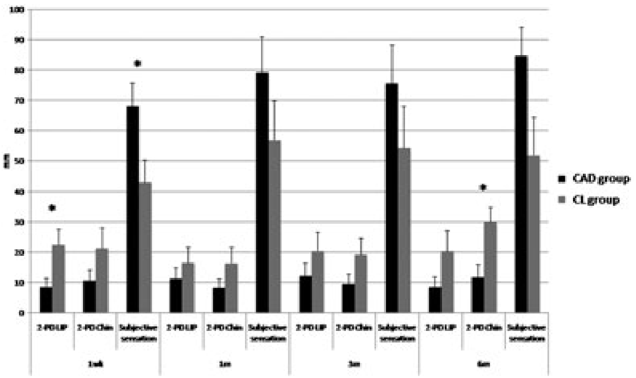

Figure 8. Incidence of lower lip and chin sensory disturbances based on the threshold to the two-point discrimination test (2-PD) and subjective sensory disturbances

Discussion

The advancement in computer-aided surgical simulation has enabled interactive visualization, simulation and surgical prediction in the craniofacial region (26–29). A computer-aided design of a metal resection template for the mandible was first reported by Eufinger *et al.* (30). Computer-based planning software was then developed to virtually simulate

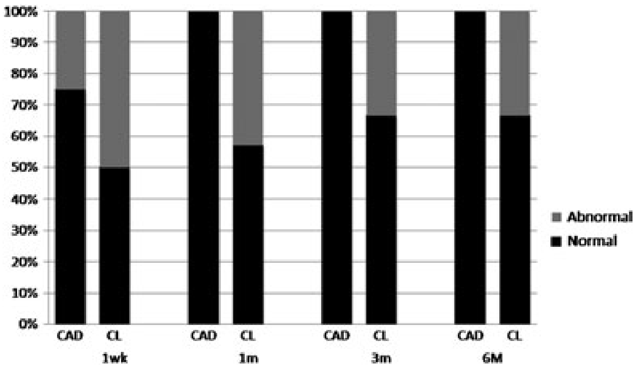

Figure 9. Incidence of lower lip and chin sensory disturbances, based on the brush stroke direction test

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surgical plans before obtaining a physical 3D model, which enables surgeons to plan complex craniomaxillofacial surgery and create 3D predictions of surgical outcomes (31), with an accuracy of 1 mm (32).

1In this study, we evaluated a SSRO surgical guide designed by virtually planning the mandibular bony cut to be positioned lateral to the course of the IAN within the ramus and posterior mandible, to minimize the incidence and severity of IAN injury, such as anatomical and iatrogenic factors including the thickness of the ramus (16), proximity of the nerve canal to the buccal plate (14,15), surgeons' experience and the surgical technique (9,33), were related to the occurrence of this type of nerve injury.

In order to evaluate neurosensory changes affecting the lower lip and chin area following SSRO and compare between the tested and control sides, objective methods were used in combination with subjective patient's evaluation, as it is recommended that clinical judgements regarding nerve injury-associated sensory dysfunction should not be based on threshold testing results without consideration of patients' subjective reports of altered sensation (34).

The neurosensory assessment using SW monofilaments indicated that computer-assisted SSRO sides had better tactile thresholds for the lower lip and chin compared to CL sides through the 6 months postoperative period, with a significant difference between the two sides at 3 months postoperatively. This difference was also seen with the two-point discrimination test results, which was significant between the two sides of the lower lip at 1 week and the chin area at 6 months postoperatively. All computer-assisted SSRO sides had normal responses to the brush stroke direction test after the first postoperative month, while 33% of the CL sides' responses remained abnormal 6 months after surgery. A follow-up period of 1 year or more was suggested by several investigators to assess neurosensory disturbances after SSRO (35,36); however, other studies stated that a 6 month follow-up was adequate (37). Thygesen *et al.* (33) suggested that a 6 month follow-up was indicative of the 12 month visit, according to their results.

Subjective evaluation by our patients for their neurosensory disturbances revealed a significant difference between the two sides 1 week after surgery, which is consistent with other investigators' findings suggesting that subjective reports of perceived sensory changes after SSRO are initially overestimated but may be underestimated as the time interval increases (38,39).

The intraoperative findings related to the IAN indicated that computer-assisted SSRO was associated with less likelihood of nerve exposure and less need for nerve free dissection. This can be attributed to safer positioning of the sagittal ramus osteotomy cut lateral to the IAN pathway, leading to a predictable bone splitting, which is the surgical step thought to be associated with the occurrence of IAN neurosensory impairment (33). Furthermore, guided bone splitting can possibly be associated with lower incidence of unfavourable fractures.

Some factors can affect the accuracy of the procedure. Silvia *et al.* (40) reported that 3D printing of prototypes had a mean error of 2.67%. Accuracy errors can also be related to the characteristic co-registration of CT scans, although this technique was reported with good clinical accuracy (41,42). Xia *et al.* (32) stated that their experience with computer-based planning to obtain a physical 3D model for complex craniomaxillofacial surgery was associated with an accuracy of 1 mm. In our study, a minimal safety distance of 1 mm or more between the IAN and the virtual cutting plane was planned to compensate for possible errors in the whole procedure if the distance between the IAN and the ramus outer cortical plate was adequate, while care was taken to avoid over-thinning of the proximal segment, which can lead to unfavourable fractures. Clinical evaluation of the IAN was performed repeatedly during the surgical procedure to avoid its injury due to improper positioning of the cutting plane in relation to possible inherent accuracy errors within the technique.

In the literature, few techniques for avoiding the IAN during SSRO surgery have been introduced. Geha *et al.* (43) reported good recovery of neurosensory deficit after SSRO using piezosurgery, with 75–80% complete neurosensory recuperation as early as the second postoperative month; however, piezosurgery was estimated to be of insufficient power for cutting thick bone (such as the mandible) and requires longer operating times (44). Lindorf reported that compression screws can lead to nerve compression between the buccal and lingual cortices, and when bicortical screws are used, care should be taken to place them above the neurovascular bundle to avoid damage (18). Other investigators stressed the importance of identifying the IAN canal course within the ramus and angle of the mandible, using 3D CT scans (17,32), as there is an increased possibility of neurosensory disturbances after SSRO when patients are found to have a shorter distance from the buccal aspect of the IAN canal to the outer buccal cortical margin. Neurosensory disturbances were also more likely to occur in female patients (15), in older patients (11) and in patients with increased mandibular bone density (45). However, in our study the possible effect of these factors was neutralized by employing the split-mouth design.

Disadvantages of the use of CAD guide to perform computer-assisted SSRO include its cost; experience is also required to perform virtual planning on dedicated software. Moreover, patients should still be warned about possible neurosensory impairment affecting the distribution of the IAN following computer-assisted SSRO. On the other hand, the CAD guide was easy to use during surgery and did not affect the operating time.

Although our study has some limitations, related to the small sample size and to the inability to blind the operating surgeon, despite blinding subjects and neurosensory assessors, we believe that the use of computer-assisted SSRO may contribute to decrease the incidence of IAN injury and control its severity following surgery. However, further prospective clinical trials with a larger number of subjects are recommended to examine the effect of computer-assisted surgical planning on controlling neurosensory disturbances associated with orthognathic surgery.

Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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