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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.

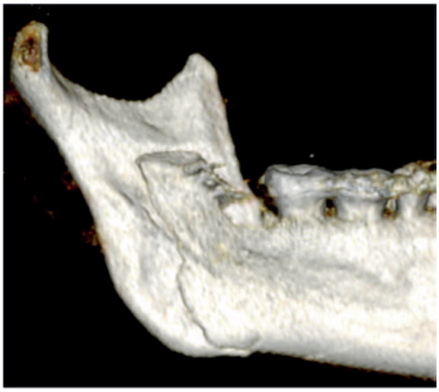

Figure 1 Postoperative cone-beam CT scan of the lingual side after SSO. The fracture line runs through the mandibular foramen and across the mylohyoid groove. Note the position of the medial horizontal osteotomy, just beyond the lingula.

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).

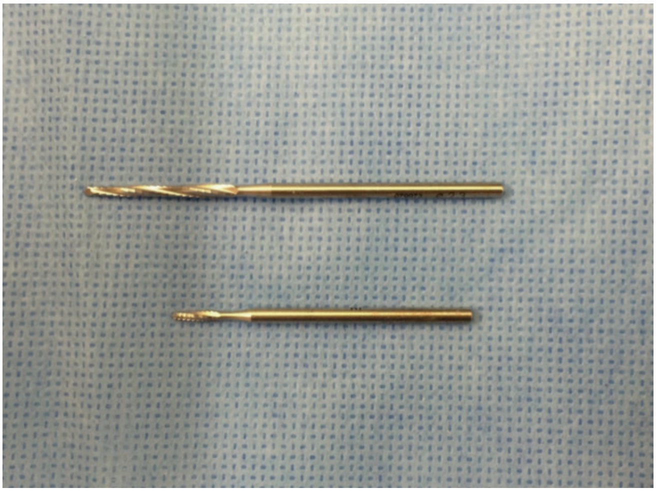

Figure 4 The Lindemann bur (2.3 × 22 mm) used for the horizontal osteotomy and the short Lindemann bur (1.4 × 5 mm) used for the vertical and sagittal osteotomies.

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 intrafascicular 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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