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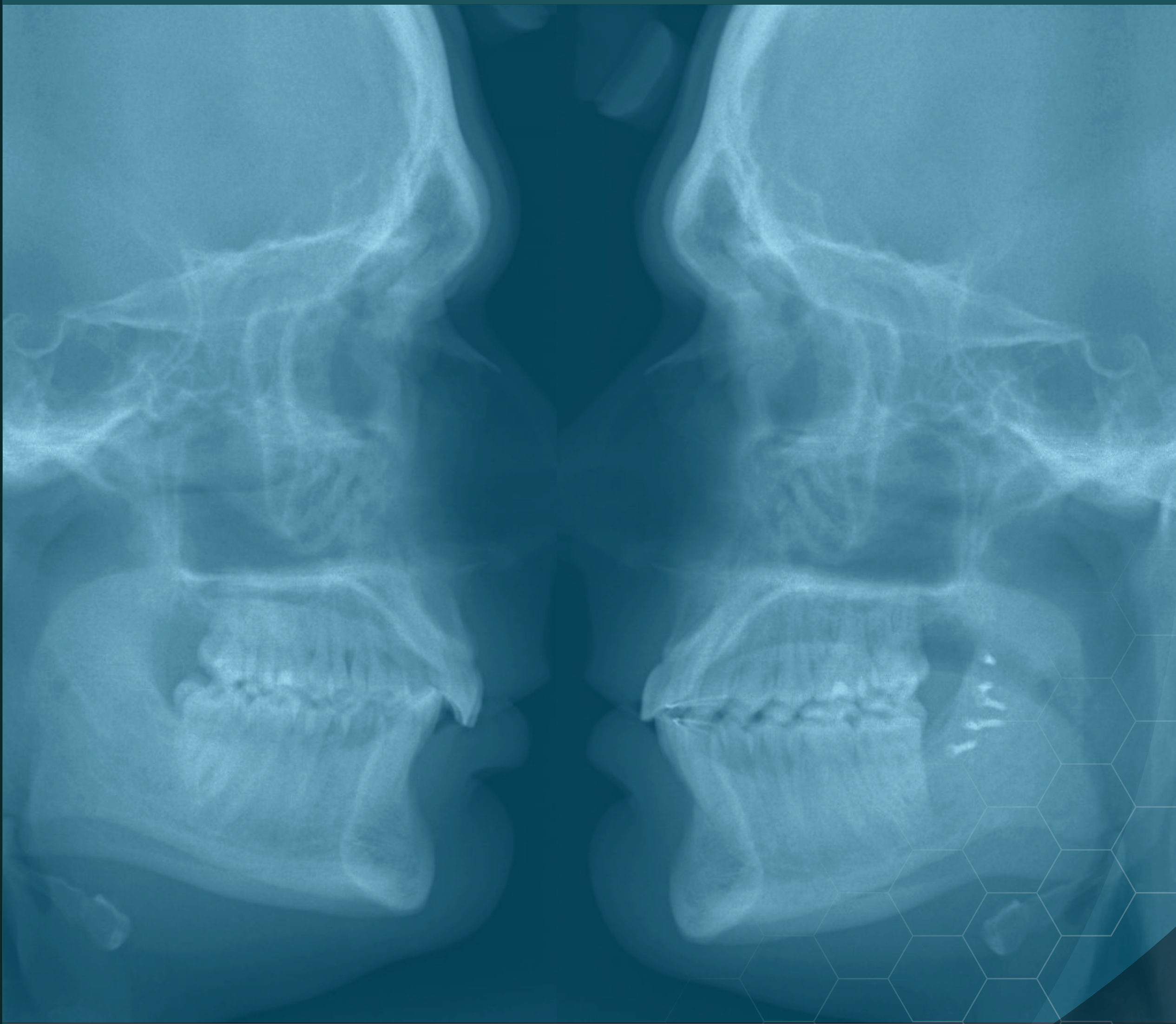
Bilateral sagittal split osteotomy by the splitter–separator technique

Technical aspects, safety, and predictability



Gertjan Mensink

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Technical aspects, safety, and predictability

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Bilateral sagittal split osteotomy by the splitter–separator technique

Technical aspects, safety, and predictability

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1

Introduction and aim of the study

Introduction

History

Orthognathic surgery is a collective term used to describe surgical procedures to correct dentofacial deformities. The term “orthognathic” originates from the Greek words *orthos*, meaning “straight,” and *gnathos*, meaning “jaw.” Orthognathic surgery can be divided into 4 categories: mandibular, maxillary, bimaxillary, and bimaxillary with additional (e.g., genioplasty) surgical procedures. Mandibular orthognathic surgery was first described in 1849 by Hullihen[1], who performed an anterior subapical osteotomy. In 1907, Blair[2] described a mandibular body osteotomy and developed the first classification of prognathism, retrognathia, and open bite. Sagittal split ramus osteotomy (oblique type) was first introduced by Schuchardt[3] in 1942. Subsequently, in 1954, Caldwell and Letterman[4] developed an intraoral vertical ramus osteotomy, which was mainly a setback procedure and did not allow anterior movement of the distal segment.

Sagittal split ramus osteotomy (SSO) was popularized by Trauner and Obwegeser[5] in 1955. Dal Pont[6], in 1961, suggested advancement of the lateral oblique osteotomy position to the molar region to increase contact of the proximal and distal segments. The medial horizontal osteotomy was shortened to just beyond the lingula by Hunsuck[7] in 1968 (Figure 1), although most current publications show this cut stopping just behind the mandibular foramen. Bell and Schendel[8] and Epker et al.[9] modified this technique in the late 1970s by extending the vertical osteotomy through the inferior border of the mandible and limiting mucoperiosteal stripping, respectively, thus reducing the risk of ischemia and necrosis and ensuring a safer procedure.

A major breakthrough in the acceptance of orthognathic surgery occurred with the publication of the classic book by Bell et al.[10]—*Surgical Correction of Dentofacial Deformities*. They recommended close cooperation between orthodontists and surgeons. With the refined surgical techniques, the procedures have predictable results and less unwanted side effects.[11]

Bilateral Sagittal Split Osteotomy

Bilateral sagittal split ramus osteotomy (BSSO) is a common mandibular orthognathic procedure. Nowadays, the Obwegeser, Dal Pont, and Hunsuck modification is probably the most used BSSO design. This procedure is indicated for many deformities including mandibular hypoplasia, hyperplasia, and asymmetry.

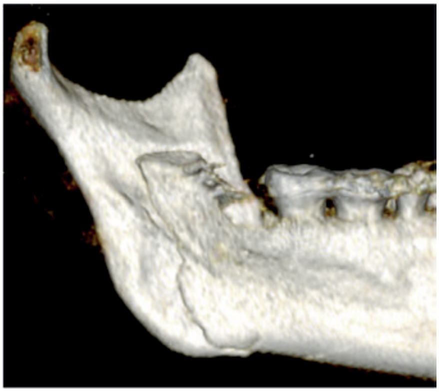

Figure 1 Postoperative cone-beam CT scan of the lingual side after SSO. The fracture line runs through the mandibular foramen and across the mylohyoid groove. Note the position of the medial horizontal osteotomy, just beyond the lingula.

Techniques

Chisel–mallet (conventional) technique

In general, the incision begins at the anterior border of the ramus and continues downward along the external oblique ridge to the vestibular area just distal to the first molar. The periosteum is reflected laterally to expose the lateral cortex of the mandible up to the inferior border. The temporalis tendon is retracted superiorly at the level of the anterior border of the mandibular ramus. Dissection proceeds medially along the ramus to above the lingula. The periosteum is carefully retracted medially to avoid injury to the inferior alveolar nerve (IAN).[12]

The surgery is started with the horizontal osteotomy through the medial cortex of the ramus, extending from a point just posterosuperior to the lingula to the anterior border of the ramus[13] and parallel to the occlusal plane. The vertical osteotomy is performed between the first and the second molars, through the external oblique ridge up to the inferior border of the mandible, perpendicular to the occlusal plane, and involving the lateral cortex but avoiding transection of the IAN. The horizontal and vertical osteotomies are connected sagittally just inside the external oblique ridge. The split is accomplished by using a series of spatulas, chisels, and spreaders along the horizontal and sagittal osteotomies and/or the inner aspect of the lateral cortex along the vertical osteotomy to the inferior border of the mandible.

However, sharp instruments could damage the IAN when used proximately. Some surgeons avoid this complication by using special instruments for separating and spreading the proximal and distal segments of the mandible instead of chisels—the sagittal splitter and separators (Figures 2 and 3).

Figure 2 Curved Smith ramus separators (Walter Lorenz Surgical, Jacksonville, FL, USA). Left side (A) and right side (B).

Figure 3 The sagittal splitter (Walter Lorenz Surgical, Jacksonville, FL, USA).

The sagittal splitter and separators were introduced at the Leiden University Medical Center in 1994. Since then, BSSO has been performed with these instruments in over 500 patients. A retrospective research of 109 patients in 2007 showed that the overall rate of neurosensory disturbance (NSD) of the IAN was 8.3%[14], suggesting that use of these instruments could minimize the most important sequelae of BSSO. This thesis focuses on the use of the sagittal splitter and separators to reduce iatrogenic damage to the IAN in BSSO.

Splitter–separator (revised) technique

In the revised BSSO technique, the sagittal splitter and separators are used instead of a chisel and mallet to spread and separate the mandibular segments. In brief, the ramus is exposed and the mandibular foramen is located. A periosteal elevator is placed just above the mandibular foramen; the horizontal osteotomy is performed with a Lindemann bur (2.3 × 22 mm) approximately 5 mm above the mandibular foramen. The vertical and sagittal osteotomies are performed with a short Lindemann bur (1.4 × 5 mm) (Figure 4).

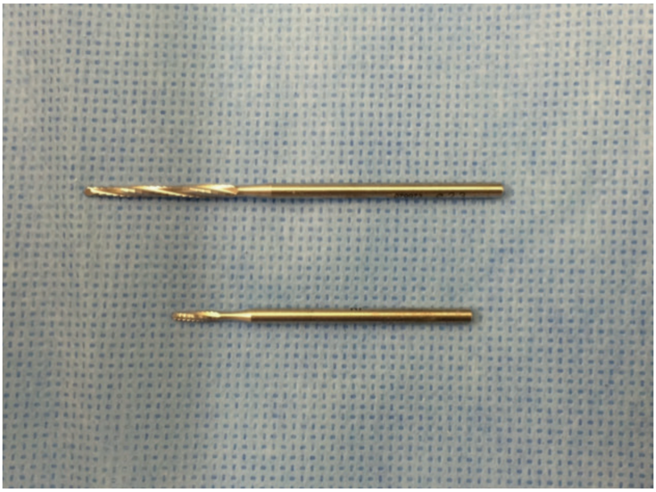

Figure 4 The Lindemann bur (2.3 × 22 mm) used for the horizontal osteotomy and the short Lindemann bur (1.4 × 5 mm) used for the vertical and sagittal osteotomies.

The inferior border of the mandible is cut perpendicularly until the bur just reaches the medial side. Splitting is performed with the separator positioned in the vertical osteotomy site and splitter in the sagittal osteotomy site. Once the superior part of the mandible begins to split, the elevator is repositioned at the inferior border in the vertical osteotomy site and splitting is completed. The IAN should be in the distal segment at this time. A chisel is used only if a small bony bridge remains between the lateral and the medial cortices at the inferior border of the mandible; this location is well below the mandibular canal. If the IAN remains in the proximal segment, it is carefully freed by using a blunt excavator alone or with a bur to remove the lateral bony part of the mandibular canal[15]; nowadays, a piezotome is also used to free the nerve. The inferior border should move with the proximal segment to avoid an unfavorable fracture. Once the split is completed, bony excess or irregularity is removed to prevent injury of the IAN. The distal segment is advanced into the predetermined position by using an acrylic splint and stabilized by intermaxillary fixation. The proximal segment is manipulated to ensure that the condyle is properly seated in the glenoid fossa and the inferior border is aligned. Finally, monocortical screws and miniplates or three bicortical screws are placed.[16] The wound is thoroughly irrigated and closed with resorbable sutures.

Intraoperative and Postoperative Complications

Common short-term sequelae of BSSO include bruising, edema, limited range of motion of the jaw, and infection. These are mostly self-limiting or relatively easy to resolve. Important long-term complications are neurosensory disturbance (NSD) of the inferior alveolar nerve (IAN), causing hypoesthesia of the lower lip, and relapse. The main intraoperative complication is unfavorable fracture, also called “bad split,” which could lead to the aforementioned long-term complications.

Neurosensory disturbance

On the medial side of the ramus, the mandibular nerve, a branch of the trigeminal nerve, enters the mandibular foramen as the IAN. Before entering the foramen, the lingual, mylohyoid, and buccal nerves separate and run along the lingual and buccal sides of the mandible. Between the premolars, the IAN leaves the mandibular canal through the mental foramen and continues as the mental nerve, which provides sensation to the lower lip and chin region. Many patients experience sensory loss on one or both sides of the lower lip immediately after BSSO. This disturbance usually resolves within a year, but up to 48% of the patients may have prolonged hypoesthesia of the lower lip.[14]

Table 1 Main differences between the conventional and the revised BSSO techniques.

Stages	*Chisel–mallet technique*	*Splitter–separator technique*
Horizontal osteotomy	The cut ends posteriorly and superiorly to the mandibular foramen; enough space is required for a small chisel to separate the cortices.	The cut ends along the midline of and about 5 mm above the mandibular foramen; no chisel is used to separate the segments.
Sagittal osteotomy	After this osteotomy has begun with a saw or bur, a chisel is used to accentuate the cut to a depth of about 10 mm[7].	A short Lindemann bur (1.4 × 5 mm) is used to perform this osteotomy on the inner aspect side of the buccal cortex.
Splitting	The mandible is spread minimally with an instrument such as a rasparatorium or a freer. Then, a chisel is used downward on the inner aspect of the buccal cortex (cortical shaving) and the inferior border is fractured with a few blows of a mallet.	Splitting is performed with the separator in the vertical osteotomy site and the splitter in the sagittal osteotomy site. Once the superior part of the mandible begins to split, the separator is repositioned at the inferior border in the vertical osteotomy site and splitting is completed.

Inferior Alveolar Nerve Anatomy

The nerve trunk is composed of 4 connective tissue sheaths: mesoneurium, epineurium, perineurium, and endoneurium. The mesoneurium suspends the nerve trunk within the soft tissue and is continuous with the epineurium. The epineurium is divided into outer and inner epineuria. The inner epineurium contains loose connective tissue that protects against mechanical stress. Fascicles are delineated by the perineurium, which is a continuation of the pia–arachnoid layer of the central nervous system. It provides structural support and acts as a diffusion barrier. Individual nerve fibers and their Schwann cells are surrounded by the endoneurium. The fascicular pattern can be monofascicular (one large fascicle), oligofascicular (2–10 fascicles), or polyfascicular (>10 fascicles). The inferior alveolar and lingual nerves are polyfascicular.

The nerve fiber is the functional unit responsible for transmitting stimuli. It is composed of an axon, a Schwann cell, and a myelin sheath in myelinated nerves. A-alpha fibers are the largest myelinated fibers with the highest conduction velocity; they mediate position and fine touch through muscle spindle afferents and skeletal muscle efferents. A-beta fibers are the second largest myelinated axons and mediate proprioception. A-delta fibers are the smallest myelinated fibers; they transmit stimuli of temperature and pain (first or fast pain). C-fibers are the smallest axons and are unmyelinated. They transmit stimuli of slow or second pain, temperature, and efferent sympathetic fibers.

Types of nerve injury

Two nerve injury classifications are generally accepted. In 1945, Seddon[17] described a three-stage classification of mechanical nerve injury: neuropraxia, axonotmesis, and neurotmesis. In 1951, Sunderland[18] revised the Seddon classification and divided nerve injury into five grades.

1. Neuropraxia

Neuropraxia is characterized by conduction block from transient anoxia due to acute epineurial and endoneurial vascular interruption. This injury is usually the result of nerve trunk manipulation, traction, or compression. Recovery is rapid and complete, without axonal degeneration. Neuropraxia corresponds to first-degree Sunderland injury, which is further divided into types I, II, and III. Type I results from mild nerve manipulation. Recovery occurs in hours when neural blood flow is restored. Type II is due to moderate traction or compression with intrafascicular edema. Return of sensation occurs in days following edema resolution. Type III results from significant nerve manipulation with segmental demyelination. Recovery occurs within days to weeks.

2. Axonotmesis

Axonotmesis is characterized by axonal injury with subsequent degeneration due to severe ischemia, intrafascicular edema, or demyelination. Traction and compression are the usual causative mechanisms. Although axons are damaged, the endoneurial sheath, perineurium, and epineurium are not disrupted. The neural response is initial anesthesia followed by paresthesia as recovery begins. Recovery occurs in 2–4 months, but improvement leading to complete recovery may take as long as 12 months. Axonotmesis corresponds with second-, third-, and fourth-degree Sunderland injuries. Second-degree injury extends through the endoneurium without significant axonal disorganization. Recovery takes weeks to months and may not be complete. Third-degree injury is due to significant neural trauma with variable degrees of intra-fascicular architectural disruption and damage extending to the perineurium.[19] Return of sensation occurs in months but could be incomplete. Fourth-degree injury extends through the perineurium to the epineurium, but the epineurium remains intact. Axonal, endoneurial, and perineural damage occurs with disorganization of the fascicles. Full recovery is unlikely. Minimal improvement may occur in 6–12 months.

3. Neurotmesis

Neurotmesis, which corresponds to fifth-degree Sunderland injury, is characterized by severe disruption and epineurial discontinuity. The etiology is nearly complete or complete transection of the nerve. The immediate neural response is anesthesia. This may be followed by paresthesia or neuropathic responses such as allodynia, hyperpathia, hyperalgesia, or chronic pain. Neuroma formation is common. The prognosis for return of sensation is poor. Sensory and functional recovery is never complete.

NSD after BSSO is most likely a combination of neuropraxia and axonotmesis, as transection of the nerve is rare.[20-22]

Risk factors of NSD during BSSO

BSSO can be divided into 4 stages: (1) removal of soft tissue to visualize the mandible, (2) osteotomy and splitting of the mandible, (3) repositioning and (4) fixation of the mandible in the new position.

1. Mechanical damage to the IAN can be caused by stretching or compression near the mandibular foramen during medial mucoperiosteal retraction.[23] A few intraoperative studies have shown decreased nerve function during medial dissection to identify the lingula or mandibular foramen. In these cases, however, total recovery was achieved either during surgery or within a short period thereafter.[24,25]
2. The IAN can be lacerated when chisels are used within the medullary bone to achieve splitting in the sagittal osteotomy. One study indicated that a decrease in intraoperative nerve function may result from additional damage to the IAN by sharp instruments such as chisels.[24] In addition, the vertical osteotomy is associated with a higher rate of postoperative NSD when the IAN is located more buccally.[26] Further, entrapment of the IAN within the proximal segment during splitting requires manipulation and possible bone removal to free the nerve, causing further mechanical damage.
3. The IAN can be stretched as the distal segment is mobilized and repositioned, resulting in neuropraxia. Direct damage to the IAN can result from the sharp bony fragments on the medial side of the proximal segment.
4. Direct injury due to drilling and placement of osteosynthesis screws. The nerve may be compressed between the proximal and the distal segments in case of use of lag screws.

Given the elective nature of BSSO, these complications should be minimized to ensure patient satisfaction. Therefore, the mucoperiosteum should be elevated only to the end of the horizontal osteotomy site rather than to the posterior border of the mandible.[8] The elevator should be used carefully to create just enough space for the bur and not pushed to the medial side to avoid bending or stretching of the nerve (stage 1). While repositioning the distal segment in the planned position, stretching of the nerve could occur, but meticulous removal of bony projections in the proximal segment is important to avoid additional trauma to the IAN. Further, precise positioning of the osteosynthetic material and avoiding lag screws are important (stage 3). Finally, spreading and prying are likely to reduce the risk of IAN injury when compared with chiseling.[14,27-29] The splitter–separator technique for BSSO avoids the use of sharp instruments along the IAN and is believed to reduce the possibility of nerve damage.

Relapse

Relapse after BSSO is the result of many factors: condylar slippage due to incorrect positioning in the glenoid fossa[30,31], condylar resorption[32,33], intersegmental relapse at an osteotomy site[34], and subsequent mandibular growth.[30]

Bad split

The reported rate of bad splits during SSO ranges from 0.7% to 20%.[35,36] Such splits can be divided into proximal (buccal plate) or distal (lingual plate) segment fractures. These can lead to difficulties in fixation, sequestration, infection, delayed union or malunion of an osteotomy site, and malocclusion. Risk factors include difficult anatomy, incomplete osteotomy, poor osteotomy design, and presence of mandibular third molars.

Aims

The goal of this thesis is to prove the safety and predictability of BSSO by the splitter–separator technique in an extensive study of its possible major sequelae.

The revised BSSO technique will be assessed by the following means:

1. Reviewing both BSSO techniques and their incidences of postoperative NSD of the IAN (chapter 2)
2. Analyzing fracture patterns in cadaveric mandibles (chapters 5 and 6)
3. Measuring postoperative hypoesthesia of the IAN in a prospective study (chapter 3)
4. Examining stability during adolescence (chapter 4)
5. Examining bad splits in a retrospective study (chapter 7)
6. Reviewing specific applications (chapters 8 and 9).

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2

Influence of BSSO surgical technique on postoperative inferior alveolar nerve hypoesthesia: a systematic review of the literature

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Abstract

Objective: The aim of this study was to evaluate the influence of different splitting techniques, namely, “mallet and chisel” versus “spreading and prying”, used during bilateral sagittal split osteotomy (BSSO) on postoperative hypoesthesia outcomes.

Study design: We systematically searched the PubMed and Cochrane databases (from January 1957 to November 2012) for studies that examined postoperative neurosensory disturbance (NSD) of the inferior alveolar nerve (IAN) after BSSO.

Results: Our initial PubMed search identified 673 studies, of which, 14 met our inclusion criteria. From these 14 studies, 3 groups were defined: (1) no chisel use (4.1% NSD/site), (2) undefined chisel use (18.4% NSD/site), and (3) explicit chisel use along the buccal cortex (37.3% NSD/site).

Conclusion: Study heterogeneity and a frequent lack of surgical detail impeded our ability to make precise comparisons between studies. However, the group of studies explicitly describing chisel use along the buccal cortex, showed the highest incidence of NSD. Moreover, comparison of the study that did not use chisels with the 2 studies that explicitly described chisel use, revealed a possible disadvantage of the “mallet and chisel” group (4.1% versus 37.3% NSD/site). These results suggest that chisel use increases NSD risk after BSSO.

Introduction

Bilateral sagittal split osteotomy (BSSO) is a successful and common treatment for mandibular hypo- and hyperplasia. The intraoral osteotomy was first described by Schuchart[1], later by Mathis[2] , and became a regular procedure after modifications developed by Trauner and Obwegeser were introduced in 1957.[3] The BSSO technique was further modified by Dal Pont in 1959[4,5], Hunsuck[6] in 1968, and Epker[7] in 1977. Despite being routinely performed, BSSO is known to give rise to various complications. The most commonly observed complications include inferior alveolar nerve (IAN) impairment and unfavorable splitting of the mandible, also known as a bad split. IAN impairment leading to permanent anesthesia of the lower lip is probably the most frequently observed complication of BSSO having the most serious impact on the patient's daily life.[8]

Multiple studies have reported persistent hypoesthesia of the IAN after BSSO, with incidences ranging from 0% to 82% with the use of various tests.[9] Neurosensory disturbance (NSD) of the IAN is a considerable morbidity for patients, especially given the elective nature of this surgery. IAN disturbance is caused by iatrogenic damage, especially from incorrect splitting techniques or osteotomies. Nerve damage may also result from excessive nerve manipulation (after soft tissue dissection at the medial aspect of the mandibular ramus), nerve laceration, incorrect placement of position or lag screws during segment fixation, large mandibular advancement, impingement by bony spiculae, or bad splits.[10-14] Iatrogenic damage of the nerve may also be a secondary consequence of surgery-induced hypoxia and edema, which frequently results in a combination of neurapraxia and partial axonotmesis.[10,15] Thus, surgical techniques should be discussed and critically evaluated to minimize potential complications of BSSO.

The type of BSSO splitting technique used may also be a factor affecting the incidence of postoperative hypoesthesia; however, such a correlation has yet to be shown. Even early on, surgeons worried about the potential for chisels to cause IAN injury during BSSO. Therefore, these surgeons used a thin cement spatula instead of a chisel, which seemed to reduce the incidence of postoperative.[16-18] More recently, a number of studies have described the use of chisels to split the mandible; specifically, the chisel is driven along the inner surface of the buccal cortex (Figures 2a and b). These studies, in which chisels were employed, report rather high incidences of postoperative NSD, ranging from 31% to 60% per patient[19-21] and 17% per side.[22] In contrast, other studies emphasize that techniques involving prying and spreading are safer for splitting the mandible compared with "mallet and chisel" methods.[23-26]

The aim of this systematic review was to assess the influence of the type of BSSO splitting technique utilized, namely, "mallet and chisel" or "spreading and prying," on postoperative hypoesthesia outcomes.

Materials and methods

A search of PubMed (including the Cochrane database) was performed, limited to the time interval from January 1957 to November 2012, using the following search strategy: ((“orthognathic surgical procedures”[Mesh] OR “orthognathic surgical procedures”[tiab]) OR (“bsso” OR “bilateral sagittal split osteotomy” OR “mandibular osteotomy” OR “mandibular advancement” OR “mandibular setback”)) AND nerve* with an English language restriction. A second search was performed using the following strategy: ((bsso) OR (bilateral sagittal split osteotomy) OR (mandibular osteotomy) OR (bssro) OR (mandibular advancement) OR (mandibular setback) OR (orthognathic surgery)) AND ((nerve injury) OR (nerve damage) OR (inferior alveolar nerve) OR (trigeminal nerve)) AND (English [lang]). To expand our search, we also evaluated studies identified through the “related citations” option in PubMed and through manual searches of the references of selected studies.

Studies were selected for inclusion based on the criteria listed in Table 1. When the title and abstract either fulfilled the inclusion criteria or did not provide sufficient information to determine whether the study was eligible for inclusion, the full-text article was retrieved. Subsequently, the Materials and Methods and Results sections were read and scored. The main outcome extracted was the frequency of NSD of the IAN in BSSO patients as assessed through both clinical and subjective methods after 1 year. Additionally, studies were categorized according to the BSSO splitting technique employed.

Results

Study inclusion

From the initial PubMed search, 77 studies were found to be eligible for evaluation in their full-text form (Figure 1). The different parameters required in order for a study to be included in our analysis are shown in Table 1. After strict application of these inclusion criteria, 14 studies were selected for analysis in our systematic review. Most reports identified in our PubMed searches were excluded due to either insufficient description of the exact splitting technique utilized (n= 22) or to an insufficient number of patients included in the study (n = 28). Additional reasons for exclusion included a follow-up period of less than 1 year (n = 5), failure to properly report the incidence of NSD (n = 6), absence of rigid fixation (n = 5), measurement of NSD by electrophysiologic tests (n = 2), and use of nonhuman subjects (n = 1). One study was excluded as it evaluated the same patient population as another report, and several articles did not meet multiple inclusion criteria.

Table 1 Inclusion criteria.

Postoperative outcome of hypoesthesia tested by subjective methods and clinical tests (e.g., mechanoceptive and nociceptive tests)
Rigid fixation (e.g., plates or screws, no IMF)
Only retrospective or prospective (case-control, cohort, or randomized) studies
Human subjects
Description of surgical technique used during BSSO
Follow-up period of at least 1 year
Inclusion of at least 50 patients

Abbreviations: BSSO, bilateral sagittal split osteotomy; IMF, intermaxillary fixation.

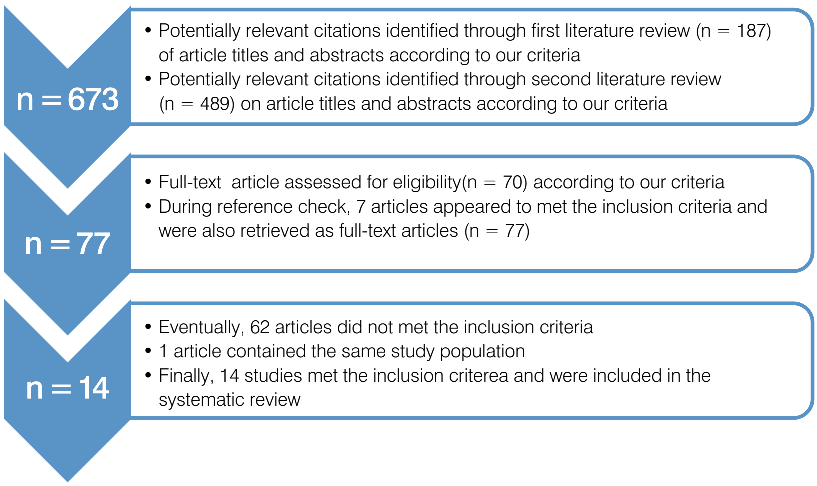

Figure 1 Flow chart summarizing the literature search for the systematic review.

Findings

Of the 14 studies included, only 2 explicitly described using the "mallet and chisel" method along the inside of the buccal cortex (Figures 2a and b). The incidences of postoperative NSD in these studies were 40% per side[27,28] and 30.1% per patient.[29]

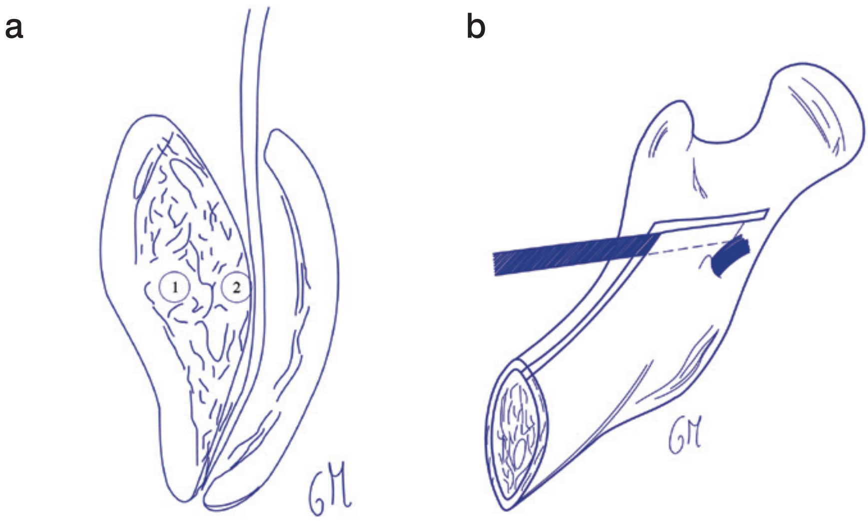

Figure 2a Coronal section of the mandible.

Chisels used to split the mandible along the inner buccal cortex. (1) Normally, the inferior alveolar nerve is positioned more lingually. (2) However, sometimes it is located more buccally. In the latter position, there is a greater risk of nerve damage. Also, compressing the spongious bone lingually while inserting the chisels may lead to damage of the nerve.

Figure 2b Medial view of the mandible.

The superior part of the entrance of the mandibular foramen with the lingula is shown. A curved chisel is used to force a Hunsuck fracture behind the mandibular foramen, which may result in damage due to the presence of a sharp instrument along the inferior alveolar nerve (IAN). There also may be traction on the IAN, and possibly on its vascular supply, at the entrance of the mandibular foramen, which may result in a temporary ischemic event.

Only 1 study explicitly stated that chisels were not used to split the mandible; instead, prying and spreading was accomplished using separators and splitters, with an NSD incidence of 8.9% per patient.[25]

Most studies described the splitting technique used by referring to a technique characterized in an earlier publication, or by reporting additional personal modifications at the same time. Of the earlier techniques described, only Epker reported not driving chisels into the mandible for more than 10 mm.[7] The other studies describe modifications in which chisels are used along the nerve to the inferior border.[3,5-7,17,30,31] In Table 2, the mean NSD incidences of these modifications are shown to range from 12.8% to 32%, which are higher than that in the study explicitly not using chisels.

Table 2 Description of BSSO modification with incidence of postoperative NSD.

Modification*	No. of studies	NSD incidence per side, %	Mean NSD incidence per side, %	Studies
Obwegeser	1	32	32	Nesari et al.[47]
Dal Pont	2	0-30.7	21.3	Fujioka et al.[48]; Jokić et al.[35];
Epker	5	1.6**-50	19.5	Scheerlinck et al.[49]; Bothur and Blomqvist[50]; Al-Bishri et al.[14]; D'Agostino et al.[51]; Hanzelka et al.[52]
Hunsuck	1	12.8	12.8	Borstlap et al.[10]

* When a study referred to multiple modifications, it was categorized by the modification published last (eg, an Obwegeser-Dal Pont modification was categorized as a Dal Pont modification).
** Hanzelka et al.[52] reported an NSD incidence of 3.1% per patient (9/290 patients); however, based on the figure shown in their study, this should be 9/580 patients, or 1.6% per side.
Abbreviations: BSSO, bilateral sagittal split osteotomy; NSD, neurosensory disturbance.

Note: Becelli et al.[53] and Raveh et al.[54] mentioned the use of chisels in their studies, but the techniques used could not be classified as one of the "classic" modifications; these studies had an NSD incidence of 13% and 6.7%, respectively. Studies with explicit or absent chisel use are not in this table (n = 3; Westermark et al.[27,28]; van Merkesteyn et al.[25]; Bruckmoser et al.[29]).

In order to show the potential influence of chisel use on NSD outcomes, the studies were divided into 3 groups depending on whether or not chisels were used and the type of technique used: (1) no chisel use during BSSO (4.1% NSD per site), (2) undefined use of chisels (18.4% NSD per site), and (3) explicit use of chisels along the buccal cortex (37.3% NSD per site). The mean NSD incidences according to BSSO technique are provided in Table 3 and Figure 3.

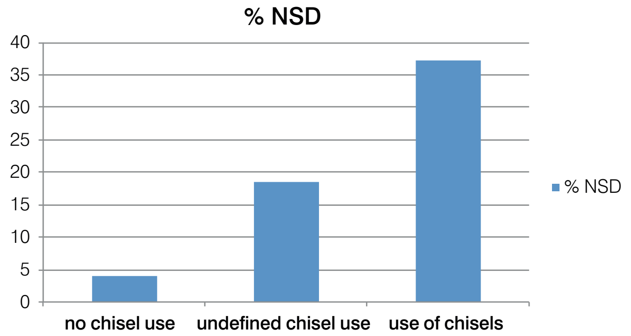

Figure 3 Incidence of postoperative neurosensory disturbance according to method of splitting the mandible.

Table 3 Incidence of postoperative NSD according to method of mandible splitting.

Method	No. of studies	Referral to a modification, if mentioned	NSD incidence per side, mean (range), %	Studies
No chisel use	1		4.1	Merkesteyn et al.[25] (9/218, 4.1%)
Undefined chisel use	11	Epker Obwegeser Dal Pont Hunsuck Bell and Schendel	18.4 (1.6*-50)	Raveh et al.[54] (27/206, 13%); Scheerlinck et al.[49] (36/206, 17.3%); Fujioka et al.[48] (70/228, 30.7%); Becelli et al.[53](6/120, 5%); Bothur and Blomqvist[50] (80/160, 50%); Borstlap et al.[10] (right NSD, 22/199; left NSD, 29/198; 12.8%); Al-Bishri et al.[14],(68/150, 37%); Nesari et al.[47] (43/136, 32%); D'Agostino et al.[51](48/100, 48%); Hanzelka et al.[52] (9/580, 1.6%); Jokić et al.[35] (0/100, 0%)
Explicit chisel use along the buccal cortex	2		37.3 (30.1-40)	Westermark et al.[27,28] (219/548, 40%); Bruckmoser et al.[29] (62/206, 30.1%)

Abbreviation: NSD, neurosensory disturbance.

* Hanzelka et al.[52] reported an NSD incidence of 3.1% per patient (9/290 patients); however, based on the figure shown in their study, this should be 9/580 patients, or 1.6% per side.

Discussion

NSD of the IAN is a major complication of orthognathic surgery that lowers the satisfaction level of patients,[32] especially because of the elective character of the surgery.[32] The purpose of using chisels is to force a fracture line along the mandible in order to create a correct sagittal split, thereby preventing a bad split; however, chisel use is associated with substantial risk of significant complications. Previous studies have shown that splitting the mandible by spreading and prying techniques, using instruments made for this purpose (e.g., splitters and separators), results in good clinical outcomes, with a “low to normal” bad split incidence (1.8% per patient) and low postoperative NSD incidence (8.3% per patient).[25,33]

Our objective in this systematic review was to reveal the importance of the actual splitting technique used on postoperative hypoesthesia. However, most of the full-text articles identified in our PubMed searches that were eligible for further research were eventually excluded because of their failure to describe the splitting technique used in sufficient detail. Many studies only characterized the BSSO splitting method used by referencing a technique described in previous studies, e.g., BSSO with Hunsuck modification. Only a few studies carefully described the actual splitting process employed, including which instruments were used. As stated in other studies, these details are likely to be important for determining the risk factors for NSD caused by BSSO.[34]

Only 14 studies met our inclusion criteria. When the selected articles were divided into 3 groups (no chisel use, undefined chisel use, and explicit chisel use), a tendency to a higher incidence of NSD in the chisel group was observed (Table 3 and Figure 3), showing a 4.1%, 18.4%, and 37.3% NSD incidence after BSSO, respectively. In addition, the modifications with the use of chisels, based on their original description in the literature, mentioned in Table 2 show rather high mean incidences (12.8%-32%) after BSSO.

One unexpected result, is a study that had a postoperative NSD incidence of 0% using a Dal Pont method not otherwise specified.[35] This NSD incidence is very low, and, as also stated by the authors, this result must be interpreted with caution because of several factors. First, all patients had hypoesthesia postoperatively, which is not in-line with the literature. Second, the 2 oldest patients showed recovery of sensation that was faster than average in this group of patients, which is also not in-line with the literature. Third, in all patients, hypoesthesia eventually resolved, which, thus far, has not been. Fourth, the study contained relatively young patients, only mandibular setbacks, and only 2 experienced surgeons.

The causes of IAN damage during surgery are likely multifactorial. In our opinion, the intraoperative technique is likely to play an important role, especially when chisels are used along the IAN—a contention supported by other authors during intraoperative measuring.[36] Medial dissection has also been described as a factor causing impairment of the IAN. A few intraoperative studies have reported a decrease in nerve function during medial dissection identifying the lingula/mandibular foramen. In these cases, however, total recovery was achieved either during surgery or within a short period following surgery. In addition, one study indicated that a decrease in intraoperative nerve function may result from additional damage to the IAN by sharp instruments, such as chisels.[37] Panula et al. [12] demonstrated the importance of minimal distraction of the soft tissue in the ramus during medial dissection, though this was not the sole cause of all IAN disturbances.

Other authors have described the potential influence of the splitting technique on postoperative NSD. Nakagawa et al.[34] stated that the mandibular split should be restricted to within the upper border of the cortical surface in order to avoid neural injury, and advised that this aspect of surgical assessment should be investigated further. This idea is in-line with our hypothesis that the technique used to split the distal and proximal mandibular segments is likely to be an important factor in postoperative NSD outcomes. We suggest that spreading and prying the mandible poses less risk for NSD of the IAN than does the classic "mallet and chisel" method, in which the chisel is forced along the medial site of the buccal cortex to separate the cortical and spongious bones lateral to the IAN and to fracture the inferior border of the mandible (Figures 2a and b). Nakagawa et al.[34] also found, by intraoperative measuring with trigeminal somatosensory-evoked potential (TSEP) spectra, that the onset of sensory deficit occurred after medial periosteal dissection and that the change in the shape of the spectra suggested that dissection was not the only inducer of postoperative NSD. Thus, subsequent surgical processes or changes in anatomic positions contribute to the change in the TSEP spectra. Furthermore, Jääskeläinen[37] stated in 2004 that the saw and chisels used during splitting of the mandible may lacerate the IAN. They demonstrated that the total disappearance of sensory action potential of the IAN that occurred during splitting of the mandible with sharp instruments was compatible with an axonal lesion of the IAN. This is especially important when the nerve is positioned more buccally, as described by Wittwer et al.[38], who mentioned an anatomically neurosensory-compromising proximity of the mandibular canal when it is in contact with or less than 1 mm from the external cortex. This results in more postoperative NSD, as shown by Yoshioka et al.[39], especially when you use chisels along the medial site of the buccal cortex to the inferior border (Figure 2a).

Forcing a lingual Hunsuck split also could harm the IAN. In this chisel technique, a curved chisel enters through a bur cut just above the mandibular foramen, and is driven along the mandibular foramen in order to start a lingual fracture behind the foramen (Figure 2b), which could potentially damage the IAN. However, this detail of the chisel technique was not included in the selected papers, so no conclusions are possible.

Other causes of IAN damage during surgery could be the length of mandibular advancement and the type of fixation. Like other studies, Bruckmoser et al.[29] showed no significant difference in postoperative hypoesthesia after BSSO between the use of position screws and plates. Therefore, the type of fixation is not considered to be an influencing factor, regardless of the splitting technique employed. This is probably because there is no major difference in the anatomy of the fixation place. Larger advancements are thought to cause more postoperative hypoesthesia, as shown previously.[40] However, because information regarding the exact replacement during surgery was unavailable for some of the studies in this review, this could not be linked to postoperative hypoesthesia. Furthermore, we assume that the amount of replacements is equally distributed and therefore will attribute in the same amount of nerve damage within the different splitting techniques and will not be influenced by the type of splitting technique (i.e., fracture pattern).

The inclusion criteria applied in the present study were chosen carefully. The measurement of postoperative hypoesthesia can be performed by purely objective sensory tests (e.g., TSEP, blink reflex, and orthodromic sensory nerve action potentials), by relatively objective clinical tests, such as mechanoceptive tests (e.g., static light touch, 2-point discrimination, and brush stroke direction) and nociceptive tests (eg, thermal discrimination or pin tactile discrimination), or by subjective tests (eg, visual analog scale and scoring lists). Purely objective tests clearly show a lower frequency of NSD compared with conventional clinical testing modalities and often approximate 0%, whereas subjective tests almost never reach such a low incidence.[37,41,42] Due to this contrast, we excluded the 2 studies that used only the TSEP measuring method. However, the significance of subjective testing versus objective clinical testing is ambiguous; in part, we believe that patients tend to adapt to neural deficit and report normal sensation, whereas clinical tests still show NSD, which also has been noted in previous studies.[9,10,43] Therefore, relatively objective clinical tests combined with subjective tests seem to be the most reliable way of testing NSD.

Although some authors consider the recovery of sensation after an IAN lesion to be stabilized 18 months after iatrogenic trauma, the general consensus is that a 12-month follow-up period is sufficient for nerve regeneration to occur and to enable informative neurologic data monitoring.[9,35,43,44] Most NSD essentially disappears within 1 year.[43] Therefore, we included all studies with a follow-up of at least 1 year. On the basis of similar studies, it was decided that a sample should consist of at least 50 patients.[35] Without a sufficiently large sample size, the absence of a single persistent IAN disturbance could significantly influence statistical inferences. After careful selection, we included all retrospective (n = 6) and prospective (n = 8) studies, even though prospective studies are generally superior to retrospective studies. The included papers were heterogeneous in many of their parameters, so that, although postoperative NSD incidences could be compared, possible confounding variables were present and should be discussed. For example, it is known that both the age of the patient at the time of surgery and the addition of a genioplasty increase the risk of NSD.[40,45] Some authors excluded cases that included genioplasty because of this influence. The experience of the surgeon is also a likely factor affecting the incidence of postoperative NSD, as more experienced surgeons have been reported to cause less damage to the IAN than do less experienced surgeons. However, diligent observation of a less experienced surgeon by one with more experience would likely avoid this problem. Paulus and Steinhauser[46] reported a higher risk of NSD of the IAN associated with rigid fixation. Presently, rigid fixation of the proximal and distal segments is the standard of care. Therefore, we excluded patients with intermaxillary fixation.

One study that is particularly interesting for our hypothesis is that of Westermark et al.[27,28] They commented on 2 types of mandible splitting techniques. In both types, they used chisels along the nerve to split the inferior border. However, in one technique, they specifically used the "cortical shaving" method, and in the other, they used a spreading and prying method to split the segment apart, and eventually used osteotomes to complete the inferior border cut. In their conclusion, they stated that "the 2 split techniques were followed by equal distributions of sensitivity scores (40% NSD per side)," but they did not elaborate further on this point. Having rather high incidences of NSD in both groups, but equally divided, unfortunately precluded our drawing any conclusions from their study.

Conclusion

It is difficult to draw solid conclusions from this systematic review for various reasons. Significant differences in the methods of information collection, heterogeneity across various parameters between studies, and the absence of explicit descriptions of the splitting techniques used made it difficult for exact comparison. However, we did find that studies in which chisels were explicitly used along the inner side of the buccal cortex showed relatively high incidences of NSD. Furthermore, the modifications reported by Epker, Hunsuck, Dal Pont, and Obwegeser (Table 2) with possible use of chisels during BSSO showed higher incidences of postoperative NSD (12.8%–32%). Furthermore, the difference between the 1 study that did not use chisels and the 2 studies that explicitly used chisels in terms of NSD incidence was large (4.1% versus 37.3% per side, respectively). This clearly indicates the disadvantage of the "mallet and chisel" group. Therefore, chiseling your way through the mandible may be considered an increased risk factor for postoperative hypoesthesia, while spreading and prying methods are likely to be safer with regard to the occurrence of bad splits and IAN damage.[23-25,45] Therefore, we strongly recommend spreading and prying the mandible with splitters and separators, or even perhaps with a chisel, over the classic "mallet and chisel" technique.

Future studies on the sequelae of BSSO with the inclusion of more patients should, in our view, precisely describe the splitting technique used. Furthermore, the results of postoperative NSD incidence should be given per side for better comparison between different studies, as suggested by Poort et al.[9] A randomized study to compare the influence of chisels during the splitting of the mandible should be performed to further analyze the advantages of the different techniques.

Supplementary Table Overview with different parameters of all 14 studies included in this systematic review.

Author	Publication year	Number of patients	Number of sides	Retrospective/ prospective research	Obw#	Hun	Dal Pont	Epker	Referral to other technique(8)	Chisel use mentioned in manuscript	"Classic" Mallet & chisel along inside buccal cortex
Bruckmoser et al.	2012	103	206	retro	N	N	N	N	According to Watzke	Y	Y
Jokic et al.	2012	50	100	pros	N	N	Y	N	N	NK	NK
Hanzelka et al.	2011	290	580	pros	N	Y	N	Y	N	Y	NK
D'Agostino et al.	2010	50	100	retro	N	Y	N	Y	N	Y	NK
van Merkesteyn et al.	2007	109	218	retro	N	Y	N	N	N	N	N
Nesari et al.	2005	68	136	retro	Y	N	N	N	N	NK	NK
Al-Bishri et al.	2005	93	185	retro	N	N	N	Y	N	NK	NK
Borstlap et al.	2004	199	397	prosp	Y	Y	Y	N	N	NK	NK
Bothur and Blomqvist	2002	80	160	retro	N	N	N	Y	According to Bell & Schendel	NK	NK
Becelli et al.	2002	60	120	prosp	N	N	N	N	N	Y	probably
Westermark et al. 1998a; Westermark et al.	1998		548	prosp	N	N	N	N	According to Bell	Y	Y(5)
Fujioka et al.	1998	114	228	prosp	Y	N	Y	N	According to Dautrey	NK	NK

2

Prying & spreading the mandible	% genioplasty	Fixation method	Mean age in years	Resident performing surgery	subj/obj	Objective measurements	% NSD after 1-y follow-up
Y	43.8%	pos screws/ plates	26.4	N	subj	NA	30.1% per side(1)
NK	0%	pos screws	22.1	N	obj	SW	0%
NK	0%	plates	27	N	subj	NA	3.1% per pat/ 1.6% per side
NK	NK	plates	27	NK	obj	LTS/PPS/S2/ M2D	48% per side
Splitters and separators	25.7%	pos screws	26.9	Y	obj+subj	LTS/PPS	8.3%per pat/ 4.1% per side
NK	0%	wires/ lag screws/ plates	28	Y	obj+subj	LTS/PPS	32% per side(2)
NK	29.2%	pos screws	35	Y	subj	NA	37% per side
NK	0%	plates	25.2	Y	subj+obj	NK	21% per pat (3)/ 12.8% per side
NK	13.8%	plates/ pos screws	27	NK	subj	NA	50% per side (4)
NK	8.3%	pos screws	25.8	NK	obj	S2D/TD/PSS	6.7% per pat/ 5% per side
NK	0%	according to Bell	25.5	Y	subj+obj	PPD/LTS	40% (per side)(5)
NK	NK	lag screws (LS)/ plates(P)	20.4	N	obj+subj	SW	Obj: 29% LS/9% P Subj: 48% LS/10% P mean 19.7% per side(7)

Supplementary Table Continued.

Author	Publication year	Number of patients	Number of sides	Retrospective/ prospective research	Obw#	Hun	Dal Pont	Epker	Referral to other technique(8)	Chisel use mentioned in manuscript	"Classic" Mallet & chisel along inside buccal cortex
Scheerlinck et al.	1994	103	206	prosp	N	N	N	Y	N	NK	NK
Raveh et al.	1988	103	206	prosp	N	N	N	N	N	Y	probably

When a study mentioned a Epker/Hunsuck modification, only these methods (Epker and Hunsuck) were marked as Y (yes). When only a standardized Dalpont method was mentioned, this was marked as Y (yes); the other parameters were marked as N (not) K (known).

Abbreviations in table: Obw: Obwegeser; Hun: Hunsuck; NSD: neurosensory disturbance; NA: not applicable Y/N: Yes/No; NK: not known; SW: Semmes Weinstein monofilament; LTS: light-touch sensation; PPS: pinprick sensation; S2D: static 2-point discrimination; M2D: moving 2-point discrimination; TSEP: trigeminal somatosensory evoked potential; TD: thermal discrimination; pos screws: positioning screws; obj: Objective measurement; subj: Subjective measurement

(1) All patients were classified on the basis of 4 regions (lip left/right; chin left/right). Subjectively 69.9% and objectively 71.8% (lowest incidence number in this study) of the patients experienced no NSD after 1 year in all regions. However 2 patients were excluded from the dataset because of transectioned IAN during the BSSO; thus the incidence of NSD should be higher.

(2) The incidence of NSD was measured at 2, 6, 18, and 30 months. To have at least 1-year follow–up, the 18-month incidence is mentioned.

2

Prying & spreading the mandible	% genioplasty	Fixation method	Mean age in years	Resident performing surgery	subj/obj	Objective measurements	% NSD after 1-y follow-up
NK	0%	plates	25.2	NK	subj+obj	PPS/TD/S2D	17.3% (per side)
NK	NK	lag screws	NK(6)	NK	obj	S2D/PPD/LTS	13% (per side) (6)

(3) The incidence of NSD was measured at 3, 6, and 24 months. To compare with the regular 1-year follow-up, the 24 months incidence is mentioned. Total amount of patients at the 24-month follow-up period.
(4) The subjective evaluation was performed between 6 months and 4 years postoperatively. No exact distinction could be made.
(5) Same study group. Only measured in sides, not in amount of patients, with a follow-up of 2 years. Two types of splitting were used: traditional split (not further specified) and cortical shaving (thin chisels along the inner surface of the lateral cortex).
(6) Follow-up 1-4 years, not otherwise specified. Age parameters not mentioned.
(7) Subjective and objective methods were compared; a combination as in other studies would be most reliable. Because some patients did not report subjective numbness, but did test positive on objective tests, NSD incidence would be higher than both results. Therefore, the highest (subjective) NSD incidence was taken.
(8) Reference in a study to another technique besides an Obwegeser/Dal Pont /Epker/Hunsuck modification was mentioned (according to Watzke). We then analysed these publications/book chapters on exact technique description.

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3

Neurosensory disturbances one year after bilateral sagittal split osteotomy of the mandibula performed with separators: A multicentre prospective study

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Abstract

Bilateral sagittal split osteotomy (BSSO) is an effective and commonly used treatment to correct mandibular hypo- and hyperplasia. Hypoesthesia of the inferior alveolar nerve (IAN) is a common complication of this surgical procedure. This prospective multi-center study aimed to determine the incidence of neurosensory disturbances of the IAN after BSSO procedures performed without the use of chisels. Our study group comprised 172 patients, with a follow-up period of 1 year, who underwent BSSO (with or without Le Fort I) that incorporated the use of sagittal split separators and splitters but no chisels. The percentage of BSSO split procedures that resulted in IAN damage was 5.1%. The percentage of patients (without genioplasty) who experienced IAN damage was 8.9%. The concomitant genioplasty in combination with BSSO was significantly associated with hypoesthesia. Peri-operative removal of the wisdom tooth or a Le Fort I procedure did not influence post-operative hypoesthesia. We believe that the use of splitting forceps and elevators without chisels leads to a lower incidence of persistent postoperative hypoesthesia after 1 year, after BSSO of the mandible, without increasing the risk of a bad split.

Introduction

Bilateral sagittal split osteotomy (BSSO), introduced by Trauner and Obwegeser in 1957,[1] is a successful and common treatment for mandibular hypo- and hyperplasia. Nevertheless, this treatment is known to give rise to various complications; hypoesthesia of the inferior alveolar nerve (IAN) is probably the most common of these.

IAN disturbances are caused by iatrogenic damage to the nerve, including excessive nerve manipulation, nerve laceration (for example, after soft tissue dissection at the medial ramus), fixation of segments by incorrect placement of position screws, large mandibular advancement, bad splits, and incorrect splitting techniques.[2-4]

Multiple studies report postoperative persistent hypoesthesia of the IAN, with the incidence ranging from 8% to 85%. Neurosensory disturbances of the IAN are highly associated with the morbidity rates of patients undergoing BSSO.[3-7] Surgical techniques aimed at minimizing these complications should thus be discussed and developed.

Based on our experience, we believe that the use of separators and splitters, without chisels, to split the mandible is less traumatic to the IAN. Our experience is supported by a retrospective study showing that 8% of the patients investigated experienced unilateral hypoesthesia; in this study[6], BSSO was also performed without chisels, and with splitters and separators. We hypothesize that BSSO performed with splitters and separators will have a lower incidence of IAN hypoesthesia compared to other splitting techniques. The aim of this prospective study is to test our hypothesis by determining the incidence of hypoesthesia of the IAN 1 year postoperatively among 172 patients who underwent BSSO without the use of chisels.

Material and methods

Patients

Of the 172 patients in the study group, 107 were treated at Leiden University Medical Centre and 65 at Helmond Elkerliek Medical Centre in the Netherlands. Treatment took place between 2005 and 2007, and involved BSSO using separators and splitters, without chisels. This method has been used regularly in both clinics for more than 10 years; hence, no approval was obtained from the institutional review board. Further, our study protocol was in accordance with the guidelines of our institution and complied with the Declaration of Helsinki.

We initially evaluated 177 patients, 5 of whom were excluded because of incomplete data. The clinical study group thus comprised 172 patients, 57 of whom were male and 115 female. The mean age was 29 years (range, 14–59 years; SD, 11). BSSO was performed without any other surgical treatment in the case of 123 patients (71.5%). In the case of 35 patients (20.3%), the BSSO was a part of bimaxillary treatment, and in the case of 4 patients (2.3%), the BSSO was combined with genioplasty. Ten patients (5.8%) underwent a bimaxillary procedure combined with genioplasty. No other concomitant surgical procedures were performed (e.g., segmental osteotomy or pre-implant surgery).

Six (3.5%) of the procedures involved setbacks, with a mean setback of 4 mm on the left side and 5.5 mm on the right side. The mean advancement achieved on the right side was 5.22 mm (SD 3.41), and it was 5.23 mm (SD 3.60) on the left side.

In the case of 34 patients (19.8%), one or more wisdom teeth (29 on both sides and 5 on one side) were removed during the operation (Figure 1). All patients were operated on by either experienced senior staff (95 patients, 55.2%) or a resident assisted by a senior staff member (75 patients, 43.6%).

The patients had no neurosensory disturbances before the operation. All patients underwent pre- and postoperative orthodontic treatment for correct dental alignment and adequate occlusion stability.

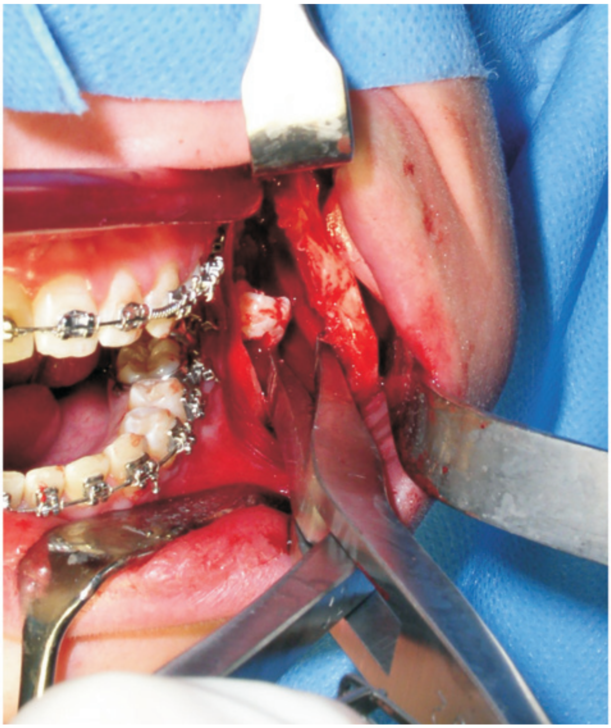

Figure 1 Sagittal split completed with the sagittal splitter (in situ) and separator on the left side. Wisdom tooth is visible in the split and removed during BSSO. Further, note the intact IAN visible just lateral to the wisdom tooth.

Surgical technique

All patients received anti-microbial prophylaxis (penicillin, 1 dose of 1 million units i.v., pre-operatively) and steroids (methylprednisolone i.v.) (for 3 days; day 1: 2 doses of 25 mg i.v., day 2: 2 doses of 12.5 mg i.v., day 3: 1dose of 12.5 mg). After general anesthesia and nasotracheal intubation, articaine and epinephrine in the ratio of 1:160.000 (Ultracaine D-S; Aventis Pharma, Hoevelaken, The Netherlands) were injected submucosally at the surgical site to prevent excessive bleeding during the procedure.

The BSSOs were performed according to the modified method of Hunsuck, except that chisels were not used[6]. Instead of chisels, splitting forceps (curved Smith Ramus separators; Walter Lorenz Surgical, Jacksonville, Florida, USA) and elevators were used. The mandibular ramus was exposed and the mandibular foramen was located. A periostal elevator was placed subperiosteally, just above the mandibular foramen; the horizontal bone cut was performed with a Lindemann bur (2.3 × 22 mm), approximately 5 mm above the mandibular foramen. Subsequently, the sagittal and vertical cuts were made with a short Lindemann bur (1.4 × 5 mm) (Figures 2 and 3). The

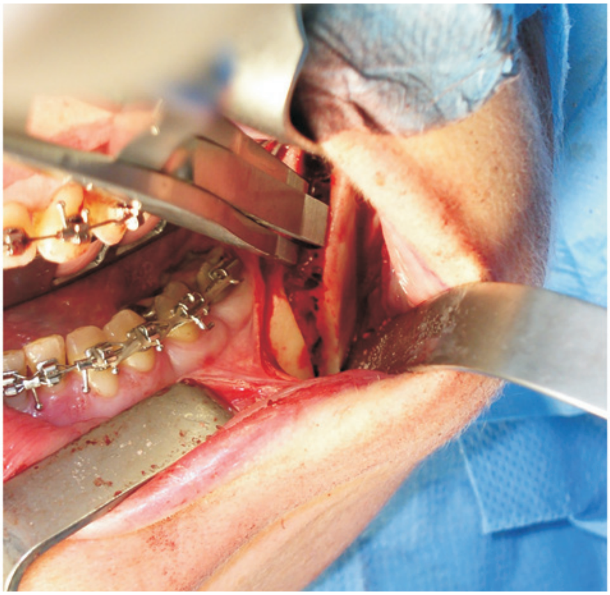

Figure 2 The beginning of the sagittal split is visualized. The sagittal splitter is in the sagittal cut. The sagittal separator is removed to visualize the unfolding of the split, clearly visible in the vertical cut. These sagittal and vertical cuts were made with the short Lindemann bur.

inferior border was cut, with this bur, perpendicularly through the inferior cortex, till it just reached the medial side. Splitting was performed with an elevator positioned in the vertical bone cut and the splitting forceps in the sagittal bone cut. Once the superior aspect of the mandible started to split, the elevator was repositioned at the inferior border of the vertical cut, and splitting was completed (Figure 2). Care was taken to ensure that the IAN was in the distal segment when the split was completed. A chisel was used, only if necessary, when a small bridge of cortical bone between the buccal and lingual segments remained at the inferior border of the mandible; this location is well below the level of the mandibular canal. When the IAN remained in the medial segment, it was carefully set free by blunt excavator preparation, or by a bur followed by blunt excavator preparation, to remove the lateral bony segments of the inferior mandibular canal. When necessary, the impacted third molar(s) were removed simultaneously after the mandible split was completed (Figures 1, 2, and 3).

After mobilization, the mandible was placed into the new intermaxillary relationship by using a wafer, and the intermaxillary wires were affixed. A stab incision was made through the skin; using a trans-buccal retractor, three 2-mm bicortical titanium screws, 9, 11, 13, and 15 mm in length (Martin GmbH, Tuttlingen, Germany), were placed in the upper border of the mandible on both sides. The temporary intermaxillary fixation was then removed, and the occlusion was checked. Elastic bands were not used immediately postoperatively; they were occasionally used 1 to 2 days postop-eratively to attend to the occlusion when necessary.

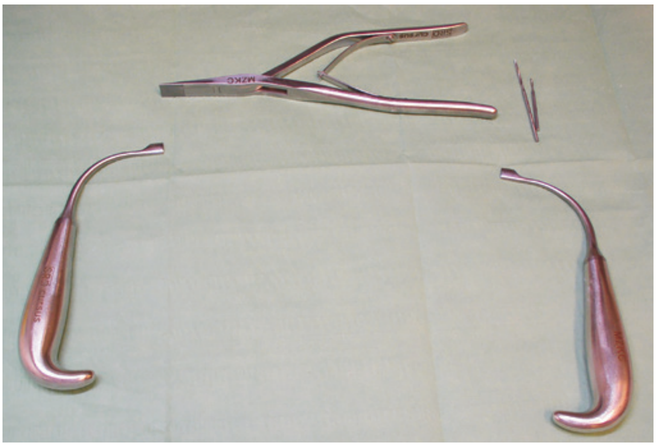

Figure 3 Instruments used during BSSO. Left and right sagittal splitters are shown in the left and right of the figure, respectively. The top shows the sagittal split separator. The top-right corner shows the long and short Lindemann bur used for the horizontal and sagittal/vertical cuts, respectively.

Evaluation

A standardized form was provided in both clinics to gather information before and after operation. Name, gender, date of birth, and operation date were collected and combined with surgical information (all divided into the left and right operation sites), including extent of mandibular advancement or setback of segments, presence of wisdom teeth, presence of a bad split, type of fixation, the use of a chisel, diameter of the screws used, concomitant surgical procedures, and whether the procedure was done by senior staff or a resident.

The peri-operative locations and conditions of the IAN can be listed as follows available: (1) IAN was not visible, and was located in the distal segment; (2) IAN was less than half visible, and was located in the distal segment; (3) IAN was more than half visible, and was located in the distal segment; (4) IAN was freed with a blunt instrument out of the proximal segment; (5) IAN was freed with the help of a bur, which was used to open the bony canal; (6) IAN was visibly damaged.

The neurosensory function of the IAN was tested before the operation; immediately after the operation (within 1 or 2 days); and 1, 6, and 12 months after the operation. IAN function was tested subjectively by asking whether the feeling of the lower lip was changed or different compared to the contra-lateral side or upper lip (or cheek or forehead in the case of bi-maxillary surgery). The postoperative function of the IAN was tested by the light touch detection method (mechanoceptive) and pinprick discrimination (nociceptive). The light touch detection method included gentle striking with a cotton tip (compared to an uncompromised site such as the lip, cheek, or forehead) and pinprick discrimination with the sharp end of a broken wooden stick. Thus, objective and subjective measurements were used to detect neurosensory disturbances; if any disturbance was noticed, the score was recorded as positive.

Statistical methods

All statistical analyses were performed using SPSS 16.0 for Windows (SPSS Inc., Chicago, USA). Crosstabs, the Pearson chi-square tests, and logistic regression were used to determine differences between parameters. Values of $p < 0.05$ were considered statistically significant.

Results

Mandibular advancement or setback was successful in all patients. At 12 months after surgery, 11 of the 172 patients (6.4%) experienced hypoesthesia on the right side; 9 patients (5.2%) experienced hypoesthesia on the left side, among these patients 2 had bilateral hypoesthesia. Thus, a total of 18 patients (10.5%; 16 unilateral and 2 bilateral) had hypoesthesia after 1 year (Table 1). No hyper-sensation was mentioned by any of the patients.

Table 1 Number of patients/sites and incidence of hypoesthesia after BSSO surgery.

Hypoesthesia after 12 months	Patients/sites	Incidence (%)
Total group (172 patients)	18	10.5%
Right site (172 sites)	11	6.4%
Left site (172 sites)	9	5.2%
Total sites (344 sites)	20	5.8%
Sub-group without genioplasty (p = 0.018) (158 patients)	14	8.9%
Right site (158 sites)	8	5,1%
Left site (158 sites)	8	5,1%

No influence of gender on hypoesthesia was found (OR = 0.99; p = 0.985). There was a significant positive association between age and hypoesthesia; the frequency of hypoesthesia increased in older patients (OR = 1.07 per year of increase in age; p = 0.006) (Table 2).

In 34 patients (19.8%), one or more wisdom teeth were present (29 on both sides and 5 on one side). With regard to unilateral BSSO split procedures (e.g., 172 left sites and 172 right sites in a total of 344 sites) with and without peri-operative removal of the wisdom teeth, no influence was found on post-operative hypoesthesia 12 months after surgery (p = 0.841). When the effect of patient variables was considered, no significant difference was found (Generalized Estimating Equations (GEE); OR = 1.1; 95% CI: 0.37–3.32; p = 0.864). The frequency of hypoesthesia in unilateral split procedures was 5.8% (Table 2). The Le Fort procedure (35 patients; 20.3%) also had no significant influence on the occurrence of hypoesthesia (14.3%) after 12 months (p = 0.209) (Table 2).

In 14 patients (8.1%), BSSO was combined with genioplasty (with or without a Le Fort I procedure); of these patients, 28.6% experienced hypoesthesia. The association of genioplasty with hypoesthesia was statistically significant (p = 0.018) (Table 2).

Table 2 Possible concomitant influence on hypoesthesia after BSSO surgery and significance (p-value), odds ratio (OR), and 95% confidence interval (95% CI).

Concomitant influence on hypoesthesia after BSSO treatment	p-value	OR	95% CI	Risk of hypoesthesia after BSSO
Gender	p = 0.985			No difference in risk
Age	p = 0.006			More risk with increasing age
Peri-operative removal of wisdom teeth	p = 0.841	1.123	0.36–3.481	No extra risk
Le Fort I procedure	p = 0.209	2.111	0.659–6.767	No extra risk
Genioplasty	p = 0.018	5.067	1.32–19.42	Increased risk
Freeing IAN by instruments (by bur or blunt instruments)	p = 0,003 (right side) p = 0,000 (left side)			Increased risk

The BSSO procedure without the concomitant genioplasty showed a hypoesthesia frequency of 8.9%, and the frequency of hypoesthesia in unilateral split procedures without the concomitant genioplasty was 5.1% (Table 1). Because genioplasty showed an association with hypoesthesia, we analyzed the remaining parameters without the 14 patients from the genioplasty group, and thus 158 patients remained in the study group.

In the remaining 158 patients (316 surgical sites), 2 direct injuries to the IAN occurred during the procedure. One resulted in hypoesthesia of the IAN that was still present 12 months after surgery; the other led to hypoesthesia that lasted 1 month, after which normal sensation was regained. In 72 surgical sites (22.8%), no nerve was visible during the split. In 51 sites (16.2%), the IAN was less than half visible, and in 183 sites (57.9%) more than half of the IAN was visible in the distal segment.

The IAN had to be released from the buccal segment with a bur for 30 surgical sites; in 45 sites, it had to be released in a blunt manner; thus, 75 sites (23.7%) required instrumentation. A (unilateral) “bad split” occurred in 7 patients (4.5%); 3 resulted in permanent hypoesthesia that persisted 12 months after surgery. The bad splits were all buccal or lingual plate fractures. Because of these bad splits, 2 IAN’s had to be freed by means of a bur, resulting in postoperative hypoesthesia after 12 months. A plate fixation was used in 4 sites, 2 of which were required because of a bad split. A chisel was used in 2 surgical sites, one of which was required because of a bad split. No hypoesthesia was found after the use of chisels. Hypoesthesia was not observed after any of the setback procedures. No significant correlations were found between any of these parameters.

Freeing the IAN from the proximal segment with a blunt instrument or by using a bur to open the bony canal was significantly associated with hypoesthesia (right side, $p = 0.003$; left side, $p = 0.000$), however there was no significant difference between the use of a bur or a blunt instrument in freeing the IAN comparing these 2 operation techniques (right side, $p = 0.053$; left side, $p = 0.709$).

Discussion

According to the current literature, persistent hypoesthesia of the IAN is the most common complication of BSSO of the mandible. Our hypothesis was that BSSO performed with splitters and separators will have a lower incidence of IAN hypoesthesia compared to other splitting techniques. The percentage of BSSO split procedures that resulted in IAN damage was 5.1% in this study, and 8.9% patients experienced IAN damage. Other studies reported persistent hypoesthesia of the IAN in 8–85% of patients who had undergone BSSO. [3-7]

Nerve fibers can be injured by surgical manipulation, such as stretching or crushing during the operation, or by compression of the nerve bundle within the mandibular canal; nerve damage can also result from the hypoxia and edema caused by these manipulations. The type of nerve injury that results is most likely a combination of neurapraxia (bruising that damages the myelin sheath) and partial axonotmesis (nerve fibre damage caused by sectioning of the axon).[3,4,8] The lower incidence of partial axonotmesis and neurapraxia in our study may be attributed to the fact that we did not use a chisel.

Our study showed no association between the persistence of hypoesthesia at post-surgery 12 months and peri-operative wisdom teeth removal or Le Fort I osteotomy (Figure 1). This observation is consistent with that of Reyneke et al., who reported that although IAN recovery was slower in patients who had un-erupted wisdom teeth at the time of surgery, the recovery rates at 1 year were equal to those who did not have un-erupted wisdom teeth.[9]

To test for neurosensory disturbances in our patients, we used both objective and subjective measurements. Variations reported in the literature on the prevalence of hypoesthesia of the IAN depend on whether objective measurements or subjective self-reports are used.[10] As Bothur and Blomqvist reported in their study, these objective and subjective measurements do not always correspond.[11,12] We therefore used both modalities; if a disturbance was noted using either test method, the score was recorded as positive. This methodology avoided underestimation of hypoesthesia.

Among the 158 patients in our study group, 8,9% experienced hypoesthesia (without the concomitant genioplasty). When the unilateral surgical sites were considered, the incidence was 5.1% (Table 1). Few authors have reported the rates of hypoesthesia to be under 10%.[2,7,8,13,14] The lower rates of hypoesthesia seen in our study suggest that the use of a splitter and separator, without the use of a chisel, could lead to fewer injuries to the IAN.

The reported incidence of a bad split at a BSSO site ranges from 0.5% to 5.4%, which is comparable to the incidence (4.5%) with our splitting technique; therefore, this technique does not lead to the development of more bad splits. Furthermore, bad splits do not seem to result in more damage to the IAN.[15,16]

As mentioned previously, genioplasty is significantly associated with hypoesthesia of the IAN. In our study, 14 patients underwent BSSO combined with genioplasty. This group of patients had a higher incidence of hypoesthesia at 12 months after surgery ($p = 0.046$) than did those without genioplasty. This observation is consistent with another study that showed an 11.1% increase in neurosensory disturbances associated with BSSO when genioplasty was used as a concomitant procedure.[13]

The type of fixation used also influences the occurrence of IAN-associated hypoesthesia. The low incidence of hypoesthesia seen in our study indicates that positional screw fixation is reliable.[2,4,17]

Another factor that may affect the occurrence of hypoesthesia as a complication of BSSO is the method of handling soft tissues during the procedure. One study showed a weak association between reduced hypoesthesia and gentle handling of soft tissues, especially the medial part of the ramus.[5] In our BSSO procedures, we never use the larger channel retractor for retraction of these medial soft tissues. Because we use a small bur instead of a saw, the retraction can be less wide, requiring only the use of a periostal elevator. Furthermore, the foramen can be identified only by lifting the periostium and not probing with, for example, a blunt ball-pointed amalgam condenser.

Most patients are satisfied with their BSSO treatment despite mildly altered sensation (87–100% satisfaction).[3,7] Nonetheless, other treatment modalities should be discussed and perfected to minimize these common complications.

Conclusion

Our findings here indicate that the use of splitting forceps and elevators leads to a lower incidence of persistent post-operative hypoesthesia after BSSO of the mandible, without increasing the risk of a bad split. Further prospective investigations to compare these different techniques and their outcomes are underway.

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Skeletal stability after mandibular advancement in bilateral sagittal split osteotomies during adolescence

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Abstract

Bilateral sagittal split osteotomy (BSSO) is the most frequently performed surgery for correcting mandibular retrognathia. Few studies have reported the use of BSSO at a young age, as growth may cause relapse. The aim of the present study was to determine the amount of relapse after performing BSSO in patients aged less than 18 years. Patients who had a mandibular advancement by BSSO surgery between January 2003 and June 2008 were evaluated. Eighteen patients were treated before the age of 18 years and compared with patients treated at 20 to 24 years of age. Cephalometric radiographs were used to determine the amount of relapse. For patients aged less than 18 years, the mean horizontal relapse after 1 year was 0.5 mm, being 10.9% of the perioperative advancement. For patients aged 20–24 years, the mean relapse was 0.9 mm, being 16.4% of the mean perioperative advancement. There were no significant differences between the age groups ($p > 0.05$). In conclusion, the BSSO procedure is a relatively stable procedure, even during adolescence.

Introduction

Bilateral sagittal split osteotomy (BSSO) was introduced in 1957 by Trauner and Obwegeser [1] and has been modified by several authors over the years. It is the preferred treatment for mandibular advancement, correcting mandibular retrognathia in adult patients.

The stability of the treatment is an important factor in the outcome of this surgery. Skeletal relapse after BSSO is the result of many different factors, including condylar slippage after bad positioning of the condylus during the procedure [2,3], condylar resorption after surgery [4,5], intersegmental relapse at the osteotomy site [6], and further mandibular growth after the BSSO [4].

To avoid relapse because of growth, the age limit for BSSO has been set at 18 years in most clinics. Recent publications about stability of mandibular orthognathic surgery in this journal were also all conducted in an adult study population, with most of population having a mean age of mid-twenty [7-9]. Around the year 1980, a few studies have reported the results of BSSO in younger patients. (Table 1) [10-12]. Because of the high relapse percentages found in these studies (up to 25%), BSSO treatment was more or less limited to patients older than 18 years. However, recent reports on the relative stability of mandibular advancement using distraction osteogenesis have reintroduced the use of BSSO in younger patients. The objective of this study was to determine the amount of relapse in a group of patients who underwent BSSO before the age of 18 years.

Table 1 Skeletal stability of BSSO at a young age.

Author	Number of patients	Mean age patients	Treatment	Mean advancement	Mean relapse at 1 year	Mean relapse/mean advancement
Huang and Ross, 1982	21	14.1 (11.2-16.9)	BSSO	10.9 mm	2.67 mm	24.5%
Wolford et al., 1979	12	13.4 (8-16)	BSSO	5.4 mm	0.24 mm[a]	4.4%
Freihofer, 1977	7	15.7 (13-17)	BSSO	5.5 mm[b]	0.72 mm[b]	13.1%

[a] After 4 months.
[b] Just stated 4-7 mm advancement; two patients with relapse, one 15% and one 80%, and two patients with growth one 1.5% and one 2%.

Material and methods

Surgical records were reviewed retrospectively for the years 2003 until 2008. Patients who underwent BSSO advancement before the age of 18 years or between 20 and 24 years (control group) were included in this study. All patients were treated in the Department of Oral and Maxillofacial Surgery at Leiden University Medical Center. A patient was included when the records were adequate, i.e., containing date and type of surgery, preoperative radiographic examinations, and follow up records with radiographic examinations. Follow-up records had to be available over a period of at least 8 months. A Le Fort I procedure and/or genioplasty conducted in the same surgical setting as well as surgical removal of impacted third molars were not exclusion criteria.

Of the patients who underwent a BSSO advancement between January 2003 and June 2008, 23 were aged less than 18 years. Of these 23 patients, 5 were excluded because follow-up was missing or inadequate. Eighteen patients remained suitable for analysis. From 8 patients preoperative a wrist film was made to determine the skeletal-age. In all 8 wrist films made the radiologist stated that growth plates were not completely closed and/or final height was not yet completely reached. It was concluded that these patients were still actively growing and consequently we could speak of an adolescent group.

From the 18 patients included in 11 patients BSSO was performed without a concomitant procedure; in 1 patient, BSSO was combined with a genioplasty. In 6 patients, BSSO was combined with Le Fort I osteotomy; from which one patient also underwent genioplasty. Fifteen of the patients were female, and 3 were male. The mean age was 16.6 years (SD, 1.0; range, 14.6 to 18.0 years). In 12 patients, the third molars were removed during surgery. The mean follow-up was 13.1 (SD, 1.7) months, with a minimum of 8 months and a maximum of 16 months (Table 2).

The control group (patient age, 20 to 24 years) consisted of 22 patients. Four patients were excluded because of inadequate follow-up. A group of 18 patients remained for analysis. In 7 patients, BSSO was performed without a concomitant procedure. In 11 patients, BSSO was combined with a Le Fort I procedure; in 2 patients, this was combined with genioplasty. Twelve of the patients were female, and 6 were male. The age at the time of osteotomy ranged from 20.1 to 23.8 years, with a mean age of 21.3 ± 1.2 years. In 7 patients, third molars present in the mandible were removed during surgery. The duration between osteotomy and one-year follow up was an average of 12.3 (SD 1.6) months, with a minimum of 8 and a maximum of 15 months (Table 2).

Table 2 Patient characteristics.

Patient	Age	Sex	Operation	Advancement BY (mm)	Relapse BY (mm)[a]
1	15	F	BSSO	1.8	+0.5
2	17	M	BSSO	5.8	2.2
3	16	M	BSSO	3.5	0.3
4	14	F	BSSO	5.5	+0.2
5	17	F	BSSO	4.8	2.0
6	16	F	BSSO	2.5	0.3
7	17	F	BSSO	3.3	2.5
8	17	F	BSSO	0.7	+1.2
9	16	F	BSSO	3.5	1.2
10	15	F	BSSO	1.5	+1.0
11	16	F	BSSO + genioplasty	1.3	+0.7
12	14	F	BSSO	3.8	1.3
13	17	F	BSSO + Le Fort I	6.7	1.7
14	17	F	BSSO + Le Fort I	11.8	0.2
15	17	F	BSSO + Le Fort I	4.3	2.3
16	16	F	BSSO + Le Fort I	6.7	0.2
17	16	M	BSSO + Le Fort I	7.0	0.3
18	16	F	BSSO + Le Fort I + genioplasty	7.2	+2.2
19	20	F	BSSO	5.8	2.0
20	22	F	BSSO	5.3	1.2
21	20	F	BSSO	1.2	+0.5
22	22	F	BSSO	1.2	+0.2
23	20	F	BSSO	3.5	1.5
24	21	F	BSSO	1.7	0.3
25	21	M	BSSO	4.8	+1.0
26	23	M	BSSO + Le Fort I	4.7	+0.7
27	21	F	BSSO + Le Fort I	5.0	3.2
28	20	F	BSSO + Le Fort I + genioplasty	7.5	+0.3
29	23	F	BSSO + Le Fort I	9.2	3.8
30	20	M	BSSO + Le Fort I	7.8	1.8
31	20	F	BSSO + Le Fort I	7.0	0.2
32	21	M	BSSO + Le Fort I	8.7	0.5
33	20	M	BSSO + Le Fort I	10.8	1.2
34	20	M	BSSO + Le Fort I	5.0	0.2
35	20	F	BSSO + Le Fort I + genioplasty	3.7	0.7
36	20	F	BSSO + Le Fort I	6.5	2.5

[a] Relapse in mm, + is further anterior movement in year after BSSO.

Surgical technique

After general anesthesia and nasotracheal intubation, articaine and epinephrine 1:160.000 (Ultracaine D-S, Aventis, Pharma, Hoevelaken, The Netherlands) were injected submucosally into the operation site to prevent excessive bleeding during the procedure. BSSOs were performed according to the modified method of Hunsuck [13] without the use of chisels. Instead, splitting forceps (Smith Ramus Separator 12 mm, Walter Lorentz Surgical, Jacksonville, FL, USA) and elevators (curved Smith Sagittal Split Separators, Walter Lorentz Surgical, Jacksonville, FL, USA) were used [14,15]. Bone cuts were performed using a Lindemann burr. Splitting was done with the elevator positioned in the vertical bone cut and the forceps in the sagittal bone cut. Once the superior part of the mandible began to split, the elevator was repositioned at the inferior end of the vertical cut, and the splitting was completed. After complete mobilization of the mandible, it was placed into the new intermaxillary position using a wafer. Intermaxillary wire fixation was applied. A stab incision was made in the skin and using a transbuccal retractor, three 2-mm bicortical screws (Martin, GmbH, Tuttlingen, Germany) (length: 9, 11, 13, or 15 mm) were placed bilaterally in the superior part of the mandible. Temporary intermaxillary fixation was removed, and occlusion was checked.

Cephalometric method

To evaluate the stability after BSSO, standard lateral cephalometric radiographs were used. Radiographs were obtained before osteotomy, postoperatively, and 1 year after BSSO in every patient. All radiographs were traced by hand by 1 author (CB). Every radiograph was traced 3 times, and the average data of these 3 tracings were used for further analysis.

To determine the horizontal and vertical relapse, a XY-coordinate system was constructed on each radiograph. The horizontal axis (SNx) was constructed 7 degrees from the sella-nasion line, an approximation of the Frankfort horizontal plane. The vertical axis (SNy) was perpendicular to this line, through the point sella (Figure 1). The perpendicular distance between point B and both axes was determined. The distance between point B and SNx was defined as BX, and the point between B and SNy was BY. Furthermore, SNB and SN-GoGn angles were determined.

Statistical analysis

All statistical analyses were performed using SPSS 17.0 for Windows (SPSS Inc, Chicago, USA). The measurements of the radiographs obtained before osteotomy, directly after, and 1 year after osteotomy were analyzed within the age groups using paired samples T-tests. The difference in advancement and relapse between the 2 age groups was analyzed with independent samples T-tests. Through linear regression, a possible relation between horizontal relapse and horizontal advancement at point B and between horizontal relapse and SN-GoGn before osteotomy was tested. Furthermore, a possible relation between the age of the patients at the time of osteotomy and horizontal relapse at B was examined.

The 2 age groups were compared according to gender and duration of follow-up, and the possible difference between BSSO and BSSO in combination with Le Fort I procedure was assessed. Using a Fisher's exact test, unpaired T-test, and a Chi-square test, the differences were tested for significance. Values of $p < 0.05$ were considered statistically significant.

Intra-observer reliability was tested using intraclass correlation coefficients. The difference in measurements of 1 variable from the same radiograph was tested based on reliability.

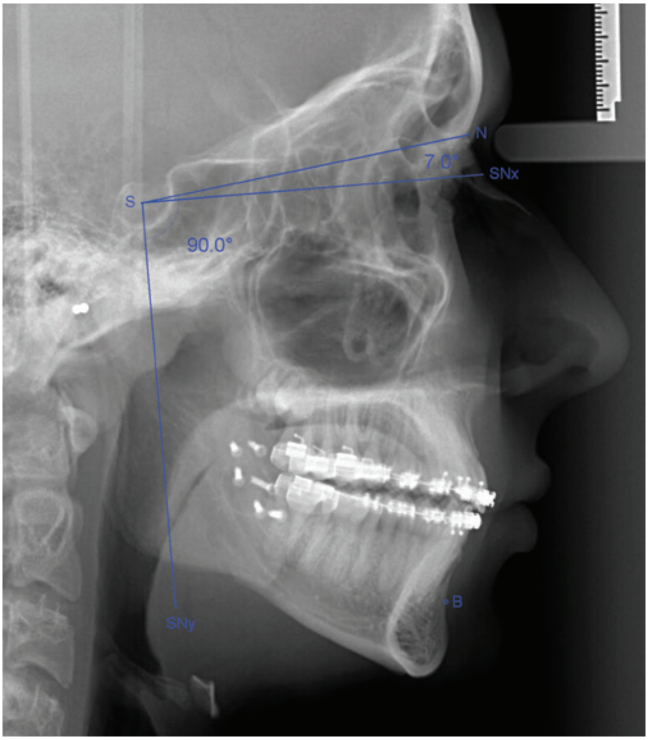

Figure 1 Post-operative lateral cephalometric radiograph shows the horizontal axis (SNx; 7° from sella-nasion line), the vertical axis (SNy) and point B, which were used to determine the stability after BSSO.

Results

Age group <18 years

In the group with patients treated before the age of 18 years, the mean horizontal relapse after a year (at point B, measured as the difference in length of BY immediately after the BSSO and the length of BY after 1 year) was 0.5 mm. This was 10.9% of the advancement, measured as the difference in length of BY immediately after osteotomy and the length before osteotomy (4.6 mm) (Table 3).

Differences in BY lengths were tested for significance. There was a statistically significant difference between pre- and postoperative BY length ($p = 0.000$), this being an approximation of the advancement caused by surgery. The difference between BY lengths immediately after osteotomy and 1 year after osteotomy was not significant ($p = 0.136$). The SNB angle decreased by 0.3 degrees 1 year following surgery. Perioperative advancement was a mean of 3.3 degrees. A significant difference was found between the pre- and postoperative SNB angle ($p = 0.000$); no statistically significant difference was found between SNB angle immediately post-operative and 1 year after osteotomy ($p = 0.199$).

Average vertical relapse after 1-year follow-up was 0.8 mm for the patients treated by single BSSO surgery.

Significant differences were found between single BSSO surgery and BSSO combined with a Le Fort I procedure in the perioperative movements of BY, BX, and SNB, respectively ($p = 0.001$, $p = 0.000$, and $p = 0.002$). A combined procedure showed a cranial and more anterior movement immediately after the operation.

At 1 year, there was no significant difference at BY, BX, and SNB between BSSO and a combined procedure ($p = 0.873$, $p = 0.826$, and $p = 0.907$). In table 3, the different results for BSSO and for BSSO combined with Le Fort I osteotomy are shown.

Age group 20–24 years

In patients aged 20–24 years, the mean horizontal relapse at point B after 1 year was 0.9 mm. This was 16.4% of the mean advancement of 5.5 mm at point B (Table 4). There was a statistically significant difference between pre- and postoperative BY length ($p = 0.000$). The difference between BY lengths immediately after the operation and 1 year postoperatively was also statistically significant ($p = 0.011$).

The SNB angle decreased by 0.4 degrees at 1 year after surgery. Mean perioperative advancement was 3.3 degrees. Significant difference was found between pre- and postoperative SNB angle ($p = 0.001$) and between SNB angle immediately after the operation and 1 year after osteotomy ($p = 0.030$).

Average vertical relapse (BX) after 1-year follow-up was 1.1 mm for the patients treated by single BSSO surgery.

Table 3 Movement and relapse of BY, BX, SNB in patients < 18 years.

	Mean movement BSSO treatment (in mm)	SD	Mean relapse after 1 year (in mm)	SD	Mean relapse after 1 year (in percentages)
Horizontal movement BY (n = 18)	+4.6	2.8	-0.5	1.3	-10.9
SRO (n = 12)	+3.2	1.7	-0.5	1.3	-15.6
SRO + Le Fort I (n = 6)	+7.3	2.5	-0.4	1.6	-5.5
SNB (n = 18)	+3.3	1.3	-0.3	0.9	-9.1
SRO (n = 12)	+2.7	0.7	-0.3	0.7	-11.1
SRO + Le Fort I (n = 6)	+4.5	1.4	-0.3	1.4	-6.7
Vertical movement BX (n = 18)					
SRO (n = 12)	+4.1	2.0	-0.8	1.3	-19.5
SRO + Le Fort I (n = 6)	-1.6	2.5	-0.6	2.2	37.5

BY, distance of point B to SNy; BX, distance of point B to SNx
+, anterior / caudal movement; –, posterior / cranial movement

Table 4 Movement and relapse of BY, BX, SNB in patients 20-24 years.

	Mean movement BSSO treatment (in mm)	SD	Mean relapse after 1 year (in mm)	SD	Mean relapse after 1 year (in percentages)
Horizontal movement BY (n = 18)	+5.5	2.7	-0.9	1.4	-16.4
SRO (n = 7)	+3.4	2.0	-0.5	1.1	-14.7
SRO + Le Fort I (n = 11)	+6.9	2.2	-1.2	1.5	-17.4
SNB (n = 18)	+3.3	1.4	-0.4	0.8	-12.1
SRO (n = 7)	+2.3	1.2	-0.2	0.5	-8.7
SRO + Le Fort I (n = 11)	+3.9	1.2	-0.6	0.9	-15.4
Vertical movement BX (n = 18)					
SRO (n = 7)	+3.5	0.8	-1.1	1.0	-31.4
SRO + Le Fort I (n = 11)	-0.9	1.6	0.2	1.0	-22.2

BY, distance of point B to SNy; BX, distance of point B to SNx
+, anterior / caudal movement; -, posterior / cranial movement

4

In patients aged 20 to 24 years, significant differences were found between single BSSO surgery and BSSO combined with Le Fort I procedure. The perioperative movements of BY, BX, and SNB were significantly different ($p = 0.003$, $p = 0.010$, and $p = 0.000$, respectively). A combined procedure showed a cranial and a more anterior movement immediately postoperatively. Relapse of BX after 1 year was also significantly different between single and combined procedures ($p = 0.013$); a more anterior movement was seen in combined surgery in contrast to a relapse in the single procedure. Relapse at BY and SNB was not significantly different between procedures ($p = 0.295$ and $p = 0.271$).

Comparisons between age groups

The duration of follow-up, gender, and number of patients treated with BSSO or a combination with Le Fort I procedure were compared between both age groups. No significant differences were found ($p = 0.246$, $p = 0.443$, and $p = 0.095$, respectively).

For perioperative horizontal advancements, no significant differences were found among the age groups between preoperative and immediately postoperative BY lengths ($p = 0.259$). There was also no significant difference in the horizontal relapse at point B after 1 year between age groups ($p = 0.359$).

The advancement and relapse of SNB and BX were compared between age groups as well. No significant difference was found in any of the variables ($p > 0.05$).

SN-GoGn appeared to have no influence on the horizontal relapse after 1 year. In addition, the amount of advancement at point B after BSSO and age did not have significant influence on the horizontal relapse.

In all patients, the function of the inferior alveolar nerve was tested during follow-up. Hypoesthesia in the lip and chin area was documented. None of the patients experienced hypoesthesia before BSSO. After 1 year, 2 patients in both age groups reported mild unilateral hypoesthesia.

The intraclass correlation coefficient was higher than 0.983 in all variables (SNA, SNB, BY, BX, SN-GoGn, and SPPL-MPL) before, immediately after, and 1 year after BSSO. This implies that good intra-observer reliability was established.

Discussion

In correcting a skeletal class II malocclusion, the stability of the chosen procedure is an important factor. The relapse percentage of 10.9% found in this study shows that sagittal split osteotomy is a reliable procedure for advancement of the mandible during adolescence. To the authors' knowledge, there have been no recent reports on the stability of mandibular advancement using BSSO during adolescence. Older reports on stability of BSSO during adolescence date from the 70's and 80's, as mentioned in the introduction. The higher relapse percentages found in these studies could be explained by differences in technique, as these studies were based on mandibular advancement with wire fixation, which is a known less stable method [16].

The control group showed a relapse percentage of 16.4% after 1 year; this percentage is presumably representative of the relapse in adult patients at our center. In the last 10 years, studies have reported inconsistent 1-year relapse percentages for mandibular advancement performed using BSSO in adult patients. Several studies show 20% to 30% relapse at B point after 1 year [5,6,17]. One study showed a relapse of only 1% after 1 year [18] and one an even more anterior movement in the first year after osteotomy [19]. The relapse percentage found in this study in the adult patient group is approximately equal to recently described results in the literature.

Although not significant, the difference in relapse percentages between both age groups, 10.9% vs. 16.4%, tended to favor the adolescent group. Furthermore, the difference in BY length immediately and 1 year after the operation was significant in the age group 20–24 years and not significant in the adolescence group. Groups were comparable with respect to duration of follow-up, gender, perioperative advancement, and the number of patients treated with BSSO or a combination with a Le Fort I procedure. The apparent difference in relapse could be explained by the fact that perioperative movement is in the same direction as postoperative growth. A part of the relapse is compensated by growth of the mandible after osteotomy; thus, young age seems to partly prevent relapse. Although, not significant, the greater amount of Le Fort I procedures (with therefore more mandibular advancement) in the control group could also explain the difference in relapse.[20]

The influence of the mandibular plane angle on relapse has been shown in several studies [6,20]. In our study, no relationship was detected between preoperative mandibular plane angle, measured as the SN-GoGn angle, and the horizontal relapse following surgery.

The patients included in this study had relatively small advancements. In series with adult patients, results have been shown to be less stable after greater advancement [20]. Further, the number of patients in this study was relatively small. However, the results of the study indicate that BSSO seems to be a stable procedure during adolescence for patients who require normal advancement. If this patient number increases in the future, the results of a larger patient population can be analyzed.

There are many advantages of correcting mandibular retrognathia at a young age. The problems experienced because of mandibular retrognathia, such as impaired speech, discomfort in chewing, malocclusion, damage of the periodontium caused by palatal interdigitation, and pain, are resolved at a young age by advancing the mandible. A relationship between higher age and more frequent permanent damage of the inferior alveolar nerve is reported in several studies [15,21,22], presumably because of bad regeneration of the damaged nerve with increased age. Surgery at a young age may prevent permanent damage of the inferior alveolar nerve in many cases. Additionally, facial aesthetics will improve after the procedure. The positive implications on social functioning and wellbeing, relevant issues in adolescence, have been described explicitly [23,24].

Conclusion

Our results indicated that a BSSO performed during adolescence is a relatively stable procedure. The presumed difference in relapse rates between surgery during adolescence and in adults is not supported. Therefore, the results of this small series suggest that BSSO can be performed in adolescence as well. To obtain more definitive conclusions, a prospective, randomized controlled trial is recommended between both techniques for analyzing stability and complications in both age groups.

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5

Bilateral sagittal split osteotomy in cadaveric pig mandibles: Evaluation of the lingual fracture line based on the use of splitters and separators

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Abstract

Objectives. To analyze the splitting pathways of the (lingual) fracture lines during a bilateral sagittal split osteotomy (BSSO) in cadaveric pig mandibles.

Study design. A BSSO was performed using splitters and separators. Special attention was paid to end the horizontal medial cut at the deepest point of the entrance of the mandibular foramen.

Results. Of all lingual fractures, 95% ended in the mandibular foramen. Forty percent of these fractures extended through the mandibular canal and 40% extended inferiorly along the mandibular canal.

Conclusion. Almost all lingual fracture lines ended in the mandibular foramen, most likely due to placement of the medial cut in the concavity of the mandibular foramen. The mandibular foramen and canal could function as the path of least resistance in which the splitting pattern is seen. We conclude that a consistent splitting pattern was achieved without increasing the incidence of possible sequelae.

Introduction

Bilateral sagittal split osteotomy (BSSO), originally described by Trauner and Obwegeser,[1] is traditionally used to correct mandibular anomalies in humans as part of surgical-orthodontic treatment, and many researchers have tried to perfect the procedure and improve its safety and reliability. The most common complications are bad splits (defined as unwanted fractures of the proximal or the distal segment of the mandible) and neurosensory disturbances resulting from injury to the inferior alveolar nerve (IAN) during surgery, which can have an impact on the daily life of patients.[2] Modifications to this technique have been proposed to address these issues.[3-6] Most techniques are based on the use of a chisel to separate the distal and proximal segments of the mandible.[7-12] Several decades ago, Wolford et al[6] emphasized the importance of the cutting technique to produce a clean split with a minimum amount of force and with minimal use of osteotomes. Other researchers already have advocated prying and spreading the mandible rather than splitting with chisels and mallets, as employed in BSSO,[13] and the use of Smith and Tessier spreaders have been described.[14] Compression of the IAN during splitting with blunt chisels has been shown to induce a decrease in sensory nerve reactions.[15]

Furthermore, Plooij et al. emphasized that the possible influence of the lingual fracture line (and its absence of control and visualization) could be a possible factor in damaging the IAN and influencing the fracture line due to placement of the (medial) bone cuts. Until now, no studies have been performed to evaluate the placement of the horizontal medial cut and to show a possible path of least resistance with regard to the lingual fracture pattern to the mandibular foramen of the mandible in 3 dimensions on cadaveric mandibles. We aimed to analyze the fracture lines in a BSSO using sagittal splitters and separators and to determine the influencing factors on the splitting pattern. We also aimed to find an explanation for the reduced risk of nerve damage and bad splits in BSSO by using sagittal splitters and separators based on the findings in other reports.[16,17] Our hypothesis was that by placing the medial cut in the concavity of and just above the mandibular foramen in combination with the use of sagittal splitters and separators and prying and spreading the mandibular segments, rather than driving chisels past the nerve, we can create a consistent fracture line at the lingual side of the mandible following the mandibular canal

To validate this approach as a safe and reliable technique, we performed a pilot study of cadaveric pig mandibles. The main aim of this pilot study was to evaluate the (lingual) splitting patterns in relation to the nerve canal and the placement of the medial cut, and to determine the incidence of unfavorable splits.

Materials and methods

We evaluated the reliability of our splitting technique in 10 cadaveric pig mandibles. The mandibles were obtained from 6- to 7-month-old female pigs, with a mean weight of approximately 100 kg and a mixed dentition phase. The pigs were originally bred for consumption. The soft tissues were used for consumption, and the mandibles were boiled to remove any soft tissue residues. The mandibles were then refrigerated at 1–3°C. The average length of the mandibles was 20 cm (range, 17–23 cm), and they contained at least 1 unerupted molar, 2 erupted molars, and 2 erupted premolars. Because the pig mandibles were slated for destruction, we did not need to obtain an approval from our institution to use the mandibles in our study.

The mandibles were cut in the midline for this experimental study. We used both sides for our splitting technique and performed BSSO using the modified method described by Hunsuck[4] as previously reported.[16,17] Since the forceps and elevators provide intra-mandibular forces only, the mandible could easily be stabilized with the hand. The horizontal bone cut was performed with a Lindemann bur (2.3 × 22 mm; Meisinger, Germany). The cut was made just above the mandibular foramen; it ended just posterior to the lingula superior of the mandibular foramen at the deepest point of the entrance of the IAN (Figure 1a). Subsequently, the sagittal and vertical cuts were made with a short Lindemann bur (1.4 × 5 mm, Meisinger). The vertical cut was made just posterior to the most distal erupted molar. The inferior border was also cut using the short Lindemann bur; this was a perpendicular cut through the inferior cortex that must reach the medial side to prevent the lingual fracture line to run to the buccal side, creating a bad split. Splitting was performed using curved Smith Ramus separators (Walter Lorentz Surgical, Jacksonville, Florida, USA) and elevators. The elevator was positioned in the vertical bone cut, and the splitting separator was positioned in the sagittal bone cut. Once the superior aspect of the mandible started to split, we repositioned the elevator at the inferior border of the vertical cut to complete the splitting (Figures 1, 2, and 3). We then analyzed the 20 separated segments comprising 10 left- and 10 right-sided split osteotomies to evaluate the patterns of splitting (especially the lingual fracture lines), unfavorable splits, and the potential impact of these on the IAN.

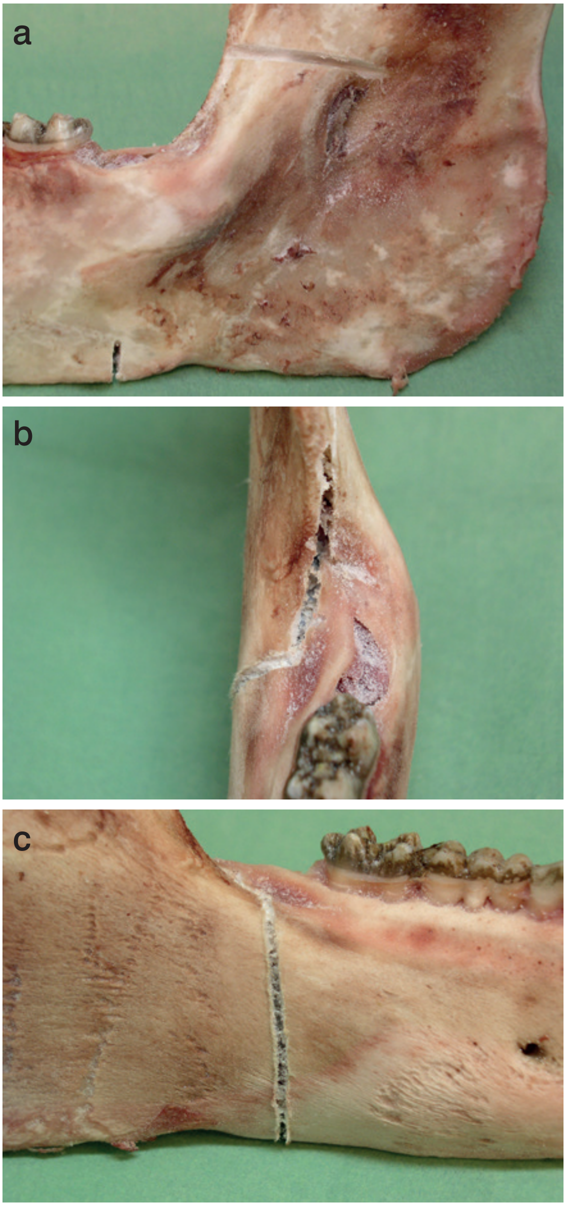

Figure 1 **a** Horizontal cut performed with a long Lindemann bur just above the mandibular foramen. The vertical cut, including the medial side, is also performed with the short Lindemann bur. **b** Sagittal cut between the horizontal and vertical cut. Note the follicle of the unerupted third molar. **c** Vertical cut made with the short Lindemann bur.

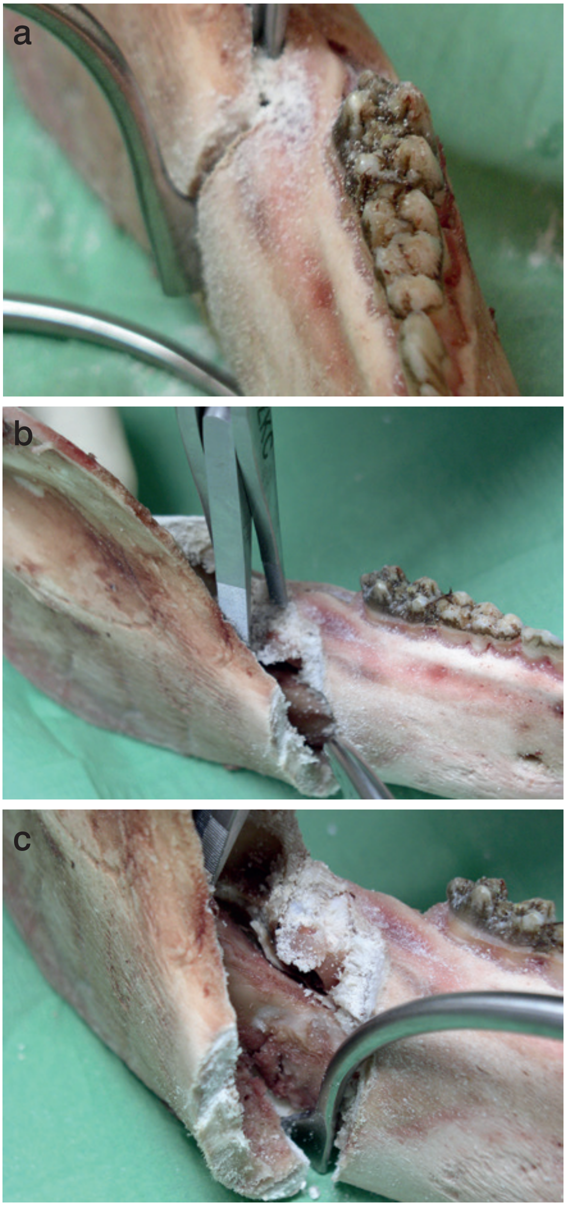

Figure 2 **a** Positioning of the sagittal splitter and separator for the sagittal and vertical cuts. Note that the separator is not yet at the inferior border of the vertical cut. **b** Unfolding of the split. Note that the separator is placed at the inferior border during the opening of the split. **c** Further unfolding of the split, also with the separator placed at the inferior border of the split.

Figure 3 Example of a lingual fracture line observed after performing the sagittal split. The fracture runs along the inferior border of the mandible, however not starting in the superior extension of the vertical lingual cut, and then runs inferior to the mandibular canal (40%) to the mandibular foramen (95%).

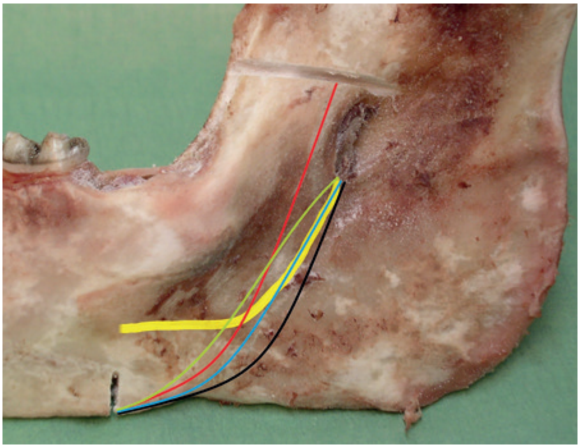

Figure 4 Lingual splitting patterns after performing a SSO. Yellow line: IAN; Blue line: the lingual fracture extended through the mandibular canal (40%); Black line: the lingual fracture originated inferior to the mandibular canal and continued and ended inferior to the canal (40%); Green line: the lingual fracture started inferior to the canal, crossed and ran superior along the mandibular canal (20%). Red line: unfavorable fracture that ended just in front of the mandibular foramen. All other lingual fracture lines ended in the concavity of the mandibular foramen (95%).

Results

On analysis of the fracture lines in relation to the mandibular foramen, we found that all but one (95%) of the lingual fractures ended in the mandibular foramen (Figure 3 and 4). The exception was an unfavorable fracture that ended just in front of the mandibular foramen. This originated from the inferior border and extended along the inferior border to cross the mandibular canal, then upwards ventrally of the mandibular foramen to the horizontal cut, which resulted the IAN still being positioned in the proximal segment (figure 4).

In relation to the mandibular canal, 40% of lingual fractures originated inferior from the vertical cut and extended through the mandibular canal, and 40% of them originated inferior to the mandibular canal and continued and ended inferior to the canal. The remaining 20% started inferior to the canal, crossed and ran superior along the mandibular canal and ended in the concavity of the mandibular foramen (Figure 3 and 4).

In relation to the inferior border, 6 lingual fracture lines (30%) originated directly from the inferior part of the vertical cut but did not run through the inferior border; instead, they extended more superiorly from the origin, eventually reaching the mandibular foramen. The remaining 70% of fractures continued through this inferior border. The average length of the fracture line at the inferior border was 11 mm (range, 7–34 mm) (Figure 3 and 4).

When the fractured segments were analyzed, no sharp bone interferences directed toward the mandibular canal causing possible damage to the IAN, were observed.

Discussion

BSSO is a relatively safe procedure for the correction of mandibular anomalies as part of surgical-orthodontic treatment. Since it is an elective procedure, it is very important to minimize the possible side effects of surgery, and modifications to existing splitting techniques should be designed to minimize complications. This pilot study shows that prying and spreading the mandible during the sagittal split osteotomy (SSO) with sagittal splitters and separators and placement of the medial cut into the concavity of the mandibular foramen leads to a predictable splitting pattern and could potentially minimize the risk of damage to the IAN and bad splits. This technique, with instruments which are especially created for prying and spreading the mandible and not driving chisels along the IAN to the mandibular border ('mallet and chisel technique'), is easy to perform and to learn (e.g.,for residents). Furthermore, prying and spreading the mandible could lead to a lower incidence of postoperative hypoesthesia, like suggested in earlier studies. [13,16,17] Using this pig model, allows good inspection of the lingual splitting patterns after SSO (compared to its absence of control and visualization due a clinical setting), which have never been analyzed in this way before. However, this pig model also has a superior visibility of the mandibular foramen when performing the bone cuts, while this degree of visualization is less in a clinical case.

The pig study model has been used successfully as a study model in earlier studies,[9,12,18-20] because there are similarities between the pig and human mandible, but caution is necessary when extrapolating the results. Pigs have longer mandibles and more teeth than humans. We placed our vertical cuts posterior to the most distal molar in the pig mandible, which is comparable to the cutting position used in humans. Unerupted molars were in situ in all the mandibles, but the fracture line always ran downwards and did not follow the follicular space of the non-erupted molar. Previous studies have also performed BSSO with the third molars in situ in the clinical setting, with no significant increase in the occurrence of bad splits or damage to the IAN compared to BSSO after removal of the third molars.[16,17] The mandibular canal is larger in pigs and has a pronounced divergent form at the beginning of the mandibular foramen. The region of the mandibular angle in pigs contains more cortical bone and less cancellous bone, which can influence the splitting pattern. However, in a normal split, this part of the mandible will be part of the proximal segment,[7] and therefore will not influence the splitting pattern.

The changes of the bony characteristics during preparation of these cadaveric pig mandibles used for SSO analyses have not been described in the literature. Thus, when analyzing the results, it is necessary to take this potential effect into consideration[21].

Bone is a composite of nanometer-sized carbonated apatite crystals (hydroxyl-apatite, containing calcium and phosphate) deposited in an organic matrix of collagen fibers with a hierarchical structure. The main constituent of the organic matrix, representing 90% of its weight, is type I collagen. When the collagen would be removed (using an alkali), one will experience 'stiff bone'. On the other hand, when all the minerals (using an acid) would be removed, one will experience 'flexible bone'. These chemical reactions will most likely not appear during a boiling or refrigerating process.

Bone collagen has a specific cross-link profile. This cross-linking influences the structure and physical properties and determines the viscoelasity of bone. Thermally induced denaturation of collagen influences the overall condition of the structure and cross-links in the collagen network. However, several studies showed that denaturation of Type I collagen in bone occurs only when temperature exceeds 120 °C and the degree of denaturation rises to approximately 50% at 160 °C. [23,24] During our short boiling process of the pig mandibles, the temperature never exceeded 100 °C and thus, it is most likely that the bone characteristics will not have changed extensively. This complies with our (subjective) feeling of the SSO's during this pilot study.

The fracture lines in this study were almost optimal, running from the inferior part of the vertical cut more or less perpendicular to the inferior border, along the mandibular canal to the mandibular foramen. The fracture lines along the inferior border or the mandibular canal to the mandibular foramen (80% of the fracture lines) seemed to follow the path of least resistance and this was probably due to the introduction of the sagittal separator immediately to the inferior border during the unfolding of the split (Figure 2c and 4). The superior extension of the inferior lingual border cut (ie., lingual vertical cut), as shown in figure 1, is meant to secure a fracture line in the lingual cortex instead of a buccal fracture line thus preventing a bad split. Using this higher extension of the lingual vertical cut, the possibility exists of the entire inferior border remaining within the proximal segment. In our experience (during our earlier reported prospective study[17] and BSSO cadaver courses) this has no influence on the retention of the IAN in either proximal or distal segment; not performing a proper vertical cut on the lingual side, did increase the amount of buccal bad splits. Entrapment of the IAN in the proximal segment is, in our opinion, more influenced by the transversal and vertical position of the canal, which may vary extensively as illustrated by Yoshioka et al.[22]

We analyzed the fracture lines that could potentially damage the IAN; we did not find any sharp bone fragments pointing toward the mandibular canal. A bad split at the site of a BSSO may be defined as unwanted fractures of the proximal or the distal segment of the mandible (buccal or lingual cortical plate fracture), and the reported incidence of these ranges from 0.5% to 5.4%.[8] We did not observe any bad splits in this study, and we observed only one unfavorable fracture during the splitting process, where the nerve was still attached to the proximal segment because the fracture line ended just ventrally to the mandibular foramen. None of the other splits resulted in the IAN being attached in the proximal segment.

We placed our vertical cut just posterior to the most distal erupted molar, unlike Bockmann et al.[9] and Schoen et al.[12], who placed it more or less at the middle of the first molar. A more anterior vertical cut produces a longer fracture along the lingual site, and therefore, in our opinion, this may result in a greater risk of unfavorable fracture along the lingual side, and potentially a greater risk of avascular necrosis in the ventral part of the buccal cortex. Schoen et al.[12] demonstrated splitting lines running along the mandibular canal (type A) or the inferior border (type B) and found that the an extra inferior bone cut along the inferior border will lead to more type B fractures. We also observed that 70% of fractures ran more or less along the inferior border and believe that this occurred due to placement of the forceps at the inferior border when performing the vertical cut and the unfolding of the split, despite not using a inferior extra bone cut, as described by Schoen et al[12]

Plooy et al. described in their study 4 different lingual splitting patterns: the lingual splitting scale (LSS 1-4: LSS1 'true' Hunsuck split; LSS2 'obwegeser' split; LSS3 split through the mandibular foramen; LSS4 other splitting type i.e. bad split)[7]. Performing the Hunsuck technique, the medial cut should be made behind the mandibular foramen and a small curved osteotome should be used to separate the cortices and create a fracture behind the mandibular foramen. The medial cut should be high enough to allow enough space through the osteotome, above the entrance of the IAN. In contrast, in this study, we used splitters and separators and extended the medial cut in the concavity of the mandibular foramen, just behind the lingula and just above the entrance of the mandibular foramen.

Plooy et al. intended to perform a 'true' Hunsuck every time, but stated that in only 51% of the cases the split ran as a 'true' Hunsuck (LSS 1). In 32% of the cases, it ran as a LSS 3 split (split through the mandibular foramen), as we intended to perform. They described also the combination of the placement of the horizontal medial cut in relation to the lingual fracture line; they emphasize more dorsal placement of the medial cut, which increases the amount of 'true' Hunsuck splits and decreases the amount of lingual fractures through the foramen by placing the medial cut more anteriorly.[7] This is in line with the findings of our pilot study.

The use of the chisel during a BSSO is, in our opinion, one of the causes of neurosensory disturbances involving the IAN. As previously reported,[6,9] chiseling downwards from the superior to the inferior border and passing or driving along the IAN increases the risk of damage to the IAN, particularly when using blunt chisels.[15] Hence, we used sagittal splitters and separators instead, for prying and spreading the mandible, however other instruments could be used.

In conclusion, our findings suggest that prying and spreading the mandible during the SSO in cadaveric pig mandibles, with the use of splitters and separators. provides a consistent splitting pattern. Creating an intended split running through the mandibular foramen along the mandibular canal could possibly follow the path of least resistance. Also, the need to place the medial horizontal cut in the concavity of the mandibular foramen (more anteriorly) could mean less mobilization of the IAN. On the basis of these results, we are currently conducting further research using human cadaveric mandibles to evaluate and validate this technique for the analysis of the pattern of the lingual fracture line and reduction of post-operative hypoesthesia of the IAN without increasing the incidence of possible other sequelae.

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6

Is the lingual fracture line influenced by the mandibular canal and/or the mylohyoid groove during a bilateral sagittal split osteotomy? A human cadaveric study

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Abstract

Purpose: Although the bilateral sagittal split osteotomy (BSSO) is a routinely performed procedure, the exact control of the lingual fracture line remains problematic. The purpose of this study was to determine the various lingual splitting patterns in cadaveric human mandibles after a BSSO and the possible influence of the mandibular canal and the mylohyoid groove on the lingual fracture line.

Methods: The investigators designed and implemented a case-series to compare the different lingual fracture lines. A standardized SSO was performed on 40 cadaveric hemi-mandibles with the use of elevators and splitting forceps. The primary outcome variable during this study was the lingual fracture pattern possibly influenced by independent variables: the mandibular canal, the mylohyoid groove and the dental status. Descriptive and analytic statistics were computed for each study variable.

Results: Most of the lingual fractures (72.5%) ended in the mandibular foramen. Only 25% of the fractures were a “true” Hunsuck fracture and no “bad splits” occurred. Meanwhile, 35% of the lingual fractures ran more than half or entirely through the mandibular canal, while only 30% of the fractures ran along the mylohyoid groove. However, when the lingual fracture ran along this groove, it had a 6-fold greater chance of ending in the mandibular foramen.

Conclusion: The hypothesis that the mandibular canal and/or the mylohyoid groove will function as the path of least resistance was only partly confirmed. The use of splitters and separators did not increase the incidence of bad splits compared with the literature.

Introduction

The inferior alveolar nerve (IAN) is an important structure during a bilateral sagittal split osteotomy (BSSO), and nerve damage is probably the most common complication of this type of surgery, causing hypoesthesia of the innervation region of the IAN.[1,2] Because BSSO is an elective surgery, it remains important to minimize these sequalae.

Before entering the mandibular canal, the IAN gives off a small mylohyoid branch that enters a shallow groove (or sometimes a partial canal, which is also described as mylohyoid bridging on the medial surface of the mandible) called the mylohyoid groove. This mylohyoid branch follows a course roughly parallel to its parent nerve (Figure 1),[3] and is primarily a motor nerve to innervate the mylohyoid muscle and the anterior belly of the digastrics muscle. Moreover, it provides a few filaments to supply the skin submentally over the point of the chin, sometimes including the lower incisor teeth (up to the first lower premolar).[4-6] Damage to the cutaneous branches of the mylohyoid nerve could also be responsible for causing (partial) hypoesthesia of the skin of the chin or even up to the lip.[5,7]

The nerve fibers of the IAN can be injured during a BSSO through surgical manipulation, including by stretching or crushing during the operation or by compression of the nerve bundle within the mandibular canal, or secondarily through hypoxia and edema caused by this manipulation. The injuries from surgical manipulation and the secondary effects can result in a combination of neuropraxia (bruising, such as damage to the myelin sheath) and partial axonotmesis (nerve fiber damage, such as sectioning of the axon).[8,9]

One of the potential causes of unwanted side effects, especially damage to the IAN, is that the classical technique used for splitting involves the use of mallet and chisels (i.e., a technique driving the chisels along the IAN to the inferior border of the mandible to split the proximal and distal parts) .[10-13] Hence, we believe a splitting technique without chisels but with sagittal splitters and elevators could potentially minimize the risk of injuries to the IAN without introducing other negative side effects.[1,2,14] In a previous pig cadaveric study, we suggested the mandibular canal and the mylohyoid groove or canal could function as a path of least resistance during the creation of a lingual fracture during BSSO.[14] If so, the use of this technique with sagittal splitters and elevators could lead to a higher predictability in the creation of a less forced lingual fracture and thereby could eventually lead to a lower percentage of patients with persistent hypoesthesia of the IAN.[15]

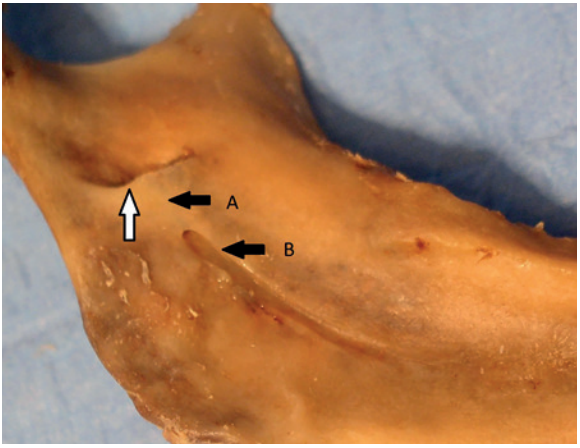

Figure 1 Image shows bridging (black arrow A) of the mylohyoid groove (black arrow B) and the mandibular foramen (white arrow).

The purpose of this study was to assess the lingual fracture line running through the mylohyoid groove and the mandibular canal and to determine the possible influence of this mandibular canal and mylohyoid groove on various lingual splitting patterns in cadaveric human mandibles after a BSSO. The investigators hypothesize that the lingual fracture during a BSSO is running through the mylohyoid groove or the mandibular canal, as a proposed weakest point of the mandible, with the lingual split subsequently ending in the mandibular foramen (Figure 2). We want to estimate a predictable "natural" fracture path of the lingual fracture using sagittal splitters and separators, without forced chiseling of the inferior border and identify possible other sequelae of this technique (ie. bad splits).

Materials and Methods

To address the research purpose, the investigators designed and implemented a case-series to compare the different lingual fracture lines. The study population was composed of 40 cadaveric hemi-mandibles. No sex or age characteristics were available. All mandibles with or without teeth were included. The presence of molars was reported, because of the possible influence during the splitting procedure. Mandibles with possible foreign bodies related to the bone (e.g. implants, metal plates) were excluded. First, the mandibles were excised out of formalinized cadaveric heads. After the mandible was excised, the soft tissue was stripped away, including the periosteum, with only the bony mandible remaining. The mandibles were split in

Figure 2 Image shows a lingual fracture line running through the mandibular canal and mylohyoid groove together as hypothesized. The lingual fracture line runs directly from the inferior border and will eventually end in the mandibular foramen as shown in 72,5% of the cases (LSS 3 fracture pattern).

a left and right mandible. Care was taken to preserve the IAN and the mylohyoid nerve. Pre-mortally, informed consent was given by all individuals to use their remains for scientific purposes. Therefore, we did not need to obtain approval from our institution to use the mandibles in our study. Parts of the heads had already been used for other scientific purposes.[16,17]

A standardized BSSO was performed on the cadaveric mandibles as reported by Hunsuck.[18] However, no chisels were used in the procedure, and the horizontal medial cut started just cranially of the mandibular foramen and ended in the deepest point of the concavity of the mandibular foramen, as reported before in our clinical setting.[1,2,14] No attempt was made to force a lingual fracture dorsally of the mandibular foramen. Instead, the primary focus was to end it exactly in the mandibular foramen and thereby to create a lingual fracture through the mandibular foramen, as in our previously reported pig pilot study.[14] First, a horizontal bone cut was performed with a Lindemann bur (2.3 × 22 mm) approximately 5 mm cranially of the entrance point of the IAN until the trabecular bone was visible and was ended precisely at the deepest point of the concavity of the mandibular foramen. Subsequently, the vertical cuts and the sagittal bone cut, which connected the horizontal and vertical bone cuts, were made with a short Lindemann bur (1.4 × 5 mm). The vertical cut was placed just behind the second molar or its estimated location. The inferior border was cut perpendicular through the inferior cortex, just reaching the medial side running vertical to the lingual cortex (about 2 mm), to show the trabecular bone (Figure 2). After the bone cuts, the splitting was performed with an elevator positioned in the vertical bone cut and the splitting forceps in the sagittal bone cut. When the superior aspect of the mandible started to split, the elevator was repositioned at the inferior border of the vertical cut, and the splitting was completed.

Study Variables

The 2 primary outcome variables during this study were first the lingual fracture line running through the mylohyoid groove and/or mandibular canal and secondly the lingual fracture pattern (according to the Lingual Splitting Scale (LSS) by Plooij et al.[15]) possibly influenced by 3 independent variables: the mandibular canal, the mylohyoid groove and the presence of molars in the cadaveric mandible.

Secondary outcome variables were entrapment of the IAN in the distal part of the mandible after a SSO and the inferior border fracture.

Lingual splitting pattern

First the aspect of the lingual split in relation to the mylohyoid groove and the mandibular canal was examined (Figure 2). The lingual fracture was categorically assessed as running entirely through the mandibular canal; running more than half through the mandibular canal; extended through less than half of the proximal area of the mandibular canal; or as no relation to the mandibular canal.

Subsequently, the lingual splitting pattern in the mandible was categorically examined using the lingual splitting scale (LSS) developed by Plooij et al.[15] The LSS categorizes the lingual splitting patterns as splitting behind the mandibular foramen (“true” Hunsuck; LSS 1), splitting to the posterior border (“Obwegeser split”; LLS 2), splitting through the mandibular foramen (LSS 3) and other patterns, such as bad splits (LSS 4; Figure 3, Table 1).

Entrapment of the IAN

After completion of the split, the mandible was twice examined to determine whether the IAN was present either in the proximal or in the distal part of the mandible. If the IAN was still present in the proximal part of the mandible, it was established whether the IAN had to be freed either with or without additional bone surgery.

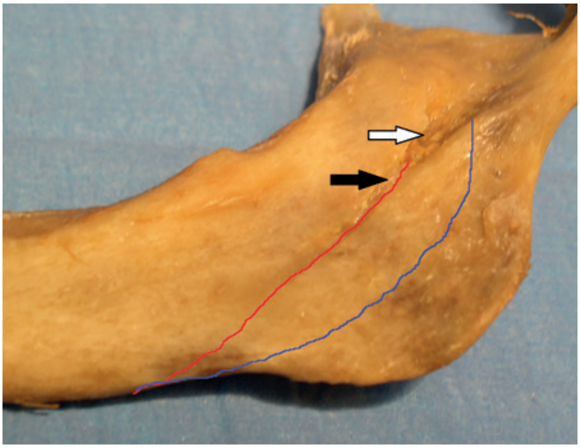

Figure 3 Illustration of the scoring system of the lingual fracture patterns. Red line: hypothesized fracture line through the mylohyoid groove ending in the mandibular foramen. Blue line: "classic" fracture pattern more posteriorly (Hunsuck fracture). Black arrow: mylohyoid groove. White arrow: indicates mandibular foramen.

Inferior border fracture

In addition to the splitting patterns, the distance and characteristics of the fractures running along the mandibular border were categorical evaluated to provide possible information about bad splits (e.g., a split starting buccally and creating a buccal plate fracture) and bony contact after advancement of the mandible. The fractures running along the mandibular border were categorized in 4 groups: 1) not running through the inferior border but directly more cranially on the lingual side of the mandible; 2) running 1–10 mm through the inferior border; 3) running more than 10 mm through the inferior border; 4) not starting lingually but buccally.

Data analyses

All statistical data were carried out with SPSS software program, version 18.0 for Windows (SPSS Inc., Chicago, USA). Descriptive statistics were computed for each study variable. Bivariate analyses (Crosstabs, the Pearson chi-square tests, logistic regression) were computed to measure the association between the primary fracture outcome with the 3 variables of interests. The variables measured were adjusted for correlation by logistic regression, because 2 observations (left and right side of a mandible) were derived within one subject. Values of $p < 0.05$ were considered statistically significant.

Results

The hemi-mandibles varied from completely dentate to completely edentulous (95% were at least edentulous posterior to the premolars). None of the mandibles contained an impacted third molar. Thirty-four hemi-mandibles (85%) had a mylohyoid groove, while 4 (10%) showed bridging of the mylohyoid groove. Two hemi-mandibles (5%) had neither a mylohyoid groove nor mylohyoid bridging (Figure 1; Table 2).

There were 40 sagittal split osteotomies (SSO) performed. None of the splits resulted in a bad split. Eleven sites (27.5%) required instrumentation to release the IAN from the proximal part of the mandible.

Lingual splitting patterns using the LSS

As evaluated using the LSS, the majority of lingual fracture lines (29 sites; 72.5%) ended in the concavity of the mandibular foramen (LSS3) (Figure 3). Meanwhile, 1 lingual fracture (2.5%) ended at the posterior border as a "Obwegeser" split (LSS2), while 10 (25%) ended just posterior to the mandibular foramen ("true" Hunsuck, LSS1). Because no bad splits occurred, no LSS4 splitting patterns were seen (Table 1).

Table 1 Comparison of LSS between the present study and the study of Plooij et al.[15].

LSS category	The present study	Plooij et al.[15]
LSS1 ("true" Hunsuck)	25%	51%
LSS2 ("Obwegeser" split)	2.5%	13%
LSS3 (split through the mandibular foramen)	72.5%	33%
LSS4 (other splitting type; i.e., bad split)	0%	3%

Relationship of the fractures to the mylohyoid groove and the mandibular canal

Twelve (30%) of the lingual fracture lines had a relation with the mylohyoid groove and ran through the mylohyoid groove (Figure 2). After leaving the inferior border, 15 (37.5%) of the lingual fracture lines ran parallel and inferior to the mylohyoid groove to the horizontal bur cut. Meanwhile, 3 (7.5%) ran parallel and superior to the mylohyoid groove, whereas 7 (17.5%) crossed the mylohyoid groove and ran to the horizontal bur cut. Two of the mandibles did not have a mylohyoid groove, and there was 1 "Obwegeser" split. When we evaluated whether a lingual fracture line running through the mylohyoid groove correlated with it ending in the foramen, instead of behind the

Table 2 Presence of a mylohyoid groove or bridging of the mylohyoid groove.

40 hemi-mandibles	total (percentages)
Mylohyoid groove	34 (85%)
Mylohyoid bridging	4 (10%)
No Mylohyoid bridging or groove	2 (5%)

mandibular foramen (LSS3), we observed a nonsignificant trend of the lingual fracture ending in the foramen (LSS3) when the fracture ran through the mylohyoid groove (odds ratio = 6.11; 95% confidence interval, 0.685–54.506; p = .105).

With respect to the mandibular canal, 7 (17.5%) of lingual fractures ran entirely through the mandibular canal; 7 (17.5%) ran through more than half of the mandibular canal; 13 (32.5%) extended through less than half of the proximal area of the mandibular canal; and 13 (32.5%) had no relation to the mandibular canal. When we evaluated whether a lingual fracture line running through the mandibular canal correlated with it ending in the mandibular foramen (LSS 3), no correlations could be computed between these 2 parameters.

The dental status (ie. hemi-mandibles containing molars) could not be correlated to a certain fracture patterns. Only 2 hemi-mandibles contained molars and no LSS variations were present within this group.

Inferior border fractures

Thirteen fracture lines (32.5%) ran directly to the lingual side; 13 splits (32.5%) ran less than 10 mm; and 14 splits (35%) ran more than 10 mm through the mandibular inferior border (Table 3.). Hence, the fracture lines running along the inferior border were almost equally divided among these 3 categories. One split showed an unexpected “Obwegeser” split and ran entirely along the inferior border; this split was included in the final of these 3 categories. None of the splits ran buccally. When the fracture ran through the inferior mandibular border, the distance varied from 2.5–22 mm (mean ± SD, 11 ± 6.5 mm).

Table 3 Divisions of groups of the lingual fracture lines running along the inferior border of the mandible. (1 split showed an unexpected 'obwegeser' split an ran entirely along the inferior border, included in group 3)

Lingual fracture line running along the inferior mandibular border divided in groups. ***(range 2,5-22 mm; mean 11 mm; SD 6,5 mm)***	**Amount of splits (percentages)**
Group 1 *(Not running through the inferior border, but directly to the horizontal medial cut)*	13 (32,5%)
Group 2 *(Running 1- 10 mm through the inferior border)*	13 (32,5%)
Group 3 *(Running more than 10 mm through the inferior border)*	14 (35%)
Group 4 *(Not starting lingual, but buccaly)*	0 (0%)

Discussion

The purpose of this study was to determine the various lingual splitting patterns in cadaveric human mandibles after a BSSO and the possible influence of the mandibular canal and the mylohyoid groove on the lingual fracture line into the mandibular foramen. The investigators hypothesized that the lingual fracture during a BSSO is running through the mylohyoid groove or the mandibular canal, as a proposed weakest point of the mandible, with the lingual split subsequently ending in the mandibular foramen. Furthermore, we wanted to estimate a predictable "natural" fracture path of the lingual fracture using sagittal splitters and separators, without forced chiseling of the inferior border and identify possible other sequelae of this technique (ie. bad splits).

The hypothesis that the mandibular canal and mylohyoid groove will function as the path of least resistance was not confirmed in our data. We observed that a minority of the splits had a relationship with the mandibular canal (35%) and/or the mylohyoid groove (30%) and that the concave contour of the lingual cortex between the mandibular foramen and the inferior border cut defined a relatively consistent fracture path. However, a trend was observed in which the occurrence of a lingual split into the mandibular foramen (LSS3) was associated with the fracture running to the mylohyoid groove. The mandibular canal or the dental status could not correlated within this limited dataset.

The inferior border fractures were classified almost equally into groups 1, 2 and 3 (0 mm, 1–10 mm, and >10 mm, respectively). No buccal fracture lines occurred in group 4. These results could explain why only 30% and 35% of the lingual fractures had a relationship with the mylohyoid groove or the mandibular canal, respectively. Instead of running more cranially, the fracture still ran through the inferior border. Furthermore, the absence of bad splits is favorable in comparison to the series of Plooij et al.[15] This previous study used chisels, and 3% of the fractures were bad splits, in keeping with the literature. In this cadaveric study no bad split occurred, which is well below the incidence (mean 4,6% per patient) mentioned in the literature.[14]

Further, in the present study, 34 (85%) mandibles had a mylohyoid groove; 4 (10%) showed bridging of the mylohyoid groove; and 2 mandibles (5%) lacked a mylohyoid groove. These findings are consistent with earlier reports, which showed a mylohyoid canal or bridging around 7% (Table 2).[3]

As shown in Table 1, the relative frequencies of the different type of splits differ between Plooij et al.[15] and the current study. The more anterior split (i.e., more splits to the mandibular foramen and less “Hunsuck” and “Obwegeser” splits) was favored in the current study. Plooij et al.[15] also previously described that the chance of splitting the ramus according to Hunsuck’s description increased from 44% to 63% when the medial bone cut ended behind the anterior border of the mandibular foramen, and that the chance of splitting through the mandibular canal was significantly reduced from 43% to 11%. In the present cadaveric study, the medial bone cut was ended in the mandibular foramen, resulting in 72.5% of the lingual fractures ending in the mandibular foramen, with 6-fold higher chance when the lingual fracture ran along the mylohyoid groove. The relation with the mandibular canal could not be explored due to the limited size of this data set. Different splitting techniques and patterns have been described for BSSO. The lingual side caudally of the mandibular foramen mandible is not visible, and no intentional lingual cut is made during clinical BSSO. Hence, the path of the lingual fracture is under little control.[15] However, in an earlier pilot study with cadaveric pig mandibles[14], we concluded that prying and spreading the mandible during the SSO, with the use of splitters and separators, provides a consistent splitting pattern. Creating an intended split running through the mandibular foramen along the mandibular canal and could possibly follow the path of least resistance.

According to these previous and current reports, we believe it is not necessary to place the horizontal bur cut dorsally from the mandibular foramen and/or perform a cortical separation by chisel cranially and dorsally from the mandibular foramen in order to obtain a predictable split. Moreover, with a more anterior split, less “bony” splitting is performed in the sagittal plane, therefore resulting in less instrumentation along the IAN during the split, probably causing less trauma to the IAN and less operation time.

In the literature, exact information on the IAN remaining in the proximal segment after the split is scarce. In the present study, 11 of the sites (27.5%) required instrumentation to release the IAN from the proximal segment, which seems to be average and in line with our previously reported clinical study (27.5% vs. 23.7%).[1] In the report of Van Merkesteyn et al.,[2] the remaining IAN in the buccal segment was slightly higher and did not seem to lead to a high incidence of hypoesthesia.

The value of studies of splitting techniques in cadaveric mandibles may be limited because of the use of formalinized mandibles and the higher frequency of edentulous mandibles when compared to a clinical setting. Also in this case-series only 2 hemi—mandibles were present containing molars, being a possible influence positioned along the bur cuts or fracture line. The increase in the gonial angle in older patients and edentate subjects is controversial, and the IAN position could vary following the degree of alveolar ridge resorption. However, according to Oth et al.[5] the use of mandibles from older individuals remains a suitable option for performing such a study. Nonetheless, extrapolating the results to a clinical setting should be done with caution, also because this model has a superior visibility of the mandibular foramen when performing the bone cuts, whereas this degree of visualization is less in a clinical case.

Conclusions

The hypothesis that the mandibular canal and/or the mylohyoid groove will function as the path of least resistance was only partially confirmed. That is, the mandibular canal and/or the mylohyoid groove did provide the point of weakest resistance, resulting in 35% and 30% of the lingual fractures, respectively. Further, 72.5% of the lingual fractures ended in the mandibular foramen, with a 6-fold greater chance of having a fracture in the mandibular foramen when it ran along the mylohyoid groove. Additionally, we showed a higher incidence of a more “anterior” split compared to Plooij et al.[15], probably because of our different splitting method. The present study showed that the use of splitters and separators does not increase the amount bad splits compared with the literature.

These results should stimulate further research into lingual fracture lines. In particular, the relation of different types of bur cuts to the various lingual fracture lines should be evaluated in a large sample size. Subsequent comparative studies could be performed in a clinical setting to evaluate the fracture lines postoperatively with cone beam CT and their possible relation to postoperative hypoesthesia. Eventually these differences could influence the post-operative hypoesthesia of the IAN, especially when not using chisels along the IAN to the inferior border of the mandible.

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Bad split during bilateral sagittal split osteotomy of the mandible with separators: a retrospective study of 427 patients

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Abstract

An unfavourable fracture, known as a bad split, is a common operative complication in bilateral sagittal split ramus osteotomy (BSSO). The reported incidence of this complication ranges from 0.5 to 5.5% per site. Since 1994 we have used sagittal splitters and separators instead of chisels for BSSO in our clinic in an attempt to prevent post-operative hypoesthesia. Theoretically an increased percentage of bad splits could be expected with this technique. In this retrospective study we aimed to find out the incidence of bad splits associated with BSSO performed with splitters and separators. We also assessed different risk factors for bad splits. The study group comprised of 427 consecutive patients among whom the incidence of bad splits in this group was 2.0% per site, which is well within the reported range. The only predictive factor for a bad split was the removal of third molars at the same time as BSSO. There was no significant association between bad splits and age, sex, occlusion class, or the experience of the surgeon.

We think that doing a BSSO, performed with splitters and separators instead of chisels, does not increase the risk of a bad split and is therefore safe with predictable results.

Introduction

Bilateral sagittal split osteotomy (BSSO) is one of the most common used operative techniques to correct mandibular deformities.[1] Since it was first described by Trauner and Obwegeser, efforts to reduce associated complications have led to several modifications.[2] However, the procedure still presents a certain degree of technical difficulty and is associated with several potential complications.

One such intra-operative complication associated with BSSO is an irregular osteotomy pattern or unfavourable fracture, known as a bad split.[3] The reported incidence of bad split at a sagittal split osteotomy (SSO) site ranges from 0.5 to 5.5%.[4-20] This unwanted fracture is normally located in either the distal (lingual plate fracture) or proximal cortical plate (buccal plate fracture) of the mandible and more rarely affects the coronoid process or the condylar neck. When a bad split is adequately treated, the chances of functional success are good, though there may be some limitations,[21] so the number of bad splits should be minimized.

Our clinic abandoned the use of chisels to minimize post-operative hypoesthesia,[22] in favour of sagittal splitters and separators (elevators) are used.[8] Theoretically, this technique could result in more bad splits, so the purpose of this study is to review retrospectively the incidence of bad splits of the mandible associated with BSSO using sagittal split separators, in a single centre over 17 years.

Patients and Methods

We retrospectively analysed the clinical records and radiographs of 427 consecutive patients who underwent BSSO in our clinic between July 1994 and December 2011. In 1994, we introduced sagittal splitters and separators instead of chisels for BSSO. All planned BSSOs, single procedures, and those associated with other procedures were included (Table 1).

The patients' medical files and orthopantomographs were screened for the patient's sex, age at surgery, pre-operative diagnosis, BSSO procedure (unilateral or bilateral), concomitant procedures, and presence of third molars. The state of third molars was classified as follows: absent at first consultation; removed prior to BSSO; removed concomitant with BSSO; or present after surgery. If third molars were left in place, they were in occlusion with maxillary antagonists. We also noted whether the BSSO was performed by a specialist or a resident, whether there was a bad split during the operation and type of bad split, the incidental use of chisels, and the method of postoperative fixation.

Table 1 Distribution of procedures other than BSSO in 427 patients.

Procedure(s)	Patients	%
BSSO	229	53.6
BSSO + Le Fort I	124	29.0
BSSO + genioplasty	31	7.3
BSSO + Le Fort I + genioplasty	43	10.1

Data are number (%).

There were 150 males and 277 females ages at the time of operation ranged from 13.8 to 55.6 years (mean (SD) age, 27.3 (9.8) years). In 363 cases, the mandible was moved ventrally to correct a class II malocclusion. A class III malocclusion was present in 59 patients, which resulted in posterior movement of the mandible. Indications for BSSO are summarized in Table 2. Five patiens had indications other than class II/III malocclusion (such as condylar hyperplasia or cleft lip and palate).

Table 2 Indications for BSSO in 427 patients.

Category	Patients	%
Class II malocclusion	363	85.0
Class III malocclusion	59	13.8
Other	5	1.2

Data are number (%).

BSSO was done without the use of chisels, as first described by van Merkesteyn et al.[8,22] Splitting forceps (Smith Ramus Separator 12 mm, Walter Lorentz Surgical, Jacksonville, FL, USA) and elevators were used. The procedures were performed while patients were under general anaesthesia. To reduce bleeding, the surgical area was infiltrated with epinephrine 1:160 000 (Ultracaine D-S, Aventis Pharma, Hoevelaken, The Netherlands). The mandibular ramus was exposed and the mandibular foramen was located. A periosteal elevator was placed subperiosteally just above the mandibular foramen, and the horizontal bone was cut with a Lindeman burr (2.3 × 22 mm) approximately 5 mm above the mandibular foramen. Subsequently, the sagittal and vertical cuts were made with a short Lindeman burr (1.4 × 5 mm). The inferior border was cut perpendicularly through the inferior cortex, just reaching the medial side. Splitting was done with an elevator positioned in the vertical bone cut and the splitting forceps in the sagittal bone cut. Once the superior aspect of the mandible started to split, the elevator was repositioned at the inferior end of the vertical cut, and splitting was completed. Care was taken to be certain that the inferior alveolar nerve was in the distal segment when the split was completed. A chisel was only used when a small bridge of cortical bone between the buccal and lingual segments remained at the inferior border of the mandible, well below the level of the mandibular canal.

After mobilization, the mandible was placed into the new intermaxillary relationship using a wafer, and intermaxillary wire fixation was applied. When possible, 3 bicortical screws (Martin GmbH, Tuttlingen, Germany; 9, 11, or 13 mm in length; 2.0 mm in diameter) were placed in the upper border of the mandible on both sides. Other fixation methods, such as Champy plates or upper wire fixation, were used if screw fixation was not optimal because of fragile bone, after removal of third molars or after a bad split. The temporary intermaxillary fixation was then removed, and the occlusion was checked. No elastic bands were used. Permanent intermaxillary fixation with upper border wiring was only used after a bad split or intra-oral vertical ramus osteotomy (IVRO).

All patients were discharged from the hospital within a week after the operation and were asked to return for evaluation 1, 6, and 12 months after the discharge.

Statistical methods

All statistical analyses were performed with the help of SPSS 16.0 for Windows (SPSS, Inc.; Chicago, IL, USA). Crosstabs, Pearson's chi-square test, and logistic regression were used, as appropriate, to assess the significance of differences among variables. All statistical associations are reported with odds ratios (ORs) and 95% confidence intervals (CIs). Probability of less than 0.05 accepted as significant.

Results

In 851 sagittal splits (427 patients), there were 17 bad splits (2.0%). All 17 were unilateral, in the form of 11 fractures of buccal plate (64.7%), 5 lingual plate fractures (29.4%) and 1 condylar neck fracture (5.9%) (Figure 1 and 2). Although BSSO was planned in all cases, sagittal split osteotomy was unilateral in 3 (0.7%) patients. One patient eventually had a intraoral vertical ramus osteotomy (IVRO) on both sides, after a large buccal plate fracture occurred during the first initial sagittal split. One patient had a sagittal split on one side and an IVRO on the other side, because of a high mandibular foramen. In the third case, the operation was terminated after the first

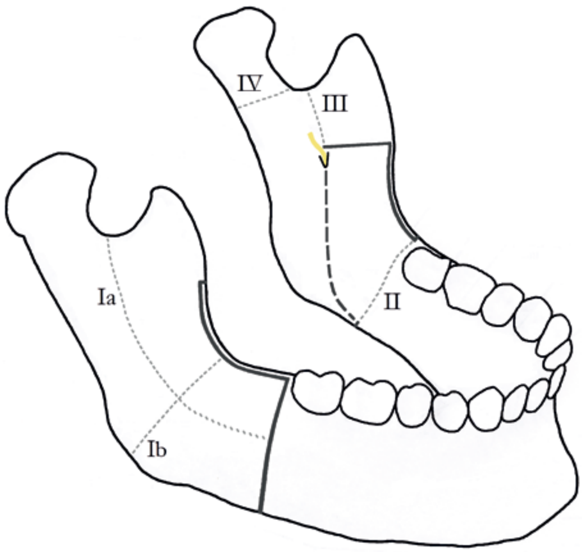

Figure 1 The fracture lines and cuts of a BSSO including the most common unfavourable fractures. Yellow line, mandibular nerve; solid grey line, bone cut made with burr; dashed grey line, favourable fracture line; and dotted grey line, bad split. **I**, fracture of buccal plate; **a**, horizontal and **b**, vertical (n=11; **II**, fracture of lingual plate (n=5); **III**, fracture of coronoid process (n=0); and **IV**, fracture of condylar neck (n=1).

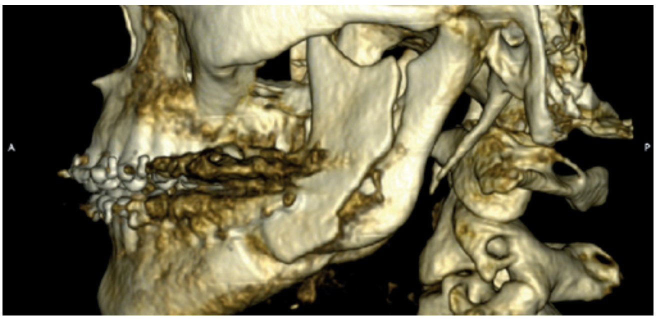

Figure 2 Cone Beam Computed Tomography (CB-CT) scan of a horizontal buccal plate fracture of the left side of the mandible during a BSSO, reaching the incisura semilunaris (figure 1; type Ia). The proximal and distal segment of the mandibula were eventually fixated with two bicortical screws on the lower border of the mandible (in this figure hidden behind the buccal segment), combined with plate fixation to attach the buccal segment.

sagittal split, and fixation was completed without translocation of the mandible because of a large buccal plate fracture. The buccal plate was fixated and both lower third molars were removed. A successful BSSO was performed 6 months after the initial procedure.

The bad splits occurred in 6 males and 11 females (mean age, 29.3 years; range, 14.83–53.89 years). Sex ($p = 0.988$, OR 1.01, 95% CI 0.363–2.711) and older age ($p = 0.399$, OR 0.980, 95% CI 0.935–1.027) were not significantly associated with bad splits during BSSO; however, more bad splits occurred in female than in male patients. Preoperative class of occlusion did not differ significantly either; bad splits occurring in 14 patients with a class II malocclusion and 2 with a class III malocclusion ($p = 0.862$, OR 1.143).

We analysed the duration between preoperative removal of third molars and bad splits. The preoperative status of third molars is summarized in Table 3. In 180 patients (328 sites), one or both third molars were absent at first consultation, making it impossible to determine the time of removal. Third molars were removed preoperatively in 177 patients (301 sites), with time of removal ranging from 1 month to 15 years prior to surgery (mean (SD) 10.4 (16.1) months). Third molars were removed during BSSO in 120 patients (219 sites) and remained present after surgery in 4 patients (6 sites). The time between removal of third molars and bad split was not significanttly associated with the occurrence of a bad split ($p = 0.149$, OR 0.998, 95% CI 0.998–1.001). However, the removal of third molars at the same time as BSSO was significantly associated with bad split ($p = 0.041$, OR 2.637). In 8 of the 17 bad splits, a third molar was present at the site of the split.

All patients were operated on either by experienced senior staff or a resident assisted by a senior staff member. In 165 (38.6%) patients, the sagittal splits on both sides were performed by senior staff; in 252 (59.1%) patients, senior staff performed

Table 3 Status of lower third molars in 427 patients.

Category	Left Side	%	Right side	%
Absent at first consultation	169	39.6	159	37.2
Removed prior to BSSRO	148	34.7	153	35.8
Removed concomitant with BSSRO	107	25.1	112	26.2
Present after surgery	3	0.7	3	0.7

Data are number (%).

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the sagittal split on one side and a resident on the other side; and in 10 (2.3%) patients, a resident, supervised by senior staff, operated on both sides. The occurrence of bad splits was not associated with the surgeons' level of experience (resident vs staff member) ($p = 0.472$, OR 1.514, CI 95% 0.489–4.687).

Of the 17 patients with a bad split, 2 had persistent neurosensory disturbances after at least 1 year.

In 403 (94.4%) patients, BSSO was done with only spreaders and separators. A chisel was necessary in only 24 (5.6%) patients, because of a small bridge of cortical bone that remained at the inferior border of the mandible.

Postoperative mandibular fixation was by bilateral screws in 414 (97.4%) patients. In this group, 4 (0.9%) involved combined fixation with mini-plates, and 2 (0.4%) patients had screw fixation in combination with intermaxillary fixation (IMF). Five (1.2%) patients, unilateral plate fixation on 1 side and screw fixation on the other; bilateral plate fixation was used in 1 patient (0.2%). Plate fixation was used because of a bad split in 4 (0.9%) patients and fragile cortical bone in the other 6 (1.4%). Intermaxillary fixation was used on 9 (2.1%) patients, 7 times after a bad split and twice after the IVRO.

All patients eventually recovered with good functional and aesthetic results.

Discussion

The exact combination of factors that result in bad split is unknown. Reported predictors are the presence of third molars and age at operation. Older patients have been reported to have an increased risk of bad split.[6] In our patients, age was not a complicating factor, as we found no relationship between age and bad split.

No association between bad split and patient's sex or surgeon's experience has been reported, and our findings are consistent with others in this regard.[10,11,12]

The removal of third molars before BSSO is controversial. Some have suggested that if third molars need to be removed, it should be done at least 6 months before orthognathic surgery.[11,13,23] Other have authors advised removal of third molars at the same time as orthognathic surgery and they describe fewer postoperative complications, such as hypoesthesia, with this method.[4,15,24] In our patients, there were significantly more bad splits during BSSO among those who had simultaneous removal of the third molars.

Although one could expect that more healing time would reduce the risk of a bad split, our retrospective study did not allow us to infer an optimal time for removal of third molars before BSSO. In our clinic, most third molars that were present during the last 5 years preoperatively were removed at the time of BSSO. This is because separate third molar removal is estimated to increase the risk of inferior alveolar nerve damage, and separate operation was also more inconvenient for the patient who would have to undergo several procedures instead of just 1 combined procedure.

One would expect bad splits to occur more often with less experienced surgeons, such as residents. However, no such differences were found between senior staff members and residents, probably because the latter were closely supervised during BSSO and corrected when necessary.

In our study sample, a bad split occurred in 17 of 851 sagittal splits, which is consistent with the average reported in the literature (Table 4). The use of splitters and separators

Table 4 Reported incidences of bad split during BSSO.

	Year of publication	Number of bad splits	SSO's (n)	Patients (n)	Incidence per site (%)	Incidence per patient (%)
Doucet[4]	2011	21	677	339	3.1	6.2
Falter[5]	2010	14	2005	1008	0.7	1.4
Kriwalsky[6]	2007	12	220	110	5.5	10.9
Kim and Park[7]	2007	11	-	214	-	5.1
Van Merkesteyn[8]	2007	2	222	111	0.9	1.8
Teltzrow[9]	2005	12	2528	1264	0.5	0.9
Borstlap[10]	2004	20	444	222	4.5	9.0
Reyneke[11]	2002	4	139	70	2.9	5.7
Panula[12]	2001	12	-	515	-	2.3
Mehra[13]	2001	11	500	262	2.2	4.2
Acebal-Bianco[14]	2000	8	-	802	-	1.0
Precious[15]	1998	24	1256	633	1.9	3.8
Van de Perre[16]	1996	97	2466	1233	3.9	7.9
Turvey[17]	1985	9	256	128	3.5	7.0
Martis[18]	1984	5	-	258	-	1.9
Macintosh[19]	1981	16	-	236	-	6.8
Behrmann[20]	1972	10	-	600	-	1.7

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without chisels, therefore, does not lead to a higher risk of bad splits. The bad splits were localised as 11 (64.7%) buccal plate fractures, 5 (29.4%) lingual plate fractures, and 1 condylar neck fracture (Figure 1 and 2). When a bad split occurred, additional fixation was usually necessary. Fractures of the buccal and lingual plate could be fixated with screws, or plates, or both and sometimes IMF, depending on the fracture lines. The fractured condylar neck resulted from a bad split of the buccal segment, with the condylar neck attached to the distal segment. The condylar process was therefore separated on purpose from the distal segment and we attempted to fix it to the proximal segment. Because this was not possible, we eventually wired the upper border and used IMF. This procedure was almost similar, although accidently, to the recently discussed supraforaminal horizontal oblique osteotomy.[25]

Although BSSO was planned in all patients, the procedure was converted to IVRO in 3 sites in 2 patients. This is only possible during a setback and requires IMF, making it a suboptimal option. However, when a safe sagittal split is not possible, it can be helpful in treating these difficult cases.

Our goal in using splitters and separators was to reduce postoperative neurosensory disturbances after BSSO, so the percentage of neurosensory disturbances after a bad split should not be increased. The incidence of persistent neurosensory disturbances after a bad split was 11.7% per patient in this study. Our reported incidence of neurosensory disturbances in previous studies using this technique was 10.5% per patient, which is slightly less.[22] Bad splits using this technique, therefore, do not introduce significantly more postoperative neurosensory disturbances.

The chances of good functional success after a bad split are high, and as such bad splits are regarded as complications without long-term consequences.[5,21] Nevertheless, the number of bad splits should always be minimized because of adverse short-term consequences, such as longer operation time, loss of concentration of the surgeon, use of intermaxillary fixation, and reoperation or conversion to IVRO with IMF. All patients in our group, including the patients with bad splits, functioned well after the operation(s).

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Bilateral sagittal split osteotomy in a mandible, previously reconstructed with a non-vascularised bone graft

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Abstract

This case reports of a bilateral sagittal split osteotomy (BSSO) in a reconstructed mandible. A 28-year old woman underwent a segmental mandibulectomy, due to a multicystic ameloblastoma in the left jaw. After primary plate reconstruction, final reconstruction was performed with a left posterior iliac crest cortico-cancellous autograft. Due to a pre-existing Class II malocclusion, the patient was analyzed for combined orthodontic-surgical treatment. Subsequently, after one year of orthodontic treatment, the BSSO was planned. The sagittal split was performed in the remaining right mandible and on the left side in the iliac crest cortico-cancellous autograft. Ten months later, oral rehabilitation was completed with implant placement in neo-mandible as well. Follow-up showed a Class I occlusion, with good function. The patient was very satisfied with the functional and aesthetic results. This shows a BSSO can be performed in a reconstructed mandible, without side effects and with good functional and aesthetic results.

Introduction

A bilateral sagittal split osteotomy (BSSO) is a procedure used frequently for the correction of a Class II malocclusion. Although the technique still presents a certain degree of technical difficulty, it has become a reliable procedure in orthognatic surgery. Reports of BSSO in a mandible, reconstructed with a non-vascularised bone graft, after hemimandibulectomy (because of an ameloblastoma), have not been published previously.

Multicystic ameloblastoma (MA) is an uncommon benign odontogenic neoplasm of the jaws. This cystic tumour is most often found in the mandible in the region of the molars and ramus. Ameloblastoma usually progresses slowly, but are locally invasive and, uncontrolled, may cause significant morbidity and sometimes death. MA is the most common ameloblastoma and is considered the most aggressive variant. As curative treatment segmental mandibulectomy with a 1- to 1.5-cm linear bony margin is the treatment of choice in these cases.[1]

After (partial) resection of mandible, due to large benign tumours, reconstruction is necessary. Several reconstructive procedures, such as vascularised and non-vascularised bone flaps, can be considered.[2,3] A common technique is reconstruction with a non-vascularised iliac crest bone graft.[4]

After mandibular reconstruction, oral rehabilitation can be completed with implant placement. High survival and success rates after implant placement in autogenous bone grafts are reported, with an excellent prognosis of implant-supported prostheses.[5]

This study reports a case of a bilateral sagittal split osteotomy, in combination with implant rehabilitation in the non-vascularised iliac crest bone graft in a 33-year old woman after hemimandibulectomy, due to a multicystic ameloblastoma.

Case report

A healthy, 28-year old, female patient was diagnosed with a follicular type multicystic ameloblastoma in the body of the mandible, near the mandibular angle on the left side. (Figure 1) The patient underwent a segmental mandibulectomy, starting between the first and second premolar to the ramus, with preservation of the left condyle.

Primary reconstruction was performed with a plate (UniLOCK Plate 2.4, angled, TiCP, SYNTHES, Oberdorf, Germany). Seven months later, after recovery and confirmation of clear pathologic margins, the mandible was reconstructed as described by Marx.[4] Restoration of the left hemimandible was performed with a left posterior iliac crest cortico-cancellous autograft. The defect of the mandible was measured (17 mm by 56 mm) preoperatively, using an orthopantomogram (OPT). Via extra-oral approach the initial reconstruction plate was visualized and freed, because it had been fractured, due to trauma. A new similar plate was placed to support and fixate the bone graft. The cortico-cancellous graft was adjusted to the lingual side of the plate and kept in place by primary closure of the soft tissues in several layers. Recovery was uneventful and the graft consolidated in a slightly inferior position. (Figure 2)

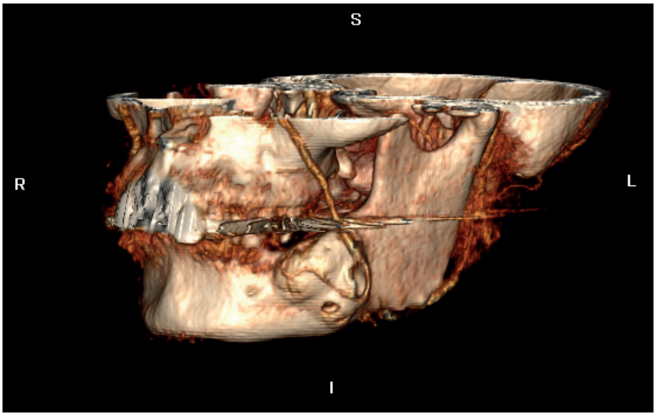

Figure 1 Three-dimensional image of the multicystic ameloblastoma in the body and angle of the left hemimandible.

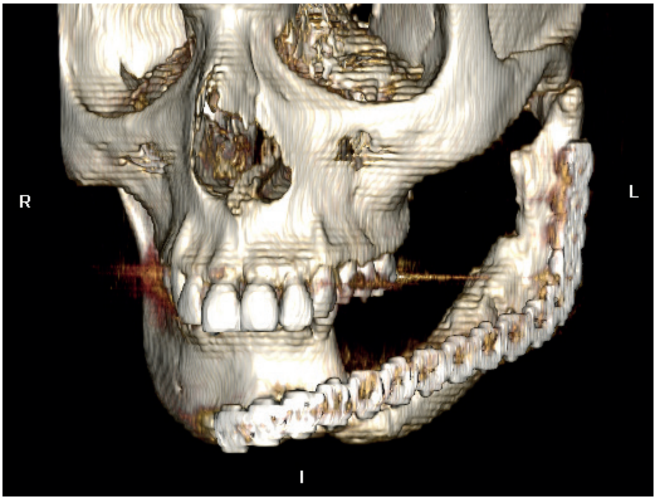

Figure 2 Three-dimensional image of the mandible after reconstruction with a plate and autologous bone from the left posterior iliac crest. The cortico-cancellous autograft consolidated in a slightly inferior position.

Postoperative follow-up showed a pre-existing Class II malocclusion with traumatic gingival recession in the maxillary incisors and generalized periodontitis. (Figures 3 and 4) The second molar in the upper left jaw was absent. The second premolar and first molar of the upper left jaw showed no occlusion because of missing antagonists, after the hemimandibulectomy.

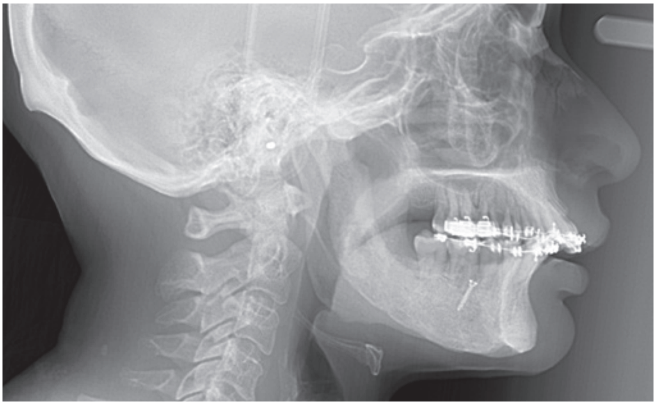

Figure 3 Lateral cephalogram taken 1 month before bilateral sagittal split osteotomy, showing a pre-existing Class II malocclusion.

Figure 4 Photograph taken before BSSO, showing the contour of the successfully reconstructed mandible, resulting in a Class II profile, with a shortened vertical length of the face.

Due to her Class II malocclusion with palatal soft tissue trauma, she was analysed for a combined orthodontic-surgical treatment and occlusal rehabilitation with implants. Radiographic examination in preparation for BSSO showed a bony union of the cortico-cancellous graft, diffuse periodontal reduction of bone and an impacted third molar in the right mandible. Initial treatment of the periodontitis was started.

Preceding the orthognatic surgery, one year previous to BSSO, the reconstruction plate was removed, combined with remodelling of the left hemimandible with autogenous bone from the right anterior iliac crest and removal of the impacted third molar (Figure 5). After successful treatment and stabilization of the periodontitis, staged orthodontic and surgical treatment was initiated to restore occlusion and prevent further palatal and periodontal trauma.

After uneventful healing the patient was planned for orthognatic treatment, 5 years after the first operation. The bilateral sagittal ramus split on the right side was performed, with the use of sagittal splitters and separators instead of chisels, as first described by Van Merkesteyn et al.[6] and Mensink et al.[7] In the neomandible, the distal end of the iliac crest graft was found to be the site with the highest bone quality and quantity, therefore the split was planned in this section of the mandible. Horizontal, sagittal and vertical cuts were made with a saw (sagittal cut) and Lindeman burr (horizontal and vertical cut) and the split was completed with chisels in combination with sagittal splitters and separators. Chisels were necessary due to the small consistent cortical bone and could be used, because of the absence of the inferior alveolar nerve after hemimandibulectomy.

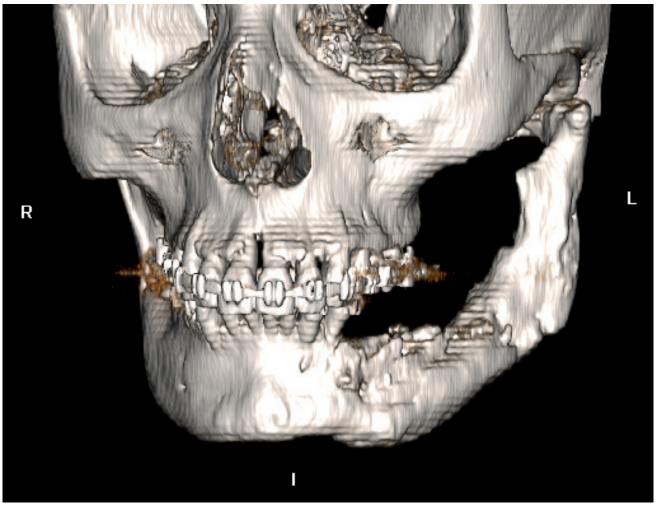

Figure 5 Three-dimensional image of the reconstructed mandible after removing the reconstruction plate and remodelling of the left hemimandible with autologous bone from the right anterior iliac crest.

After complete mobilisation of the proximal and distal parts, the mandible was placed into the new intermaxillary relationship using a wafer and intermaxillary wire fixation was applied.

After precise placement of the proximal segments, with normal clinical support of the temporomandibular joints, the right side was fixated with three bicortical screws in the upper border of the mandible. Then the iliac crest graft was subsequently fixated with two bicortical screws. After removal of the temporary intermaxillary fixation a new symmetrical Class I occlusion was created. (Figures 6 and 7)

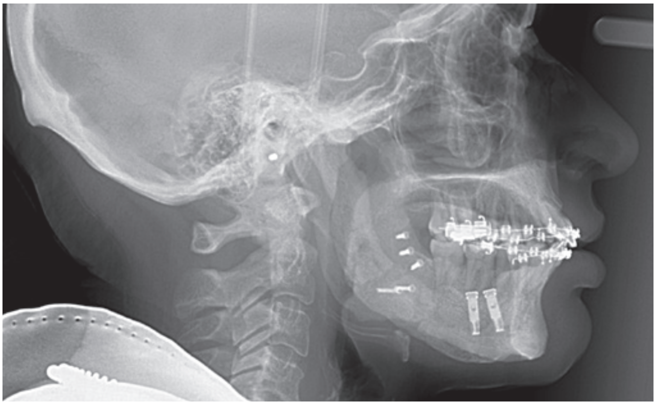

Figure 6 Lateral cephalogram showing a Class I occlusion after bilateral sagittal split osteotomy and subsequent implant placement.

Figure 7 Photograph taken after BSSO, showing a Class I profile as a result of the operation, with a normalized vertical length of the face.

Three months after BSSO, the initial stage of implant treatment took place. Two submucosal implants (length 13mm, diameter 3.8mm, Branemark, Nobel biocare, Houten, the Netherlands) were placed in the position of the former second premolar and first molar of the left mandible. Seven months after implant placement, the implants were recovered to place 2 healing abutments. Subsequently the prosthetic phase started, after healing of the wound.

From the first operation to the Class I occlusal rehabilitation took about 6 years. At the last follow-up the patient had a good function and was satisfied with the result.

Discussion

The different treatment options for patients with ameloblastoma range from enucleation and curettage to more radical surgical management, such as marginal or segmental resection. MAs are more aggressive and associated with a higher rate of recurrence in comparison with unicystic or peripheral ameloblastoma.[1] MAs of the follicular type shows the highest percentage of recurrence. As this patient was diagnosed with a MA of the follicular type, radical surgical management was indicated. Segmental mandibulectomy with histopathologically clear bony margins is the most effective in preventing recurrence and was therefore the treatment of choice in this case.[1]

After segmental resection of the mandible, different methods of reconstruction can be chosen. The two most frequently used techniques are reconstruction with a vascularized bone flap (VBF) or a non-vascularized bone graft (NVBG). VBF, often in the form of a vascularized fibular free flap, is the most commonly used technique for reconstruction, with high success rates and high endosseous implant success.[8] In patients with prior radiation therapy or very large defects (>60 mm), reconstruction with a VBG is the therapy of choice, because these factors significantly decrease success rates of NVBG.[9]

However, NVBG are widely used as well and can be very useful, especially in secondary reconstructions. Non-vascularized bone grafts allow for an easier reconstruction, with higher functional success and create a better contour and bone volume for facial esthetics and subsequent implant insertion than VBF.[9,10] In this case, no prior radiation therapy was necessary because of the nature of the tumor and the mandibular defect was less than 60 mm. Primary reconstruction with a plate was performed in order to be able to confirm histopathologically clear bony margins before secondary reconstruction. Owing to the mentioned advantages, secondary reconstruction was subsequently done with a non-vascularized iliac crest posterior autograft.

The most common complication after BSSO is damage to the inferior alveolar nerve, resulting in neurosensory disturbances of the lip and/or chin, also known as hypoesthesia. In this patient hypoesthesia was already present on the left side, due to the previous hemimandibulectomy. This made the use of chisels in addition to our conventional technique favorable, because of small cortical bone in the iliac crest autograft. On the right side the inferior alveolar nerve was not damaged using only sagittal splitters and separators and no hypoesthesia was present after BSSO. Other complications after BSSO, such as bad splits, infection, non-union, bleeding complications and osteomyelitis are not very frequent and were not present in this patient.

Oral rehabilitation with implant placement is often an important part of the dental reconstruction after mandibular reconstruction and helps prevent recurrence of malocclusion. High success and survival rates after implant placement in bone grafts have been reported.[8] Dental implants placed in a non-vascularized bone graft provide a reliable basis for dental rehabilitation.[5] The moment of implant placement is normally several months (3-4 months) after bone augmentation or reconstruction. In this case implant placement concomitant with BSSO was considered, but postoperative implant placement was preferred, because of the altered position of the mandible after BSSO. When the patient discovered she was pregnant, placement of dental implants was delayed. Dental implant placement was nevertheless necessary, because of the proceeding bone reduction and was thus commenced later than planned, after more than five months of pregnancy.

In our patient, occlusion Class I remained present after BSSO, with good functional and aesthetic results. Anesthesia on the left side was pre-existenting after hemimandibulectomy and hypoesthesia was absent on the right side. No other complications after BSSO were present and successful implant placement resulted in full oral rehabilitation. This shows the bilateral sagittal split osteotomy can be performed in a reconstructed mandible, with no side effects and a good result.

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Experiencing your own orthognathic surgery: A personal case report

In press

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Abstract

There has been much research on minimizing the side effects of orthognathic surgery. However, there are very few doctors and researchers who have themselves undergone this surgery. This case report describes the findings of a maxillofacial surgeon who underwent combined orthodontic and orthognathic treatment for correction of Class II malocclusion. In March 2012, the surgeon was referred to an orthodontist, and an orthodontic examination revealed a Class II, division II malocclusion with a traumatic palatal bite and attrition of the lower front teeth. He underwent alignment of the upper and lower arches, followed by a bilateral sagittal split osteotomy. During this treatment, he made many interesting observations and learning as a patient, which can have implications in improving the outcomes and quality of care for patients receiving such treatment. Thus, this case report aims to provide a critical perspective of the surgical procedure and treatment from the viewpoint of a maxillofacial surgeon who himself experienced the surgery as a patient.

Introduction

Orthognathic surgery is a routine procedure performed by many surgeons to correct malocclusions, with predictable results. Clinicians and researchers have sought to minimize unwanted side effects during such an elective procedure.[1] However, very few of these doctors and researchers have undergone the surgical procedure themselves. Presently, many doctors report their own personal experiences.[2,3] Such reports reveal what we fail to tell our patients, and what they fail to tell us.[2]

This case report aims to describe the findings of a maxillofacial surgeon whose Class II malocclusion was corrected by a surgical-orthodontical procedure. We sought to provide a critical perspective in order to improve treatment outcomes and the quality of patient care.

Case Report

History

At the age of 12 years, I underwent orthodontic treatment for about 2.5 years. The treatment involved activator and bracket treatment. However, stable results were not achieved. Eight years ago, a dental practitioner referred me because of Class II malocclusion with a traumatic palatal bite. In March 2012, I eventually visited the orthodontist. At that point, my symptoms had worsened: (1) progressive attrition of the lower front teeth; (2) progressive crowding of the upper front teeth; and (3) recurrent traumatization of the palatal gingiva by the lower front teeth with minor complaints of discomfort or pain. Furthermore, there was a history of bruxism and clenching, which was subsequently treated using a night guard splint.

The clinical orthodontic examination revealed a retruded mandibular profile with a deep mental fold in combination with eversion of the lower lip. The positions of the maxilla and upper lip were normal. Lower vertical facial height was reduced. The intra-oral examination revealed a Class II, division II malocclusion (3/4 pb) with a traumatic palatal bite and attrition of the lower front teeth with an overjet of 6 mm. No other dental pathology was found (Figure 1A). The wisdom teeth had been removed >7 years earlier.

Assessment

Radiologic examination of the lateral cephalogram confirmed the clinical diagnosis of a Class II, division II malocclusion. The cephalometric measurements are summarized in Table 1. The orthopantomogram revealed no dental pathology (Figure 2A and Figure 3A).

Figure 1 (**A**) Class II 2 malocclusion with retruded incisors and deep palatal bite. (**B**) Class I occlusion 1 year after surgery.

Treatment

The proposed treatment plan consisted in aligning the upper and lower arches, followed by a bilateral sagittal split osteotomy (BSSO). Because of the proper horizontal position of the chin in combination with the shortened vertical facial height, special care was taken to preserve the curve of Spee, to allow for more clockwise rotation of the mandible during the surgery (Figures 2, 4, 5, and 6).

Treatment was started in April 2012. The orthodontic phase of the treatment utilized self-ligating brackets (In–Ovation, TP Orthodontics, Inc., La Porte, USA). After 11 months of decompensation through alignment of the upper and lower arches, the upper front teeth were intruded and proclined and the curve of Spee in the mandible had been preserved. I was deemed ready for surgery (Figure 4). I recorded observations of damage to the cheeks and tongue as well as a dry lower lip, which resolved 1–2 weeks after each wire change, in the diary that I kept during my

Table 1 Cephalometric measurements.

	PREOP	POSTOP 12 MONTHS
SAGITTAL		
SNA	90	89
SNB	82	84
ANB	7	5
VERTICAL		
SPPL-MPL	12	15
Ans-Me	53	57
DENTAL		
+1/NA (mm)	0	3
+1/NA (<)	10	32
-1/NB (mm)	2	6
-1/NB (<)	25	35
-1/MPL	110	116
Wits	6	5
+1/-1	138	108

orthodontic treatment. A cone-beam CT (CBCT) was performed to visualize the anatomical position of the inferior alveolar nerve (IAN) and for three-dimensional planning of the BSSO (Simplant O&O, Leuven, Belgium) (Figure 5). The images showed a preserved deep bite, with an overjet and overbite and proper clockwise rotation of the mandible. A final wafer was manufactured.

On March 12, 2013, I underwent BSSO, which was performed according to the modified method of Hunsuck, except for use of chisels. Instead of chisels, splitting forceps (curved Smith Ramus separators; Walter Lorentz Surgical, Jacksonville, Florida, USA) and elevators were used, as described previously.[4] After mobilization, the mandible was positioned correctly for the new intermaxillary relationship using a wafer, and intermaxillary wires were affixed. A stab incision was made through the skin; using a trans-buccal retractor, three 2-mm bicortical titanium screws (9, 11, and 13 mm in length; Martin GmbH, Tuttlingen, Germany) were placed bilaterally at the upper border of the mandible. The temporary intermaxillary fixation was removed, and the occlusion was checked. Elastic bands were not used immediately post-operatively. The post-operative pain protocol prescribed paracetamol and naproxen and methadone (i.m.) if necessary.

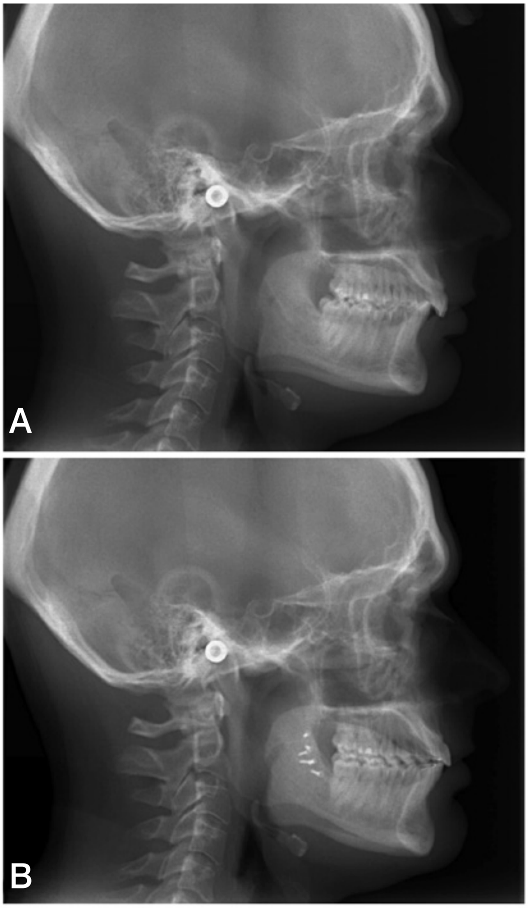

Figure 2 (**A**) Pre-operative lateral cephalogram confirming the retrognathic mandible with a deep bite and a corresponding deep mental fold. (**B**) Post-operative lateral cephalogram 1 year after surgery. Neutral relationship with a class I occlusion and adequate overjet and overbite. The fixation screws used are still in place.

Results

After undergoing a 2-h surgery, I was moved to the recovery room. My discomfort taught me that a patient cannot be expected to comprehend important instructions given during the immediate post-operative period. The first day after surgery was largely unremarkable; I was able to eat soft food and drink cold beverages. Drinking

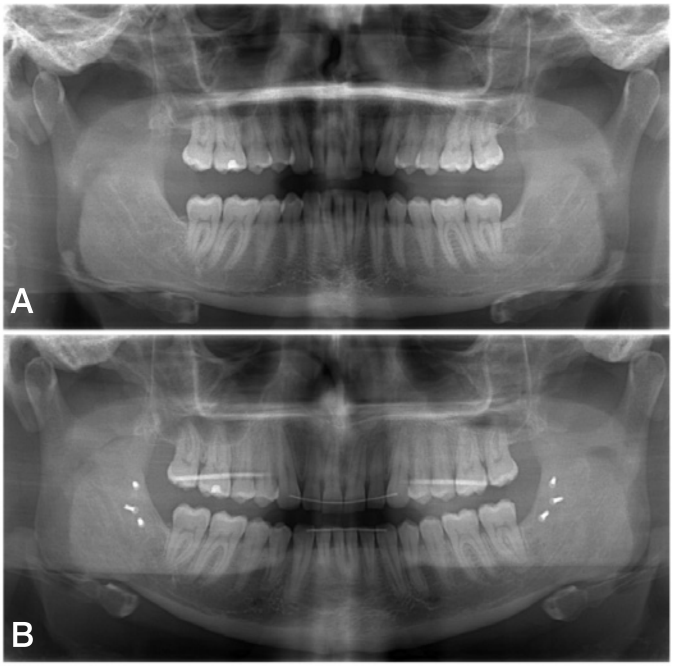

Figure 3 (**A**) Pre-operative orthopantomogram. No pathology is visible. (**B**) Post-operative orthopantomogram 1 year after surgery. Fixation screws still in place. The joints retain a normal aspect.

alleviated the xerostomia that resulted from not being able to close my mouth properly. My pain was effectively managed with analgesic oral medication.

Quantitative sensory (pinprick) testing revealed only a small area of hypoesthesia (Figure 7) at the right corner of the mouth on day 2.

Swelling developed within 48 h (Figure 8). Occlusion was not possible due to interpositioning of the cheek on both sides. I experienced an unpleasant 'pressure-like' feeling on the joint. Despite my experience as an orthognathic surgeon, the awkwardness of a mandible fixed by 6 screws gave me new insight into the patient's experience post-operatively.

After 2 days, I was discharged. I achieved full cognitive capability rapidly but physical recovery took longer. I also found loud noises particularly bothersome. After 4 days, my face started to turn yellow. I was able to perform limited dental hygiene procedures as the facial swelling decreased slowly. The inside of the cheek was numb. Occlusion was not possible despite contact with the front teeth. Normal

Figure 4 Orthodontic preparation for surgery. The mental fold deepened because of the increased anterior inclination of the upper teeth. The curve of Spee was maintained to promote clockwise rotation of the mandible, to increase vertical dimension and to minimize horizontal positioning of the chin.

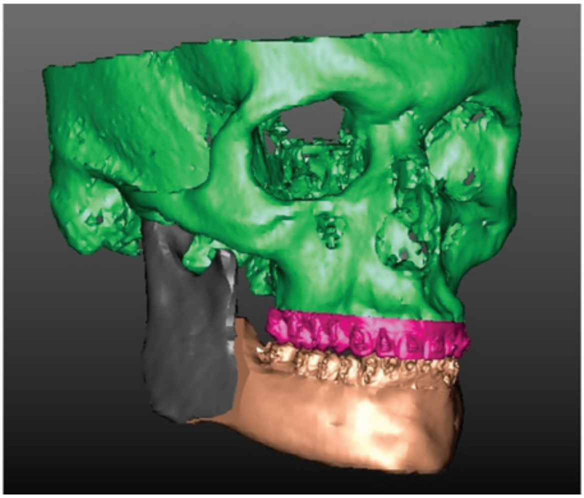

Figure 5 Simplant 3D planning. Clockwise rotation of the mandible is apparent in the difference between the proximal and distal segments (see also Figure 6). Adequate frontal contact, with an open bite in the premolar region due to preservation of the curve of Spee, to enhance clockwise rotation.

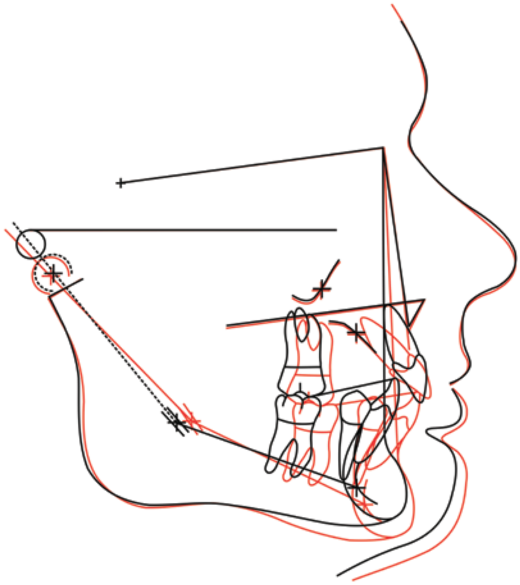

Figure 6 Superpositioning of the pre- and post-operative tracing of the lateral cephalogram. Black line: pre-operative, red line: 12 months post-operative. Class I occlusion is achieved by advancing the mandible. Vertical face height is lengthened by clockwise rotation of the mandible with a slight decrease in depth of the mental fold. Note the increased proclination of the upper incisor due to correction by orthodontic treatment.

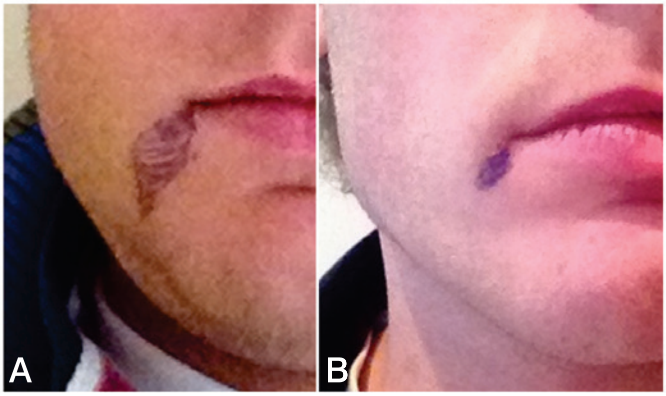

Figure 7 Area of numbness at the right corner of the mouth (marked in blue). **A**: 6 days after surgery, swelling and yellow bruising can be seen. **B**: 8 months after surgery, minor numbness persists.

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Figure 8 Photos taken (**A**) pre-operatively, (**B**) 4 days post-operatively, and (**C**) 12 months post-operatively. There are no visible scars of the stab incisions.

occlusion was not possible throughout the first week, likely because of mild edema in the temporomandibular joint (TMJ).

After 9 days, analgesic medication was no longer necessary. After 12 days, I experienced pain at my left TMJ that prevented me from having an uninterrupted sleep. Oral fluid intake was adequate; after 1 week, I started on a soft diet. I resumed work, treating my own patients 20 days after surgery.

One month after surgery, I still experienced some numbness at the right corner of the mouth (Figure 7). The insides of my cheeks felt different, as if they had been touched by cotton wool. The buccal gingiva at the level of the first and second molars felt numb as well. The chin projection (in horizontal and vertical height) had resulted as planned. The lower lip was 'unfolding', resulting in reduced depth of the mental fold (Figure 8).

I continued to awake with TMJ sensitivity while sleeping. After 2 months, the numbness of the gingiva had resolved completely, but numbness persisted at the buccal mucosa. The occlusion still felt awkward. After 3 months, more balanced occlusion evolved. As a result, there was less pain at the left TMJ, despite some clicking. During the last 3 months of the orthodontic phase, a solid Class I occlusion was achieved. The partial paresthesia of the corner of the mouth persisted up to this point (Figure 7). This sensitivity disturbance is occasional and noted only when I touch the corner of my mouth. However, when drinking cold beverages, I sometimes experience a sensation like fluid running along the right corner of my mouth.

The duration of the post-operative orthodontic treatment was 6 months. Debonding of the orthodontic appliance and insertion of the frontal retainers were performed during a single session. Directly after debonding and removal of the appliance, the settling was felt as a change in occlusion due to minimal tooth movement. Though the tongue was initially injured on the dental lingual and palatal retainers, it had adapted to the new 'hardware' after 7 days. Clicking of the left joint persisted.

Six weeks after removal of the brackets, further settling resulted in successful interdigitation of the left molars and frontal region, with the premolars erupting reaching an improved occlusion. There was moderate settling on the right side, though this had not yet resulted in occlusion. Eight weeks after debonding (8 months post-surgery), the clicking at the left joint had nearly resolved. Nine months after surgery, clicking at the left joint had ceased. One year after surgery, I achieved full occlusion and normal function.

Discussion

My greatest concerns prior to the operation were anesthesia or hypoesthesia of the lower lip as well as the post-operative position of the chin. I consider the surgery to have been successful, despite some minor numbness at the right corner of my mouth. Previous studies have shown that about half of the patients experience side-effects (such as numbness, painful teeth or pain in the TMJ), but nearly all patients felt that they have benefited from their treatment.[5] This finding also supports reports that subjective symptoms are less than objective measurements of hypoesthesia, most likely due to patient habituation.[4]

Patients find it very helpful to receive information on their treatment and outcomes. This helps to reduce concerns as mentioned above. Information leaflets, pictures of treated patients, or meeting other patients are mentioned in questionnaires to be helpful for almost all patients.[6]

In my case, treatment was delayed due to my lack of concern for the aesthetic impact of my malocclusion/hypoplasia and only minor complaints. I noticed a functional impairment with continuous attrition of the lower frontal teeth. I was mildly concerned about the unfavorable palatal bite and the progressive crowding of my upper front teeth. This is in line with a previous report where patients who underwent orthognathic surgical evaluation for treatment of a skeletal deformity experienced a primary complaint that was more functional than aesthetic in nature.[7] However other reports describe straight teeth/dentofacial attractiveness as the most common reason for seeking treatment, followed by prevention of future dental problems (as seen from continuous attrition of my lower teeth).[6,8] However, patients treated in these studies had a mean age of 22-24 years, which could explain this esthetic difference with my case as younger patients are more insecure about the appearance of their teeth. While my treatment started when I was 34 years old, the malocclusion was present long before. The results of the surgery highlight the importance of early diagnosis; delaying treatment increases the risk of complications such as neurosensory disturbances.[4]

My primary complaints during the orthodontics phase were minor damage to the buccal mucosa of the cheek, lips, and tongue caused by the brackets. However, hyperplasia of the mucosa allowed the tissue to adapt to the brackets and wires after 2–3 weeks. This adaptation process occurred after every orthodontic visit and took 2–3 days. During this period, I routinely switched to a soft diet due to increased sensitivity of the teeth during loading. Notably, published reports identify certain side effects associated with fixed orthodontic treatment: toothache, ulceration, and soreness. Similar to my experience, patients reported difficulty with eating and/or chewing during the early post-operative period.[6,9]

My experience with the self-ligating brackets was good. Without the banding elastics, one does not encounter elastic discoloration. Changing the wires proceeded more easily as well. The self-ligating system also involves reduced chair-time.[10]

The main complaints reported during orthognathic surgery are post-surgery sequelae such as nausea or swelling, discomfort/pain, delayed recovery of oral function, and a slow return to pre-surgical lifestyle and activity levels. The reported findings are in line with the observation about my own post-operative discomfort, except for breathing difficulties .[5,11] Swelling and bruising resolved in about 1-2 weeks. Proper pain management with naproxen (for 1 week) and paracetamol (not as needed, but rather on a regular schedule according to the post-operative pain protocol) protected me from pain during the daytime. Problems associated with eating, chewing, and opening of the mouth took the longest to resolve—approximately 6–8 weeks. It is interesting that many patients, despite being informed about these post-operative sequelae, are surprised by the severity and duration of their post-operative symptoms. This could also be biased since patients indeed having sequelae often avoid criticizing their doctors.[8] I returned to work 2–3 weeks after the surgical procedure; this time period for resuming work was similar to that reported previously.[5,11] However, patients generally need to take more time off than advised before.[5]

I experienced moderate pain of the left TMJ, most likely due to clenching at night. The clicking of my left joint did not resolve until 7 months after the surgery, most likely due to a lack of proper stabilized occlusion on the left side during the first 6 weeks after surgery. During this healing period, my left TMJ was probably overloaded, due to my clenching habit. After establishing stable occlusion on the left side after starting the orthodontic phase again, both TMJs were loaded in a stable functional way, which finally resulted in complete resolution of the cranio-mandibular dysfunction at my left TMJ.

Condylar bone changes and disk displacements after orthognathic surgery are related to parafunctional habits such as bruxism and clenching and incorrect repositioning of the condyle.[12] Frey et al.[13] showed that long advancements (>7 mm) and clockwise rotation were associated with increased joint sounds, but no independent association was found. Furthermore, when joint sounds occurred, these declined over the 2-year follow-up period. Thus, increased joint symptoms after surgery might be clinically significant only in the short term.[13]

The General Medical Council guidelines recommend to avoid wherever possible the provision of medical care to anyone with whom the doctor/surgeon has a close personal relationship.[14] However, this is quite difficult if you participate in a small group of specialists such as the community of maxillofacial surgeons in the Netherlands. Having many recall appointments during the orthodontic treatment period makes it difficult to be treated by someone who you are not familiar with. However, I believe it could have been more difficult for the surgeon and orthodontist treating me than for me as the patient. As requested, I was treated like other patients but with some extra privileges.

This experience as a patient was illuminating to me as a specialist. Klitzman[15] in his study on healthcare among doctors observed that as a patient, the doctors learned much than they knew before (Table 2). Several doctor-patient participants in Klitzman's study suggest that doctors must remain familiar with 'helplessness, loss of power over one's very body and life, confusion and confrontation with the unknown.[15] In addition to achieving a normal Class I occlusion without further damage to my teeth, this experience taught me a great lesson with regard to understanding and empathizing with patients. As surgeons we should keep in mind that orthognathic surgery should never be 'business as usual' and in this regard not only treat every patient as being a different individual with a unique harmonization of dental, bony and soft tissue, but especially as someone with doubts, fears and uncertainty. We should supply these patients with the proper information so they are able to understand the underlying dental/skeletal abnormality and the treatment necessary to correct these deviations.

The final question I have received over and over again: "Would you do it again?" is peculiar in my opinion. If you treat your orthognathic cases with the knowledge we have, I believe it would be worthy each time you operate a patient.

Table 2 Post- and preoperative advices for patients and surgeons/orthodontists.

Pre-operative advice for surgeons/orthodontists
Explain why it is sometimes difficult to predict the exact duration of an orthodontic treatment (i.e., a small movement of teeth takes another 1-2 sessions and could mean elongation up to 1-3 months), especially after the healing period of the surgical correction.
Address the concerns of the patients.
Match your expectations with those of the patients'.
Post-operative explanations for patients
Occlusion will not be directly perfect after surgery; therefore, orthodontic treatment is still necessary.
After debonding, the occlusion might cause some discomfort feeling, due discrepancy between the moment of debonding and the settling phase.
Numbness resolves very slowly and is accompanied by a tingling sensation. Moreover, the numbness in all parts will not resolve at the same time.
Have a regular schedule of taking pain medications for at least one week; do not wait until you feel the pain.
At the beginning of the treatment, one will experience some pain/sensitive feeling/clicking of the joints/muscles.
General anesthesia can cause some physical/cognitive discomfort.
About 2-3 weeks leave from work is sufficient after undergoing a bilateral sagittal split osteotomy.
Postoperative visits to the orthodontists/surgeons are important in case elastic traction is necessary.
Post-operative advice for surgeons/orthodontists
A patient might not be able to fully comprehend post-operative instructions in the recovery room.
Listen to complaints from the patients, however trivial or small they may sound to you
Review the concerns of a patient during post-operative discussion.

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Discussion and future perspectives

The aim of this thesis was to prove the safety and predictability of bilateral sagittal split osteotomy (BSSO) performed with the splitter–separator technique. This was achieved through the following analysis:

1. Systematic review of the incidence of NSD of the IAN (chapter 2)
2. Cadaveric studies of fracture patterns (chapters 5 and 6)
3. Prospective multicenter human study of the incidence of hypoesthesia of the IAN (chapter 3)
4. Retrospective controlled investigation of the stability of BSSO during adolescence (chapter 4)
5. Analysis of the incidence of bad splits (chapter 7).

Systematic review of the incidence of NSD of the IAN

The systematic review was aimed at revealing the effect of the splitting technique on the incidence of postoperative NSD. Most full-length articles identified by a specific PubMed search were excluded because of their failure to describe the splitting technique in sufficient detail or meet the inclusion criteria. When the selected articles were divided into 3 groups (no chisel use, undefined chisel use, and explicit chisel use), higher incidence of postoperative NSD was observed in the chisel group (4.1% and 18.4% vs. 37.3%). In addition, modifications with the use of chisels resulted in rather high mean incidences of NSD (12.8–32%) after BSSO. Of course, the etiology of IAN damage during surgery is multifactorial.

Medial dissection has also been described as a cause of impairment of the IAN. A few intraoperative studies showed decreased nerve function during medial dissection to identify the lingula or mandibular foramen.[1-3] In these cases, however, total recovery was achieved either during surgery or within a short period thereafter. In addition, a decrease in intraoperative nerve function may result from damage to the IAN by sharp instruments.[1] The intraoperative technique is likely to play an important role, especially when chisels are used along the IAN ("cortical shaving"), a view supported by other authors.[4]

Therefore, chiseling is considered as a risk factor for postoperative NSD, while spreading and prying are likely to be safer.[5-8]

Cadaveric studies of fracture patterns

A. Pig mandibles

The pilot study using 10 pig mandibles showed that prying and spreading in the revised BSSO technique and placement of the horizontal osteotomy in the concavity of the mandibular foramen lead to a predictable fracture pattern and can minimize the risk of damage to the IAN and bad splits. The technique is easy to perform and learn. Furthermore, it could lower the incidence of postoperative hypoesthesia, as suggested in earlier studies.[6,8,9] The pig model allowed thorough inspection of the lingual splitting patterns after BSSO. Further, superior visibility of the mandibular foramen was achieved, compared with the degree of visualization in the clinical setting.

The pig model has been used successfully in earlier studies.[10-14] because of the similarities between the pig and the human mandible, but caution is necessary when extrapolating the results. Pigs have longer mandibles and more teeth than humans. The vertical osteotomy was placed posterior to the most distal molar in the pig mandible in the pilot study, which seems to be comparable to the osteotomy site in humans. Unerupted molars were present in all the mandibles, but the fracture line always ran downward and did not follow the follicular space of these molars. In previous clinical studies, BSSO was performed in the presence of third molars and no significant increase in the incidence of bad splits or damage to the IAN was noted when compared with BSSO after third molar removal.[8,9] Further, the pig mandibular canal is larger and has a pronounced divergence at the mandibular foramen. The mandibular angle contains more cortical bone and less cancellous bone, which can influence the fracture pattern. However, in a normal split, this part of the mandible is located in the proximal segment[15] and will not influence the fracture pattern.

The fracture lines in this study were almost optimal, running nearly perpendicular from the inferior part of the vertical osteotomy site to the inferior border and along the mandibular canal to the mandibular foramen. Many (80% of the fractures) seemed to follow the path of least resistance, probably because the separator was introduced immediately at the inferior border during the unfolding of the split, therefore avoiding the inferior bone cut described by Schoen et al.[16]

No sharp bone fragments pointed toward the mandibular canal. The reported rate of bad splits ranges from 0.5% to 5.4%,[17] but bad splits were not observed in this study. Only one unfavorable fracture occurred during the splitting process, where the nerve was still attached to the proximal segment because the fracture line ended just anteriorly to the mandibular foramen. None of the other splits resulted in the IAN being attached to the proximal segment.

Plooij et al.[15] described 4 lingual fracture patterns on the basis of the lingual splitting scale (LSS): LSS1 or “true” Hunsuck split, LSS2 or Obwegeser split, LSS3 or split through the mandibular foramen, and LSS4 or other splitting type (i.e., bad split). Performing the Hunsuck technique, they stated that the horizontal osteotomy should be placed behind the mandibular foramen and a small curved osteotome should be used to fracture the bone behind the mandibular foramen and separate the cortices. The medial cut should be high enough to allow space for the osteotome above the mandibular foramen. In contrast, in the revised BSSO technique, this cut is extended to the concavity of the mandibular foramen, just behind the anterior border of the lingula and just above the entrance of the mandibular foramen.

Although Plooij et al.[15] intended to perform a “true” Hunsuck split every time, only 51% of the splits were classified as LSS1; in 32% of the cases, an LSS3 pattern was obtained, as is desirable in the revised BSSO technique. They emphasize further dorsal placement of the horizontal osteotomy site, increasing the number of “true” Hunsuck splits and decreasing the number of lingual fractures through the mandibular foramen.[15] This is in line with the findings of the pilot study. Of note, Hunsuck advised that the horizontal osteotomy should be made through the cortical bone superior to the lingula, which is not located as posterior as suggested by Plooij et al.
Therefore, BSSO by the splitter–separator technique ensures a consistent fracture pattern in pig mandibles. A fracture running through the mandibular foramen and

along the mandibular canal could follow the path of least resistance. Placement of the horizontal osteotomy in the concavity of the mandibular foramen (i.e., more anteriorly) could mean less mobilization of the IAN.

B. Human mandibles

The human cadaveric study was conducted to evaluate the revised BSSO technique further. The hypothesis was that the lingual fracture line will run through the mylohyoid groove or mandibular canal, as the possibly weakest region of the mandible, and end in the mandibular foramen. However, the results did not prove the hypothesis. Some splits ran along the mandibular canal (35%) and/or mylohyoid groove (30%), and the concavity between the mandibular foramen and the inferior border defined a relatively consistent fracture path. However, an LSS3 split was associated with the fracture running through the mylohyoid groove. The mandibular canal or dental status showed no correlation within this limited dataset. Inferior border fractures were classified almost equally into groups 1, 2, and 3 (0 mm, 1–10 mm, and >10 mm, respectively). No buccal fracture lines occurred in group 4. These results could explain why only a few lingual fractures were associated with the mylohyoid groove or mandibular canal. Instead of running more cranially, the fracture ran through the inferior border. Furthermore, the absence of bad splits is favorable in comparison with the series of Plooij et al.[15] In their study, 3% of the fractures were bad splits, in keeping with the literature. No bad split occurred in the cadaveric study, which is well below the reported rate (mean, 4.6% per patient).[18]

Table 1 Comparison of the lingual fracture patterns between the human cadaveric study and the Plooij et al.[15] study.

Category	Human cadaveric study	Plooij et al.[15] study
LSS1 (“true” Hunsuck split)	25%	51%
LSS2 (Obwegeser split)	2.5%	13%
LSS3 (split through the mandibular foramen)	72.5%	33%
LSS4 (bad split)	0%	3%

As shown in Table 1, the frequencies of the splits differ between the Plooij et al.[15] and the current studies. The more anterior split (i.e., LSS3) was common in the current study. Plooij et al. also stated that the chance of splitting the ramus according to the Hunsuck description increases from 44% to 63% when the horizontal osteotomy ends behind the anterior border of the mandibular foramen and the chance of splitting through the mandibular canal is significantly reduced from 43% to 11%. In the human cadaveric study, the horizontal osteotomy in the mandibular foramen resulted in 72.5% of the lingual fractures ending in the mandibular foramen, with a 6-fold higher chance when the lingual fracture ran along the mylohyoid groove. The relationship with the mandibular canal could not be explored because of the limited sample size.

Accordingly, the horizontal osteotomy need not be placed dorsally to the mandibular foramen and/or cortical separation by chiseling cranially and dorsally from the mandibular foramen is unnecessary to obtain a predictable split. Moreover, with a more anterior split, less splitting is required in the sagittal plane, reducing instrumentation along the IAN, trauma to the IAN, and operative time.

The value of cadaveric studies of splitting techniques may be limited by the use of formalinized mandibles and higher frequency of edentulous mandibles than in the clinical setting. Further, in this series, only 2 hemi-mandibles contained molars, which might have influenced the fracture patterns. The increased gonial angle in older and edentate subjects is also controversial, and the IAN position could vary depending on the degree of alveolar ridge resorption. However, according to Oth et al.[19], the use of mandibles from older individuals remains a suitable option for such studies. Nonetheless, the results should be interpreted cautiously, because the degree of visualization is poorer clinically.

In conclusion, the hypothesis that the mandibular canal and/or mylohyoid groove act as the path of least resistance was only partially confirmed. Furthermore, 72.5% of the lingual fractures ended in the mandibular foramen, with a 6-fold chance of a fracture in the mandibular foramen when it ran along the mylohyoid groove. The study also showed that the revised BSSO technique does not increase the incidence of bad splits, implying its safety and predictability.

Multicenter human study of the incidence of hypoesthesia of the IAN

In the 2-year prospective controlled multicenter study, 2 clinics used the chisel–mallet technique and the other 2 used the splitter–separator technique to prove that the revised technique is associated with a lower rate of hypoesthesia of the IAN. The percentage of SSOs that resulted in IAN hypoesthesia after 1 year was 5.1%, and 8.9% in the 158 patients who did not undergo concomitant genioplasty. Considering that the reported rates of hypoesthesia are rarely under 10%[20-24] and the mean incidences of NSD with undefined and explicit use of chisels per side are 18.4% and up to 37.3%, respectively[3,25-27], the clinical findings confirm the hypothesis of lower incidence of hypoesthesia of the IAN by the splitter-separator technique. Of note, a standardized form was provided to all the clinics to gather information before and after the operation.

Unfortunately, despite all efforts, the 2 clinics that used the chisel–mallet technique did not supply data at all or provided insufficient data, so the findings of the control group were not analyzed. However, the clinics that used the splitter–separator technique supplied sufficient data of 172 patients, with results of postoperative NSD. Therefore, the research was published as a prospective multicenter cohort study.

No association between persistent hypoesthesia at 12 months after BSSO and perioperative third molar removal was found. This observation is consistent with that of Reyneke et al.[28], who reported that although IAN recovery is slower in patients with unerupted third molars at the time of surgery, their recovery rates at 1 year are equal to those without unerupted third molars.

NSD was tested by both objective and subjective measurements, because the prevalence of hypoesthesia of the IAN varies according to the type of assessment.[29] An NSD noted by either test was recorded as a positive finding. This methodology avoids underestimation of hypoesthesia.

This study therefore showed that BSSO performed with a sagittal splitter and separators leads to fewer injuries of the IAN compared with the literature, regardless of the presence of unerupted third molars.

Stability of BSSO during adolescence

While correcting skeletal class II malocclusion, stability of the surgical procedure is important. In the retrospective controlled study to evaluate relapse in adolescents and adults (control) with the revised BSSO technique for mandibular advancement, only 10.9% of the adolescents showed relapse. The higher relapse rates in previous studies[30-32] could be explained by the different surgical technique, namely mandibular advancement with wire fixation, which is a less-stable method[33]. The control group showed a relapse rate of 16.4% after 1 year. The reported 1-year relapse rates of mandibular advancement by BSSO in adults are inconsistent: from 20–30% at B point[34-36] to only 1%[37] or even anterior movement.[38]

Although not significant, relapse occurred less frequently in the adolescent group. The apparent difference could be explained by the fact that any relapse would be partly compensated by postoperative mandibular growth, implying that young age could prevent relapse. The higher number of Le Fort I procedures (and further mandibular advancement) in the control group could also explain the difference in relapse rates.[39] The influence of the mandibular plane angle on relapse has been shown in several studies[40,41], but no relationship was detected between the preoperative mandibular plane angle and the horizontal relapse following surgery.

In a series of adult patients, less-stable outcomes were obtained after greater mandibular advancement.[34] Although the retrospective study included a relatively small number of patients and involved less mandibular advancement, its results indicate that the revised BSSO technique is a stable procedure during adolescence for patients who require “normal” advancement of the mandible.

Analysis of the incidence of bad splits

The rate of bad splits during SSO ranges from 0.5% to 5.4%.[7,42] Therefore, the rate of 4.5% during the splitter–separator BSSO technique in the prospective study is within the reported range. In the retrospective study of all patients treated with the revised BSSO technique at the Leiden University Medical Center, the rate of bad splits was 2% (17 of 851 SSOs in 427 patients), which is consistent with the average reported in the literature (2%). Therefore, the revised technique does not raise the risk of bad splits when compared with chiselling.

The exact combination of factors that result in a bad split is unknown. Older patients have an increased risk of bad split.[43] However, no relationship between age and bad splits was found in the retrospective study. Further, no association with patient gender and surgeon’s experience has been reported, consistent with the present findings.[44-46] Third molar removal before BSSO is controversial. Some have suggested that if third molars need to be removed, extraction should be performed at least 6 months before orthognathic surgery.[6,44,47,48] Others have advised removal of third molars simultaneously with orthognathic surgery to reduce complications such as hypoesthesia.[7,49,50] In the present patients, significantly more bad splits during BSSO occurred among those who underwent simultaneous removal of third molars. In our clinic, most third molars that were present during the last 5 years preoperatively were removed at the time of BSSO because separate removal was considered to increase the risk of damage to the IAN (when a relationship with the IAN exists) and be inconvenient for the patient (1 combined procedure instead of several procedures). One would expect bad splits to occur more often during BSSO by less-experienced surgeons such as residents. However, no such differences were found between senior staff members and residents, probably because the latter were closely supervised during BSSO and corrected when necessary. Therefore, the splitter–separator technique does not raise the risk of bad splits compared with the use of chisels, but a slight increase is possible when third molars are present during BSSO.

Conclusion

BSSO with the use of splitters and separators is a safe and predictable technique, resulting in lower rates of NSD of the IAN than the chisel–mallet technique, and providing a consistent splitting pattern without increasing the rate of bad splits.

Furthermore the results show that a BSSO performed during adolescence is a relatively stable procedure which does not show more relapse than a young adult group.

Future perspectives

An important feature in BSSO is control of the lingual fracture. A randomized controlled study with CBCT to compare the conventional and the revised techniques would reveal the determinants of the fracture pattern. With greater accessibility to CBCT in different maxillofacial surgery departments in the Netherlands, this comparison should be easier to perform in a multicenter design.

A controlled cadaveric study would show the differences between both techniques and elucidate the influence of differently placed cuts on the lingual fracture pattern in both the techniques. This assessment could also be achieved in the clinical setting, where the use of instruments such as a piezotome could enable easier and more controlled fracturing of the mandible.

Finally, the different sequelae related to concomitant removal of third molars should be explored.

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11

Summary

Summary

Chapter 1 starts with a general introduction about the bilateral sagittal split osteotomy (BSSO) in a historical perspective of this procedure. Two techniques are presented, the classic 'mallet and chisel' technique and the splitting of the mandible, prying and spreading, with sagittal splitters and separators. The advantages of the use of the sagittal splitters and separators over the chisel technique are stated. As in any surgery, complications occur during or after the BSSO procedure which are divided in this thesis, in neurosensory disturbances, possible relapse and bad splits during surgery. The most important and most often occurring is the neurosensory disturbances of the lower lip, which may occur due to nerve damage. The type of injury of the nerve could be, neuropraxia, axonotmesis and neurotmesis with respectively recovery within days and weeks and no total recovery. The different risks of injury during the BSSO are then discussed. Especially chiseling your way through the mandible without direct visualization of the inferior alveolar nerve is considered to cause high incidences of neurosensory disturbances (NSD) or post-operative hypoesthesia of the lower lip.

In **Chapter 2** a systematic review is described in which the available evidence was investigated to evaluate the influence of different splitting techniques, namely, "mallet and chisel" versus "spreading and prying," used during BSSO on postoperative hypoesthesia outcomes. Eventually 14 publications met our inclusion criteria. From these 14 studies, 3 groups were defined: (1) no chisel use (4.1% NSD/site), (2) undefined chisel use (18.4% NSD/site), and (3) explicit chisel use along the buccal cortex (37.3% NSD/site). Study heterogeneity and a frequent lack of surgical detail impeded our ability to make precise comparisons between studies. However, the group of studies explicitly describing chisel use along the buccal cortex showed the highest incidence of NSD. Moreover, comparison of the study that did not use chisels with the 2 studies that explicitly described chisel use, revealed a possible disadvantage of the "mallet and chisel" group (4.1% versus 37.3% NSD/site). These results suggest that chisel use increases NSD risk after BSSO.

Chapter 3 describes a prospective multi-center study on a group of 158 patients, aimed to determine the incidence of post-operative neurosensory disturbances of the IAN after BSSO procedures performed without the use of chisels. The percentage of BSSO split procedures that resulted in postoperative NSD was 5.1% after a follow-up period of 1 year. The percentage of patients (without genioplasty) who experienced post-operative NSD was 8.9%. The concomitant genioplasty in combination with BSSO was significantly associated with post-operative NSD. Peri-operative removal of the wisdom tooth or a Le Fort I procedure did not influence post-operative NSD.

We concluded that the use of splitting forceps and elevators without chisels leads to a lower incidence of persistent postoperative NSD after 1 year, after BSSO of the mandible, without increasing the risk of a bad split.

Chapter 4 presents a retrospective study on a group of 18 patients to determine the amount of relapse after performing BSSO advancement in patients aged less than 18 years. A control group consisted of patients treated at 20 to 24 years of age. Cephalometric radiographs were used to determine the amount of relapse. For patients aged less than 18 years, the mean horizontal relapse after 1 year was 0.5 mm, being 10.9% of the perioperative advancement. For patients aged 20–24 years, the mean relapse was 0.9 mm, being 16.4% of the mean perioperative advancement. There were no significant differences between the age groups ($p > 0.05$). We concluded that the BSSO procedure is a relatively stable procedure, even during adolescence.

Chapter 5 describes the results of a pilot study on 10 cadaveric pig mandibles to analyze the splitting pathways of the (lingual) fracture lines during a BSSO. A BSSO was performed using splitters and separators. Special attention was paid to end the horizontal medial cut at the deepest point of the entrance of the mandibular foramen. Of all lingual fractures, 95% ended in the mandibular foramen. Forty percent of these fractures extended through the mandibular canal and 40% extended inferiorly along the mandibular canal. Almost all lingual fracture lines ended in the mandibular foramen, most likely due to placement of the medial cut in the concavity of the mandibular foramen. The mandibular foramen and canal could function as the path of least resistance in which the splitting pattern is seen. We concluded that a consistent splitting pattern was achieved without increasing the incidence of possible sequelae.

Chapter 6 describes a study to determine the various lingual splitting patterns in 40 cadaveric human hemi- mandibles after a BSSO and the possible influence of the mandibular canal and the mylohyoid groove on the lingual fracture line. The investigators designed and implemented a case-series to compare the different lingual fracture lines. The primary outcome variable during this study was the lingual fracture pattern possibly influenced by independent variables: the mandibular canal, the mylohyoid groove and the dental status. Descriptive and analytic statistics were computed for each study variable. Most of the lingual fractures (72.5%) ended in the mandibular foramen. Only 25% of the fractures were a “true” Hunsuck fracture, while no bad splits occurred. Meanwhile, 35% of the lingual fractures ran more than half or entirely through the mandibular canal, while only 30% of the fractures ran along the mylohyoid groove. However, when the lingual fracture ran along this groove, it had a 6-fold greater chance of ending in the mandibular foramen. The hypothesis that the mandibular canal and/or the mylohyoid groove will function as the path of least resistance was only partly confirmed. The use of splitters and separators did not increase the incidence of bad splits compared with the literature.

In **Chapter 7** a retrospective study on a group 427 patients study was presented which aimed to determine the incidence of bad splits associated with BSSO performed with splitters and separators. Furthermore, we assessed different risk factors for bad splits. The incidence of bad splits in this group was 2.0% per site. This is well within the range reported in the literature. The only predicting factor for a bad split was the removal of third molars concomitant with BSSO. There was no significant association between bad splits and age, sex, occlusion class, or the experience of the surgeon. We concluded that BSSO, performed with splitters and separators instead of chisels, does not increase the risk of a bad split and is therefore a safe technique with predictable results.

Chapter 8 presents a case report of a BSSO in a reconstructed mandible. A 28-year old woman underwent a segmental mandibulectomy, due to a multicystic ameloblastoma in the left lower jaw. After primary plate reconstruction, final reconstruction was performed with a left posterior iliac crest cortico-cancellous autograft. After successful reconstruction the patient was analyzed for combined orthodontic-surgical treatment. Because of a pre-existing Class II malocclusion. Subsequently, after one year of orthodontic treatment, the BSSO was planned. The sagittal split was performed in the remaining right mandible and on the left side in the iliac crest cortico-cancellous autograft. Ten months later, oral rehabilitation was completed with implant placement in the neo-mandible as well. Follow-up showed a Class I occlusion, with good function. The patient was very satisfied with the functional and aesthetic results. This shows a BSSO can be performed in a reconstructed mandible, without side effects and with good functional and aesthetic results.

Chapter 9 describes a case report to state the experiences of an oral and maxillofacial surgeon, who has undergone a combined orthodontic and orthognathic treatment.

12

Dutch Summary

Samenvatting

Hoofdstuk 1 begint met een algemene inleiding over de bilaterale sagittale splijtings osteotomie (BSSO) in een historisch perspectief. Twee technieken worden besproken, de klassieke “hamer en beitel” techniek en het splijten van de onderkaak met splijttangen en splijthevels. Het voordeel van het gebruik van deze instrumenten in vergelijking met het gebruik van beitels wordt toegelicht. Complicaties gedurende of na een BSSO zijn in dit proefschrift onderverdeeld in: 1. Mogelijke postoperatieve gevoelsstoornissen van de onderlip (hypesthesie), 2. Terugval van het resultaat van de behandeling (relaps) en 3. Ongewenste fractu(u)r(en) tijdens de splijting van de onderkaak (bad split). De belangrijkste en meest voorkomende complicatie is hypesthesie van de onderlip, veroorzaakt door direct trauma van de nervus alveolaris inferior. Het type beschadiging van de zenuw kan onderverdeeld worden in neuropraxia, axonotmesis and neurotmesis met respectievelijk, herstel binnen dagen, weken en totaal geen herstel. De verschillende risico’s van beschadiging gedurende de BSSO worden besproken. Vooral het ‘blind’ doorbeitelen zonder zicht op de nervus alveolaris inferior wordt beschouwd als een hoog risico op postoperatieve hypesthesie van de onderlip.

In **hoofdstuk 2** wordt de beschikbare evidence in de literatuur onderzocht middels een systematisch literatuuronderzoek. Hierbij werd gekeken naar het verschil in postoperatieve verminderde zenuwfunctie na een BSSO, in relatie tot de gebruikte splijttechnieken tijdens deze BSSO en met name specifiek tussen de ‘hamer en beitel’ methode en het splijten van de onderkaak met splijttangen en splijthevels. Uiteindelijke konden 14 studies worden geïncludeerd. In deze 14 studies, konden 3 groepen onderscheiden worden: (1) geen gebruik van beitels (4.1% hypesthesie/kant), (2) ongedefinieerd gebruik van beitels (18.4% hypesthesie /kant), en (3) expliciet gebruik van een beitel (37.3% hypesthesie /kant). Verschillen in de studie opzet en vaak weinig gedetailleerd beschreven chirurgische technieken in de studies maakte het moeilijk om de resultaten van deze studies te vergelijken. Maar de studies die expliciet gebruik maakten van beitels tijdens een BSSO laten het hoogste vóórkomen zien van postoperatieve hypesthesie. Als we deze incidenties vergelijken met de 2 studies die expliciet geen beitels gebruiken, zien we toch een mogelijk risico in het gebruik van ‘hamer en beitel’ (4,1% t.o.v. 37,3% hypesthesie /kant). Deze resultaten van een verhoogd risico op hypesthesie, kunnen het gevolg zijn van het gebruik van beitels gedurende deze ingreep.

In **hoofdstuk 3** wordt een prospectieve multi-center studie beschreven van een groep van 172 patiënten. Het doel was om het vóórkomen van postoperatieve hypesthesie na een BSSO (zonder gebruik van beitels) te bepalen. Het percentage van de BSSO splijtingen resulteerde in een postoperatieve hypesthesie van 5,1% bij een follow-up van 1 jaar. Het percentage patiënten (zonder kinosteotomie) met een hypesthesie was 8,9%. Een kinosteotomie tezamen met een BSSO was significant gerelateerd aan meer hypesthesie. Het gelijktijdig verwijderen van verstandkiezen gedurende een BSSO of het eveneens uitvoeren van een Le Fort I osteotomie was niet van invloed op de postoperatieve hypesthesie. We concludeerden dat het gebruik van splijttangen en splijthevels tijdens een BSSO, tot minder post- operatieve hypesthesie leidt, zonder het risico van een bad split te vergroten.

Hoofdstuk 4 beschrijft een retrospectieve studie over een groep van 18 patiënten onder de 18 jaar, om de hoeveelheid relaps bepalen na een BSSO advancement. Een controle groep bestond uit patiënten tussen de 20 en 24 jaar. Laterale schedel-opname's werden gebruikt om de relapse te bepalen. In de groep patiënten onder de 18 jaar, was de horizontale relapse na een jaar 0,5 mm, ongeveer 10,9% van de advancement per-operatief. In de groep patiënten van 20-24 jaar, was de gemiddelde relapse 0,9 mm, ongeveer 16,4% van de gemiddelde advancement. Er waren geen significante verschillen tussen beide leeftijdsgroepen ($p > 0,05$). We concludeerden dat een BSSO een relatief stabiele procedure is, zelfs gedurende adolescentie.

Hoofdstuk 5 beschrijft een pilot studie op 10 kadaver varkenskaken om de splijtlijnen van de linguale fractuur te analyseren. De BSSO werd verricht met splijttangen en splijthevels. Speciale aandacht werd gegeven aan de horizontale mediale boorsnede, geplaatst in het diepste punt van de ingang van het foramen mandibulare. Van alle linguale fracturen, eindigde 95% in het foramen mandibulare. Veertig procent van deze fracturen liep door de canalis en 40% verliep onder de canalis mandibularis. Dat alle fracturen in het foramen mandibulare eindigden komt waarschijnlijk door plaatsing van de horizontale mediale boorsnede in de concaviteit van het foramen mandibulare. Door het type splijtpatroon, zouden het foramen mandibulare en het mandibulaire kanaal als weg van minste weerstand gezien kunnen worden. We concludeerden dat we een consistent splijtpatroon zagen, zonder toename van andere complicaties.

In **hoofdstuk 6** wordt vervolgens een studie beschreven op 40 halve humane kadaverkaken, waarop een SSO is verricht. Hierop werd beoordeeld of het mandibulaire kanaal en/of de mylohyoid groeve van mogelijke invloed zou kunnen zijn op de linguale fractuurlijn. We ontwierpen een case-serie om de verschillende breuklijnen te beoordelen. Onze primaire uitkomst variabele was het linguale fractuur patroon, mogelijk beïnvloed door de volgende onafhankelijke variabelen: het mandibulaire kanaal, de mylohyoid groeve en de aanwezigheid van tanden. Descriptieve and analytische statistieken werden berekend voor iedere variabele. De meeste linguale fracturen (72.5%) eindigden in het foramen mandibulaire. In maar 25% van de gevallen was er sprake van een ‘echte’ Hunsuck. Er werd geen bad split gezien. Verder zagen we, dat 35% van de linguale fracturen meer dan de helft of volledig door het mandibulaire kanaal liep, terwijl maar 30% van de linguale fracturen door de mylohyoid groeve liep. Maar wanneer de linguale fractuur door deze groeve liep, was er een 6x grotere kans dat de breuk in het foramen mandibulaire eindigde. De hypothese dat het mandibulaire kanaal en/of the mylohyoid groeve functioneert als de weg van de minste weerstand werd maar gedeeltelijk bevestigd. Het gebruik van de splijttangen en splijthevels verhoogde niet de kans op bad splits in vergelijking met de literatuur.

In **hoofdstuk 7** wordt een retrospectieve studie beschreven over een groep van 427 patiënten, die een BSSO hebben ondergaan met splijttangen en splijthevels, om de incidentie van bad splits te onderzoeken. Verder werden verschillende risico factoren als oorzaak voor bad splits onderzocht. Het vóórkomen van bad splits in deze groep was 2,0% per kant. Dit is ruim binnen de range die beschreven wordt in de literatuur. De enige voorspellende factor voor een bad split was de verwijdering van verstandskiezen gedurende een BSSO. Er was geen significant verband tussen bad splits en leeftijd, sexe, occlusie klasse en ervaring van de chirurg. We concludeerden dat een BSSO, verricht met splijttangen en splijthevels, in plaats van beitels, de kans op een bad split niet verhoogd. Daarom wordt dit gezien als een veilige en voorspelbare techniek.

In **hoofdstuk 8** wordt een case report gepresenteerd van een BSSO in een gereconstrueerde mandibula. Een 28-jarige vrouw onderging een segmentale mandibulectomie, in verband met een multicysteus ameloblastoom in de linker onderkaak. Na een primaire plaatreconstructie, werd een definitieve reconstructie verricht met een bottransplantaat van de linker crista iliaca posterior. Na een succesvolle kaakreconstructie werd de patiënt voorbereid voor een orthodontisch-chirurgische behandeling in verband met een al bestaande klasse II malocclusie. Na een jaar van orthodontische voorbehandeling, werd de BSSO gepland. Een sagittale split werd verricht in de bestaande rechter mandibula en in de links gereconstrueerde kaak. Na 10 maanden werden er vervolgens implantaten geplaatst in de gereconstrueerde kaak om verder occlusie herstel te kunnen bewerkstelligen. Tijdens vervolg bezoeken, zagen we een klasse I occlusie met goede functie. De patiënt was uiteindelijk erg tevreden met het functionele en esthetische resultaat. Dit laat zien dat een BSSO verricht kan worden in een gereconstrueerde mandibula, zonder neven effecten en met goede functionele en esthetische resultaten.

Ten slotte beschrijft **hoofdstuk 9** de ervaringen van een Mond-, Kaak- en Aangezichts chirurg, die zelf een gecombineerde orthodontische-chirurgische behandeling heeft ondergaan.

List of publications
Curriculum vitae

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Curriculum vitae

Gertjan Mensink werd geboren op 26 december 1978 in Groningen. Na het behalen van zijn VWO diploma aan het Nienoordcollege te Leek in 1997, studeerde hij van 1997-2003 Tandheelkunde aan het ACTA (Vrije Universiteit), waarvan de propedeuse cum laude werd behaald. Vervolgens studeerde hij van 2003 tot 2005 Geneeskunde aan het VUmc en behaalde zijn doctoraal geneeskunde. In dezelfde periode werkte hij als tandarts algemeen practicus in Amsterdam. In 2005 ging hij in opleiding tot specialist in Mondziekten, Kaak-, en Aangezichtschirurgie in het Leids Universitair Medisch Centrum te Leiden (hoofd: Prof. Dr. van Merkesteyn). Zijn perifere jaar van de opleiding werd in 2008 gevolgd in het Kennemer Gasthuis te Haarlem (opleider: Prof. Dr. A.G. Becking). Vervolgens liep hij zijn co-schappen Geneeskunde in het LUMC van 2009 – 2010, waarna hij zijn arts-examen behaalde. In deze periode werd ook het promotie traject begonnen in het LUMC. In oktober 2010 werd hij ingeschreven als specialist in Mondziekten, Kaak-, en Aangezichtschirurgie en trad hij toe tot de maatschap kaakchirurgie West-Brabant. Speciale aandachtsgebieden zijn de orthognatische chirurgie, (pre)implantologische chirurgie, traumatologie en botpathologie. Per september 2014 is hij begonnen met een Master of Science in esthetische aangezichtschirurgie aan de Universiteit van Witten-Herdecke, Duitsland.

Gertjan is getrouwd met Florine Mensink-Mulder. Zij hebben 3 kinderen, Jorren (geboren 20-09-2009), Fiene (geboren 03-12-2010) en Rosemijn (geboren 05-01-2014).

Bilateral sagittal split osteotomy by the splitter–separator technique

Gertjan Mensink