NEUROSENSORY DISTURBANCE AFTER BILATERAL SAGITTAL SPLIT OSTEOTOMY

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Neurosensory disturbance is a common complication of bilateral sagittal split osteotomy (BSSO). This study focuses on the evaluation of factors affecting neurosensory disturbance after BSSO. Furthermore, the study focuses on the measurement of neurosensory disturbance with easily available bedside tests, not only on evaluating the state of sensory disturbance at each follow-up, but also on predicting the potential for recovery. Moreover, panoramic radiography, computerized tomography (CT) and conventional spiral tomography are assessed on locating the mandibular canal.

The study was carried out involving a total of 50 patients undergoing BSSO for the correction of mandibular deficiency. In addition, 20 voluntary healthy students participated in this study. Questionnaires, a battery of neurosensory tests and preoperative imaging of the mandibular canal were used.

A high incidence of neurosensory disturbance of the lower lip and chin was found after BSSO. However, recovery of sensation occurred with increasing frequency during the follow-up, and after one year sensation of the lower lip and chin returned to the presurgical situation in most patients. A prolonged neurosensory disturbance was more frequent in older patients, in large surgical movements of the mandible and in cases where the inferior alveolar nerve was manipulated during surgery. The bedside tests used in this study correlated well with the patients' subjective evaluation of neurosensory disturbance, and the repeatability of these tests was good. Furthermore, the sensibility testing of the mandibular teeth correlated well with the other tests and patient's subjective evaluation. Four days after surgery, sensibility testing of the mandibular teeth was an efficient test alone to predict the recovery from neurosensory disturbance. On radiographic imaging, the risk for neurosensory disturbance after BSSO could not be predicted from the panoramic radiograph. Before BSSO, CT was the best method to visualize the buccolingual location of the mandibular canal.

After BSSO, a clinical follow-up using a battery of mechano- and nociceptive tests in the examination of sensation of the lower lip and chin, sensibility testing of the teeth, and subjective evaluation is needed. CT should be a part of treatment planning of the patients with thin rami or severe asymmetries of the mandible.

Keywords: radiology, sensory, disturbance, mandibular nerve, surgery
To Veikko, Mikael, Essi and Kasperi
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Leena Ylikontiola
Abbreviations

ANT between the first and second molar
BSD brush stroke direction
BR blink reflex
BSSO bilateral sagittal split osteotomy
CAT computer-assisted tomography
CT computerized tomography
IAN inferior alveolar nerve
IVRO intraoral vertical ramus osteotomy
LT light touch discrimination
MMF maxillomandibular fixation
MN mental nerve
PIN pin tactile discrimination
POST posterior to the second molar
SNAP sensory nerve action potential
PPV positive predictive value
ST sensibility testing of the teeth
TH thermal stimuli
TMD temporomandibular joint dysfunction
TSEP trigeminal somatosensory evoked potentials
2-P two-point discrimination
Glossary of terms

Allodynia  Pain due to a stimulus that does not normally provoke pain.
Analgesia  Absence of pain in response to stimulation that would normally be painful.
Anesthesia  Absence of any sensation in response to stimulation that would normally be painful or nonpainful.
Distal segment  The segment of the mandible produced by a sagittal split osteotomy that contains the tooth bearing portion of the mandible. It is also called the medial fragment.
Dysesthesia  Unpleasant abnormal sensation, whether spontaneous or evoked.
Hyperesthesia  Increased sensitivity to stimulation.
Hyperalgesia  Increased response to a stimulus that is normally painful.
Hypoalgesia  Diminished pain in response to a normally painful stimulus.
Hyperpathia  A painful syndrome, characterized by increased reaction to a stimulus, especially a repetitive stimulus.
Mental nerve  The distal part of the inferior alveolar nerve.
Neuralgia  Pain which follows the distribution of a nerve or nerves.
Neuropathy  Disturbance of function or pathologic change in a nerve.
Osteosynthesis  A method of attaching bone fragments to each other.
Osteotomy  Bony cut, performed with saws, burs, chisels or osteotomes.
Paresthesia  Abnormal sensation, whether spontaneous or evoked.
Prognathia  The jaw is longer than normal, its forward border being located anteriorly compared to its usual position, relative to the other facial bones.
Proximal segment  The segment of the mandible produced by a sagittal split osteotomy that contains the mandibular condyle, the coronoid process, the lateral border of the ramus and body of the mandible. It is also called the lateral fragment.
Rethrognathia  The jaw is retruded or shorter than normal, its anterior border being located posteriorly compared to its usual position, relative to the other facial bones.
List of original papers

The thesis is based on the following original articles, which are referred to in the text by numerals I to V:


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Contents

Abstract
Acknowledgements
Abbreviations
Glossary of terms
List of original papers
1 Introduction ................................................................. 17
2 Review of the literature .................................................. 19
  2.1 Orthognathic surgery of the mandible ... 19
     2.1.1 Bilateral sagittal split osteotomy (BSSO) ................. 20
     2.1.2 Other mandibular osteotomy methods ......................... 23
     2.1.3 Complications after mandibular orthognathic surgery ........ 26
  2.2 Anatomy of the inferior alveolar and the mental nerves .......... 29
     2.2.1 Anatomy of the mandibular nerve .......................... 29
     2.2.2 Anatomical variations ....................................... 30
  2.3 Mechanisms of nerve injury ........................................ 31
     2.3.1 Nerve morphology ............................................ 31
     2.3.2 Neuropraxia .................................................. 32
     2.3.3 Axonotmesis .................................................. 32
     2.3.4 Neurotmesis .................................................. 33
  2.4 Inferior alveolar nerve injury .................................... 33
     2.4.1 Inferior alveolar nerve injury in BSSO ..................... 33
     2.4.2 Inferior alveolar nerve injury in other surgical procedures .. 35
     2.4.3 Other causes of inferior alveolar nerve dysfunction ........ 35
  2.5 Methods for measuring the function of the inferior alveolar nerve .... 36
     2.5.1 Subjective clinical sensory testing .......................... 36
         2.5.1.1 Mechanoceptive tests .................................. 36
         2.5.1.2 Nociceptive tests ..................................... 37
         2.5.1.3 Other subjective clinical sensory tests ................. 37
     2.5.2 Objective sensory tests ..................................... 38
         2.5.2.1 Trigeminal somatosensory evoked potentials ............. 38
         2.5.2.2 Orthodromic sensory nerve action potentials .......... 38
         2.5.2.3 Blink reflex ............................................. 38
  2.6 Factors affecting neurosensory disturbances after BSSO .......... 39
1 Introduction

The bilateral sagittal split osteotomy (BSSO) is one of the most common procedures used in the treatment of mandibular deformity. It is generally followed by predictable and stable results (Bell et al. 1980). One drawback of this technique, however, is a varying degree of postoperative neurosensory disturbance of the lower lip and chin. Many retrospective and prospective studies report an 80% to 100% incidence of neurosensory disturbance immediately after BSSO. In most patients, the sensation of the lower lip and chin recovers spontaneously. One or two years after BSSO the prevalence of neurosensory disturbance can still range from 0% up to 85% one or two years after BSSO (MacIntosh 1981, Martis 1984, Raveh et al. 1988, Scheerlink et al. 1994, Bouwman et al. 1994, Fridrich et al. 1995, Cunningham et al. 1996, Fujioka et al. 1998, Blomqvist et al. 1998, Westermark et al. 1998a, August et al. 1998).

During the history of oral and maxillofacial surgery the mandibular nerve has been of interest to surgeons. The methods of evaluation of the neurosensory disturbance vary in the literature, from patient questioning (August et al. 1998) to sophisticated neurosensory testing (Zaytoun et al. 1986, Campbell et al. 1987, Ghali et al. 1989, Jones et al. 1990, Leira et al. 1991, Essick 1992, de Vries et al. 1993, Fridrich et al. 1995, Cunnigham et al. 1996, Pratt et al. 1996, Zuniga et al. 1998). Even though there are objective and quantitative methods to assess nerve conductive qualities (Jones et al. 1990, Jääskeläinen 1995a), the problem with those tests is that they are expensive and not available in everyday practise. Furthermore, the sensation of the mandibular region is finally judged by the patient with subjective point of view. The relationship between objective assessments and the patient’s subjective evaluation of neurosensory disturbance is also unclear. Some studies claim that patients tend to overreport their sensory loss as compared with objective measurements (LeBanc & Gregg 1992, Rosenqvist 1994, Cunningham et al. 1996), whereas other studies have shown more sensory loss when measured objectively (Koltzenburg et al. 1994). Thus, it is important to develop bedside methods that are readily available and simple to use, not only for research purposes but also to predict the recovery of the neurosensory disturbance for the patient. In general, it is important to follow up the patients and to encourage them to wait for recovery of their neurosensory disturbance. During the first postoperative year, the patients should be examined frequently by the surgeon, not only because possible relapse of the osteotomy
segments may continue as long as one year or more (Wall 2001), but also for controlling the recovery of neurosensory disturbance.

In BSSO, the osteotomy is performed in close proximity to the IAN, and therefore it can easily result in a postoperative neurosensory disturbance of the lower lip and chin (Behrman 1972, Turvey 1985, Martis 1984, MacIntosh 1981, Karas et al. 1990, Yoshida et al. 1989, Leira & Gilhuus-Moe 1991, Zaytoun et al. 1986, Naples et al. 1994, Jääskeläinen 1995c). Postoperative paresthesia is generally considered to be caused by mechanical damage of the sensory fibers of the IAN. Conversely, paresthesia seems to occur even when the nerve remains visibly intact during the operative procedure (Takeuchi et al. 1994, Westermark et al. 1998b). More attention to the factors affecting neurosensory disturbance after BSSO is needed in order to predict the prognosis of neurosensory disturbance to the patient both before and after surgery. Furthermore, special attention should be given to the exact location of the mandibular nerve in preventing and reducing damage to the IAN during surgery.

In clinical follow-up, there is a need for easily available bedside methods testing neurosensory disturbance after BSSO. In prevention of neurosensory disturbance following BSSO, more knowledge is required regarding the different factors causing sensory disturbance. To reduce complications and to improve the quality of care, a well-planned surgical approach should include a proper anamnestic and clinical evaluation and selected radiographs that localize the anatomic structures in the surgical field.
2 Review of the literature

2.1 Orthognathic surgery of the mandible

The term orthognathic originates from the words orthos and gnathos (Gr. orthos = straight; gnathos = jaw). Orthognathic surgery refers to surgical procedures designed to correct jaw deformities. Orthognathic procedures are divided into three categories: maxillary surgery, mandibular surgery, and bimaxillary procedures. Indications for orthognathic surgery include impaired mastication, temporomandibular pain and dysfunction, sleep apnea and susceptibility to caries and periodontal disease. This may be due to difficulty in maintaining oral hygiene because of severely protruding and irregular teeth. One indication is also the unaesthetic appearance of a dentofacial deformity resulting in undesirable psychosocial effects. In severe malocclusion there are three possibilities for correction: growth modification, orthodontic treatment or orthognathic surgery in conjunction with orthodontics to establish proper jaw relationship. Once growth has ceased, the combination of orthognathic surgery with orthodontics, usually becomes the only means of correcting severe dentofacial deformities.

Hullihen is regarded as the first surgeon to describe some type of mandibular orthognathic surgery. In 1849, he reported an anterior subapical osteotomy. The mandibular body osteotomy was first described by Blair in 1907 as an extraoral procedure. Later Dingman (1944) popularised the mandibular step osteotomy using a combination of intraoral and extraoral access with preservation of the neurovascular bundle. Caldwell and Letterman developed the intraoral vertical ramus osteotomy (IVRO) in 1954. This was mainly a setback procedure and did not allow for anterior movement of the distal segment. Sagittal split ramus osteotomy was first introduced by Schuchardt in 1942, but the current technique follows descriptions published by Trauner & Obwegeser in 1957. It was later modified by DalPont (1961), Hunsuck (1968), Gallo et al. (1976), and Epker (1977) among others (Fig. 1).
The subsequent modifications have generally focused on the attempts to manage or minimize the intra- or postoperative problems that have since emerged. The major problems include neurosensory disturbances of the lower lip and chin, unfavourable splits, relapse, fragment resorption, and condylar displacement (Behrman et al. 1972, Martis 1984, Turvey 1985, Jääskeläinen et al. 1996). However, during these years it has proved to be a versatile method for correcting mandibular skeletal malocclusions (Proffitt et al. 1992) and it has become a standard procedure within mandibular orthognathic surgery (Wyatt 1997).

### 2.1.1 Bilateral sagittal split osteotomy (BSSO)

Today the bilateral sagittal split ramus osteotomy, BSSO is the most commonly used procedure in the treatment of maxillofacial deformities such as prognathism or retrognathism (Jones et al. 1990, Proffitt et al. 1992, Wyatt 1997). It is a versatile technique, because it allows movement of the mandible in a posterior direction, but it also allows for relatively large anterior movements (Fig. 2).
Fig. 2. Mandibular ramus sagittal split osteotomy is the most common technique used for mandibular advancement (Wolford & Fields 1999).

In most cases the treatment results are good, and severe complications are rare (MacIntosh 1981, Martis 1984, Turvey 1985, O’Ryan 1990, van den Perre et al. 1996, Panula et al. 2001). Various benefits of BSSO as all orthognathic procedures include better masticatory function (Karabouta & Martis 1985, Magnusson et al. 1990, White & Dolwick 1992, Raustia & Oikarinen 1994), reduced facial pain (Magnusson et al. 1986), and improved facial aesthetics (Cheng et al. 1998).

The incision begins on the anterior border of the ramus near the midpoint. It is then continued down on the lateral crest of the alveolus, along the oblique ridge to the vestibular area of the second molar. The periosteum is reflected laterally to expose the body of the mandible down to the inferior border. The medial surface is also exposed with a retractor, and the medial cut is made through the medial cortex into medullary bone from just above the lingula (Smith et al. 1991). Caution should be used in retraction on the medial aspect, because decreased nerve conduction have been noted when the inferior alveolar nerve is compressed (Jones & Thrash 1992, Jääskeläinen et al. 1995b, Westermark et al. 1998a). During the cutting, it’s important to place a curved clamp as close to the coronoid tip as possible to allow access to the medial aspect of the ramus. Furthermore, releasing tissue inferiorly to the level of the occlusal plane allows access and visualization of the medial aspect of the ramus. The vertical cut is made with a bur through the cortex on buccal surface of the mandible between the first and the second molar. The two cuts are jointed by a bur or a saw to cut the cortical bone in a sagittal direction. The fine, flexible spatula chisel is driven directly onto the inner aspect of the buccal cortex and slides down it closely following the buccal cortical wall so that it stays lateral to the neurovascular bundle (Spiessl 1976, Brusati et al. 1981, Simpson 1981, Leonard et al. 1985). Following the cortical plate in that manner is reported to decrease injuries to the inferior alveolar nerve (Mercier 1973, Spiessl 1976, Brusati et al. 1981,
Simpson 1981). The cortices should be gently separated, looking for the neurovascular bundle. Once located, the osteotome is placed beyond the nerve and the split is completed. The gap between the proximal and the distal segment is inspected. The neurovascular bundle can stay inside the medial fragment so that it is not encountered, especially if the bony cut is made by a flexible spatula chisel along the inner aspect of the buccal cortex (Mercier 1973, Brusati et al. 1981). In most cases the neurovascular bundle is visible but embedded in the medial fragment. If the nerve is seen passing from the buccal to the lingual side, the surgeon should gently lift it of the medullary bone. If the neurovascular bundle is surrounded by cortical bone, fine osteotomes should be used to gently free it (Smith et al. 1991). Following completion of the split, the medial pterygoid muscle attachments should be stripped to allow for movement of the segments into their new positions.

After the osteotomy, the distal segment is advanced to the desired position. A prefabricated acrylic splint is placed to the maxillary dentition. In some centres the splint is not used, and in that case the teeth in the opposing jaw are used as reference instead of a splint (Krekmanov et al. 1988). When the lower teeth fit passively into the maxillary splint or the teeth, the teeth are placed into maxillomandibular fixation (MMF). Bony irregularities of the interior surface of the two contacting segments should be removed to prevent torquing of the segments and compression of the neurovascular bundle. When the bony contact and the occlusion are acceptable, bone fixation is achieved usually with two or three bicortical bone screws or with the monocortical screws and miniplates (Spiessl 1976, Jeter et al. 1984, Wolford et al. 1987, Krekmanov et al. 1988, Blomqvist et al. 1997). Also wiring has been used to achieve stabilization (Fig. 3). However, rigid fixation eliminates the use of MMF following surgery (Ellis 1988).

Fig. 3. a: Incision and medial reflection, with retractors in place. b: Lateral and horizontal cuts extending completely through cortex. c: Splitting segments apart and identifying inferior alveolar neurovascular bundle. d: Stabilization with wires (Epker 1977).
2.1.2 Other mandibular osteotomy methods

There are also other types of osteotomies that are used in mandibular orthognathic surgery. The vertical ramus osteotomy (IVRO) divides the mandibular ramus from the sigmoid notch down to the angular region (Caldwell & Letterman 1954, Hebert et al. 1970, Hall & McKenna 1987, Hibi & Ueda 1995). The bony cut is made posterior to the point where the mandibular nerve enters the bone, and this is why it has lower incidence of IAN injury than BSSO. Also patients tend to have fewer TMJ complaints after IVRO than BSSO (Bell et al. 1990). A great disadvantage of this method is, however, that it can be used only to setback procedures of the mandible (Fig. 4).

Fig. 4. The vertical ramus osteotomy can be used to set the mandible posteriorly (Wolford & Fields 1999).

The inverted L-osteotomy is a versatile procedure to treat severe mandibular deformities (Dattilo et al. 1985, van Sickels et al. 1990). In large asymmetry cases, an inverted L-osteotomy or IVRO may be preferable to the BSSO. The inverted L-osteotomy is also a good procedure for secondary correction of proximal segment malrotation following BSSO. Exposure of the lateral ramus and completion of the inferior vertical osteotomy are the same as for the IVRO. The main difference is that the vertical osteotomy ends just superior to the mandibular foramen (Fig. 5).
Fig. 5. The inverted L-osteotomy can be used to set the mandible posteriorly. It also allows vertical lengthening or shortening of the ramus without affecting the major muscles of mastication (Wolford & Fields 1999).

The vertical body osteotomy involves the removal of a piece of the mandibular body usually through combined extraoral and intraoral approaches (Blair 1907, Dingman 1944). Indications for this procedure are mandibular prognathism where the body is long in relation to the ramus or when it is useful to utilize space from planned extractions sites or already missing teeth (Fig. 6).

Fig. 6. The vertical body osteotomies can be performed in any area of the mandible to move the anterior segment of the mandible posteriorly, or alter the vertical and transverse position (Wolford & Fields 1999).
The step osteotomy may be indicated in cases of mandibular prognathism, retrognathism, asymmetry, and apertognathia (Pichler 1918, Dingman 1948, Converse & Shapiro 1952, Onland & Merkx 1972, Fordyce & Wedgewood 1976). By performing bilateral step-shaped cuts in the body of the mandible, the lower jaw is divided into three separate, independently moveable pieces. This osteotomy is particularly well suited in cases with edentulous spaces (Fig. 7).

![Fig. 7. The step osteotomy to allow retrusion of the anterior fragment of the mandible (Sàndor et al. 1982).](image)

The mandibular subapical osteotomies are designed to alter portions of the mandibular dental alveolus. Indications include leveling the occlusal plane, changing the anteroposterior position of the teeth, correcting asymmetries and changing the axial angulation of the teeth (Fig. 8).

![Fig. 8. The anterior subapical osteotomy (Wolford & Fields 1999).](image)

In 1942, the horizontal osteotomy of the symphysis called genioplasty was introduced by Hofer. Other than the introduction of an intraoral approach by Obwegeser (1957), very
little has changed. It cuts the mandible in a horizontal direction in the front of the chin. The bone cut is anterior and inferior to the point where the nerve exits the bone (Fig.9). The genioplasty is also often used in combination with BSSO, which may increase the tension on the nerve (Lindquist & Obeid 1988, Posnick et al. 1996, Acebal-Bianco et al. 2000).

Fig. 9. The genioplasty (modified from Salyer 1999).

### 2.1.3 Complications after mandibular orthognathic surgery

Postoperative neurosensory disturbance of the lower lip and chin is a major concern in all mandibular osteotomies, but particularly with the BSSO (Behrman 1972, Martis 1984, Turvey 1985, Panula et al. 2001). The reported incidences of IAN injury following orthognathic surgery vary according to the more or less objective methods used to test the neurosensory disturbance, time of follow-up, and the surgical techniques used. The incidence of neurosensory disturbance reported after BSSO is between 0% to 85% (Walter & Gregg 1979, Brusati et al. 1981, MacIntosh 1981, Sivartz et al. 1983, Martis 1984, Coghlan & Irvine 1986, Zaytoun et al. 1986, Campbell et al. 1987, Raveh et al. 1988, Yoshida et al. 1989, Jones et al. 1990, Karas et al. 1990, Naples et al. 1994, Scheerlink et al. 1994, Fridrich et al. 1995, Jääskeläinen et al. 1995b, Pratt et al. 1996, Nishioka et al. 1997, August et al. 1998, Fujioka et al. 1998, WESTERMARK et al. 1998a, Panula et al. 2001). At various stages of the operation, the IAN is at great risk of injury (Behrman et al. 1972, MacIntosh 1981, Martis 1984, Turvey 1985, van Merkesteyn et al. 1987, O’Ryan 1990, Westermark et al. 1998b). The nerve may be stretched or compressed near the mandibular foramen during medial retraction, or directly severed by surgical instruments, because the splitting line often traverses the mandibular canal and the neurovascular bundle within it. If the nerve has been exposed, it may be necessary to manipulate it when detaching it from the bony fragments. The nerve may also be stretched as the distal bone fragment is mobilized and repositioned. The nerve may be compressed between the distal and proximal fragments with compression osteosynthesis techniques. The vascular supply of the IAN may be compromised, resulting in ischaemic damage. Also some cases of traumatic neuroma after BSSO have been reported (Chau et
al. 1989, Appiah-Anane 1991, Sayan & Ucok 2002). Finally, if the screws are placed too
inferiorly, or if the screws used with the miniplates are too long, they can enter the
mandibular canal and damage the nerve. Postoperatively, edema or hematoma in the
mandibular canal may also lead to compression neuropathy (Pepersack & Chausse 1978,
Fiamminghi & Aversa 1979, Walter & Gregg 1979, Zaytoun et al. 1986, Jones et al.

After IVRO, obvious intraoperative IAN damage is uncommon (Tuinzing & Greebe
1985, Hall & McKenna 1987, van Merkesteyn et al. 1987), and long-term sensory
disturbance varies between 2% and 14% (Tuinzing & Greebe 1985, Zaytoun et al. 1986,
Hall & McKenna 1987). In 1986, Zaytoun and co-workers testing with brush directional
stroke, found a significantly higher long-term incidence of IAN injury a mean 3.2 years
after BSSO (63.6% of the 22 operated sides) as compared with transoral vertical ramus
osteotomy (0% of the 30 operated sides).

Complications with segmental mandibular body osteotomies are similar to those seen
in other mandibular osteotomies. Those particularly common to segmental osteotomy are
nerve damage, damage to the roots of the teeth, postoperative periodontal defect at the
osteotomy site, and non-union (Epker et al. 1996). The mandibular step osteotomy may
also pose a risk to the IAN than BSSO. In 1982, using brush directional stroke, two-point
discrimination and thermal testing with ice, Sàndor and co-workers reported a 68%
incidence of sensory disturbances in the immediate postoperative period which resolved
to 9% by 2 years after surgery (Sàndor et al. 1982).

The nerve is also at risk during genioplasty, with a long-term incidence of paresthesia
reported between 0% and 20% (Lindquist & Obeid 1988, Karas et al. 1990, Posnick et al.
increases the risk of sensory deficit. Two studies have reported the incidence of long-term
neurosensory deficit as 10% in genioplasty, 30% in sagittal split osteotomy, and 70% in

Vascular compromise may occur and affects both the soft tissues and the bone. Mild
ischemia can lead to periodontal defects, pulp necrosis, infection and delayed union.
Ischemic problems, such as nonunion, infection and avascular necrosis, have been
reported mostly in vertical ramus osteotomy. Genioplasty may also be associated with
avascular necrosis. After mandibular osteotomy, however, arterial flow is thought to
reverse through peripheral anastamoses (Aurlick et al. 1971).

Major hemorrhage associated with mandibular orthognathic surgery is uncommon.
There are a number of vessels at risk during ramus osteotomies, including the maxillary,
facial and inferior alveolar arteries, the masseteric vessels, the retromandibular vein and
the pterygoid venous plexus. Significant hemorrhage may also follow subapical
osteotomies or genioplasty as a result of injury to muscular vessels in the floor of the
mouth (Lanigan et al. 1991).

Failure to seat the segments properly can result in rotation of the proximal segment
and condylar torque. These malpositions of the condyle can result in pain, skeletal
relapse, malocclusion, hypomobility, and condylar resorption (van Sickels et al. 1990,
Panula et al. 2001).

The incidence of temporomandibular dysfunction (TMD) in the general population
varies usually between 20% and 25%. In a study of 280 orthognathic surgery patients
undergoing a BSSO, the incidence of TMD was reported a 41% preoperatively
The most frequent symptoms were pain and clicking of the temporomandibular joint. Following BSSO, only 11% of the patients had temporomandibular dysfunction. However, new symptoms of TMD were noted in 4% of the patients postoperatively. In the prospective study of Panula and co-workers, 73% BSSO patients had signs and symptoms of TMD preoperatively, and 60% had some symptoms after 4 years follow-up. Seven percent of the patients who had no TMD preoperatively, developed signs and symptoms of TMD postoperatively (Panula et al. 2000). In most studies, TMD symptoms are likely to resolve or improve following orthognathic surgery although some asymptomatic patients also develop new symptoms of TMD after surgery (Karabouta & Martis 1985, Kerstens et al. 1989, Panula et al. 2000).

The incidence of condylar resorption after orthognathic surgery has been reported to range from 1% to 31% (Bowman et al. 1994, de Clercq et al. 1994, Cutbirth et al. 1998, Panula et al. 2001). In the study of Panula and co-workers, condylar resorption was found in 58/527 (11%) of the patients. 35 of these 58 patients had resorption before any treatment, 2 patients developed it after the orthodontics, and 21 developed it after orthognathic surgery. No correlation was noted between the age of the patient and condylar resorption (Panula et al. 2001). Condylar resorption has been noted more frequently in females with high mandibular planes, preoperative TMJ dysfunction, large mandibular advancement and distal segment counterclockwise rotation (Kerstens et al. 1989, Moore et al. 1991, de Clercq et al. 1994, Scheerlink et al. 1994.).

Postoperative malocclusion as an anterior open bite is usually the result of inadequate fixation of the proximal and distal segments. Midline shifts are most likely a result of torquing of the proximal segment while the patient is under general anesthesia.

Fractures or undesirable osteotomy patterns may occur particularly in BSSO. The incidence of bad splits after a BSSO varies between 3% and 23% (Guernsey & de Champlain 1971, MacIntosh 1981, Turvey et al. 1985, van Merkesteyn et al. 1987, Panula et al. 2001). The risk of bad splits is reduced by careful technique, although problems may occur despite good technical surgery.

Hypomobility of the mandible or trismus may occur following orthognathic surgery. Excessive manipulation of the proximal fragment has been reported to cause intraarticular hematomata, leading to pain and limited opening (Kerstens et al. 1989). Other reported causes for hypomobility are fibrosis and preexisting temporomandibular joint disorders (Onizawa et al. 1995) and condylar torquing after the use of rigid fixation in BSSO (van Sickels et al. 1997).

Relapse following a mandibular osteotomy depends on the amount of mandibular movement and the type of fixation. Relapse is expected with mandibular advancements greater than 7mm (van Sickels et al. 1997) In the study of Panula and co-workers, severe relapse was seen in 3% and mild relapse in 8% of the patients (Panula et al. 2001). One method to prevent skeletal relapse include orthodontic over correction. Also the type of fixation plays an important role in preventing the relapse. If no internal fixation is used between the proximal and distal fragments in a BSSO, then significant skeletal and occlusal relapse will occur (Sándor et al. 1984). Bicortical screws either alone or in combination with a plate work better than a plate and monocortical screws (Murphy et al. 1997).
The teeth and periodontium are at risk for many reasons. Vascular compromise may result in tooth mobility, periodontal defects, and necrosis of gingiva and bone with tooth and possibly segment loss. Periodontal damage is most common in segmental procedures. Mechanical damage to the teeth from saws, burs and screws are possible (Panula et al. 2001). However, the risk of root resorption is greater in orthodontic treatment than in orthognathic surgery (Tucker 1995). In the study of Panula and co-workers, less than 4% of the patients developed symptomless root resorption during the orthodontic treatment. Orthognathic surgery patients may not require as much compressive orthodontic force against the root because the time and extent of tooth shift is less than with orthodontics alone (Panula et al. 2001).

Other potential complications of orthognathic surgery are legion. Accidental damage to the endotracheal tube, the pilot tube, or both, may occur during surgery (El Deeb et al. 1989). Postoperatively, soft-tissue swelling and hemorrhage may compromise the airway (Panula et al. 2001). Furthermore, postoperative surgical infection in intraoral orthognathic surgery may occur (Martis 1984, Panula et al. 2001). Because antibiotics are used almost universally, the appearance of postoperative infection following orthognathic surgery is uncommon. Usually, it is related to contamination of a hematoma, a bone sequestrum or loosened internal rigid fixation material.

Lingual nerve injury is an infrequent complication following BSSO. However, many cases have been reported in the literature (Hegtvedt & Zuniga 1990, Meyer 1990a, Bouwman et al. 1995, Schow et al. 1996, Acebal-Bianco et al. 2000). In most cases, lingual nerve paresthesia resolves spontaneously, but also long-lasting paresthesia has been reported (Pepersack & Chausse 1978). Mainly the cases of lingual nerve injury are a result of wire or bicortical screw placement near the superior border of the mandible in the region of the third molar. The findings of Schow and co-workers (1996) indicate the importance of accurately determining proper screw length for fixation of a BSSO.

The incidence of facial nerve injury following mandibular ramus osteotomies is between 0.4% and 1% (Behrman 1972, MacIntosh 1981, Karabouta-Vougaropoulou & Martis 1984, de Vries et al. 1993, Acebal-Bianco et al. 2000). Usually it resolves spontaneously. In most cases of incomplete recovery, it is mainly associated with large mandibular setbacks in which the osteotomy was extended to the posterior border of the mandible (MacIntosh 1981, Karabouta-Vougaropoulou & Martis 1984, Consolo & Salgarelli 1992).

Complications with BSSO are rare today or occur with a low frequency. Complications related to the IAN, however, still remain a problem to reduce or avoid injury. In the following, the thesis will focus on the IAN.

### 2.2 Anatomy of the inferior alveolar and the mental nerves

#### 2.2.1 Anatomy of the mandibular nerve

The mandibular nerve is the third and inferiormost division of the trigeminal nerve, or the fifth cranial nerve. The trigeminal nerve is predominantly a sensory nerve, innervating
most of the face. The upper branch of the trigeminal nerve is called the ophthalmic nerve and innervates the forehead. The middle branch is called the maxillary nerve and innervates the maxilla and the midface. The lower branch is called the mandibular nerve and innervates the teeth and the mandible, the lateral mucosa of the mandible, and the mucosa and skin of the cheek, lower lip and chin (Scothorne 1976, Gosling et al. 1985). The mandibular nerve runs from the trigeminal ganglion through the foramen ovale down towards the mandible. The nerve enters the mandible through the mandibular foramen on the medial surface of the ascending mandibular ramus. Before it enters the bone, the mandibular nerve gives branches to the tongue and to the soft tissues of the cheek. After passing through the mandibular foramen, the nerve is called the inferior alveolar nerve (IAN). The IAN contains mainly sensory fibres and only a few motor fibres distributed by the mylohyoid nerve to the mylohyoid and the anterior belly of the digastric muscles. Within the mandibular canal, the IAN runs forwards in company with the inferior alveolar artery and together they are called the inferior alveolar neurovascular bundle. The IAN supplies the lower molar and premolar teeth and adjacent parts of the gingiva. Its larger terminal branch emerges from the mental foramen as the mental nerve to innervate the skin of the chin and the lower lip, while the smaller incisive branch supplies the canine and incisor teeth. Disturbances of the IAN and mental nerve will predominantly give sensitivity symptoms in the soft tissue of the lower lip and chin. (Aldskogius et al. 1985).

2.2.2 Anatomical variations

Different variations in the course of the inferior alveolar neurovascular bundle are described (Anderson & Kosinski 1991). The classification by Carter and Keen (1971) in the mandible is illustrated in Fig.10. These results were obtained from only eight dissected mandibles. In another larger study the course of the IAN was evaluated from 3612 radiographs (Nortje et al. 1977). The radiographs were divided into four categories: 1) high mandibular canals (within 2mm of the apices of the first and second molars), 2) intermediate mandibular canals, 3) low mandibular canals, and 4) other variations – these included duplication or division of the canal, apparent partial or complete absence of the canal or lack of symmetry. Of the 3612 subjects, 47% of the canals were high, 49% were low, and only 3% could not be fitted into the high or low canal categories. The main conclusion of this study was, that the mandibular canals are usually, but not invariably, bilaterally symmetrical, and the majority of hemimandibles contain only one major canal.
Multiple mandibular canals of the bifid variety characterized by a single mandibular foramen and two nearly equal canals are unusual. In the study of Nortje and co-workers, duplication or division of the canal was found in 0.9% (33/3612) of the cases in the panoramic radiographs in otherwise normal patients (Nortje et al. 1977). In another study only 0.08% bifurcation of the IAN in 5000 US Army recruits, aged 17 to 26, was found (Grover & Lorton 1983). Furthermore, Langlais and co-workers (1985) evaluated routine panoramic radiographs of 6000 patients, and they found 57 (0.95%) cases of bifid inferior mandibular canals, 19 in males and 38 in females. However, no cases of multiple canals in orthognathic surgical cases have been reported.

2.3 Mechanisms of nerve injury

2.3.1 Nerve morphology

The nerve trunk is composed of four connective tissue sheaths. From the outside inward these are the mesoneurium, epineurium, perineurium, and endoneurium (Daniel & Terzis 1977, May 1986, Millesi & Terzis 1987, Lundborg 1988). The mesoneurium is a connective tissue sheath analogous to the mesentery of the intestine. It suspends the nerve trunk within the soft tissue, contains the segmental blood supply of the nerve, and is continuous with the epineurium. The epineurium is the loose connective tissue sheath that defines the nerve trunk and protects it against mechanical stress. Fascicles are delineated
by the perineurium, which surrounds the axons and endoneurial sheaths. The fascicles form a complex branching pattern that varies from millimetre to millimetre along the path of the nerve trunk. The fascicular pattern can be monofascicular (one large fascicle), oligofascicular (2-10 rather large fascicles) or polyfascicular (more than 10 fascicles of different sizes). Individual nerve fibers and their Schwann cells are surrounded by the endoneurium. Together, the perineurium and endoneurium provide elasticity. Polyfascicular nerves such as the IAN with many small fascicles are better able to withstand stretch than are monofascicular or oligofascicular nerves (Sunderland 1951).

The nerve fiber is the functional component of the peripheral nerve responsible for transmitting stimuli. The nerve fiber is composed of an axon, a Schwann cell, and a myelin sheath in myelinated nerve fibers. The axon is an extension of a neuron and can be characterized by morphology, conduction velocity and function. A-alpha fibers are the largest myelinated fibers, functionally they are encoded for the transmission of muscle spindle and tendon organ afferents and skeletal muscle efferents. The A-beta fibers are the next largest myelinated axons. The sensation of touch is attributed to these axons. The smallest of the myelinated fibers are the A-delta fibers, which transmit stimuli encoded for temperature and pain. The smallest axons are the unmyelinated C-fibers. They transmit stimuli encoded for slow or second pain, temperature, and efferent sympathetic fibers (LaBanc 1992).

In 1943, Seddon described a triple classification of mechanical nerve injuries to characterize the morphophysiologic types of mechanical nerve injuries. Seddon’s classification (neuropraxia, axonotmesis and neurtmesis) is based on the time course and completeness of sensory recovery.

2.3.2 Neuropraxia

The majority of IAN injuries following BSSO are neuropraxias. A neuropraxia is characterized by a conduction block, the rapid and virtually complete return of sensation or function, and no degeneration of the axon. It may be the result of nerve trunk manipulation, traction, or compression of a nerve such as might occur during sagittal ramus osteotomy. Trauma of sufficient magnitude to injure the endoneurial capillaries causes intrafascicular edema, resulting in a conduction block. Normal sensation or function returns within 1 to 2 days following the resolution of intrafascicular edema, generally within 1 week following nerve injury. Pressure on the nerve may also result in segmental demyelinisation or mechanical disruption of the myelin sheaths. In this case sensory and functional recovery are complete within 1 to 2 months. The response to this type of injury is paresthesia (LaBanc 1992).

2.3.3 Axonotmesis

An axonotmesis is characterized by axonal injury with subsequent degeneration or regeneration. Traction and compression are the usual mechanisms of this type of injury
and may cause severe ischemia, intrafascicular edema, or demyelination. Even though the axons are damaged, there is no disruption of the endoneurial sheath, perineurium, or epineurium. Complete recovery occurs in 2 to 4 months, but improvement leading to complete recovery may take as long as 12 months. It is important to know that within 2 to 4 months following injury there are signs of sensation or function which continue to improve over the next 8 to 10 months. The psychophysical response to an axonotmesis is an initial anesthesia followed by a paresthesia as recovery begins (LaBanc 1992).

### 2.3.4 Neurotmesis

A neurotmesis is characterized by severe disruption of the connective tissue components of the nerve trunk with compromised sensory and functional recovery. The etiology of nerve injury is traction, compression, injection injury, chemical injury or in a complete disruption of the nerve trunk laceration and avulsion. With this type of nerve injury there is a poor prognosis for recovery, and sensory and functional recovery is never complete. The psychophysical response to these injuries is an immediate anestesia. This may be followed by paresthesia or possibly neuropathic responses such as allodynia, hyperpathia, hyperalgesia, or chronic pain. This type of nerve injury has a high probability of development of a central neuroma (LaBanc 1992).

### 2.4 Inferior alveolar nerve injury

#### 2.4.1 Inferior alveolar nerve injury in BSSO

Sensory disturbance is a major concern particularly in BSSO (Martis 1984, MacIntosh 1981). The inferior alveolar nerve (IAN) is at significant risk during the operation (Brusati et al. 1981, Jääskeläinen et al. 1995b). It is at risk in all stages of surgery, including incision, dissection, retraction, bone cuts, mobilization and internal fixation. Nerve damage apparent at operation during BSSO is reported from 1.3% to 18% (Turvey 1985, Guernsey & de Champlain 1971, van Merkesteyn et al. 1987).

However, sensory changes following BSSO tend to be temporary in most cases.

A neurosensory disturbance of the lower lip and chin has been described as something that does not bother the patient or only rarely does so. (Martis 1984, Nishioka et al. 1987, Leira & Gilhuus-Moe 1991, van den Perre et al. 1996, Forssell et al. 1998, Lemke et al. 1998). Obwegeser discussed the indications for BSSO in his article of 1964 without even mentioning the risk of neurosensory disturbance. In spite of the fact that the deficit of the IAN is of a purely sensory nature in a small area, of the lower lip and the skin of the chin, this altered sensation is often reported as the most distressing complication after orthognathic surgery. IAN injury not only gives rise to unpleasant sensations, but may also affect the ability to talk and masticate effectively without traumatizing the affected area (Jones et al. 1990). The nerve deficit may give rise to continuous aching in the lower face (hyperalgesia, neuralgia) and social suffering. Some patients complain of pain or other strange sensations (allodynia, dysesthesia, paresthesia) when touching the area of altered sensation in the lower lip. Furthermore, kissing may become an unpleasant experience. Despite the risk of IAN injury in BSSO, the treatment benefits are considered to outweigh the treatment drawbacks (Campbell et al. 1987).

The mandibular nerve above the level at the lingula is at risk to injury during exposure of the medial side of the ramus. Some authors have suggested that the soft tissue dissection on the medial aspect of the mandibular ramus might be, to some extent, responsible for neurosensory disturbance after BSSO (Jääskeläinen et al. 1995b, Westermark et al. 1998a). It is claimed, that the soft tissue dissection on the medial aspect of the mandibular ramus may compress the nerve both over the lingula and under the dissecting instrument and the nerve may also be torn between those two points (Westermark et al. 1998a). The nerve is also at risk during the lingual osteotomy cut, when it may be crushed or damaged by the bur. The anterior vertical cut in the buccal cortex can also damage the IAN (Fiamminghi & Aversa 1979). The neurovascular canal lies approximately 5 mm medially from the buccal cortex at the site of the second molar, with a range of 3-7 mm (Mercier 1973). In initiating the split, the IAN is at risk when the osteotome is driven into the bone cut on the upper surface of the external oblique ridge. In most cases the IAN is situated between 4 and 11 mm below the surface of the ridge, but in 5% of cases the distance may be from 1 to 4 mm (Mercier 1973).

The method of fixation may also have an effect on nerve damage (Karas et al. 1990). Compression screws should not be used, as compression of the buccal and lingual plates may compress the nerve (Lindorf 1986). Bicortical non-compression screws are better for this purpose (Nishioka et al. 1997, Lindorf 1986), as long as they are not over-tightened. However, care should be taken in placing bicortical screws above the neurovascular bundle to avoid damage to it (Lindorf 1986).

The relationship between objective assessments and the patient’s subjective evaluation of neurosensory disturbance is unclear. In 1978, Pepersack & Chausse found a reasonably high incidence (61%) of permanent sensory alteration at least 5 years after BSSO for mandibular prognathism in 123 operated patients with sensory testing (tactile as well as thermal and sharp/blunt discrimination). Subjectively, only 41.8% of the patients reported sensory disturbances that were characterized as hyperesthesia or paresthesia in the lower lip. Also Coghlan & Irvine (1986) reported a higher incidence of neurosensory disturbances in clinical neurosensory testing (65.8% of the osteotomy sides)
than of subjective symptoms (26.3% of the sides) two years after BSSO in 19 patients. All their patients had felt numbness bilaterally in the distributions of the IAN immediately after the operation. Conversely, in another study (Leira & Gilhuus-Moe 1991) clinical sensory testing revealed sensory dysfunction of the IAN in 34% of the operated sides 4 days after the BSSO, and in 8% at six months in 25 patients. Subjective claims were more often encountered in this study: in 54% of the sites immediately after the operation, and still in 34% at six months.

Nishioka et al. (1987) found a statistically significant correlation between subjective claims of neurosensory disturbance and objective alteration in at least one of the neurosensory tests in 71.4% of 21 patients at a mean of 21.1 months after BSSO. They found most abnormalities in the brush directional stroke test, whereas the thermal test was considered the most insensitive. Also other studies have found the subjective claims and assessments reasonably equal in sensitivity (Yoshida et al. 1989). They used a battery of clinical sensory testing consisting of light touch, anesthesiometer and two-point discrimination. One week after the operation, 67% of the sides showed sensory alteration. Half of the severely affected sides recovered within three to 12 months, while mildly affected sides were normal within one to three months.

Any nerve division seen at operation should be repaired if possible. One or two epineural sutures will coapt the cut ends without tension in set-back procedures. In advancements this may result in too much tension on the nerve repair, in which case the nerve should be carefully dissected out of its bone canal, to free the nerve ends before repairing or interpositional nerve grafting is considered.

### 2.4.2 Inferior alveolar nerve injury in other surgical procedures

IAN injury can also follow other surgical procedures in the mandible. The proximity of the roots of the third molar to the mandibular canal exposes the IAN to an injury during extraction of the third molar (Kipp et al. 1980). The risk of nerve injury is higher with difficult impaction of the third molar (Merrill 1979, Kipp et al. 1980, Carmichael & McGowan 1992). Furthermore, injection of local anesthetics into the IAN has been considered a potential source of nerve damage (Jones & Trash 1992), although some other studies did not find a significant correlation between injection of local anesthetics and postoperative dysesthesia (Kipp et al. 1980).

The repositioning and manipulation of the IAN during placement of endosseous implants in the posterior mandible is also a risk for nerve injury (Smiler 1993). Furthermore, mandibular fractures situated in the area traversed by the mandibular canal are frequently associated with IAN injury (Iizuka & Lindqvist 1991).

### 2.4.3 Other causes of inferior alveolar nerve dysfunction

The second and third branches of the trigeminal nerve are particularly susceptible to an idiopathic sensory neuropathy causing facial numbness (Blau et al. 1969, Penarrocha et
The same preponderance of the maxillary and mandibular branches has been shown in trigeminal neuropathy associated with connective tissue disorder (Teasdall et al. 1980, Lecky et al. 1987, Hagen et al. 1990). Viral infection by herpes simplex (Fisher 1983) or herpes zoster (Goor & Ongerboer de Visser 1976) are also known to cause trigeminal dysfunction. Osteomyelitis, tumours and cysts of the mandible and their surgical treatment may also give rise to sensory alteration in the distribution of the IAN (Robinson 1988). In addition, root canal treatment for dental caries has also been shown to lead to permanent paresthesia of the IAN (Brodin 1988).

2.5 Methods for measuring the function of the inferior alveolar nerve

The purpose of the sensory diagnostic evaluation is to document whether or not a neurosensory disturbance exists, to quantitate the disturbance, to monitor sensory recovery, to determine whether or not microreconstructive surgery may be indicated, and to monitor sensory recovery following microreconstructive surgery. The methods of evaluation of the neurosensory function of the lower lip and chin has varied widely, from pure patient questioning to sophisticated, high-technological examination modalities.

2.5.1 Subjective clinical sensory testing

At present, diagnosis of sensory disturbances of the IAN is still mostly based on clinical sensory testing. Clinical neurosensory testing can be divided into two basic categories, mechanoreceptive and nociceptive, based upon the specific receptors stimulated through cutaneous contact. Mechanoreceptive tests include static light touch, two-point discrimination and brush stroke direction. Pin tactile discrimination and thermal discrimination are nociceptive tests. Each test assesses specific categories of receptors and axons. The results of these tests provide important information leading to the diagnosis of the nerve injury.

2.5.1.1 Mechanoreceptive tests

Static light touch detection (LT). The static light touch detection assesses the integrity of the cells, which are innervated by myelinated afferent A-beta axons. These receptors adapt slowly, and their putative sensory modality is pressure. The large myelinated A-beta fibers are highly susceptible to compression injury. The patient closes his eyes and says “yes” whenever he feels a light touch to the face and points to the exact spot where he felt the touch.

Brush directional discrimination (BSD). This is a test of proprioception and assesses the integrity of the large a-alpha and A-beta myelinated axons. The sensory modalities for
these receptors are vibration, touch and flutter. The patient tells if any sensation is detected and in which direction the filament or brush moved.

**Two-point discrimination (2-P).** This is a test which assesses the quantity and density of functional sensory receptors and afferent fibers. If sharp points are used, the small myelinated A-delta and unmyelinated C-afferent fibers are assessed. If blunt points are used, the larger myelinated A-alpha afferent fibers are assessed. 2-P is measured with any instrument with which the distance between two points can be altered. With the patient’s eyes closed the test is initiated with the points essentially touching so that the patient is able to discriminate only one point. The normal values vary a lot, the average value being around 5mm (Kawamura & Wessberg 1985).

### 2.5.1.2 Nociceptive tests

**Pin pressure nociception (PIN).** This test assesses the free nerve endings and the small A-delta and C-fibers that innervate the free nerve endings responsible for nociception. For this test the most common instrument is algesimeter. This instrument is made from a needle and an orthodontic strain gauge. The sharp point of the needle is used to test nociception and the blunt end to test for pressure detection. The magnitude of force necessary to feel the sharpness of the unaffected area is recorded as the nociceptive threshold for the affected area. The normal values also vary a lot in this test, but 15 g is considered to be an adequate force to elicit this response (Walter *et al.* 1979). An exaggerated response to pin pressure relative to an unaffected area is defined as hyperalgesia. A reduced response (touch) relative to an unaffected area is hypoalgesia. No response is defined as anesthesia.

**Thermal discrimination (TH).** Thermal discrimination is a useful test of sensation but is not essential. It assesses also the integrity of small myelinated and unmyelinated fibers similar to those tested with PIN. Warmth sensation is attributed to A-delta fibers and cold to C-fibers. Different instruments are available for thermal testing, including thermodes and Minnesota Thermal Disks, as well as ice, ethyl chloride sprays, acetone, and water.

### 2.5.1.3 Other subjective clinical sensory tests

**Diagnostic nerve block.** Diagnostic nerve blocks is one part of the diagnostic evaluation when pain is a symptom. The purpose of it is to aid in determining the mechanism of pain, locating the source of the pain, identifying the pain pathway, and determining the prognosis for decreasing or eliminating the pain. If the block relieves the pain, then microreconstructive surgery usually offers a favourable prognosis.
2.5.2 Objective sensory tests

2.5.2.1 Trigeminal somatosensory evoked potentials

Trigeminal somatosensory evoked potentials (TSEP) is an electrophysiologic method of evaluating the trigeminal pathway. The potential changes of cerebral origin will be detected on the scalp in human subjects after electrical stimulation of peripheral nerves (Nakagawa et al. 2001). The central nervous system response is recorded by signal averaging the electroencephalogram. Stimulating electrodes are applied to the cutaneous region to be tested and recording electrodes are applied to the scalp. The responses are analysed and plotted by a signal averaging system. The resultant response plot is analysed for peak latencies and amplitudes. However, contemporary devices have many disadvantages including contamination with undesirable myographs and artefacts in a record, recording difficulties, and varying clinical techniques (Jones et al. 1990).

2.5.2.2 Orthodromic sensory nerve action potentials

Another method to monitor the function of the IAN is orthodromic sensory nerve action potential (SNAP) recording (Jääskeläinen et al. 1995, Jääskeläinen et al. 2000). It is used routinely in combination with electromyography (EMG) to assess peripheral nerve function. The recording electrode is inserted beneath the zygomatic arch in front of the temporomandibular joint, as near the mandibular branch of the trigeminal nerve as possible. The stimulating needle tips are inserted at the mental foramen as close to the nerve as possible. The onset latencies of the SNAPs and the amplitudes are recorded. Furthermore, the nerve conduction velocity of the IAN is calculated.

2.5.2.3 Blink reflex

Since the introduction of a method for electrically elicited blink reflex (BR) by Kugelberg (1952), the physiology and anatomy of this cranial reflex has been under extensive study. Jääskeläinen and co-workers (1995c) published the first study concerning the BR with stimulation of the mental nerve. In this technique, the active recording electrodes are placed on the outer border eyelids on the orbicularis oculi muscles on both sides. Reference electrodes are fixed on both sides of the nose. A ground electrode is wrapped around the arm. The BRs are elicited by electrical stimulation with a small bipolar surface electrode with 10 mm interelectrode distance. The stimulating cathode is placed on the vermilion border of the lower lip midway between the midline and the corner of the mouth, the anode lay below on each side. Stimulation of the mental nerve is made with a larger bipolar surface electrode between the stimulating cathode and the anode. The blink reflex responses are recorded simultaneously on both sides. BR proved to be a sensitive test in detecting IAN lesions within two to three months from injury (Jääskeläinen &
They also recorded the sensory action potentials of the IAN intraoperatively during BSSO and noticed that most of the nerve lesions occurred during the actual splitting procedure (Jääskeläinen et al. 1995c). Partial transection and mobilization of the IAN during the BSSO were equally potent in producing abnormal results both in the objective electrophysiological tests intra- and postoperatively and in the postoperative clinical testing.

2.6 Factors affecting neurosensory disturbances after BSSO

2.6.1 The operation technique

Various reports suggest, that direct trauma to the neurovascular bundle during the sagittal split osteotomy creates neurosensory disturbances (Brusati et al. 1981, El Deeb et al. 1989, Fridrich et al. 1995, Leira & Gilhuus-Moe 1991, Zaytoun et al. 1986). It has also been claimed that the dissection techniques aiming to protect the nerve might disturb the nerve function (Walter & Gregg 1979, Zaytoun et al. 1986, Nishioka et al. 1987, Karas et al. 1990, Jones et al. 1990, Leira & Gilhuus-Moe 1991, Naples et al. 1994, Jääskeläinen et al. 1995b). In 1978 Pepersack & Chausse noted that all those IANs that had been freed from the buccal flange and thus manipulated during the operation showed signs of persisting sensory alteration. Leira & Gilhuus-Moe (1991) reported a correlation between the intraoperative strain and the postoperative sensory deficit after BSSO based on the observation that all the nerves not visibly harmed during the operation showed normal sensation in clinical sensory testing at six months, while the persisting sensory deficits were found in the cases where the nerves had been visibly lesioned. There were, however, two patients complaining about subjective sensory impairment at six months even though these nerves had not been exposed during the operation.

Other intraoperative parameters have also been mentioned as potential threats to the nerve. Thus, it has been suggested that the advancement or setback of the mandible would disturb the nerve by stretching or compressing it (Takeuchi et al. 1994, Pratt et al. 1996). Also the soft tissue dissection on the medial aspect of the mandibular ramus might compress the nerve over the bony edge where the nerve enters the bone (Jääskeläinen et al. 1995b, Westermark et al. 1998b, Teerijoki-Oksa et al. 2002). It has also been suggested that different types of osteosynthesis might create nerve compression between the fragments (Paulus & Steinhauser 1982, Bouwman et al. 1994, Pratt et al. 1996, Fujioka et al. 1998, Lenke et al. 2000). There seem, however, not to be any significant difference in nerve disturbances between different types of osteosynthesis (McDonald 1990, Scheerlink et al. 1994).
2.6.2 General factors

General factors, such as the age of the patients (MacIntosh 1981, Nishioka et al. 1987, Upton et al. 1987, Karas et al. 1990, Blomqvist et al. 1998), and even gender (MacIntosh 1981), have been suggested to influence the recovery of neurosensory function. According to many studies, there seems to be a direct relationship between increasing age and postoperative paresthesia after BSSO (McIntosh 1981, Lindquist et al. 1988, Nishioka et al. 1997, August et al. 1998, Westermark et al. 1998b, Panula et al. 2001). The older the patient, the more protracted the neurosensory disturbance (Nishioka et al. 1987, Panula 2001). In addition, the females seem to have more postoperative neurosensory disturbances after BSSO than males (MacIntosh et al. 1981). Also the skill of the surgeon influence the recovery as well (Zaytoun et al. 1986). Furthermore, the left-sided preponderance of neurosensory disturbances following mandibular BSSO has been found in several previous reports (Pepersack and Chausse 1978, Zaytoun et al. 1986, Leira & Gilhuus-Moe 1991). This has been attributed to the more difficult access on the left for a right-handed surgeon (Leira & Gilhuus-Moe 1991).

2.7 Radiographic methods used to locate the mandibular canal

The BSSO is performed in close proximity to the neurovascular bundle of the mandible and therefore special attention should be given to the exact location of the mandibular nerve. Although the buccolingual location of the mandibular canal cannot be obtained in the panoramic view, panoramic projection is commonly used for diagnostic purposes. To obtain the more precise location of the mandibular canal, the clinician may use different tomographies. Tomography can be utilized to section or slice an object. This is accomplished by the simultaneous movement of the tube and the film, which is connected so that the movement occurs around a point of a fulcrum. The objects closest to the point or fulcrum are seen most sharply, while the objects farthest away from the point of rotation are almost completely blurred. Tomographic methods can be broadly classified into three categories: conventional tomography, computer-assisted tomography (CAT), and computerized tomography (CT).

2.7.1 Panoramic radiography

Even until today panoramic radiography has remained the standard and simplest diagnostic aid for imaging of maxillofacial structures before orthognathic surgery. They are routinely used in pre- and postsurgical evaluations of the jaws. Osteotomy cuts can be planned and postsurgical results can be assessed utilizing panoramic radiographs. One of the limitations of this technique is that the structures are not localized in the buccolingual dimension.


2.7.2 Conventional tomography

In conventional tomography, different types of motion of the x-ray tube and the film are employed. They are linear, circular, trispiral, elliptical, and hypocycloidal, the simplest of the motions being linear. The more complex the motion is, the sharper the image. There is always some degree of blurring in tomography, the greatest amount of blurring being at the periphery.

Spiral tomography is performed with the Scanora X-ray machine. The patient is oriented in a position such that tomographic cuts are perpendicular to the lower border of the mandible and to the buccal and lingual cortices. Then cross-sectional images of the mandible are obtained.

2.7.3 Computer-assisted tomography (CAT)

In CAT, all of the standard cranial x-ray tomographic techniques are contained in the computer menu. Images can be recorded using the standard film-screen combination. Cassette-placement is also automatic, eliminating operator error and allowing for efficient use of x-ray film.

2.7.4 Computerized tomography (CT)

CT was introduced in imaging the maxillofacial structure in the early 1970’s. It was greatly developed after the introduction of dental implantology, when the need increased for advanced radiologic procedures to document the availability or nonavailability of bone and to identify important anatomic structures such as the mandibular canal. Then came the era of image acquisition and storage and the manipulation of intraoral and extraoral areas utilizing computer software applications. It became possible to acquire radiographs of maxillofacial structures either directly digitally or via scanning into the computer. X-ray images were converted into digital images, which were manipulated so they would be adequate for viewing.

CT images are produced by x-ray beams that penetrate patients to varying degrees and strike a detector. The generation of the scanner is determined by the placement of the x-ray tube relative to the detectors. The entire CT process is divided into three segments: data acquisition, image reconstruction and image display. A generator and a table are necessary to acquire data. Raw data include all measurements obtained from the detector array. After the raw data is averaged and each pixel is assigned a CT number (quantified measurement of density), an image can be reconstructed. The data that form this image is then referred as image data (Romas 1995).
2.7.5 Studies about locating the mandibular canal preoperatively

The attempts to determine the buccolingual location of the mandibular canal was earlier mostly based on cadaver studies (Carter & Keen 1971, Tamas 1987, Gowgiel 1992). There are also radiographic studies (Nortje et al. 1977, Tamas 1987, Heasman 1988, Fox 1989) that note the position of the mandibular canal to the apices of the teeth, but cannot determine if the canal is buccal or lingual to the teeth. However, some radiographic methods have been used to locate the mandibular canal buccolingually, mostly before the implant surgery (Schwartz et al. 1987, Klinge et al. 1989, Lindh & Petersson 1989, Jacobs et al. 1999, Yang et al. 1999, Hallikainen et al. 1992).

It has been assumed that in the areas where the neurovascular bundle is in contact with either the buccal or lingual cortex, the mandibular canal is well visualized in radiographs. (Miller et al. 1990). It is suggested that cortication of the mandibular canal on the panoramic film may serve as a predictor of the proximity of the mandibular canal to the cortical plates.

The anatomic features of the ascent of the canal, as well as its buccolingual relationships, have been studied earlier (Mercier 1973, Tamas 1987, Gowgiel 1992). According to the report of Gowgiel (1992) on dissections of the IAN, the neurovascular bundle from the mandibular foramen to the mental foramen is always in contact with, or in close proximity to the lingual mandibular cortex. Furthermore, the mandibular canal ascends slightly toward the mental foramen. However, it has been shown, that vascular and nerve bundles may also be extremely close to the buccal cortex of the mandible in broad and thick mandibular rami. In the study of Tamas (1987) this buccal position of the IAN was observed in 6% (10/164) of the mandibles. His conclusion was, however, that in cases with wide and thick rami, the BSSO does not involve surgical risk, for a great majority of cases. In the case with thin rami, the sagittal splitting technique poses a risk for a poor comminuted bony split or neurological injury. According to his report, in cases when the preoperative radiological and CT findings point to thin ramus, the indication for the sagittal splitting technique is open to question. In certain instances, an operative technique other than the BSSO should be used to prevent surgical injury to the IAN.

The study of Rajchel et al. (1986) on 45 Asian adults demonstrated that the mandibular canal, when proximal to the third-molar region, is usually a single large structure, 2.0 to 2.4 mm in diameter. It courses approximately 2.0 mm from the inner lingual cortex, 1.6 to 2.0 mm from the medial aspect of the buccal plate, and about 10 mm from the inferior border. There also seems to be a relationship between the close location of the mandibular canal to the buccal cortex and neurosensory disturbance after BSSO. Yoshida and co-workers reported that in cases where the distance between the mandibular canal and the buccal cortex was less than 1.2mm that 91% of sides suffered a severe grade neurosensory disturbance after BSSO.

In the study of Hallikainen and co-workers, the mandibular canal could be located in most patients (65.5%) by cross-sectional spiral tomography. In patients with mandibular protrusion, the mean buccolingual width was significantly smaller and the mandibular canal was more often buccally located than in patients with retrognathia (Hallikainen et al. 1992).

Sonick and co-workers (1994) studied the accuracy of periapical, panoramic, and computerized tomographic radiographs in locating the mandibular canal. They found CT
to be superior to the other techniques in locating the mandibular canal. Lindh et al. (1992) studied visualization of the mandibular canal by five different radiographic techniques: periapical radiography, panoramic radiography, hypocycloidal tomography, spiral tomography and computerized tomography. They noticed that direct CT visualized the mandibular canal best of the examined techniques, and it also gave a high inter- and intraobserver agreement rate. Klinge and co-workers (1989) showed earlier, that more exact measurements were obtained with CT compared with hypocycloidal tomography and panoramic radiography. Comparing the tomographic techniques with panoramic radiography, CT-scans have been found to be more precise in measuring the distance between the bony crest and the mandibular canal compared to panoramic radiography (Tal & Moses 1990), and the tomographic radiographs have an additional advantage in presurgical planning, since they reveal the horizontal dimension and shape of the mandible, and the topography and buccolingual location of the mandibular canal.
3 Aims of the study

The aim of the present study was to advance the state of the knowledge regarding neurosensory deficit of the inferior alveolar nerve (IAN) after bilateral sagittal split osteotomy (BSSO). More specifically, the aims of the study were:

1. To observe the occurrence of neurosensory disturbance of the lower lip and chin after BSSO and the suitability of different tests in assessing neurosensory disturbance and in predicting recovery from it.

2. To describe the factors affecting neurosensory disturbance after BSSO.

3. To compare the suitability of panoramic radiography, computerized tomographic (CT) and conventional tomographic (Scanora) radiographs in locating the mandibular canal in the buccolingual direction before BSSO.
4 Materials and methods

4.1 Subjects

The study was carried out involving a total of 50 patients undergoing bilateral sagittal split osteotomy (BSSO) for the correction of mandibular prognathism or retrognathism at Oulu University Hospital. In addition, 20 voluntary healthy students participated in this study. The number of subjects with their demographic data are listed in Table 1.

Table 1. Gender and age of the subjects participating the five studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>N (Female/Male)</th>
<th>Age X (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I, II, IV</td>
<td>30 (20/10)</td>
<td>28 (16-48)</td>
</tr>
<tr>
<td>III</td>
<td>20 (11/9)</td>
<td>23 (21-27)</td>
</tr>
<tr>
<td>V</td>
<td>20 (11/9)</td>
<td>32 (17-55)</td>
</tr>
</tbody>
</table>

The studies were approved by the ethical committee at the University of Oulu, Oulu, Finland. In studies I, II and IV, the patients underwent a total of 60 osteotomies. The indication for osteotomy was prognathism in 8 patients and retrognathism in 22 patients. The magnitude of movement of the operated distal segment of the mandible, measured at the occlusal level, ranged from 1 to 12 mm, with a mean of 6.7 mm. The mean movement was 7.8 mm in the group treated with mandibular setback (prognathic group) and 6.2 mm in the group requiring mandibular advancement (retrognathic group). Prior to surgery, all the patients were informed that they might experience altered sensation in the lower lip and/or chin postoperatively.

In study III, the study group consisted of voluntary healthy dental students. The subjects did not have craniofacial or congenital anomalies or previous trauma of the orofacial region. Subjectively, all subjects had totally normal sensibility of the lower lip and mental regions.

In study IV, the 30 patients were classified into two age groups: under 30 years and 30 years or over. The magnitude of mandibular movement was also classified into two groups: mandibular sides with movement of less than or equal to 7 or more than 7
millimeters. During surgery, the degree of manipulation of the nerve was documented as: 1) nerve not encountered, 2) nerve visible, but embedded in the medial fragment, 3) nerve between the fragments or dissected from the lateral fragment and 4) nerve transected. The indications for osteotomy, the magnitude of mandibular movement, the degree of manipulation of the nerve and intra- and postoperative complications are listed in Table 2.

Table 2. The indication for osteotomy, the magnitude of mandibular movement, the degree of nerve encounter, and intra- and postoperative complications by the age of the patients who underwent BSSO (60 mandibular sides of 30 patients).

<table>
<thead>
<tr>
<th>Age</th>
<th>Indication</th>
<th>Movement</th>
<th>Nerve encounter</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>retr.</td>
<td>progr.</td>
<td>≤7 mm</td>
<td>&gt;7 mm</td>
</tr>
<tr>
<td>&lt;30 years (n=32)</td>
<td>26</td>
<td>6</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>≥30 years (n=28)</td>
<td>18</td>
<td>10</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Total (n=60)</td>
<td>44</td>
<td>16</td>
<td>39</td>
<td>19</td>
</tr>
</tbody>
</table>

Nerve encounter: 1= not encountered, 2 = embedded in the medial fragment, 3 = free between the fragments or dissected from the lateral fragment

In study V, the patients underwent a total of 40 osteotomies. The indication for the operation was retrognathism in 16 cases and prognathism in 4 cases.

4.2 Methods

4.2.1 Surgery

The operation was performed using the Obwegeser-Dal Pont modification of the original method of sagittal split osteotomy. All the operations were made by one surgeon (JK). During the operation, the medial surface of the mandible was exposed with a retractor and the horizontal cut was made above the lingula on the medial surface and the vertical cut between the first and second molar on the buccal surface of the mandible with a bur. A reciprocating saw was used to cut the cortical bone in a sagittal direction. Bone splitting was performed with a thin spatula osteotome. The degree of manipulation of the IAN was noted and documented. Bone fixation was achieved with two or three bicortical bone screws. No intermaxillary fixation was used after surgery. Furthermore, neither guiding elastics nor splints were used after surgery. The complications during and after the operation were recorded. All the patients received one million units phenoxymethylpenicillin three times a day for ten days after the operation. The drains were on the operated area for one or two days after surgery.
4.2.2 Evaluation of the neurosensory status

In studies I-II, the patients were examined by one examiner (LY) preoperatively and postoperatively at four days, three weeks, three months, six months, and one year. The patients were subjected to a battery of neurosensory tests consisting of light touch (LT), two-point discrimination (2-P), pin tactile discrimination (PIN), thermal stimuli (TH), and sensibility testing (ST) of the mandibular teeth. The follow-up was continued for one year or until the neurosensory deficit had disappeared.

In study III, all the subjects were tested by two observers (LY & JV) at an interval of six months. On both occasions, the neurosensory tests were performed by both observers. The battery of neurosensory tests was the same as in studies I-II. One of the observers was well experienced and the other one less experienced with these tests. The subjects were tested in a randomized order.

In study IV, the patients self-evaluated the subjective neurosensory status of the lower lip and chin on both sides preoperatively and four days, three weeks, three months, six months, and one year after surgery.

In study V, the patients self-evaluated the subjective neurosensory status of the lower lip and chin on both sides preoperatively and at four days, three weeks and three months after surgery.

4.2.2.1 Questionnaire

At every follow-up, each patient was asked to complete a questionnaire indicating whether they had any alterations in sensation of their lower lip or in the mental region of the skin. A five-point scale was used to describe the sensation: 1) no sensation, 2) almost no sensation, 3) some sensation, 4) almost normal sensation and 5) completely normal sensation.

4.2.2.2 Neurosensory tests

In studies I-III, neurosensory function in the mental area was measured at every follow-up. The lower lip and the mental region were divided into four zones, and each zone was measured separately. Testing was performed over a one cm area above and beneath the labiomental fold on both sides of the chin. (Fig. 11)
Each of the four facial zones was stimulated three times; a correct response was considered two out of three appropriate answers. During testing, the patients closed their eyes and separated their lips comfortably.

In LT, each facial zone of the lower lip and the mental skin was lightly touched with a cotton wisp to check if the touch was perceptible. A positive or negative reply was the only option at each point.

In 2-P, each zone was measured with a sharp millimeter caliper. The test was conducted by beginning with the points closed and progressively opening them in 1 mm increments until the patient could discriminate two points of contact. This distance was then recorded. Care was taken to ensure that the points touched the cutaneous surface at the same time. Distances two millimeters greater than the preoperative value were considered abnormal. Similarly, in study III, differences greater than two millimeters between the intra- and interobserver as well as the interinterval measurements were estimated to be significant.

In PIN, each zone was measured with needles weighting from 0.3 g to 15 g. A set of needles was constructed for this investigation (Fig. 12).
The needles pressed the measured zone through the loop by their own weight. The lightest needle that the patient felt sharp was then recorded. If the difference from preoperative value was more than 1 g, the result was estimated as abnormal. Similarly, in study III, the intra- and interobserver as well as the interinterval difference between the measurements was estimated to be significant if it was more than 1 g.

In TH, two small glass tubes containing water at 50°C (T(w)) and 15°C (T(c)) were used. The patients were asked to indicate whether they felt a warm or a cold sensation. The subject’s report of each stimulus (ie, cold versus hot) was recorded.

In ST, the sensibility of all the mandibular teeth on the right and left side of the mandible was measured by using the vitality scanner (Model 2006 Vitality Scanner, Analytic Technology®, Washington, USA). The scale of the vitality scanner was from 0 to 80. The first measurement of each tooth was recorded. The teeth that failed to respond to the sensibility test preoperatively were excluded as well as the third molars. The sensibility was estimated to be postoperatively normal if all the preoperatively included teeth on the side reacted positively to the sensibility test. If one or more teeth did not react positively to the sensibility test, the result was recorded as abnormal. In study II, the sensibility of the teeth was registered only from the first and second molars. The patients were divided into two groups according to the preoperative sensibility testing results: (1) only one of the two molars responded to the vitality scanner, and (2) both of the molars responded to the vitality scanner. In study III, the teeth were classified into four different groups: incisors, canines, premolars and molars, and repeatability was evaluated in these different groups. The intra- and interobserver as well as the interinterval difference between the measurements was evaluated to be significant if it was more than 10.

4.3 Radiographic imaging

Before surgery, the position of the mandibular canal was evaluated based on panoramic radiography, conventional spiral tomographic radiography (Scanora), and computerized tomography (CT). A regular panoramic radiograph was taken from all the patients preoperatively. Furthermore, all patients underwent radiographic imaging by a General Electric Hispeed Advantage CT scanner (General Electric Medical Systems, Paris, France). The patients were positioned with the head tilted backward, so that the scanning plane was parallel to the mandibular base. The scanning was performed in the helical (spiral) scanning mode. Scan pitch was 1:1 and scan thickness 1 mm. The exposure conditions were set at 120 kV and 80 mAs. Reformatted images perpendicular to the mandibular body were produced by using DentaScan (GE Medical Systems, Paris, France).

The Scanora imaging mode used was a spiral tomography with three revolutions, to obtain 4 mm slice thickness, and four consecutive slices. The slices were taken between the first and second molars, and from the lower third molar region of the mandible. The orientation of the slices was axially corrected to the body of the mandible. The reference points in the measurement were located: 1) posteriorly to the second molar (POST) and 2) between the first and second molars (ANT). The following distances were measured from the mandible: the width of the mandibular canal, the width of the buccal cortex, the
distance between the base of the mandible and the inferior border of the mandibular canal, the distance between the lingual border and the lingual side of the canal, the distance between the buccal border and the buccal side of the canal (Fig. 13).

The measurements were made to the nearest 0.1 mm with a Vernier caliper and each measurement was made by two radiologists. In case of disagreement, the distance was remeasured by both radiologists together. The visibility of the cortication of the mandibular canal was estimated at the reference points on panoramic radiographs and classified as follows: 1) both borders clearly visible, 2) only one border visible, or 3) neither of the borders visible.

Fig. 13. Diagram illustrating a coronal section through the third molar region and indicating the horizontal and vertical measurements from the different sides of the mandible to the mandibular canal (A. The distance from the canal to the buccal border of the mandible; B. The diameter of the buccal cortex; C. The distance from the canal to the lower border of the mandible; D. The distance from the canal to the lingual border of the mandible; E. The diameter of the lingual cortex; F. The diameter of the canal).

4.3.1 Statistics

Before the statistical analysis, all the subjective and objective neurosensory measurements were categorized into two classes: normal and abnormal. The percentages of the normal and abnormal findings were calculated for each time of testing. All the tests were compared with subjective evaluation, which was the golden standard. In categorizing subjective evaluation, no sensation, almost no sensation and some sensation (1, 2 and 3) were considered as abnormal, and the almost and completely normal sensation (4 and 5) as normal.

In study I, the statistical comparison was made separately for each test. The analysis of equality between the tests was made by a chi-square analysis. The tests were judged
equal with a $p$-value $< 0.05$. The recovery of neurosensory disturbance during the follow-up was graphically illustrated and a curve for each neurosensory test was drawn separately.

In study II, the occurrence of neurosensory deficit of the IAN after BSSO was calculated as assessed by LT, 2-P, PIN, TH and ST of the molars at every follow-up. In the second stage, the predictive ability of every neurosensory test was evaluated by calculating the positive predictive value (PPV) of each test. The PPV shows the percentage of mandibular sides that reacted normally in the test at follow-up and were subjectively evaluated as “totally normal” at one year after BSSO. Furthermore, different tests were combined to find an easily available combination of tests, that could predict neurosensory disturbance of after BSSO. Cross-tabulation was performed between the combination of tests at every follow up and the patient’s subjective evaluation of his/her neurosensory disturbance one year postoperatively. The combined test score was considered normal when both tests or all the three tests in the combination were normal.

In study III, the measurements by both observers were recorded on the same day and the variability within each test was calculated. With 2-P, PIN, and ST, the most common numerical values could be calculated. The measurements of the first observer were compared to the measurements of the second observer. Furthermore, the measurements in the first observation were compared to the measurements in the second observation. The degree of agreement between measurements was illustrated graphically. In ST, analysis of variance (ANOVA) was used to explore the possible components of variability (subject, tooth, observer, order of observers or observations) as well as the 2nd order interactions between the components. The degree of agreement in the sensibility values of the teeth between the two observers and between the two observations was illustrated graphically in the four groups: incisors, canines, premolars, and molars.

In study IV, the percentages of the mandibular sides with abnormal sensation at four days, three weeks, three months, six months and one year were calculated. Differences between the categories of the determinants were calculated and descriptive curves were drawn for the two categories of age, the indication of osteotomy, the magnitude of mandibular movement and the three categories of nerve encounter. The number of numb days (the dependent variable) per individual was estimated from data according to Matthews et al. 1990). We observed the differences in the number of numb days according to age, gender, indication of osteotomy, magnitude of mandibular movement, operated side, and degree of intraoperative manipulation. Because distribution of the dependent variable is positively skewed, the non-parametric tests were used: the Mann-Whitney U-test to compare two groups and the Kruskal-Wallis test to compare several groups.

In study V, the results obtained with Scanora and CT in locating the position and course of the mandibular canal were compared. The lower and upper limits of the 95% confidence interval for the proportion of visualization of the mandibular canal on radiographic imaging was calculated. Furthermore, the 1-way ANOVA was used to compare the correlation between the visibility of the cortication on panoramic radiographs and the distance from the mandibular canal to the buccal and lingual cortices. The correlation was considered statistically significant at a $p$-value $< 0.05$. The distance of the mandibular canal from the buccal cortex of the mandible was compared with subjective evaluation. Before the statistical analysis, the subjective evaluations were
categorized into two classes: normal and abnormal. Crosstabulation was performed between the two categories of the self-evaluation of the sensation on the lower lip and chin following BSSO and the distance between the mandibular canal and the buccal cortex of the mandible on CT. The correlation was then analysed by using the chi-square method. The correlation was judged statistically significant at a $p$-value < 0.05.
5 Results

5.1 Occurrence of neurosensory disturbance after BSSO

According to the subjective evaluations, the incidence of neurosensory disturbance in a total of 60 mandibular sides was 61% at four days, 43% at three weeks, 22% at three months, 10% at six months, and 0% at one year. Prior to surgery, no patient had impaired function of the inferior alveolar nerve (IAN) in any of the four zones in the lower lip and the mental region. During the operation, none of the mandibular nerves were transectioned, but moderate haemorrhage complicated the operation in three cases. Postoperatively, one patient had abnormally intense pain and swelling postoperatively on one side. Exploration showed a fracture of the proximal fragment due to tight fixation of an intraosseous screw. Postoperatively, three patients suffered from temporomandibular joint dysfunction (TMD), and one patient complained of nausea for a few weeks after the operation.

When the five categories of subjective evaluation were divided, at four days, there was “totally no sensation” in five operated sides of the mandible (8%), “almost no sensation” in 14 (23%), “some sensation” in 15 (25%), “almost normal sensation” in 16 (27%), and “totally normal sensation” in 8 (13%) sides. Four patients reported unilateral mandibular sensation loss, and 23 reported bilateral sensation disturbance. Two observations of the mandibular sides (one patient) were missing at the four-day follow-up. After one year, the degree of sensation was “totally normal” in 41 (68%) sides of the mandible and “almost normal” in 19 (32%) sides. The percentages of mandibular sides in the five categories of subjective sensation at four days, three weeks, three months, six months and one year are demonstrated in Fig. 14.

Four days after BSSO, there were five sides as having ”totally no sensation”. After one year, two of these sides were evaluated as “almost normal” and three sides as ”totally normal”. Four days after surgery, 14 sides were evaluated as having ”almost no sensation”. After one year, five of these sides were evaluated as ”almost normal” and nine sides as ”totally normal”. The medians of the different groups are shown in Fig. 15.
Fig. 14. Percentages of different degrees of subjective neurosensory disturbance at 4 days, 3 weeks, 3 months, 6 months, and one year after BSSO.

Fig. 15. Follow-up of neurosensory disturbance according to degree of subjective evaluation four days after BSSO. Medians of sensation categories are illustrated.
5.1.1 Observation with the use of five neurosensory tests

Most patients who subjectively reported neurosensory disturbance of the lower lip and chin also exhibited impaired function of the nerve in one or more of the neurosensory tests. The percentages of cases that revealed neurosensory disturbance in the subjective evaluation and the tests in use are shown in Fig. 16.

Fig. 16. Percentages of cases that revealed neurosensory disturbance postoperatively in subjective evaluation and in different tests as function of time.

The sensibility test (ST) of the teeth correlated with the patient’s subjective evaluation better than the other tests. Statistically, a significant equality occurred at four days and at three weeks for all the neurosensory testing modalities, but at three months only for the ST (Chi-square, \( p < 0.05 \)). At six months and at one year, the number of nerves classified as normal by subjective evaluation was 54 and 60, respectively. Due to the very low frequency of abnormal findings, the statistical analysis was not meaningful. As a sign of neurosensory disturbance, the ST was more sensitive than any of the other objective measurements. It was even more sensitive than the subjective evaluation.

With ST, measurements of the molars seemed to correlate with the subjective evaluation of neurosensory disturbance better than the measurements of the other mandibular teeth. The percentages of the different teeth that did not respond to ST after sagittal split osteotomy are demonstrated in Fig. 17.
Fig. 17. Percentages of mandibular teeth not responding to sensibility testing postoperatively as function of time.

5.1.2 Predictive suitability of the neurosensory tests

The predictive ability of every neurosensory test was evaluated by calculating the positive predictive value (PPV) of each test. The PPVs of the different tests are shown in Table 3. When different neurosensory tests were combined, the PPVs improved slightly. The PPVs of the combinations of tests are shown in Table 4.
Table 3. Positive predictive values of light touch (LT), 2-point discrimination (2-P), pin tactile discrimination (PIN), thermal discrimination (TH), and sensibility testing (ST) of mandibular molars at 4 days, 3 weeks, 3 months, and 6 months after BSSO.

<table>
<thead>
<tr>
<th>Assessment Result</th>
<th>Four days</th>
<th>Three weeks</th>
<th>Three months</th>
<th>Six months</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Normal</td>
<td>76%</td>
<td>71%</td>
<td>68%</td>
<td>68%</td>
</tr>
<tr>
<td>2-P</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Normal</td>
<td>74%</td>
<td>78%</td>
<td>76%</td>
<td>73%</td>
</tr>
<tr>
<td>PIN</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Normal</td>
<td>76%</td>
<td>78%</td>
<td>78%</td>
<td>76%</td>
</tr>
<tr>
<td>TH (w)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>74%</td>
<td>73%</td>
<td>73%</td>
<td>70%</td>
</tr>
<tr>
<td>TH (c)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>72%</td>
<td>77%</td>
<td>71%</td>
<td>68%</td>
</tr>
<tr>
<td>ST (1)</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Recovery of one</td>
<td>100%</td>
<td>80%</td>
<td>82%</td>
<td>91%</td>
</tr>
<tr>
<td>ST (2)</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Recovery of one</td>
<td>100%</td>
<td>67%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Recovery of both</td>
<td>100%</td>
<td>87%</td>
<td>74%</td>
<td>72%</td>
</tr>
</tbody>
</table>

TH (w) = warm; TH (c) = cold
ST (1) = only one of the two molars responded to the vitality scanner preoperatively
ST (2) = both the molars responded to the vitality scanner preoperatively

Table 4. The positive predictive values of different combinations of tests for totally normal sensation at one year. The two best combinations without and with the sensibility testing of mandibular molars.

<table>
<thead>
<tr>
<th>Combinations of different tests</th>
<th>Four days</th>
<th>Three weeks</th>
<th>Three months</th>
<th>Six months</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-P + PIN</td>
<td>80%</td>
<td>80%</td>
<td>83%</td>
<td>82%</td>
</tr>
<tr>
<td>LT + PIN</td>
<td>83%</td>
<td>78%</td>
<td>78%</td>
<td>75%</td>
</tr>
<tr>
<td>2-P + PIN + ST</td>
<td>100%</td>
<td>76%</td>
<td>87%</td>
<td>83%</td>
</tr>
<tr>
<td>LT + PIN + ST</td>
<td>100%</td>
<td>83%</td>
<td>82%</td>
<td>81%</td>
</tr>
</tbody>
</table>

5.1.3 Repeatability of the neurosensory tests

In study III, no neurological deficiencies were noticed within healthy students, volunteers of the study. All subjects responded normally to LT and TH at every observation. Analysis of all 2-P data shows the most common discrimination value to be 2 mm (ranging from 1 to 12 mm). With PIN, the most common value found was 0.5 g (ranging from 0.5 to 15 g). With these tests, both the intraexaminer and interexaminer repeatabilities were good. In ST, the most common values (75% of the values) measured with the vitality scanner were between 15 and 35 for incisors, between 30 and 40 for canines, between 30 and 45 for premolars, and between 30 and 60 for molars. All the
teeth that reacted positively to the vitality scanner in the first observation also reacted positively in the other observations. However, when the limit of the variation between the two observers and between the two observations was set at –10 to +10, the repeatability was poor.

In ST, we used three different ANOVA models to evaluate whether there was a 2nd order interaction between the dependent variable when the sensibility of the tooth was an independent variable. The dependent variables were the subject, the tooth and the examiner. The value of the ST measurement was significantly dependent on the subject (p=0.0001), the tooth (p=0.0001), and the examiner (p=0.002), but not on the order of examiners or the order of observations when the limits of variation between the two observations were set at -10 to +10 when comparing the result to the previous one. The percentages of instances in which the values were within these limits in every group of teeth are presented in Table 5.

Table 5. The percentages of instances in which the sensibility re-test value in each group of teeth was within +/- 10 when comparing the sensibility re-test value to the previous one.

<table>
<thead>
<tr>
<th>Teeth</th>
<th>Examiner 1</th>
<th>Examiner 2</th>
<th>Examiner 2/Examiner 1</th>
<th>Observation 2/Observation 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incisors</td>
<td>71</td>
<td>74</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>Canines</td>
<td>70</td>
<td>68</td>
<td>61</td>
<td>69</td>
</tr>
<tr>
<td>Premolars</td>
<td>55</td>
<td>72</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>Molars</td>
<td>39</td>
<td>56</td>
<td>46</td>
<td>48</td>
</tr>
</tbody>
</table>

5.2 Factors affecting neurosensory disturbance after BSSO

There was no significant difference in the impairment of sensation of the IAN between males and females. The present data, however, showed a close correlation between the patient’s age and the occurrence of neurosensory disturbance. Patients under 30 years had less neurosensory problems than patients aged 30 years or over during follow up (Mann-Whitney, p=0.04). The sensation in the mental area, however, was almost or totally normal in both groups at one year postoperatively (Fig. 18).
Fig. 18. Percentages of mandibular sides (n=60) with neurosensory disturbance after BSSO with a one-year follow-up by patients’ age.

The magnitude of mandibular movement was found to be in close relation to the impairment of sensation of the IAN. When the movement was more than 7 millimeters, the neurosensory disturbance was significantly greater (Mann-Whitney, \(p=0.04\)) from the fourth day until three months postoperatively than in the other group, where the movement was 1-7 millimeters (Fig. 19).

Fig. 19. Percentages of mandibular sides (n=60) with neurosensory disturbance after BSSO with a one-year follow-up by magnitude of mandibular movement.
The inferior alveolar nerve (IAN) was not exposed during 17 osteotomies, while in 24 osteotomies the IAN was visible but embedded in the medial fragments, and in 19 osteotomies the IAN was found to be lying between the fragments or had to be dissected from the lateral segment. A high correlation was found between the degree of manipulation of the IAN and the degree of sensory loss of the mental area. The incidence of neurosensory disturbance four days postoperatively was highest in the groups where the nerve was between the fragments or had to be dissected from the lateral fragment during the surgery. Sensory loss was much more pronounced until one year after surgery in these groups than in the groups where the nerve was not encountered or was visible but embedded in medial fragment (Kruskal-Wallis, $p=0.0007$) (Fig. 20).

![Fig. 20. Percentages of mandibular sides (n=60) with neurosensory disturbance after BSSO with a one-year follow-up by degree of nerve encounter.](image)

Fig. 20. Percentages of mandibular sides (n=60) with neurosensory disturbance after BSSO with a one-year follow-up by degree of nerve encounter.

Prognathic patients seemed to have more sensory loss than retrognathic patients from the fourth day onwards until three months after surgery, but this difference was not statistically significant. Neither was any statistically significant difference found in the occurrence of neurosensory disturbance between the sides of the operated mandible. Three patients had some haemorrhage during surgery, and five patients had postoperative complications, which were resolved within a few months. However, there were no correlations between intra- or postoperative complications and neurosensory disturbances.

In study V, when the distance between the mandibular canal and the buccal cortex of the mandible was 2 mm or less, the neurosensory disturbance of the mental area seemed to last longer than when the distance was 2 mm or more.
5.3 Comparison of panoramic radiography, CT and conventional tomography in locating the mandibular canal before BSSO

All the patients in study V had normal sensation in the mental area before the operation. Both cortices of the mandibular canal were seen at the posterior reference point of the mandible in 34 (85%) sides, while neither was seen in 6 (15%) sides. On the anterior reference point, both cortices were seen in 5 (12%) sides, one cortex was seen in 26 (65%) sides, and neither of the cortices was seen in 9 (23%) sides of the mandible.

The mandibular canal was better visualized on CT than on conventional radiographs. A comparison of the abilities of these two imaging methods to visualize the distance from the mandibular canal to the buccal and lingual borders of the mandible is presented in Table 6.

Table 6. Visualization of the mandibular canals in 40 mandibular sides observed on computerized tomography (CT), and conventional tomography (Scanora) on the posterior and anterior reference points.

<table>
<thead>
<tr>
<th>Reference point</th>
<th>CT</th>
<th>Scanora</th>
<th>95% CI of pScanora</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pCT (n)</td>
<td>pScanora (n)</td>
<td>Lower limit</td>
</tr>
<tr>
<td>Posterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccal</td>
<td>100 (40)</td>
<td>95 (38)</td>
<td>83</td>
</tr>
<tr>
<td>Lingual</td>
<td>100 (40)</td>
<td>60 (24)</td>
<td>44</td>
</tr>
<tr>
<td>Anterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buccal</td>
<td>100 (40)</td>
<td>95 (38)</td>
<td>83</td>
</tr>
<tr>
<td>Lingual</td>
<td>100 (40)</td>
<td>83 (33)</td>
<td>68</td>
</tr>
</tbody>
</table>

pCT = the proportion of visualization of the mandibular canal on computerized tomography
pScanora = the proportion of visualization of the mandibular canal on conventional tomography
95%CI = 95% confidence interval

The mandibular canal could be seen in all CT scans, whereas in Scanora imaging it could be seen in only 60% to 95% of cases depending on the side of the mandible. When the lower and upper limits of the 95% confidence interval for the proportions of visualization on Scanora was calculated, it was lower than 100% at every reference point. The mandibular canal was consistently better visualized buccolingually on CT scans than on conventional spiral radiographs.

On the panoramic radiographs, cortication was clearly visible at the posterior and anterior reference points in 34 and 5 sides respectively. Visualization of the cortication of the mandibular canal in panoramic radiography according to the mean distance from the mandibular canal to the buccal and lingual cortices in the mandible in CT is shown in Table 7.
Table 7. Visualization of the cortication of the mandibular canal in panoramic radiography; mean distance from the mandibular canal to the buccal and lingual cortices of the mandible in CT.

<table>
<thead>
<tr>
<th>Cortication</th>
<th>Mean distance to the buccal cortical plate mm (n)</th>
<th>Mean distance to the lingual cortical plate mm (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not visible</td>
<td>2.5 (6)</td>
<td>0.1 (6)</td>
</tr>
<tr>
<td>Partially visible</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Clearly visible</td>
<td>2.5 (34)</td>
<td>0.7 (34)</td>
</tr>
<tr>
<td>Anterior</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not visible</td>
<td>3.6 (9)</td>
<td>0.3 (9)</td>
</tr>
<tr>
<td>Partially visible</td>
<td>3.7 (26)</td>
<td>0.8 (26)</td>
</tr>
<tr>
<td>Clearly visible</td>
<td>2.9 (5)</td>
<td>0.3 (5)</td>
</tr>
</tbody>
</table>

When we compared the visibility of the cortication on panoramic radiographs and the distance from the mandibular canal to the buccal or lingual cortices of the mandible, no significant correlation was found between them for any of the reference points (1-way ANOVA). At the posterior reference point CT revealed only 3 sides (7%) in which the mandibular canal was in direct contact (<1mm) with the buccal cortex, but in 27 sides (67%), the mandibular canal was in direct contact with the lingual cortex. In the anterior reference point, there was only one side where the mandibular canal was in direct contact with the buccal cortex, but there were 30 sides where the mandibular canal was in direct contact with the lingual cortex. In general, the mandibular canal at the reference points was closer to the lingual than to the buccal cortex of the mandible.

The comparison between the subjective evaluation of the neurosensory disturbance and the distance between the mandibular canal and the buccal cortex of the mandible is shown in Table 8. When analysed, the correlation between the degree of sensation and the distance from the mandibular canal to the buccal cortex was statistically significant at 4 days and 3 months (Chi-square, $p<0.05$). In conclusion, when the distance between the mandibular canal and the buccal cortex of the mandible was 2 mm or less, the neurosensory disturbance lasted longer than when it was 2 mm or more.

Table 8. Follow up of the self-evaluation of lower lip and chin sensation following BSSO in relation to the distance between the mandibular canal and the buccal cortex of the mandible on computerized tomographic radiography.

<table>
<thead>
<tr>
<th>Sensation category</th>
<th>4 days (n)</th>
<th>3 weeks (n)</th>
<th>3 months (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance ≤ 2 mm</td>
<td>0</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Distance &gt; 2 mm</td>
<td>8</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Abnormal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance ≤ 2 mm</td>
<td>18</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Distance &gt; 2 mm</td>
<td>14</td>
<td>13</td>
<td>1</td>
</tr>
</tbody>
</table>
6 Discussion

6.1 General comments

The bilateral sagittal split osteotomy (BSSO) is an excellent operation for mandibular correction. Despite several risks inherent with this technique, it is the best choice for correction severe malocclusions and deformations in the mandible. Therefore, the risks of this technique are acceptable. However, it is important to inform the patients about the risks before the operation. Neurosensory disturbance of the lower lip and chin induced by damage to the inferior alveolar nerve (IAN) is the most common immediate finding after BSSO.

In spite of the fact that the deficit of the IAN is of sensory nature in a small area of the lower lip and chin, this altered sensation is often reported as the most distressing complication after orthognathic surgery (Guernsey & de Champlain 1971). It may affect talking and masticating (Jones et al. 1990). The nerve injury may also give rise to continuous, unbearable aching in the lower facial area and psychosocial suffering. Thus, it is a common cause of claims against dentists after extraction of lower third molars in the United Kingdom (Haskell 1986, Carmichael & McGowan 1992) and in the United States (Meyer 1990a). Similarly in Finland, damage of the inferior alveolar and the lingual nerves is the most common cause of complaints to the Patient Insurance Association following dental and oral surgical treatments (Ventä & Lindqvist 1998). During 1987-93 there were 139 claims for permanent sensory or motor disturbances related to removal of the third lower molars in Finland. The IAN was injured in 41% of the claims. These claims resulted in compensation to the patient in 46% of these cases. Given all available data, Finnish authorities have considered these nerve injuries to be avoidable in most cases. Symptoms of neurosensory loss are largely subjective and based on what the patient states. However, in this series objective sensory testing such as TSEP was applied in only one case. The usual methods reported were light touch, two-point, and pin prick discrimination.

Even though there are objective and quantitative methods to assess nerve conductive qualities, the problem with those tests is that they are expensive and not available in everyday practise. Thus, it is important to develop repeatable bedside methods that are
readily available and easy to use, not only for research purposes but also to predict the recovery of the neurosensory disturbance for the patient. In our study III, the repeatability of the commonly used bedside tests (LT, 2-P, PIN and TH) was good. In this study, we assessed healthy subjects, and this may have resulted in some selection bias. Another purpose of our study was to find tests that could predict recovery of neurosensory disturbance soon after surgery. We also assessed neurosensory disturbance after BSSO with sensibility testing of the teeth and we compared it with more traditional bedside methods and patient’s subjective evaluation of neurosensory disturbance. Sensibility testing of the teeth has not been used before to assess neurosensory disturbance after BSSO. In our study it correlated well with the other tests and patient’s subjective evaluation. It also proved to be a reliable test in predicting neurosensory disturbance of IAN when applied four days after the operation.

The number of independent variables investigated is large, given a relatively small number of patients. The advantage of this study, however, was that all the patients were operated by the same surgeon and the follow-up was conducted by the same researcher until one year after surgery. All the tests except in study III were performed by the same person. Also all these patients underwent only BSSO, and no other orthognathic surgery was made at the same time. This kind of study group is not easy to find, because nowadays many orthognathic patients are treated with bimaxillary surgery.

The risk of neurosensory disturbance after BSSO was high among patients older than 30 years, when the magnitude of mandibular movement was more than 7 millimeters, and when the nerve had been manipulated during surgery. These results, however, do not break new ground but rather confirm the results of many earlier studies. One of the established factors is the influence of age. The finding of a significant association between patient’s age and neurosensory disturbance has been reported earlier (MacIntosh 1981, Nishioka et al. 1987, Upton et al. 1987, Westermark et al. 1998a, Panula et al. 2001). A significant correlation between intraoperative nerve encounter and duration of neurosensory disturbance after BSSO has also been found in some other studies (Leira & Gilhuus-Moe 1991, Fridrich et al. 1995), but there are also studies where no correlation or only a weak correlation has been found (Brusati et al. 1981, Takeuchi et al. 1994, August et al. 1998, Westermark et al. 1998b, Teerijoki-Oksa et al. 2002). Furthermore, a significant correlation between the magnitude of mandibular movement and the severity of neurosensory disturbance was found in our study. These results emphasize presurgical patient counselling regarding the risks of neurosensory disturbances.

There was a high incidence of neurosensory disturbance immediately after BSSO, but nearly all the patients returned to their presurgical status within one year. Even those patients, who at the one year follow-up point evaluated the sensation of their lower lip and chin as being slightly altered, did not feel any discomfort because of it. One reason for such good results could be that all the operations were made by one, experienced surgeon. We also think that good preoperative imaging of the mandibular canal gives good information for a surgeon and improves the quality of surgery. Proper imaging can even prevent neurosensory complications in some cases.
6.2 Methodological aspects

The findings in this study were based on bedside sensory examinations. As anticipated, there was a good correlation between the patient’s own evaluation and the assessments. Most patients who reported neurosensory disturbance, also showed impaired function of the nerve in one or more of the tests. The tests used here are all described in the literature, and we could show them to be accurate in spite of their relative simplicity. The fact that the same person did most of the recordings helped to avoid the problems of interexaminer variability. In study III all the subjects were healthy dental students, and the function of the IAN was measured by the author and the other researcher to compare the intraexaminer and interexaminer repeatability of the tests. The recordings of the subjects were made under the same external conditions and according to the particular protocol of testing. The repeatability of the tests seemed to be reasonably good in most of the tests in study III, and this corroborates the results presented in studies I and II.

The concept of objective and subjective neurosensory testing is confusing in the literature. There are some objective methods where electrical neurosensory tests are used and recordings are displayed on the screen. The TSEP, BR and SNAP are such purely objective neurosensory tests (Jones et al. 1990, Jääskeläinen et al. 1995c, Teerijoki-Oksa et al. 2002). In other tests the patient’s response is subjective even though the threshold is measured with different instruments. So these tests should be considered as subjective tests. Also the sensibility testing of the teeth is subjective, because the patient informs the threshold of sensation in each tooth.

The sensibility testing of the teeth, however, had some disadvantages. Preoperatively, and sometimes also postoperatively, sensibility testing was unpleasant and it was even painful for some patients. Another problem was the difficulty in measuring sensation of the molars 4 days after surgery, due to swelling and pain of lower part of the face. In addition the repeatability had a wide numeric distribution. The reason for the lack of good repeatability might be because the vitality scanner in this study was working with batteries, and that is why the voltage level and further the current level did not stay stable.

The frequencies of neurosensory disturbances in different studies vary depending on the testing methods used. Disparate rates of neurosensory disturbance after BSSO in the literature are probably related to lack of standardization in the methods and timing of postoperative neurosensory testing, or simply to the lack of evaluation by investigators. Walter & Gregg (1979) showed that the use of standardized neurosensory examination, including individual tests done at least 6 months postoperatively, results in rates of neurosensory disturbance which are higher than previously reported (85%). Martis (1984) evaluated 258 BSSO procedures prospectively. Neurosensory testing in this group consisted only of pin-prick, and persistant neurosensory disturbance was reported in 2% of patients 2 years postoperatively. One reason for varying results can be related to the use of a control area other than the surgical site. Another area of the face has been used as a control for the IAN. In our study, presurgical testing has been done to allow the non-operated IAN to serve as its own control.

It is also common to find a discrepancy between the patient’s subjective impression of sensory loss and the results of clinical neurosensory testing. This relies in some extent to the patient’s subjective responses even though objective evaluation with evoked potentials or action potentials/conduction velocities are being used. Some authors report
good correlation with subjective evaluation and neurosensory testing (Cunningham et al. 1996, Zuniga et al. 1998). Some studies (Rosenquist 1994, Fridrich et al. 1995) indicate that patients tend to overreport sensory loss compared with neurosensory testing, whereas others have shown the opposite (Leira & Gilhuus-Moe 1991, Koltzenburg et al. 1994), with patients reporting normal neurosensory function despite negative findings in neurosensory tests. So it seems that the threshold for reporting normal sensation varies between patients and is not entirely dependent on complete regeneration of the injured nerve.

In the present study, a total of 68% of all sides were evaluated as “totally normal” after one year, while 32% of all sides were “almost normal”. However, none of these patients suffered any discomfort one year postoperatively. Patients probably adapt to a slight neurosensory disturbance and report their sensation as “normal” even if the sensation is slightly different from that present preoperatively. On the other hand, the more severe the degree of neurosensory disturbance was four days postoperatively, the more severe it was during the entire follow-up period. We think that these are important facts when predicting the prognosis of neurosensory disturbance to the patient before and after surgery.

6.3 Occurrence of neurosensory disturbance after BSSO

The overall results of this study corresponded well with those previously reported, both with respect to the frequency of neurosensory disturbances and factors affecting them. A number of reports during the past few decades have dealt with the evaluation of sensory disturbance after mandibular sagittal split osteotomy (White & Dolwick 1969, Pepersack & Chausse 1978, Brusati et al. 1981, MacIntosh 1981, Paulus & Steinhäuser 1982, Campbell et al. 1987, Yoshida et al. 1989, Jones et al. 1990, Naples et al. 1994, Scheerlink et al. 1994, Fridrich et al. 1995). The incidence of sensory disturbance immediately after surgery has been 80% or more in most reports, while the incidence at one or two years postoperatively has shown a variation ranging from 0% up to 85% (Sasaki et al. 1974, Pepersack & Chausse 1978, Coghlan & Irvine 1986, MacIntosh 1981, Martis 1984, Fujimura et al. 1985, Nishioka et al. 1987). Even though the neurosensory disturbance occurs in a small area in the lower lip and chin, a permanent disturbance can be very stressful for the patients. Many patients complain of pain or other strange sensations (allodynia, paresthesia) when touching the area of altered sensation in the lower lip.

The incidence of subjective disturbance was 61% four days after surgery and 0% after one year, when scores 4 and 5 were summed up. Even though all the patients reported their sensation of the lip and chin as normal one year after surgery, 32% of them evaluated sensation to be slightly different (score 4). This correlates well with some previous studies (Lindorf et al. 1986, Fridrich et al. 1995, Posnick et al. 1996, Bouwman et al. 1995, Leira et al. 1991, Blomqvist et al. 1998, Westermark et al. 1998) even though in many of them these frequencies are much lower (Krekmanov et al. 1989, Takeuchi et al. 1994, Scheerlinck et al. 1994, Martis et al. 1984, MacIntosh et al. 1981, Raveh et al. 1988), and in some studies the frequencies are much higher (Walter & Gregg 1979,

6.3.1 Observation with the use of five neurosensory tests

A variety of methods have been used in neurosensory examination. The commonly used bedside tests; LT, 2-P, PIN and TH functioned well in this study and correlated with subjective sensation. To the best of our knowledge, sensibility testing of the teeth by the vitality scanner has not been reported previously in evaluating the neurosensory disturbance after BSSO. The sensation of the teeth seemed to correspond to the results obtained with the other methods, but it tended to normalize more slowly than the sensation of the skin. However, it correlated even better with the subjective evaluation than the other tests.

6.3.2 Predictive suitability of the neurosensory tests

The purpose of this study was to evaluate the specific methods available for clinical neurosensory testing, and to find a combination of two or three tests that could reliably predict neurosensory disturbance. Because our study showed that the sensibility testing of the mandibular first and second molars correlated reasonably well with the patient’s subjective evaluation of neurosensory disturbance throughout the follow-up, we wanted to observe how the sensibility testing of the molars could predict recovery from neurosensory disturbance. When we observed the predictive ability of different tests, we noticed that none of the tests alone was able to predict the neurosensory disturbance after BSSO. On the whole, the best positive predictive value (PPV) at four days was achieved by sensibility testing of the mandibular molars. If the teeth had reacted to sensibility testing preoperatively and reacted to it four days postoperatively, the PPV was 100%. Also, at three weeks, the PPV obtained with sensibility testing was the best. At three and six months, the differences between the PPVs of the different tests were no longer significant.

Skin has multiple innervations with receptor terminals that are specific for only warm, cold, pain, or touch (LaBanc 1992). When different tests are combined, the PPV improves. The best PPV was achieved by a combination of mechanoceptive and nociceptive tests with sensibility testing of the molars. The best combinations were LT, PIN and sensibility testing (ST) of the mandibular molars or 2-P, PIN and ST. The differences between these combinations were not significant. If sensibility testing could not be used postoperatively, as in the case where the teeth did not react to sensibility testing preoperatively, the best combination seemed to be the combination of LT and PIN or the combination of 2-P and PIN. TH was not an appropriate test in this study, because most of the patients already discriminated warm and cold at three weeks follow-up, including those who evaluated their subjective sensation as abnormal after one year. This
may also mean that our thermal discrimination test was too nonspecific to be able to discriminate between normal and abnormal thermal sensations.

### 6.3.3 Repeatability of the neurosensory tests

In this study, five different methods to assess neurosensory disturbance of the IAN were used. Four of these (LT, 2-P, PIN, TH) have commonly been used for similar purposes in maxillofacial surgery and other medical fields (Ghali & Epker 1989, Yoshida et al. 1989, Blomqvist et al. 1998, Robinson et al. 1992). However, there are only a few articles where the repeatability of these tests in healthy subjects has been evaluated (Essick 1992, Chen et al. 1995).

The fact that most neurosensory measurements are based on subjective feeling of sensation during the objective stimulus procedure mostly explains the wide range of results obtained here among healthy study subjects. There was also marked biological variability between the study subjects. It should be important to use methods that avoid these problems. In this study, both examiners tested the same subjects on both occasions, and this is why biological variability had no effect on intra- or interexaminer repeatability. Furthermore, all the subjects were dental students, and their cooperation was very good. One potential problem in measuring only healthy subjects is the precision of the results. Both examiners examined 20 subjects, but made several measurements per subject in both observations. It was hence possible to get more measurements and more reliable results.

In testing with LT, we used a cotton wisp, because it is easily available in every practice. However, since we tested only subjects with normal sensation of the lower lip and chin, this method did not distinguish any possible differences in sensation between normal and abnormal subjects. As expected, all the subjects responded positively to this test in every observation. Therefore even though this test may be inaccurate, it seemed to be quite repeatable in normal subjects.

One problem pertaining to the 2-P test is the requirement to always place the probe so that it has the consistent pressure on the skin. However, it is important to be aware of the individual variation of thresholds, as, for example, the values between individuals ranged from 1mm to 15 mm. In 1985, Kawamura & Wessberg have shown that 2-P discrimination appears to be most sensitive near the midline of the face, with an average of 5 mm, which increases to 9 mm as one progresses laterally. Campbell and coworkers (1987) reported that the normal measures for 2-P discrimination in trigeminal distribution vary from 7 to 14 mm and discrimination was considered diminished at 15 to 20 mm and absent above 20 mm. In 1989, Ghali & Epker reported the normal values for 2-P discrimination to vary between 5 and 15 mm. In another study, the mean value of 2-P discrimination was 3.9 +/- 0.8 mm (SD) (Yoshida et al. 1989). In our study, 95% of the subjects responded to a 2-P perception threshold under 6 mm, and the mean value was 3.3 +/- 1.8 mm (SD), closer to the mean reported by Yoshida and co-workers (1989). Because the assumption of normal distribution is unrealistic and the distribution of 2-P discrimination is skewed to the right, the median reflects more accurately where the bulk of the numbers lie than does the mean. In our study, the median was 3 mm. It was also
shown that the experience in measuring plays a role with this test. The difference in measurements between the experienced and inexperienced examiners was obvious. Similar results have also been reported earlier; Feldman with his co-workers (1997) reported the 2-P discrimination test to be useful in evaluating trigeminal nerve-injured patient, but the training of examiners and a standard calibration protocol are particularly important when using the 2-P perception threshold.

Bedside neurosensory observations are often crude; the testing stimuli may be poorly controlled, and various human variables may be introduced by both the examiner and the patient. It is most unlikely that different methods agree exactly, giving identical results for all individuals. How far apart measurements can be without causing difficulties is a question of judgment. With subjective measurements, we do not usually know the true value, and the limits of agreement are the only estimates which apply to the whole population. The advantage of these bedside type tests is that they rarely need any expensive instruments; in LT only a cotton wisp is needed. In 2-P, PIN and TH tests some instruments are needed, but they can be rather simple as in our studies.

Very limited data is available regarding pin-prick modality in subjects with normal sensation. In most studies, the postoperative threshold is usually compared individually to the preoperative value. The difference between the pre- and postoperative values is then calculated and analyzed, but according to our knowledge, no “normal” value for pin tactile discrimination is given. However, some authors have suggested that 15 g is an adequate force to elicit this response (Walter & Gregg 1979). One of our present subjects did not respond to the pin tactile test until 15 g, even though he had subjectively normal sensitivity in the area. This shows, that individual variability can be quite large.

Temperature has classically been tested with the Minnesota thermal disks. The patient is required to identify the time interval at which the colder disk (i.e. the glass disk) is applied. In 1987, Nishioka with his co-workers reported that a nerve is considered to have a neurosensory temperature deficit if there are fewer than 80% correct responses at one or both of the test sites. In our study, the discrimination between cold and warm temperatures was measured with two glass tubes, which contained cold and warm water. Again, because all the subjects were healthy and had normal sensation of the chin, they responded positively to the test in every observation. However, this indicates that this test was also perfectly repeatable.

In the sensibility testing, intraexaminer or interexaminer repeatability was not good. The vitality scanner in this study worked with batteries, and this might be why the values were not repeatable. If we wish to obtain repeatable values, an instrument operating with a current generator should be used.

### 6.4 Factors affecting neurosensory disturbance after BSSO

Although this study was based on a rather small number of patients (30 patients with a total of 60 osteotomies), the data suggest some possible causes of the neurosensory disturbance after BSSO. As we assumed, gender had no influence on the neurosensory disturbance, whereas patient’s age seemed to be a significant factor in the sensory loss of the mental area during the whole follow-up. The correlation between neurosensory
disturbance and increasing age of the patient supports previous findings (MacIntosh 1981, Nishioka et al. 1987, Upton et al. 1987, August et al. 1998, Westermark et al. 1998a). On the other hand, some studies have not revealed significant differences in the incidence of neurosensory disturbances by age, but this may be because the age range has been small (Fridrich et al. 1995). In our study, the patients’ ages ranged from 16 years to 48 years, and the results showed significantly more neurosensory disturbances in the patients aged 30 or over than in those aged under 30 years.

The magnitude of mandibular movement during operation had a significant influence on the occurrence of neurosensory disturbance on the mandible. There was more neurosensory disturbance in the patients with mandibular movement of more than 7 millimeters. One explanation for this could be excessive stretching of the nerve during operation. Westermark and co-workers (1998b) did not find any statistically significant correlation between neurosensory disturbance of the mental area and the magnitude of mandibular movement, but this may have been explained by the fact that they compared mandibular movements less than and more than 5 millimeters.

The relationship between neurosensory disturbance of the mental area and the degree of manipulation of the IAN was obvious. The degree of manipulation correlated well with the postoperative neurosensory disturbance and recovery. Other studies have also shown, that sensory disturbance after BSSO is closely related to the degree of intraoperative strain on the nerve (Peipersack & Chausse 1978, Leira & Gilhuus-Moe 1991, Fridrich et al. 1995). Also Jääskeläinen and co-workers (1995b) evaluated function of the IAN with repeated nerve conduction tests during BSSO, and the sensory nerve action potential remained stable in the IANs not exposed during surgery. Although nerves “between the fragments” or “dissected from the lateral fragment” resulted in a greater degree of neurosensory disturbance during follow-up, they ultimately (within one year) recovered to the same level as the nerves “not encountered” or “visible but embedded in the medial fragment”. Similar results have also been obtained in previous studies (Fridrich et al. 1995). On the other hand, in two other studies (Westermark et al. 1998b, Teerijoki-Oksa et al. 2002) intraoperative nerve encounter such as nerve manipulation correlated with neurosensory disturbance to a much lesser degree than expected. They suggested, that it could be the dissection of the soft tissue on the medial aspect of the mandibular ramus that might be partly responsible for neurosensory disturbance of the lower lip and chin after BSSO (Westermark et al. 1998b, Teerijoki-Oksa et al. 2002). In our study, we carefully protected the tissues on the medial surface of the ramus with a retractor before cutting the bone on the medial surface of the mandible in every patient. In spite of this, our patients did not have more neurosensory disturbance than patients in other studies. However, in our study manipulation of the nerve seemed to be one of the main factors causing neurosensory disturbance of the mandible.

In our study, prognathic patients seemed to have more sensory loss than retrognathic patients from the fourth day after surgery until three months after surgery, but this difference was not statistically significant. However, there have been presurgical observations where the body areas of the mandibles of retrognathic patients were wider than the body areas of the mandibles of prognathic patients. This difference has been assumed to be accounted for the increased incidence of nerve related problems in prognathic patients postoperatively. (Rajchel et al. 1986, Hallikainen et al. 1992).
6.5 Comparison of panoramic radiography, CT and conventional tomography in locating the mandibular canal before BSSO

CT provided better imaging of the mandibular canal than conventional tomography. CT has been reported to be useful in revealing the mandibular canal and its surrounding bone in three dimensions in other studies as well (Schwartz et al. 1987, Lindh et al. 1992, Williams et al. 1992). CT accurately reveals the position of the nerve canal along the entire course through the mandible (Schwartz et al. 1987, Williams et al. 1992). This image will allow the clinician to know the location of the mandibular canal. It also enables the oral and maxillofacial surgeon to better inform the patient of the surgical risks and possible complications and to prevent or minimize damage to the IAN during mandibular orthognathic surgery.

Panoramic radiographs cannot be used to measure the buccolingual location of the mandibular canal. By supplementing with an additional technique, a more precise demonstration of the anatomy can be achieved. Scanora slices were taken between the first and second molars as perpendicular as possible to the tangent of the outer surface of the lower mandibular cortex. Posterior to the second molars, this was not always possible, due to difficulties in positioning the patient.

The location of the mandibular canal could not be predicted from the panoramic radiograph. In 1990, Miller and co-workers suggested that cortication of the mandibular canal on the panoramic film may serve as a predictor of the proximity of the mandibular canal to the cortical plates. We could not confirm their finding. We were unable to find any signs from panoramic radiographs that could help in evaluating the buccolingual location of the mandibular canal.

The standard anatomy textbooks do not give a detailed description of the course of the mandibular canal (DuBruel 1980, Clemente 1985, Liebgott 1986). Other anatomical features, including the width and thickness of the ascending ramus as well as the relationship between the positions of the canals, therefore, have been studied earlier (Mercier 1973, Tamas 1987). In cases where the mandibular ramus is wide and thick, the mandibular canal is usually more distant from the buccal cortical plate than in the case of thin ramus. Obviously, in the case of thin rami, the sagittal splitting technique involves a risk either for a bad split or neurological injury. It has also been shown, that vascular and nerve bundles may be extremely close to the buccal cortex of the mandible in broad and thick rami. In the study of Tamas and co-workers (1987), this was observed in only 6% of the mandibles. In our study, the mandibular canal was in direct contact with the buccal cortex of the mandible in 7% (3/40) of the mandibular sides. Because the major risk for nerve injury during sagittal split osteotomy is in mandibles with thin rami, it is recommendable to study the location of the mandibular canal at least in these cases by precise tomography.

The clinically significant potential application of CT imaging modality is in preventing nerve injury in patients at risk for nerve injury during BSSO. The risk for neurosensory disturbance was significantly greater if the distance between the mandibular canal and the buccal cortex of the mandible was 2 mm or less. Similar results have been published earlier. In the study of Yoshida and co-workers (1989) the distance between the mandibular canal and the buccal cortex was less than 1.2 mm in 91% of sides with a severe grade neurosensory disturbance after BSSO. In our study, there were only 3 out of
40 sides where the distance between the mandibular canal and the buccal cortex was very close (less than 1.2 mm), but in these cases, the subjective evaluation of the neurosensory disturbance was still abnormal at 3-month follow up.

The mandibular canal was more visible on CT images than with the other imaging techniques we evaluated. CT techniques, however, have a disadvantage of involving high radiation doses. Whereas the use of spiral reformatted CT images requires scanning of the whole jaw, conventional spiral tomography can be limited to the potential surgical site. This means that the biologic risk from radiographs related to cross-sectional imaging is lower in conventional tomography, especially in the mandible (Dula et al. 2001). In our study, when 8 slices from both sides of the mandible were taken by conventional spiral tomography, the biologic risk involved was considered to be about 80% of that in CT. Compared with panoramic radiography, the biologic risk is about eight times greater in conventional spiral tomography and ten times greater in CT (Dula et al. 2001). Furthermore, the techniques have a disadvantage of potential artifacts created by metal fillings. Also the cost of CT examination is 20% higher than that of conventional tomography. On the other hand, conventional spiral tomography may be difficult to use, owing to problems in positioning the patient.

6.6 Clinical implications and recommendations

Bilateral sagittal split osteotomy is a versatile technique to advance or setback the mandible. Postoperative complications, such as anesthesia or paraesthesia of the lower lip, the chin and the teeth, are common. The sensory impairment may lead to long-term discomfort in some patients. Although the present study is based on a limited number of patients (30 patients with a total of 60 osteotomies), the data suggests the possibility of predicting the recovery of normal sensation using a combination of neurosensory tests at an early stage of postoperative follow-up.

The goals of the clinical examination include determination of whether or not there is a neurosensory deficit of the IAN, determination of the type and magnitude of it and reliable and reproducible documentation of the level of sensation. The combination of a mechanoceptive test (LT, 2-P), a nociceptive test (PIN, TH) and sensibility testing of mandibular molars seems to predict quite reliably neurosensory recovery of IAN. When predicting neurosensory recovery of the IAN after BSSO procedures, the sensibility of the mandibular molars should be measured, if possible. At 4 days follow-up, it is an efficient test when used alone to predict neurosensory disturbance one year after the surgery. It is almost always possible to be used in young adults, because they do not have large restorations and the teeth are not often treated endodontically. Sometimes also the orthodontic devices can give some trouble in measuring the sensibility of the teeth, particularly if there are large fillings on the teeth. At later follow-ups, we recommend the combination of the sensibility testing of the molars with a mechanoceptive and nociceptive test (LT + PIN or 2-P + PIN). In older or edentulous patients, our recommendation for neurosensory testing is the combination of LT and PIN or 2-P and PIN. In selected cases, the results of these neurosensory tests might provide a basis for microneurosurgical intervention.
After all, serious complications seem to be rather rare in orthognathic surgery. In special cases, however, it may be advisable to offer the patients other treatment than a BSSO, for example if an elderly patient who, for social or occupational reasons, needs intact sensory nerve function in his or her lip and chin. During operation, manipulation of the nerve should be avoided, because it seems to be one of the main factors causing neurosensory disturbance of the mandible.

An injury to a single nerve fiber affects the whole nerve cell itself. The regeneration of a nerve is a very slow and complicated process. Therefore, efforts must be directed towards the protection of the nerve during surgery in order to prevent any injury. A well-planned surgical approach should include a proper patient historical and clinical evaluation, and selected dental radiographs that localize anatomic structures involved in the surgical field. Views that provide precise localization of the mandibular canal and provide minimal risk of exposure to ionizing radiation should be selected.

Preoperative radiographic images are necessary as a preventive tool for avoiding long lasting neurosensory disturbances. Recommendations for the application of imaging techniques should be based on clinical necessity, for example the need for portrayal of anatomic or topographic conditions; ease in image production, information expected from the image; biologic risks for the patient, and financial considerations. In presurgical planning, it is essential that the position of the mandibular canal is known if it is close to the buccal cortex of the mandible. This information enables the oral and maxillofacial surgeon to inform the patient of the surgical risks and possible complications and to make efforts to prevent or reduce damage to the inferior alveolar neurovascular bundle during mandibular surgery. CT provides the most accurate information regarding this.
7 Conclusions

The following main conclusions can be drawn from the results obtained in the present studies:

1. There is a high incidence of neurosensory disturbance of the lower lip and chin after mandibular ramus sagittal osteotomy. However, recovery of sensation occurs with increasing frequency during the follow-up, and after one year most of the patients return to the presurgical situation. The sensibility test of the mandibular teeth is a reliable method in testing for altered sensation of the inferior alveolar nerve. Four days after surgery, it is an effective test used alone to predict the recovery of neurosensory disturbance. At later follow-ups, combining the sensibility testing of the molars with a mechanoreceptive test and nociceptive test (LT + PIN or 2-P + PIN) is more reliable than the sensibility testing alone.

2. After BSSO, a prolonged neurosensory disturbance is strongly related to age, the intraoperative magnitude of mandibular movement, and the degree of manipulation of the inferior alveolar nerve.

3. Computerized tomography is the most accurate method to visualize the buccolingual location of the mandibular canal before BSSO. It should be a part of treatment planning of patients with a thin ramus of the mandible and patients with severe asymmetry of the mandible.
8 References


