Distraction osteogenesis of the anterior mandibular process

Christof Urs Joss

Christof Urs Joss

Distraction osteogenesis of the anterior mandibular process

Thesis Radboud university medical center, Nijmegen, the Netherlands
ISBN 978-90-824180-0-2

Cover design by: Rosita Joss
Printed by: Drukkerij Efficiënt, Nijmegen

Distraction osteogenesis of the anterior mandibular process

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus
volgens besluit van het College van Decanen
in het openbaar te verdedigen op 7 december 2015
16.30 uur precies

door

Christof Urs Joss
geboren op 1 juli 1977
te Bern, Zwitserland

Promotoren
Prof. dr. A.M. Kuijpers-Jagtman
Prof. dr. S. Kiliaridis (Université de Genève, Zwitserland)

Manuscriptcommissie
Prof. dr. G.J. Meijer
Prof. dr. Y. Ren (UMC Groningen)
Dr. W.A. Borstlap

Paranimfen
MSc M.A.R. Kuijpers
Dr. A.M. Renkema

The study presented in this thesis was conducted at the Division d'orthodontie, Section de Médecine Dentaire, Université de Genève, Switzerland and the Department of Orthodontics and Craniofacial Biology, Radboudumc Department of Dentistry, Nijmegen, The Netherlands.
This research project was part of the Radboud Institute for Health Sciences (RIHS).

To my wife, Isabella and my children Alessia Ileana and Luca Mattia

*"Was glänzt, ist für den Augenblick geboren;
Das Echte bleibt der Nachwelt unverloren."*

Goethe in Faust I, Vers 73 f.

Table of contents

Chapter 1

General introduction

1.1 Introduction

A Class II malocclusion is a very common condition in the orthodontic office. A Class II malocclusion is diagnosed in 23% of children, 15% of adolescents, and 13% of adults. Severe Class II and Class III problems, at the limit of orthodontic correction, occur in about 4% of the American population whereas severe Class II is much more prevalent than Class III.[1]

Other epidemiologic studies reveal that about 20 to 30% of all Caucasian children show signs of a Class II occlusion during dental development.[2-6] There are some racial differences regarding the prevalence of Class II malocclusion. It was reported that Latino American adolescents showed 21.5%,[7] Chinese adolescents 21.5%,[8] American Blacks 16% and Kenyan Blacks 7.9% of Class II malocclusion.[9] It could be said that white individuals of Northern European origin are most likely to be affected whereas it is less common in black and oriental races. Furthermore a significant increase in the frequency of Class II malocclusion seems to have taken place during the last century. About 13% of the children had distal occlusion in the 1920s whereas the frequency has almost doubled by the 1960s.[4,10]

In general, malocclusion appears to be acquired but it has been shown that there is a fundamental genetic control of craniofacial form with moderate to high heritability.[22] Functional factors like non-nutritive sucking habits, swallowing pattern and mode of breathing play an important role as well. Habits such as prolonged finger or thumb sucking can cause an anterior open bite, proclination and protrusion of the maxillary incisors, a lengthening of the upper arch, a constriction of the maxillary arch, an anterior displacement of the maxilla or a Class II malocclusion.[11] Spontaneous correction of some of the acquired dental effects is possible if finger or thumb sucking is terminated in an early age.[11] The constricted maxillary arch is the aspect of the malocclusion least likely to correct spontaneously.[12] Furthermore individuals with an anterior open bite and increased overjet like in Class II malocclusions tend to place their tongue between the anterior teeth when they swallow.

This is defined as tongue thrust swallowing.[12] A change in swallowing pattern should be expected when correcting the tooth and jaw position.

Treatment indications for Class II correction are functional and aesthetic. Aesthetically, normalisation of a protruded upper lip by retrusion of the upper incisors and correction of the interdental lip position must be mentioned. Functionally, good occlusal intercuspation following correction of Class II malocclusion improves chewing and swallowing. However, it seems that a different biting force among individuals is an effect rather than a cause of malocclusion.[12] It has also been reported that good occlusal intercuspation is needed to prevent dental and skeletal relapse.[13]

Reducing an increased overjet has an impact on reducing the risk of dental trauma of the anterior teeth. It was found that children with an overjet larger than 3 mm are approximately twice as much at risk of injury to anterior teeth than children with an overjet smaller than 3 mm.[14] Although normal speech is possible even in extreme anatomic conditions, occasionally orthodontic therapy has the potential to facilitate speech and / or speech therapy.[15]

Recently, it has been recognized that mandibular deficiency among factors like obesity, alcohol, age and gender can contribute to the development of obstructive sleep apnea.[16] Oral appliances for mandibular advancement are advocated as a non-invasive treatment option instead of continuous positive airway pressure (CPAP) with mild to moderate obstructive sleep apnoea.[17,18]

1.2 Features of Class II malocclusion

Based only on the sagittal dental or occlusal relationship of the first permanent molars, Edward H. Angle described four different classifications of dental malocclusion. The following three of them are still widely used: An Angle Class I consists of a normal relationship of the first molars whereas the lower molar is slightly mesially positioned in the sagittal view compared to the upper first molar. In an Angle Class II malocclusion, the lower first molar is now distally positioned relative to the upper first molar. The lower first permanent molar is mesially positioned relative to the upper first permanent molar in an Angle Class III malocclusion.[19]

Besides the Angle classification to describe the dental relationship, the term “Class II malocclusion” is expanded and variably used in orthodontic literature. The terminology of Class II malocclusion refers either to a dental, a skeletal (based on upper to lower jaw relationship) or to both, a combination of dental and skeletal Class II. Furthermore the term Class II malocclusion often lacks a clear definition and demarcation into Class II division 1 and Class II division 2 in scientific literature.[20] Dentally, Class II /1 patients represent an increased overjet whereas Class II/2 patients show an increased overbite (deep bite) which could be combined with a traumatic deep bite for the palatal mucosa or recessions of the buccal gingiva of the lower anterior teeth. Cephalometrically, findings in Caucasians with Class II division 1 and Class II division 2 malocclusions did not show any basic difference in dentoskeletal morphology with the exception of the maxillary incisor position. Broad variation in dentoskeletal morphology prevailed in both Class II types.[20] A convex facial profile indicates a Class II jaw relationship, which can result from either a maxilla that projects too far forward or a mandible too far backward.[21] Further features of a Class II malocclusion could be a retrognathic mandible, an increased overjet, upper lip prominence indicating dentoalveolar protrusion with the presence of lip incompetence or an interdental lip relationship.[15,22] This PhD-thesis is focussing on patients with skeletal Class II malocclusion and mandibular retrognatism.

1.3 Correction of Class II malocclusion with retrognathic mandible in growing children

The choice of the treatment modality to correct mandibular retrognathism depends on the age of the patient and the expected remaining growth (heritability of the mandibular retrognathism and growth potential), the severity of the malocclusion, the preferences of the orthodontist and, of course, the patient’s perception and expected compliance.

The range of orthodontic treatment modalities to correct a dental Class II malocclusion is quite wide. It has been assumed that different types of functional appliances are able to create additional growth in response to the movement of the mandibular condyle out of the fossa.[23-26] Even though an acceleration of mandibular growth is likely to occur, mediated by reduced pressure on the condylar tissues or by altered muscle tension, a long-term increase in mandibular size is difficult to demonstrate.[27] However, discomfort, lack of compliance, reduced time of wear, and thus increased treatment duration should be named as disadvantages of orthodontic treatment by functional appliances. The success rate and efficiency of activator treatment was lately examined in a multicentre study.[28] Improvement of the Class II dental arch relationships in subjects with a Class II division 1 malocclusion can be expected in approximately 65 % of subjects. Activator treatment was more efficient in the late than in the early mixed dentition.

In general, the orthodontist has to deal with the dilemma whether to treat the patient early or to wait until the child is older and provide orthodontic treatment during adolescence. In a Cochrane review, Harrison *et al.* analysed the effectiveness of orthodontic treatment to correct prominent upper front teeth if provided at 7 to 9 years or in early adolescence.[29] Based on eight trials retrieved out of 185 publications, they suggest that providing early orthodontic Class II treatment is no more effective than providing one course of orthodontic treatment when the child is in early adolescence.

Alternatively, the Herbst appliance, as it was reintroduced by Pancherz in the early eighties of the last century, has the potential to overcome compliance problems and thus can result in reduced wearing time. The Herbst appliance as cast splint or the banded type is bonded or cemented to the maxillary and mandibular teeth to produce a constant protrusion of the mandible. For this reason, the Herbst appliance is able stimulate condylar growth and remodel the glenoid fossa in children and even in adults shown in magnetic resonance imaging.[30] It was thus stated that the Herbst appliance might be a facial orthopedic tool for non-surgical, non-extraction treatment in borderline Class II adults, especially when a major facial improvement is not the main treatment wish.[31]

1.4 Correction of Class II malocclusion with retrognathic mandible in non-growing individuals

Fundamental different treatment approaches are necessary in adult Class II patients where jaw growth is completed. Basically, two treatment options exist: orthodontic camouflage therapy (with or without additional genioplasty) and surgical correction of the dysgnathia in combination with orthodontic treatment.

1.4.1 Camouflage therapy

Orthodontic camouflage therapy includes extraction of two upper first premolars to allow retraction of the upper anterior segment and thereby reducing the increased overjet while maintaining the upper first molars in a Class II relationship. Posterior anchorage to prevent mesial movement of the maxillary first molars has to be reinforced by means of appliances such as Class II elastics, headgear or Pendulum.[32,33] Nowadays, the introduction of temporary skeletal anchorage devices such as miniscrews,[34] palatal implants,[35] or even zygoma anchors[36] has gained much popularity among orthodontists. Temporary skeletal anchorage devices have the potential to avoid loss of posterior anchorage or even to distalize the molars into a Class I relationship to prevent extraction of first premolars.

Although with this treatment approach a good intra-arch occlusal relationship either through extraction of premolars or the distalisation of molars can be established, extra-orally the anterior-posterior skeletal discrepancy is still noticeable. Unfortunately, orthodontic camouflage therapy deals with the symptom, mostly the increased overjet, but fails to correct the underlying skeletal maxilla-mandibular discrepancy of the jaws and thus the soft tissue profile will not benefit from this therapy. Therefore camouflage therapy with first premolar extractions might only be indicated if the patient has a full upper lip and only a relative mandibular deficiency. However, the decrease in lip projection after camouflage therapy is much less than the amount of incisor retraction.[37]

Especially in Class II division 2 patients with thinner lips care has to be taken to avoid further incisor retrusion and thus opening of the nasio-labial-angle with relative lengthening of the nose. An increase in the nasolabial angle, which is often aesthetically undesirable, has to be discussed as a potential side effect of orthodontic camouflage therapy and has to be taken into account when considering the different therapeutic approaches.[38] Retroclining upper incisors to achieve a therapeutic Class II in a patient with a dished-in profile, thin lips and little vermilion border is contraindicated. Retracting upper incisors in a patient with this facial morphology could prematurely age the face. Due to the loss of soft tissue elasticity the face tends to flatten with age and the lips become less full.

The facial appearance in so-called "borderline cases" generally is judged to be better without premolar extraction by both dentists and patients.[39] Surgery is likely to be needed for successful correction of the malocclusion if the overjet is greater than 10mm in Class II adolescents beyond the growth spurt.[40]

1.4.2 Surgical correction in combination with orthodontic treatment

The decision whether or not to opt for surgical correction of a skeletal Class II depends on different criteria: besides the severity of the skeletal discrepancy and its beneficial aesthetic impact on the new soft tissue profile, the risks of surgery, the patient's fear of surgery, the uncertainty of the real treatment result, and lack of insurance coverage for orthognathic surgery may play an important role for the patient as well. Nevertheless, the search for aesthetic perfection combined with newer surgical treatment modalities and decreasing operation risks may guide us nowadays towards a surgical correction in combination with orthodontic treatment as the preferred treatment option. The most frequently used surgical procedures to address a retrognathic mandible, i.e. the bilateral sagittal split osteotomy (BSSO), distraction osteogenesis (DO), and DO of the anterior mandibular process are presented here below.

1.4.3 Bilateral sagittal split osteotomy for mandibular advancement (BSSO)

The major indication for bilateral sagittal split osteotomy (BSSO) used to be advancement and setback of the mandible to correct mandibular retrognathism (skeletal Class II) and prognathism (skeletal Class III). After introduction by Trauner and Obwegeser in 1955[41] and 1957,[42] the BSSO has gained much popularity, especially when it was combined with rigid internal fixation (RIF) first described by Spiessl[43] in 1974. Several important modifications of the BSSO technique have been proposed by Dal Pont in 1961,[44] Hunsuck in 1968,[45] Gallo *et al*. in 1976,[46] and Epker in 1977.[47]

Spiessel's method for RIF involved the use of 3 lag-screws at the osteotomy site (2 above the neurovascular bundle, and 1 below) to stabilize the bony fragments. Since then, many modifications of the screw osteosynthesis principle have been used, varying in relation to number, sites, sizes, placement patterns, and types (i.e., stainless steel, titanium, biodegradable, or allogenic cortical bone) of screws.

Miniplates were introduced for rigid fixation in BSSO by Rubens *et al*. in 1988.[48] Miniplates have several advantages compared with bicortical screw osteosynthesis. Miniplates can be placed from a transoral approach. The plate application obviates the need for transcutaneous puncture, with subsequent scarring, and the increased risk of facial-nerve damage. The removal of third molars and the preservation of a sufficient bulk of bone on the distal segment are not necessary for screw placement, and the risk of damaging adjacent teeth is also lower. Passive plate bending helps to maintain the axial condylar orientation within the fossa. Plates are easily removed under local anesthesia after 6 months[48] but most of the time they stay in place.

1.4.4 Distraction osteogenesis for mandibular advancement (DO)

The principles of distraction osteogenesis were first described by Codivilla already in 1905[49] and it took more than eighty years to have them widely applied and refined by Ilizarov in the late eighties of last century.[50-52] In 1972 Snyder *et al*.[53] applied the technique of distraction osteogenesis the first time to lengthen a canine mandible and in 1989 the first human mandibular distraction was performed by McCarthy and co-workers.[54]

The DO procedure consists of four different phases: the osteotomy (rarely a corticotomy), the latency period, the distraction phase and finally the consolidation phase.

At the start of a DO procedure the osteotomy is carried out by the surgeon to obtain a controlled fracture of the bone. The distraction device is then fixated and tested on the bone to connect the segments. The healing period of 5 to 7 days for adequate maturation of the newly formed callus is called latency phase. After an appropriate latency period, tension is placed on the bony segments by activating the distractor, which marks the start of the distraction phase. In general, it is suggested to activate the distractor twice a day (rhythm) to have an activation of about 0.5 mm per day (rate). Once sufficient distraction has been achieved, the distraction is stopped and the distraction device is kept in place for stabilization of the bony segments. The newly created bone matures and is subject to remodelling in the so-called consolidation period. The minimum length of time needed for consolidation was described anywhere between 3 weeks and 3 months depending on the total amount of distraction and osteotomy site.[55]

Nowadays, the applications comprise mandibular lengthening[56] or widening,[57] reconstruction of the alveolar process for implant placement,[58] DO for bone transport after trauma or tumor resection for reconstruction of segmental defects or a neocondyle,[59] maxillary DOG for unilateral and bilateral cleft patients,[60] and midfacial or cranial DOG for different types of craniosynostosis.[61]

The main application of mandibular body distraction was in congenital micrognathia[62] such as hemifacial microsomia[63,64] and different types of syndromes, i.e., Nager, Pierre Robin, Treacher-Collins, and Goldenhar. In a review of Swennen *et al.*[62] it was concluded that a less frequent indication of mandibular DOG was acquired micrognathia (trauma, TMJ ankylosis), and almost no patient data is available on mandibular retrognathia in non-syndromic adult patients, while there is a lack of appropriate data on long-term results with skeletal relapse rates.

1.4.5 Distraction osteogenesis of the anterior mandibular alveolar process

Orthognathic surgery has evolved into one of the standards of care in the orthodontic field to correct mandibular skeletal deformity. Considering the historical development in orthognathic surgery, the earliest report goes back to the American surgeon Simon Hullihen. In 1849, he published a case of an elongation of the mandible after distortion of the face caused by a burning.[65] The early evolution was often credited to the American plastic surgeon Vilray Blair who, in conjunction with the famous orthodontist Edward H. Angle, developed orthognathic surgery.[66,67] Even though mandibular surgical procedures to correct skeletal deformity were described early in the 19th century, they were not performed routinely until the 1950s among others due to an extraoral approach. Finally, intraoral maxillofacial surgery to lengthen the mandible was popularized by the European surgeons Trauner and Obwegeser[41,42] from Switzerland and Austria by the introduction and several modifications of the bilateral sagittal split osteotomy described earlier in this chapter.[43-47]

An alternative surgical option of skeletal Class II correction instead of lengthening the mandible as a whole by a BSSO is the distraction osteogenesis of the mandibular anterior alveolar process, which is the subject of this thesis. This was first described in 2001 by Triaca *et al.*[68] It could be indicated in specific cases such as in patients with a skeletal Class I with a dental Class II to create space of one premolar width and overjet normalization, and in patients with a skeletal and dental Class I with crowding to avoid extraction and the often resulting unfavorable profile. In skeletal Class II patients, the indication could be space creation to resolve lower incisor crowding in combination with the reduction of the sagittal discrepancy to be achieved normally by BSSO for mandibular advancement.

Figure 1. *The horizontal osteotomy is made about 5 mm inferior to the apices of the teeth. A joint plate is loosely fixed with screws before completion of the vertical osteotomies.*

Prior to surgery, the inter-root space of the teeth next to the vertical osteotomies is increased by tipping them orthodontically. The desired new anterior position of the anterior alveolar segment has to be defined by the orthodontist and surgeon, from which the required position of the hinge axis is derived. The surgery can be performed under local or general anesthesia. A horizontal incision is made from canine to canine 1 cm from the attached gingiva. The osteotomy is then made about 5 mm inferior to the apices of the teeth with the help of a thin burr-type bone cutter (Cutter E0540, Maillefer, Ballaigues/Switzerland). After the horizontal osteotomy is completed, incomplete vertical osteotomies are made mostly between the canine and first premolars (less often between the lateral incisors and canines). When creating the osteotomies, care must be taken to keep the lingual periosteum and mucosa largely intact. A hinge plate is then loosely fixed with screws before completion of the vertical osteotomies (Fig.1). The vertical osteotomies are then completed, the segment is mobilised with a chisel, and the screws holding the plate are tightened (Fig. 2). The free rotation of the anterior bone segment is then confirmed, and the wound is closed, and sutured. After 5 days of healing, the orthodontic appliance to distract the anterior alveolar segment is activated for 0.5 mm/day. After the desired position is reached, the segment is held in position for 6 weeks with the help of the activation appliance, which is locked in the final position.[68]

Figure 2. *After the horizontal osteotomy is completed, incomplete vertical osteotomies are made mostly between the canine and first premolars. The vertical osteotomies are then completed, the mandibular anterior alveolar segment is mobilized with a chisel, and the screws holding the plate are tightened.*

As with all surgical procedures, the risks of surgery and anesthesia must be weighed against the benefits which are expected to result from the outcome of the surgery. There are still several questions remaining regarding possible advantages and disadvantages of this type of DO. Possible side effects like skeletal, dental or soft tissue changes and stability, the neurosensory status and craniomandibular function, root resorption, changes in pulp condition (devitalized teeth), tooth mobility or ankylosis, the outcome of implants placed in the newly distracted bone, and periodontal findings such as the possible occurrence of pockets of this particular procedure have not been examined until now.

The present thesis is focusing on some of possible problems after DO such as the neurosensory status and craniomandibular function, skeletal, dental or soft tissue changes and stability.

1.5 Aim of the thesis

The purpose of the research presented in this thesis is to provide a scientific basis of the short- and long-term outcome of DO of the anterior mandibular alveolar process in patients with a skeletal Class II. The main question set out to answer was whether DO of the anterior mandibular alveolar process is a stable and safe procedure. We aimed to get more insight into the outcome after DO of the anterior mandibular alveolar process and to identify possible secondary effects. The specific aims were:

- To systematically review the short- and long-term soft/hard tissue ratio in bilateral sagittal split osteotomy with rigid internal fixation or wire fixation
- To evaluate the short- and long-term dental and skeletal effect as well as the amount of skeletal relapse and dental changes in patients treated with DO of the anterior mandibular alveolar process and to identify factors related to dental and skeletal stability.
- To assess the short- and long-term soft tissue changes after DO of the anterior mandibular alveolar process and relate them to different skeletal and soft tissue parameters.
- To analyse the neurosensory status and craniomandibular function of patients receiving DO of the anterior mandibular alveolar process and compare the data with a control group of non-surgically treated orthodontic patients.

1.6 Overview of the thesis

Chapter 1 provides a general introduction of the features of Class II malocclusions and its orthodontic correction by different types of functional appliances and camouflage therapy or surgical correction by BSSO and DO.

In Chapter 2 the short- and long-term soft/hard tissue ratio in bilateral sagittal split osteotomy with rigid internal fixation or wire fixation was systematically reviewed.

In Chapter 3 and 4 the skeletal and dental as well as the soft tissue stability 2-years after DO of the anterior mandibular alveolar process were described.

In Chapter 5 the neurosensory status and craniomandibular function of patients receiving DO of the anterior mandibular alveolar process were compared to a control group of non-surgically treated orthodontic patients.

In Chapter 6 and 7 the long-term skeletal, dental and soft tissue stability 5.5-years post-surgically in DO of the anterior mandibular alveolar process were evaluated.

In Chapter 8 the most important findings are discussed together with suggestions for future research.

1.7 References

1. Proffit WR, Fields HW, Jr., Moray LJ. Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey. *Int J Adult Orthod Orthognath Surg* 1998;13:97-106.
2. Bowden DE, Davies RM, Holloway PJ, Lennon MA, Rugg-Gunn AJ. A treatment need survey of a 15-year-old population. *British dental journal* 1973;134:375-9.
3. Horowitz HS. A study of occlusal relations in 10 to 12 year old Caucasian and Negro children-summary report. *Int Dent J* 1970;20:593-605.
4. Myllarniemi S. Malocclusion in Finnish rural children. An epidemiological study of different stages of dental development. Suomen Hammaslaakariseuran toimituksia = *Finska tandlakarsallskapets forhandlingar* 1970;66:219-64.

5. Roberts EE, Goose DH. Malocclusion in a North Wales population. *British dental journal* 1979;146:17-20.
6. Lavelle CL. A study of multiracial malocclusions. *Community Dent Oral Epidemiol* 1976;4:38-41.
7. Silva RG, Kang DS. Prevalence of malocclusion among Latino adolescents. *Am J Orthod Dentofacial Orthop* 2001;119:313-5.
8. Lew KK, Foong WC, Loh E. Malocclusion prevalence in an ethnic Chinese population. *Aust Dent J* 1993;38:442-9.
9. Garner LD, Butt MH. Malocclusion in black Americans and Nyeri Kenyans. An epidemiologic study. *Angle Orthod* 1985;55:139-46.
10. Varrela J. Early developmental traits in class II malocclusion. *Acta Odontol Scand* 1998;56:375-7.
11. Larsson E. The effect of finger-sucking on the occlusion: a review. *Eur J Orthod* 1987;9:279-82.
12. Proffit WR, Fields HW, Sarver DM. The Etiology of Orthodontic Problems, in eds: St. Louis, Missouri: *Mosby Elsevier* 2007:130-65.
13. Pancherz H. The nature of Class II relapse after Herbst appliance treatment: a cephalometric long-term investigation. *Am J Orthod Dentofacial Orthop* 1991;100:220-33.
14. Nguyen QV, Bezemer PD, Habets L, Prahl-Andersen B. A systematic review of the relationship between overjet size and traumatic dental injuries. *Eur J Orthod* 1999;21:503-15.
15. Proffit WR, Fields HW, Sarver DM. Orthodontic treatment planning: From Problem list to specific plan, in eds: St. Louis, Missouri: *Mosby Elsevier* 2007:234-67.
16. Lowe AA, Ozbek MM, Miyamoto K, Pae EK, Fleetham JA. Cephalometric and demographic characteristics of obstructive sleep apnea: an evaluation with partial least squares analysis. *Angle Orthod* 1997;67:143-53.
17. Ahrens A, McGrath C, Hagg U. A systematic review of the efficacy of oral appliance design in the management of obstructive sleep apnoea. *Eur J Orthod* 2011;33:318-24.
18. Lim J, Lasserson TJ, Fleetham J, Wright J. Oral appliances for obstructive sleep apnoea. Cochrane Database Syst Rev 2006;CD004435.
19. Angle EH. Treatment of malocclusion of the teeth and fractures of the maxillae, Angel's System. Philadelphia: SS White Dental Mfg Co 1900.

20. Pancherz H, Zieber K, Hoyer B. Cephalometric characteristics of Class II division 1 and Class II division 2 malocclusions: a comparative study in children. *Angle Orthod* 1997;67:111-20.
21. Proffit WR, Fields HW, Sarver DM. Orthodontic Diagnosis: The Development of a Prolem List, in eds: St. Louis, Missouri: *Mosby Elsevier* 2007:167-233.
22. McNamara JA, Jr. Components of class II malocclusion in children 8-10 years of age. *Angle Orthod* 1981;51:177-202.
23. Andreasen V. The Norwegian system of functional gnatho-orthopedics. *Acta Gnathol* 1936;1:4-36.
24. van Beek H. Overjet correction by a combined headgear and activator. *Eur J Orthod* 1982;4:279-90.
25. Stöckli PW, Teuscher UM. Combined activator headgear orthopedics, in eds: St. Louis: Mosby 1994.
26. Fränkel R. Funktionskieferorthopädie und der Mundvorhof als apparative Basis, Berlin: VEB Verlag, Volk und Gesundheit 1967.
27. Keeling SD, Wheeler TT, King GJ, Garvan CW, Cohen DA, Cabassa S, McGorray SP, Taylor MG. Anteroposterior skeletal and dental changes after early Class II treatment with bionators and headgear. *Am J Orthod Dentofacial Orthop* 1998;113:40-50.
28. Casutt C, Pancherz H, Gawora M, Ruf S. Success rate and efficiency of activator treatment. *Eur J Orthod* 2007;29:614-21.
29. Harrison JE, O'Brien KD, Worthington HV. Orthodontic treatment for prominent upper front teeth in children. *Cochrane Database Syst Rev* 2007;CD003452.
30. Ruf S, Pancherz H. Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: A prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation. *Am J Orthod Dentofacial Orthop* 1999;115:607-18.
31. Ruf S, Pancherz H. Orthognathic surgery and dentofacial orthopedics in adult Class II Division 1 treatment: mandibular sagittal split osteotomy versus Herbst appliance. *Am J Orthod Dentofacial Orthop* 2004;126:140-52; quiz 254-145.
32. Byloff FK, Darendeliler MA. Distal molar movement using the pendulum appliance. Part 1: Clinical and radiological evaluation. *Angle Orthod* 1997;67:249-60.
33. Byloff FK, Darendeliler MA, Clar E, Darendeliler A. Distal molar movement using the pendulum appliance. Part 2: The effects of maxillary molar root uprighting bends. *Angle Orthod* 1997;67:261-70.

34. Costa A, Raffainl M, Melsen B. Miniscrews as orthodontic anchorage: a preliminary report. *Int J Adult Orthod Orthognath Surg* 1998;13:201-9.
35. Triaca A, Antonini M, Wintermantel E. Ein neues Titan-Flachschrauben-Implantat zu orthodontischen Verankerung am anterioren Gaumen. *Informationen aus Orthodontie und Kieferorthopädie* 1992;24:251-7.
36. De Clerck H, Geerinckx V, Siciliano S. The Zygoma Anchorage System. *J Clin Orthod* 2002;36:455-9.
37. Scott Conley R, Jernigan C. Soft tissue changes after upper premolar extraction in Class II camouflage therapy. *Angle Orthod* 2006;76:59-65.
38. Kinzinger G, Frye L, Diedrich P. Class II Treatment in Adults: Comparing Camouflage Orthodontics, Dentofacial Orthopedics and Orthognathic Surgery - A Cephalometric Study to Evaluate Various Therapeutic Effects*. *J Orofac Orthop* 2009;70:63-91.
39. Proffit WR, Fields HW, Sarver DM. Limitations, Controversies, and Special Problems, in eds: St. Louis, Missouri: *Mosby Elsevier* 2007:268-327.
40. Proffit WR, Phillips C, Tulloch JF, Medland PH. Surgical versus orthodontic correction of skeletal Class II malocclusion in adolescents: effects and indications. *Int J Adult Orthod Orthognath Surg* 1992;7:209-20.
41. Trauner R, Obwegeser H. Zur Operationstechnik bei der Progenie und anderen Unterkieferanomalien. *Dtsch Zahn-, Mund- und Kieferheilk* 1955;23:1-26.
42. Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty. *J Oral Surg* 1957;10:677-89.
43. Spiessl B. Osteosynthese bei sagittaler Osteotomie nach Obwegeser/Dal Pont., Fortschritte in Kiefer- und Gesichtschirurgie. Thieme, Stuttgart XVIII;1974.
44. Dal Pont G. Retromolar osteotomy for the correction of prognathism. *J Oral Surg Anesth Hosp Dent Serv* 1961;19:42-7.
45. Hunsuck EE. A modified intraoral sagittal splitting technique for correction of mandibular prognathism. *J Oral Surg* 1968;26:250-3.
46. Gallo W, Moss M, Gaul J. Modification of the sagittal split ramus osteotomy for retrognathia. *J Oral Surg* 1976;34:178.
47. Epker BN. Modifications in the sagittal osteotomy of the mandible. *J Oral Surg* 1977;35:157-9.
48. Rubens BC, Stoelinga PJW, Blijdorp PA, Schoenaers JHA, Politis C. Skeletal stability following sagittal split osteotomy using monocortical miniplate internal fixation. *Int J Oral Maxillofac Surg* 1988;17:371-6.

49. Codivilla A. On the means of lengthening in the lower limbs, the muscles and tissues which are shortened through deformity. *Am J Orthop Surg* 1905;2:353-69.
50. Ilizarov GA. The possibilities offered by our method for lengthening various segments in upper and lower limbs. *Basic Life Sci* 1988;48:323-4.
51. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. *Clin Orthop Relat Res* 1989;263-85.
52. Ilizarov GA. The tension-stress effect on the genesis and growth of tissues. Part I. The influence of stability of fixation and soft-tissue preservation. *Clin Orthop Relat Res* 1989;249-81.
53. Snyder CC, Levine GA, Swanson HM, Browne EZ, Jr. Mandibular lengthening by gradual distraction. Preliminary report. *Plast Reconstr Surg* 1973;51:506-8.
54. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. *Plast Reconstr Surg* 1992;89:1-8; discussion 9-10.
55. Proffit WR, White RP, Sarver DM. Maxillofacial distraction osteogenesis, in eds: St. Louis, Missouri: *Mosby* 2003:357-93.
56. van Strijen PJ, Perdijk FB, Becking AG, Breuning KH. Distraction osteogenesis for mandibular advancement. *Int J Oral Maxillofac Surg* 2000;29:81-5.
57. Guerrero CA, Bell WH, Contasti GI, Rodriguez AM. Mandibular widening by intraoral distraction osteogenesis. *Br J Oral Surg* 1997;35:383-92.
58. Chiapasco M, Lang NP, Bosshardt DD. Quality and quantity of bone following alveolar distraction osteogenesis in the human mandible. *Clin Oral Implants Res* 2006;17:394-402.
59. Stucki-McCormick SU. Reconstruction of the mandibular condyle using transport distraction osteogenesis. *J Craniofac Surg* 1997;8:48-52; discussion 53.
60. Swennen G, Colle F, De May A, Malevez C. Maxillary distraction in cleft lip palate patients: a review of six cases. *J Craniofac Surg* 1999;10:117-22.
61. Meazzini MC, Mazzoleni F, Caronni E, Bozzetti A. Le Fort III advancement osteotomy in the growing child affected by Crouzon's and Apert's syndromes: presurgical and postsurgical growth. *J Craniofac Surg* 2005;16:369-77.
62. Swennen G, Schliephake H, Dempf R, Schierle H, Malevez C. Craniofacial distraction osteogenesis: a review of the literature: Part 1: clinical studies. *Int J Oral Maxillofac Surg* 2001;30:89-103.

63. Meazzini MC, Mazzoleni F, Gabriele C, Bozzetti A. Mandibular distraction osteogenesis in hemifacial microsomia: long-term follow-up. *J craniomaxillofac surg* 2005;33:370-6.
64. Shetye PR, Grayson BH, Mackool RJ, McCarthy JG. Long-term stability and growth following unilateral mandibular distraction in growing children with craniofacial microsomia. *Plast Reconstr Surg* 2006;118:985-95.
65. Hullihen SP. Case of elongation of the under jaw and distortion of the face and neck caused by a burn, successfully treated. *Am J Dent Sci* 1849;9:157-165
66. Blair VP. Operations on jaw bones and face: Study of aetiology and pathological anatomy of developmental malrelations of maxilla and mandible to each other and to facial outline and of operative treatment when beyond the scope of the orthodontist. *Gynecol Obstet* 1907;4:67-78.
67. Blair VP. Underdeveloped jaw with limited excursion. *J Am Dent Assoc* 1909;17:178-18.8
68. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001;59:26-34; discussion 34-25.

Chapter 2

Soft tissue profile changes after bilateral sagittal split osteotomy for mandibular advancement: A systematic review

C.U. Joss
I.M. Joss-Vassalli
S. Kiliaridis
A.M. Kuijpers-Jagtman

J Oral Maxillofac Surg 2010;68:1260-9

Summary

Purpose: The purpose of the present systematic review was to evaluate the soft tissue/hard tissue ratio in bilateral sagittal split advancement osteotomy (BSSO) with rigid internal fixation (RIF) or wire fixation (WF).

Materials and Methods: The databases PubMed, Medline, CINAHL, Web of Science, Cochrane Library, and Google Scholar Beta were searched. From the original 711 articles identified, 12 were finally included. Only 3 studies were prospective and 9 were retrospective. The postoperative follow-up ranged from 3 months to 12.7 years for RIF and 6 months to 5 years for WF.

Results: The short- and long-term ratios for the lower lip to lower incisor for BSSO with RIF or WF were 50%. No difference between the short- and long-term ratios for the mentolabial-fold to point B and soft tissue pogonion to pogonion could be observed. It was a 1:1 ratio. One exception was seen for the long-term results of the soft tissue pogonion to pogonion in BSSO with RIF; they tended to be greater than a 1:1 ratio. The upper lip mainly showed retrusion but with high variability.

Conclusions: Despite a large number of studies on the short- and long-term effects of mandibular advancement by BSSO, the results of the present systematic review have shown that evidence-based conclusions on soft tissue changes are still unknown. This is mostly because of the inherent problems of retrospective studies, inferior study designs, and the lack of standardized outcome measures. Well-designed prospective studies with sufficient sample sizes that have excluded patients undergoing additional surgery (ie, genioplasty or maxillary surgery) are needed.

2.1 Introduction

The major indication for bilateral sagittal split advancement osteotomy (BSSO) is the advancement and setback of the mandible to correct skeletal Class II and III defects.[1,2] Moderate to severe mandibular retrognathism and prognathism often require a combined orthodontic and surgical approach for optimal function and best esthetic results. Generally, when an orthognathic surgery case is planned, the skeletal tissues are used to determine the amount of change necessary to provide the appropriate soft tissue profile change.

Orthognathic surgery has the potential to change facial esthetics. Surgical procedures to correct skeletal deformities result in changes in the shape and position of the overlying soft tissues. The patient seeking combined surgical-orthodontic therapy needs precise information about the facial changes that will appear after treatment to decide whether to undergo the treatment. Therefore, accurate prediction of the postoperative facial profile has become an essential part of the diagnostic and treatment planning procedure of combined surgical-orthodontic therapy.

Currently, different computer imaging algorithms and programs allow one to provide the patient and clinician with some idea of the expected treatment result. The relationship and behavior of the soft tissues in relationship to the underlying skeletal movements shown in different studies should be the database for these programs and techniques. Nevertheless, the accuracy of the prediction is highly dependent on the clinician's knowledge of the soft tissue response to skeletal repositioning. Recently, a trend has been seen for quantifying the soft tissue profile changes using a 3-dimensional evaluation (ie, optical laser surface scanners,[3] stereophotogrammetry with 2 cameras,[4] or computed tomography-assisted imaging).[5]

Although the skeletal stability in BSSO advancements[6] has been systematically reviewed, the soft tissue profile after mandibular advancement surgery has not yet been systematically reviewed.

The aim of the present study was to systematically review the published data on the soft tissue profile after BSSO to advance the mandible using different types of rigid internal fixation (RIF) and wire fixation (WF). The specific research questions were to determine *1)* the relationship between the soft tissue and skeletal movements in BSSO advancement surgery with RIF and WF; *2)* whether a difference exists between the short- and long-term results; *3)* the influence of genioplasty; and *4)* whether any difference in the outcomes results from using RIF versus WF.

2.2 Materials and Methods

2.2.1 Literature search

A literature search was performed using the following databases: PubMed (from 1966 to the third week of March 2009), Medline (from 1966 to the third week of March 2009), Google Scholar Beta (to the third week of March 2009), EMBASE Excerpta Medica (from 1980 to the third week of March 2009), CINAHL (from 1982 to the third week of March 2009), Web of Science (from 1945 to the third week of March 2009), and CENTRAL of the Cochrane Library (to the third week of March 2009), to identify articles reporting BSSO advancement surgical-orthodontic treatment with RIF or WF and soft/hard tissue ratios. Free text words and MeSH terms were used. The heading sequence ("BSSO" OR "bilateral sagittal split osteotomy" OR "sagittal split osteotomy" OR "mandibular osteotomy" OR "orthognathic surgery") AND ("soft tissue" OR "soft tissue profile" OR "soft tissue relapse" OR "relapse" OR "stability") AND "cephalometry" [MeSH] NOT "distraction") was selected. No exclusion of articles because of the language used was performed. To complete the search, the references of each selected publication on the soft tissue profile after BSSO advancement surgical-orthodontic treatment were searched by hand.

2.2.2 Selection criteria

The following inclusion criteria were chosen initially to select potential articles from the published abstract results: *1)* human clinical trials; *2)* no syndromic or medically compromised patients, and no diseases; *3)* no case reports, case series of fewer than 10 patients, descriptive studies, review articles, or opinion articles; *4)* no surgical intervention other than BSSO for mandibular advancement (ie, Le Fort I, other types of mandibular surgery) with RIF or WF; and *5)* lateral cephalograms used for horizontal soft tissue stability, which was measured at the pogonion (Pg) and/or point B and/or lower incisor to their corresponding soft tissue points (Fig 1). Genioplasty was accepted. In the case of duplicate publications in more than one language, it was decided to use the publication in English.

The articles that met the inclusion criteria were divided into 2 groups according to the method of fixation (RIF or WF). Furthermore, we distinguished between those with short- and long-term results, for which a cutoff value of 2 years was chosen to separate the short- and long-term studies.[6,7] In cases of more than one publication of the same patient group for the same postoperative follow-up period, the most informative and relevant article was included.

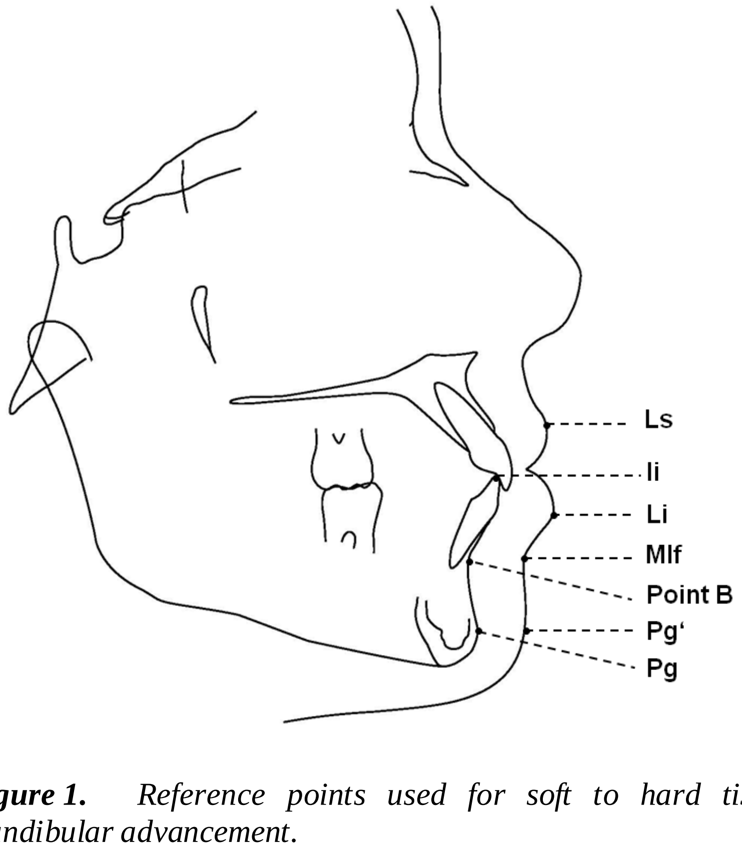

Figure 1. *Reference points used for soft to hard tissue ratios after BSSO for mandibular advancement.*

2.2.3 Data extraction

The data were extracted and methodologically assessed for quality independently by 2 observers (C.J. and I.J.-V.). The data were recorded on specially designed data extraction forms. First, the abstracts were reviewed without considering the number of patients reported. Articles that apparently fulfilled the inclusion criteria and the articles for which the title or abstract did not present enough relevant information were obtained in full text. Second, the following data were extracted from the full-text articles: year of publication; study design; follow-up; number and mean age of patients; ethnic background of patients; number of surgeons operating; type of RIF or WF; combined surgical-orthodontic patients with BSSO and RIF or WF for mandibular advancement; presence of orthodontic treatment; maxillomandibular fixation; genioplasty; intraoperative splint and presence in postoperative radiographs; mean skeletal advancement; mean ratio between the lower incisor, point B, pogonion, and their corresponding soft tissue points (labrale inferior, mentolabial fold, and soft tissue pogonion [Pg']); ratios for labrale superior to lower incisor, points B or Pg when present; correlations between the soft tissue points and different variables such as age, gender, relapse, and so forth. Missing ratios between the soft and hard tissue points were calculated from the published data.

To assess the methodologic soundness of each article, a quality evaluation modified from the methods described by Jadad *et al.*[8] and Petren *et al.*[9] was performed using the following characteristics: study design; sample size and previous estimate of sample size; selection descriptions; withdrawals (dropouts); valid methods; confounding factors (eg, genioplasty, presence of a splint in the immediate postoperative radiographs, and brackets bonded on teeth in follow-up photographs); method error analysis; blinding in measurements; and adequate statistical analysis. The quality was categorized as low, medium, or high. In the event of a discrepancy regarding the inclusion criteria, quality evaluation, or extracted data between the observers, a consensus decision was made.

2.3 Results

2.3.1 Search results

The search strategy resulted in 711 articles, and the number of abstracts selected was 203 (Table 1).

Table 1. *Search results from databases.*

Database	Abstract Series Found	Abstract Series Selected	Abstracts Not in PubMed
PubMed	260	79	1
Medline	243	68	1
Google Scholar Beta	104	28	0
EMBASE Excerpta Medica	62	17	0
CINAHL	32	8	0
Web of Science	10	3	0
Cochrane	0	0	0
Total	711	203	2

The titles of the eliminated 508 articles were not topic related. The Quorum-flow diagram gives an overview of the selection process (Fig 2).

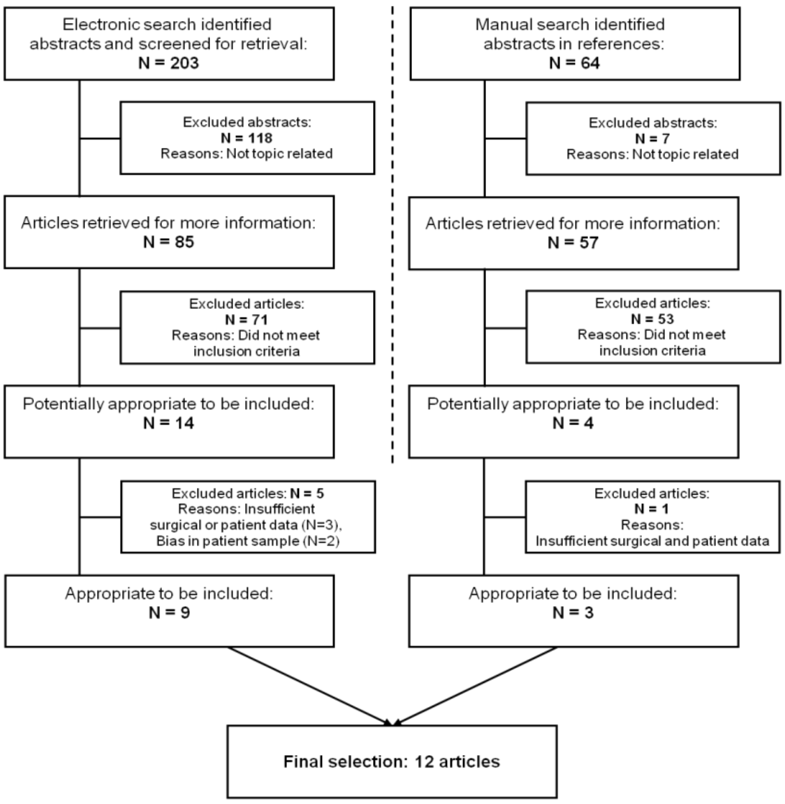

Figure 2. *QUORUM-flow diagram.*

A manual search of the references revealed 64 studies, and 57 were selected and studied with the 85 articles derived from the electronic search. Potentially, 18 articles were appropriate to include. However, 6 articles were finally rejected because the patients had undergone other types of surgery or the exact surgical procedure was not described (2 studies[10,11]), advancement and setback surgery were mixed (1 study[12]), only white females had been included (2 studies[13,14]), or insufficient patient and/or surgical data (3 studies[12,13,15]). Finally, 12 suitable studies[16-27] (9 articles from the electronic database search and 3 articles from the manual search) were included (Table 2).

Table 2. *Articles (N = 12) included in revieuw.*

Investigators	Year	Country	Study Design	Judged Quality Standard
Alves *et al.*[16]	2008	Brazil	CT,R	Low
Joss and Thüer[17]	2008	Switzerland	CT,P	Medium
Dolce *et al.*[18]	2003	US	MCT, RCT	High
Hamada *et al.*[19]	2001	Japan	CT,R	Low
Mobarak *et al.*[20]	2001	Norway	CT,R	Low
Pangrazio-Kulbersh *et al.*[21]	2001	US	CT,R	Low
Thüer *et al.*[22]	1994	Switzerland	CT,R	Medium
Ewing and Ross[23]	1992	Canada	CT,R	Low
Athanasiou *et al.*[24]	1990	Denmark	CT,R	Low
Dermaut and De smit[25]	1989	Belgium	CT,R	Low
Hernandez-Orsini *et al.*[26]	1989	US	CT,R	Low
Mommaerts and Marxer[27]	1987	Switzerland	CT,R	Low

Abbreviations: CT, clinical trial; R, retrospective study; P, prospective study; MCT, multicenter clinical trial; RCT, randomiyed clinical trial

2.3.2 Quality analysis

Only 3 studies had a prospective study design,[17,18,22] and only 1 study was a multicenter randomized, clinical trial.[18] The ethnic background of the patients in all reviewed studies was mainly white, except for the study by Hamada *et al.*[19] on Asian subjects.

Table 2 lists the research quality or methodologic soundness of the 12 studies. It was low in 9 studies, medium in 2 studies, and high in 1 study. The most obvious findings were small sample sizes, implying low power, a lack of error analysis, no blinding of measurements, and deficient or a lack of statistics. Furthermore, no study declared any power analysis. Seven studies[16,18,20,22,25-27] were judged to have an adequate sample size, ranging from 30 to more than 90.

In all studies, the methods used to detect and analyze the postoperative ratios between the soft and hard tissue were valid and well known. However, 3 studies did not include a method error analysis,[18,23,26] and none of the studies used blinding in the measurements. Correlation statistics for other variables such as gender, age, and so forth were used in 6 studies.[17-20,22,27]

Considering the confounding variable, genioplasty, 1 study declared that additional genioplasty was performed in only 2 patients; however, point Pg, Pg', menton (Me), and soft tissue menton (Me') were excluded for data analysis.[22] Also, in 1 study,[19] it was not clear whether some patients with genioplasty had been included. In another study,[18] patients with additional genioplasty were grouped together. None of the studies analyzed the presence of bonded brackets and its influence in the follow-up cephalograms.

Another confounding variable was the presence of a splint in the immediate postoperative radiographs. This did not play an important role because this systematic review did not consider the immediate postoperative ratios. Nevertheless, the extracted data concerning the postoperative splint has been discussed for accuracy.

Surgical splints were not used in some studies,[16,17,22] and in the study by Mobarak *et al.*,[20] only in some patients were splints present in the postoperative radiographs. The immediate postoperative data from these patients were excluded.[20] In 1 study,[18] the lateral cephalogram was taken with the splints in place 1 week after surgery. No other studies commented on the presence of a splint in the immediate postoperative radiographs nor did they compensate for its presence. Hence, the autorotation of the mandible caused by removal of the splint, depending on its thickness, would result in a relative anterior displacement of the mandible, and this must be considered when assessing relapse.[28,29] Surgical splints could have an effect on the soft tissue profile of the lips and mentolabial fold, depending on the thickness and design, and cause an increase in the anterior facial height. The removal of the splint often results in autorotation and advancement of point B and Pg, as described in studies on the skeletal stability after BSSO for mandibular advancement.[30,31]

2.3.3 Follow-up period

The range of follow-up was 3 months[19] to 12.7 years[17] for RIF (Table 3) and 6 months[18] to 5 years[18] for WF (Table 4). For RIF, only 2 studies reported the long-term results,[17,20] and 1 study reported the shortand long-term results.18 For WF, only 1 study had long-term results.[18]

2.3.4 Short-term soft tissue ratios

The short-term ratios for RIF without genioplasty (Table 3) were -2%[26] to 29%[16] for the upper lip to incision inferior, 35%[18] to 108%[16] for the lower lip to the incision inferior, 88%[22] to 111%[18] for the mentolabial fold to point B, 90%[19] to 124%[16] for Pg' to Pg.

The short-term ratios for WF without genioplasty (Table 4) were -28%[25] for the upper lip to the incision inferior, 26%[25] to 63%[18] for the lower lip to incision inferior, 87%[18] to 119%[25] for the mentolabial fold to point B, and 77%[18] to 110%[25] for Pg' to Pg.

The results from the study groups that included only patients with genioplasty were not considered for these listings of RIF and WF.[18]

2.3.5 Long-term soft tissue ratios

The long-term ratios for RIF without genioplasty (Table 3) were -10%[20] to -67%[17] for the upper lip to incision inferior, 31%[18] to 60%[20] for the lower lip to the incision inferior, 86%[20] to 111%[18] for the mentolabial fold to point B, and 102%[20] to 127%[18] for Pg’ to Pg.

The long-term ratios for WF without genioplasty (Table 4) were 38% to 80%[18] for the lower lip to the incision inferior, 82% to 96%[18] for the mentolabial fold to point B, and 84% to 107%[18] for Pg' to Pg. No studies were found with the long-term ratios for WF of the upper lip.

2.3.6 Correlations

Correlation statistics were used in 6 studies.[17-20,22,27] However, most studies used correlation statistics only to assess the relationship between the change in the hard and soft tissue structures.[18-22,24,27] Interesting research questions such as the associations between the soft tissue changes and gender, preoperative age, low- and high-angle patients, and the amount of advancement were not addressed.

Table 3. *Summarized data of 8 studies with BSSO advancement surgery with RIF.*

Study	Surgery	Surgeons (*n*)	Patients (*n*)	Mean Age (Range) (yt)	Follow-Up	Ls	Li/li	Mlf/B	Pg'/Pg
Alves *et al.*,[16] 2008	2 titanium bicortical screws, no GP, no splints	1	36	23	13.2 mo	29% (Ls/Ii) 23% (Ls/Pg)	108%	NR	124%
Joss and Thüer,[17] 2008	3 titanium lag bicortical screws (Ø 3.5 mm), no GP, MMF for 4-6 days, no splints	4	16	21.4 (17.0-31.1)	12.7 yr	-67% (Ls/Ii) -67% (Ls/B) -76% (Ls/Pg)	55%	94%	119%
Dolce *et al.*,[18] 2003	BSSO, groups for RIF with or without GP, 3 bicortical screws (Ø 2 mm), MMF 5-7 days	NR	29 (RIF, GP) 28 (RIF, no GP)	33.1 ± 11.3 28.2 ± 8.8	5 yr	NR	57% 46%	112% 111%	86% 127%
		NR	34 (RIF, GP) 39 (RIF, no GP)	NR	2 yr	NR	36% 31%	114% 102%	81% 106%
		NR	31 (RIF, GP) 40 (RIF, no GP)	NR	1 yr	NR	54% 35%	119% 108%	84% 106%
		NR	34 (RIF, GP) 41 (RIF, no GP)	NR	6 mo	NR	62% 59%	120% 111%	85% 102%
Hamada *et al.*,[19] 2001	BSSO with RIF (screws), 1 patient with WF, GP?	NR	14	23 yr, 11 mo	3 mo	NR	48%	89%	90%
Mobarak *et al.*,[20] 2001	3 Salzburg titanium bicortical lag screws (Ø 2.0 mm) and washers, no GP, with or without splints, no MMF	7	61	28.2 ± 9.3 (16.2-50.9)	3 yr				
						High -17% (Ls/Ii) -14% (Ls/B) -13% (Ls/Pg)	60% (high)	86% (high)	102% (high)
						Med -10% (Ls/Ii) -11% (Ls/B) -11% (Ls/Pg)	60% (med)	93% (med)	111% (med)
						Low -18% (Ls/Ii) -20% (Ls/B) -26% (Ls/Pg)	60% (low)	95% (low)	111% (low)
Pangrazio-Kulbersh *et al.*,[21] 2001	Bicortical screws, no GP, splint	1	20	24.4 (16.7-39.4)	1 yr	NR	61%	93%	100%
Thüer *et al.*,[22] 1994	3 titanium lag screws (Ø 3.5 mm), MMF for 4-6 days, 2 with GP (but excluded for evaluation of Pg, Pg'), no splints intra- or postoperatively	4	30	20 yr, 5 mo (17-32.5)	13 mo	NR	66%	88%	100%
Hernandez-Orsini *et al.*,[26] 1989	BSSO with RIF (type missing), no GP	NR	31	28.3 (14-48)	8 mo	-2% (Ls/Ii) -2% (Ls/B) -2% (Ls/Pg)	43%	93%	94%

Abbreviations: Ls, labrale superior; Li, labrale inferior; Ii, incision inferior; Mlf, mentolabial fold; B, point B; Pg', soft tissue pogonion; Pg, pogonion; GP, genioplasty; WF, wire fixation; NR, not reported; Ø, diameter; MMF, maxillomandibular fixation; BSSO, bilateral sagittal split advancement osteotomy; RIF, rigid internal fixation; Low, low-angle cases; High, high-angle cases; Med, medium-angle cases.
Negative values imply posterior movement; positive values, anterior movement.

In their long-term study, Joss and Thüer[17] did not find any correlations between the soft tissue changes and preoperative age, gender, and the amount of advancement.

Table 4. *Summarized data of 5 studies with BSSO advancement surgery with WF.*

Study	Surgery	Surgeons (*n*)	Patients (*n*)	Mean Age (Range) (yt)	Follow-Up	Ls	Li/li	Mlf/B	Pg'/Pg
Dolce *et al.*,[18] 2003	BSSO, groups with/without GP, WF with 6 wk MMF	NR	18(WF, GP) 15 (WF, no GP)	29.3 ± 10.5 28.0 ± 10.2	5 yr	NR	13% 80%	101 96%	71% 107%
		NR	23 (WF, GP) 25 (WF, no GP)	NR	2 yr	NR	26% 38%	93% 82%	76% 84%
		NR	23 (WF, GP) 25 (WF, no GP)	NR	1 yr	NR	36% 58%	104% 87%	71% 82%
		NR	24 (WF, GP) 25 (WF, no GP)	NR	6 m	NR	56% 63%	119% 93%	81% 77%
Ewing and Ross,[23] 1992	BSSO with WF, MMF, no GP	1	14	19.5 (11.2-35.5) for whole group (n = 31)	1 yr	NR	80%	100%	100%
Athanasiou *et al.*,[24] 1990	BSSO with WF, MMF for 6 wk, no GP	1	14	(16-41)	1 yr	NR	NR	97%	104%
Dermaut and de Smit,[25] 1989	BSSO with WF, MMF for 6 wk, no GP	NR	31	Females, 17 yr, 6 mo (14-25) Males, 17 yr, 9 mo (15-26)	1 yr	-28% (Ls/li) -44% (Ls/B) -60% (Ls/Pg)	26%	119%	110%
Mommaerts and Marxer,[27] 1987	BSSO with WF, no GP, no splint	NR	35	21.5 ± 8.5	1 YR	Nr	56%	106%	103%

Abbreviations as in Table 3. Negative values indicate posterior movement; positive values, anterior movement.

2.4 Discussion

Optimal treatment planning for maxillofacial surgery requires an understanding of the stability of the postoperative skeletal position and the soft tissue response to skeletal movement. The postoperative skeletal stability after BSSO for mandibular advancement was addressed earlier in a systematic review.[6] It is difficult to exactly determine the changes in the soft tissue profile that are specific to BSSO for mandibular advancement when other, simultaneous, orthognathic surgical procedures, such as genioplasty or Le Fort I osteotomy, have been included. The inclusion in the present study of patients treated with either RIF or WF was thought to promote the possibility for their separate analysis and direct comparison in the short and long term. Clinical trends for fixating the proximal to the distal segment intraoperatively have shown an increased use of RIF instead of WF. The same trend was seen when reviewing the studies of soft tissue stability (ie, no recent studies of WF were found, with the exception of the randomized clinical trial by Dolce *et al.*).[18]

The Quality of Reporting of Meta-analyses statement[32] was used as the basis to report the present systematic review. Of the 12 included studies, only 1 randomized, clinical trial and 2 prospective studies were found. Therefore, at present, a meta-analysis of the data was impossible.

To increase the power of our systematic review, it would have been necessary to include only randomized, clinical trials; prospective multicenter articles; or prospective clinical trials.

We tried to provide a summarized database for commercially available surgical prediction software packages for the mean ratios of soft tissue to hard tissue movements in BSSO for mandibular advancement, even though evidence to date is lacking. Thus, the present computer programs that attempt to predict the soft tissue profile have been based on weak evidence and 2-dimensional records of 3-dimensional phenomena. It might be possible that 3-dimensional imaging techniques will provide better insight in the near future. Furthermore, it would be necessary to standardize the outcome variables between centers, exclude or separate patients with genioplasty, evaluate the error of the method, standardize the superimposing of the lateral cephalograms (ie, the sella-nasion line minus 7°), and list all essential patient data and correlation statistics, as was partly noted in our earlier reviews.[6,7]

In all the reviewed studies, the soft tissue prediction was, or could be, calculated as the ratio between the amount of change in the hard and soft tissue during the same interval. The relationship between the hard and soft tissue changes could be very complex because of differing soft tissue morphology, thickness combined with weight changes, posture, elasticity, and/or tonicity, which can vary from person to person.[33] Mobarak *et al.*[20] showed that individual variability was greatest in small skeletal advancements or large skeletal relapses. However, problems that could evolve when using prediction software based on mean data from the studies included in the present systematic review could be the large individual variability in the soft tissue response.

Another problem is the question of whether we should use linear or nonlinear soft/hard tissue ratios in predictions as has been proposed and adopted by some software programs.[34] The idea behind the use of nonlinear ratios is that the soft tissue becomes more resistant to movements the more the mandible is advanced. For the chin, we could argue that the initial ratio would be rather high compared with the last ratio. However, contact of the lower lip to the upper lip and upper incisors is often present before surgery. The initial labrale inferior/incision inferior ratios could be rather small, and the more the lower incisors are advanced, the greater the ratio. At present, the available data are not sufficient to support any of these hypotheses.

2.4.1 Influence of genioplasty

Genioplasty can be a powerful adjunctive procedure to improve the facial profile. The question that arises is whether a difference occurs in soft tissue stability when BSSO for mandibular advancement is combined with genioplasty.

Genioplasty alone mainly has an effect on the Pg', and the mentolabial fold depth increases because of the treatment. The effects on the lips have been small, and no change in lip thickness was noted.[35] Depending on the type of genioplasty, it is possible to move Pg and point B anteriorly with its surrounding soft tissue. The anterior movement of point B could also influence the lower lip profile. Furthermore, the chin undergoes remodeling patterns in the area of the osteotomy depending on the type of genioplasty, which will result in more variability of the soft tissue profile.[36]

Several studies[18,23,37] have shown that adding another surgical procedure (ie, genioplasty) to BSSO would influence the results. Soft tissue scarring in the anterior chin region can be present in patients treated with genioplasty. It has been claimed that the scar contracture during the postoperative healing period might cause decreased soft tissue thickness compared with the preoperative measurements.[38] RIF in the form of miniplates adds more volume on the anterior surface of the chin bone and has an effect on the soft tissue profile and limits the exact location of the cephalometric landmarks. Therefore, the evaluation of patients undergoing BSSO with and without genioplasty as a single group is questionable.

Ewing and Ross[23] found, in their group of BSSO and genioplasty, that the results were much less consistent compared with the results from patients without genioplasty. They attributed these differences to the fact that the patients requiring genioplasty often had more severe cases, and the soft tissue drape in severe retrognathia is usually abnormal.[23] Greater edema from additional surgical manipulation such as genioplasty has been shown to have an effect on increased soft tissue advancement.[18,33] Dolce *et al.*[18] compared 4 groups of patients with RIF with or without genioplasty and WF with or without genioplasty. They concluded that the soft tissue profiles of these 4 groups were not significantly different, even though 2 of these 4 groups had a considerable incidence of skeletal relapse.

2.4.2 Short-term versus long-term ratios

When analyzing the long-term effects, the effect of aging and changes in soft tissue elasticity must be considered. Studies that have evaluated the soft tissue profile over time in nontreated patients found that the distance between the sella and the labrale superior increased in adulthood, that a loss of soft tissue tension occurred, and that the labrale superior moved downward.[39,40] Also, a forward and downward movement of Pg' and Me' was found for both genders in adulthood. Males achieved a more prominent Pg', a less accentuated mentolabial fold, a longer and more prominent lower lip, and a larger and more angular nose compared with females. Forsberg[41] performed a longitudinal study of facial growth in those 24 to 34 years of age. During that period, the nose moved forward, with a retrusion of the lips and a posterior movement of Pg'. He reported that a close relationship between the changes in the soft tissue and underlying hard tissue could not be expected, because the soft tissues are also subject to the tension from the oral musculature and the amount of subcutaneous fat present at different ages.

The present systematic review has shown that the differences between the short- and long-term lower lip/lower incisors ratios for BSSO with RIF or WF were quite small (Fig 3). The ratios were all about 50%. No distinction was found between the short- and long-term ratios for the mentolabial fold or Pg'. Patients treated with WF and RIF had similar outcomes. It could be described as a 1:1 ratio for the mentolabial fold to point B and for Pg' to Pg. One exception was seen for the long-term results of Pg' in BSSO with RIF: the Pg'/Pg ratio tended to be greater than 100%. However, high variability was seen for the upper lip measured as a ratio to incision inferior, point B, or Pg.

In addition to the new mandibular soft tissue position, another important effect of BSSO is the postoperative swelling caused by the surgery. Thus, the immediate short-term soft tissue profile changes measured on the lateral cephalogram are always a combined effect of surgery, swelling, and the thickness of the orthodontic brackets. A more anterior soft tissue location would result in greater ratios for the soft tissue points immediately after surgery. Thus, it is advisable to consider an adequate healing period of several months for follow-up measurements. Dolce *et al.*[18] showed that the swelling caused by the surgery had began to resolve by 8 weeks and had fully resolved by 6 months. The data in their 5-year, longterm study showed that the soft/hard tissue ratios vary over time. The soft to hard tissue correlations were strongest immediately after surgery and weaker later.

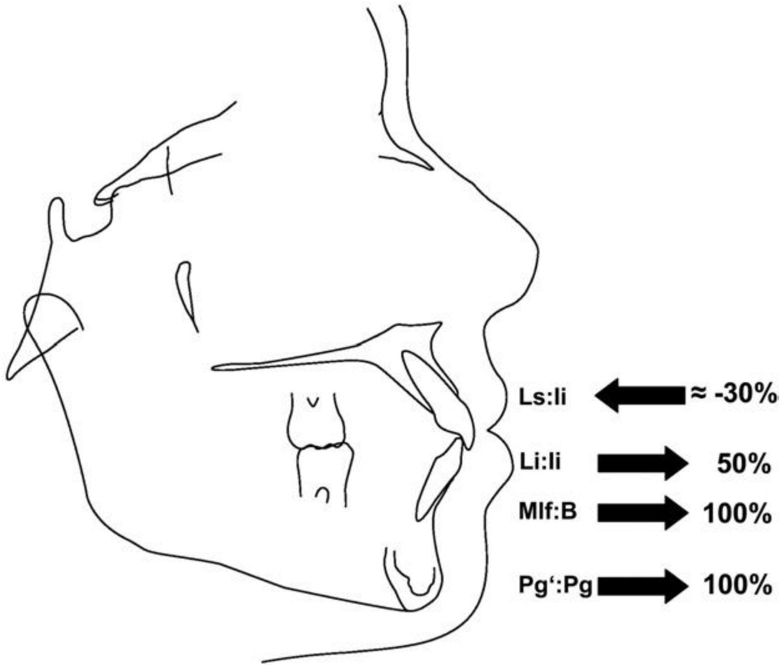

Figure 3. *Soft to hard tissue ratios after BSSO for mandibular advancement with RIF or WF in the short- and long-term. Long-term ratios for Pg':Pg tend to be higher than 100%. High variability is seen for the ratio of Ls compared to Ii, point B, or Pg.*

The effects of BSSO for mandibular advancement surgery on the upper lip are generally believed to be small[20,26,27] and clinically irrelevant.[26] Nevertheless, the effects on the upper lip especially for low-angle cases should be considered.[16,20] The initial anterior movement of the upper lip was probably related to postoperative edema, which gradually faded,[14,20,26] but a net posterior relocation of the labrale superior was evident in the long term.[17,20] An important confounding variable in the short term might have been the possible presence of orthodontic brackets on the buccal surface of the incisors. In summary, there appear to be some long-term effects of mandibular advancement surgery, probably combined with aging, on the upper lip position. A continuous lowering of the labrale superior described in the reviewed longterm studies can be attributed to the lack of soft tissue strength with age.[17,20]

The lower lip failed to follow the total amount of mandibular advancement measured at the incision inferior compared with the mentolabial fold and Pg'. One explanation for this difference could be that preoperatively the lower lip position is mostly supported by the maxillary incisors and already maintained in a more anterior position. Another effect on lower lip support is created by the orthodontic brackets. Bracket removal after surgery at the end of orthodontic treatment will let the lower lip move posteriorly again. However, soft tissue profile photographic analysis showed that the presence of bonded labial appliances had no effect on the lip posture.[42] Furthermore, the weak reproducibility of a relaxed lip position could also affect the findings for the labrale inferior and could be a source of error.[26]

Mobarak *et al.*[20] found that preoperative lower lip thickness correlated significantly with the net change in its thickness. Thus, patients with a thicker lower lip were likely to have comparatively less anterior repositioning of the lip as it became thinner. The relatively smaller amount of lower lip advancement compared with the mentolabial fold and chin was partly related to the decrease in lower lip thickness. The accompanying decrease in the mentolabial fold depth was more pronounced in the low-angle than in the high-angle group, probably owing to the increase in anterior facial height by the surgery.

Several reviewed studies reported a tendency of the lower lip length to increase after mandibular advancement surgery.[11,20,25] This could have resulted from an increase of the lower anterior facial height when the mandible was rotated clockwise in low-angle patients.

The long-term effects of the labrale inferior and stomion inferior in the vertical plane surprisingly showed a small upward movement. In the horizontal plane, the labrale inferior, mentolabial fold, and Pg' had a larger posterior movement, probably owing to skeletal relapse.[17,18,20] The mentolabial fold and Pg' showed little change in either vertical direction.[20] In contrast, others described a downward movement.[17] However, these values were missing in the other long-term study reviewed.[18]

Despite a large number of studies of the short- and long-term effects of mandibular advancement by BSSO, the results of the present systematic review showed that evidence-based conclusions of soft tissue changes are still lacking. This is mostly because of the inherent problems of retrospective studies, inferior study designs, and a lack of standardized outcome measures. Well-designed prospective studies with sufficient sample sizes that have excluded additional surgery (ie, genioplasty or maxillary surgery) are needed.

2.5 References

1. Trauner R, Obwegeser H. Zur Operationstechnik bei der Progenie und anderen Unterkieferanomalien. *Dtsch Zahn Mund und Kieferheilk* 1955;23:1-26.
2. Obwegeser H. The surgical correction of mandibular prognathism and retrognathia with consideration of genioplasty. *J Oral Surg* 1957;10:677-89.
3. Nkenke E, Vairaktaris E, Kramer M, et al. Three-dimensional analysis of changes of the malar-midfacial region after Le Fort I osteotomy and maxillary advancement. *Oral Maxillofac Surg* 2008;12:5-12.
4. Hajeer MY, Ayoub AF, Millett DT. Three-dimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery. *Br J Oral Maxillofac Surg* 2004;42:396-404.
5. Terajima M, Yanagita N, Ozeki K, et al. Three-dimensional analysis system for orthognathic surgery patients with jaw deformities. *Am J Orthod Dentofac Orthop* 2008;134:100-11.
6. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: A systematic review. *J Oral Maxillofac Surg* 2009;67:301-13.

7. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy setback surgery with rigid internal fixation: A systematic review. *J Oral Maxillofac Surg* 2008;66:1634-43.
8. Jadad AR, Moore RA, Carroll D, et al. Assessing the quality of reports of randomized clinical trials: Is blinding necessary? *Control Clin Trials* 1996;17:1-12.
9. Petren S, Bondemark L, Soderfeldt B. A systematic review concerning early orthodontic treatment of unilateral posterior crossbite. *Angle Orthod* 2003;73:588-96.
10. Lines PA, Steinhauser EW. Soft tissue changes in relationship to movement of hard structures in orthognathic surgery: A preliminary report. *J Oral Surg* 1974;32:891-6.
11. Quast DC, Biggerstaff RH, Haley JV. The short-term and longterm soft-tissue profile changes accompanying mandibular advancement surgery. *Am J Orthod Dentofac Orthop* 1983;84:29-36.
12. Clemente-Panichella D, Suzuki S, Cisneros GJ. Soft to hard tissue movement ratios: Orthognathic surgery in a Hispanic population. *Int J Adult Orthodon Orthognath Surg* 2000;15:255-64.
13. Bailey LTJ, Collie FM, White RP. Long-term soft tissue changes after orthognathic surgery. *Int J Adult Orthodon Orthognath Surg* 1996;11:7-18.
14. Keeling SD, LaBanc JP, Van Sickels JE, et al. Skeletal change at surgery as a predictor of long-term soft tissue profile change after mandibular advancement. *J Oral Maxillofac Surg* 1996;54:134-44.
15. Albrechtsen L, Larsen B. Changes in lower lip cross-sectional area subsequent to mandibular advancement surgery. *Int J Adult Orthodon Orthognath Surg* 1997;12:287-96.
16. Alves PV, Mazucheli J, Vogel CJ, et al. How the lower face soft tissue changes after mandibular advancement or setback. *J Craniofac Surg* 2008;19:593-8.
17. Joss CU, Thuer UW. Stability of the hard and soft tissue profile after mandibular advancement in sagittal split osteotomies: A longitudinal and long-term follow-up study. *Eur J Orthod* 2008;30:16-23.
18. Dolce C, Hatch JP, Van Sickels JE, et al. Five-year outcome and predictability of soft tissue profiles when wire or rigid fixation is used in mandibular advancement surgery. *Am J Orthod Dentofac Orthop* 2003;124:249-56.
19. Hamada T, Motohashi N, Kawamoto T, et al. Two-dimensional changes in soft tissue profile following surgical mandibular advancement in Japanese retrognathic adults. *Int J Adult Orthodon Orthognath Surg* 2001;16:272-9.

20. Mobarak KA, Espeland L, Krogstad O, et al. Soft tissue profile changes following mandibular advancement surgery: Predictability and long-term outcome. *Am J Orthod Dentofac Orthop* 2001;119:353-67.
21. Pangrazio-Kulbersh V, Berger JL, Kaczynski R, et al. Stability of skeletal Class II correction with 2 surgical techniques: The sagittal split ramus osteotomy and the total mandibular subapical alveolar osteotomy. *Am J Orthod Dentofac Orthop* 2001;120:134-43.
22. Thüer U, Ingervall B, Vuillemin T. Stability and effect on the soft tissue profile of mandibular advancement with sagittal split osteotomy and rigid internal fixation. *Int J Adult Orthodon Orthognath Surg* 1994;9:175-85.
23. Ewing M, Ross BR. Soft tissue response to mandibular advancement and genioplasty. *Am J Orthod Dentofac Orthop* 1992;101:550-5.
24. Athanasiou AE, Gjorup H, Toutountzakis N. [Soft tissue and dentoskeletal profile changes associated with mandibular advancement osteotomy]. *Hell Periodontol Stomat Gnathoprosopike Cheir* 1990;5:157-63.
25. Dermaut LR, De Smit AA. Effects of sagittal split advancement osteotomy on facial profiles. *Eur J Orthod* 1989;11:366-74.
26. Hernandez-Orsini R, Jacobson A, Sarver DM, et al. Short-term and long-term soft tissue profile changes after mandibular advancement using rigid fixation techniques. *Int J Adult Orthodon Orthognath Surg* 1989;4:209-18
27. Mommaerts MY, Marxer H. A cephalometric analysis of the long-term, soft tissue profile changes which accompany the advancement of the mandible by sagittal split ramus osteotomies. *J Craniomaxillofac Surg* 1987;15:127-31.
28. Blomqvist JE, Isaksson S. Skeletal stability after mandibular advancement: A comparison of two rigid internal fixation techniques. *J Oral Maxillofac Surg* 1994;52:1133-7.
29. Kierl MJ, Nanda RS, Currier GF. A 3-year evaluation of skeletal stability of mandibular advancement with rigid fixation. *J Oral Maxillofac Surg* 1990;48:587-92.
30. Watzke IM, Turvey TA, Phillips C, et al. Stability of mandibular advancement after sagittal osteotomy with screw or wire fixation: A comparative study. *J Oral Maxillofac Surg* 1990;48:108-21.
31. Abeloos J, De Clercq C, Neyt L. Skeletal stability following miniplate fixation after bilateral sagittal split osteotomy for mandibular advancement. *J Oral Maxillofac Surg* 1993;51:366-9.

32. Moher D, Cook DJ, Eastwood S, et al. Improving the quality of reports of meta-analyses of randomised controlled trials: The QUOROM statement. Quality of Reporting of Meta-analyses. *Lancet* 1999;354:1896-1900.
33. Dolce C, Johnson PD, Van Sickels JE, et al. Maintenance of soft tissue changes after rigid versus wire fixation for mandibular advancement, with and without genioplasty. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2001;92:142-9.
34. Smith JD, Thomas PM, Proffit WR. A comparison of current prediction imaging programs. *Am J Orthod Dentofac Orthop* 2004;125:527-36.
35. Shaughnessy S, Mobarak KA, Hogevold HE, et al. Long-term skeletal and soft-tissue responses after advancement genioplasty. *Am J Orthod Dentofac Orthop* 2006;130:8-17.
36. Precious DS, Armstrong JE, Morais D. Anatomic placement of fixation devices in genioplasty. *Oral Surg Oral Med Oral Pathol* 1992;73:2-8.
37. Dolce C, Hatch JP, Van Sickels JE, et al. Rigid versus wire fixation for mandibular advancement: Skeletal and dental changes after 5 years. *Am J Orthod Dentofac Orthop* 2002;121:610-9.
38. Polido WD, de Clairefont Regis L, Bell WH. Bone resorption, stability, and soft-tissue changes following large chin advancements. *J Oral Maxillofac Surg* 1991;49:251-6.
39. Behrents RG. Growth in the aging craniofacial skeleton, in McNamara JA (ed): Monograph 17, Craniofacial Growth Series. Ann Arbor, MI, University of Michigan, 1985.
40. Behrents RG. An atlas of growth in the aging craniofacial skeleton, in McNamara JA (ed): Monograph 18, Craniofacial Growth Series. Ann Arbor, MI, University of Michigan, 1985.
41. Forsberg CM. Facial morphology and ageing: A longitudinal cephalometric investigation of young adults. *Eur J Orthod* 1979;1:15-23.
42. Abed Y, Har-Zion G, Redlich M. Lip posture following debonding of labial appliances based on conventional profile photographs. *Angle Orthod* 2009;79:235-9.

Chapter 3

Skeletal and dental stability of segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up

C.U. Joss
A. Triaca
M. Antonini
S. Kiliaridis
A.M. Kuijpers-Jagtman

Int. J. Oral Maxillofac. Surg. 2012;41:553–9

Summary

33 patients (27 females; 6 males) were retrospectively analysed for skeletal and dental relapse before distraction osteogenesis (DOG) of the mandibular anterior alveolar process at T1 (17.0 days), after DOG at T2 (mean 6.5 days), at T3 (mean 24.4 days), and at T4 (mean 2.0 years). Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated. Skeletal correction (T3 T1) was mainly achieved through the distraction of the anterior alveolar segment in a rotational manner where the incisors were more proclined. The horizontal backward relapse (T4 T3) measured 0.8 mm or 19.0% at point B ($p < 0.001$) and 1.6 mm or 25.0% at incision inferior ($p < 0.001$). Age, gender, amount and type (rotational versus translational) of advancement were not correlated with the amount of relapse. High angle patients (NL/ML'; $p < 0.01$) and patients with large gonial angle ($p < 0.05$) showed significantly smaller relapse rates at point B. Overcorrection of the overjet achieved by the distraction was seen in a third of the patients and could be a reason for relapse. Considering the amount of skeletal relapse the DOG could be an alternative to bilateral sagittal split osteotomy for mandibular advancement in selected cases.

3.1 Introduction

Since the clinical introduction of distraction osteogenesis (DOG) in the field of maxillofacial surgery by McCarthy *et al.*[7] the indications for use in the craniofacial area have significantly increased. The applications comprise mandibular lengthening[20] or widening,[4] reconstruction of the alveolar process for implant placement,[2] DOG for bone transport after trauma or tumour resection for reconstruction of segmental defects or a neocondyle,[15] maxillary DOG for unilateral and bilateral cleft patients,[16] and midfacial or cranial DOG for different types of craniosynostosis.[9]

The main applications of mandibular distraction were in congenital micrognathia,[17] such as hemifacial microsomia,[10,14] and different syndromes, such as Treacher-Collins, Pierre Robin, Nager, and Goldenhar. A review by Swennen *et al.*[17] showed that less frequent indications of mandibular DOG were in acquired micrognathia (trauma, temporomandibular joint ankylosis), and that almost no patient data are available for mandibular retrognathia in non-syndromic adult patients, and there is a lack of appropriate data on long-term results with skeletal relapse rates in DOG.

DOG of the lower alveolar segment was introduced by Triaca *et al.*,[18,19] and allows the creation of space to align teeth and/or implant placement in patients with increased overjet and retruded alveolar process. The extraction of lower premolars for tooth alignment can thus be eliminated. It is possible to achieve overjet reduction by moving the mandibular anterior alveolar process in a more translational or rotational manner. It is still not clear how translational and rotational movements of the lower alveolar segment influence the skeletal stability of DOG.

The aim of the present study was to evaluate the immediate skeletal and dental effect as well as the amount of skeletal relapse and dental changes 2 years after treatment in patients treated with DOG of the mandibular anterior alveolar process, and to identify factors related to skeletal and dental stability.

3.2 Material and methods

The patient sample consisted of 33 Caucasians (27 females; 6 males), aged 16.5–56.0 years (mean age 30.3 years, SD 10.7). They were treated orthodontically by one orthodontist (MA) and underwent DOG of the mandibular anterior alveolar process to correct a skeletal Class II and large overjet with or without incisor crowding from 1998 to 2004. The female patients had a mean age of 30.8 years (16.8–56.0 years, SD 10.9 years) and the male patients 28.3 years (16.5–43.7 years, SD 10.5 years). The surgical procedure was performed by one experienced maxillofacial surgeon (AT); the technique has been published.[18,19] Patients simultaneously receiving other surgical procedures on the mandible and maxilla, such as genioplasty and bilateral sagittal split osteotomy (BSSO) were excluded. Syndromic or medically compromised patients were excluded.

Ethical approval was admitted by the Ethic Committee of the Kanton Zürich, Switzerland, number 593. All subjects signed a written, informed consent.

Four cephalograms were taken: the first on average 17.0 days before surgery (T1), the second (T2) between days 0 and 12 (mean 6.5 days) after the osteotomy and before any distraction was carried out. The third (T3) cephalogram was taken between days 13 and 92 (mean 24.4 days), and the fourth (T4) between 0.9 and 3.7 years (mean 2.0 years) after distraction of the mandibular anterior alveolar process. The distraction was completed at T3 and the orthodontic treatment at T4. The retention of the lower incisors was achieved with a bonded canine-to-canine retainer. The DOG procedure has been described earlier.[18,19]

3.2.1 Cephalometric analysis

The skeletal tissue changes were evaluated on profile cephalograms taken with the teeth in the intercuspal position, and including a linear enlargement of 1.2%. The cephalograms were taken with the subject standing upright in the natural head position and with relaxed lips. The same X-ray machine and the same settings were used to obtain all cephalograms.

The lateral cephalograms of each patient were scanned and evaluated with the program Viewbox 3.1® (dHal software, Kifissia, Greece). The conventional cephalometric analysis for T1, T2, T3, and T4 was carried out by one author (CUJ) and included the reference points and lines shown in Fig. 1. Horizontal (*x* values) and vertical (*y* values) linear measurements were obtained by superimposing the tracings of the different stages (T2, T3, and T4) on the first radiograph (T1), and the reference lines were transferred to each consecutive tracing. During superimposition, particular attention was given to fitting the tracings of the cribriform plate and the anterior wall of the sella turcica, which undergo minimal remodeling.[1] A template of the outline of the mandible of the preoperative cephalogram (T1) was made to minimize errors for superimposing on subsequent radiographs.

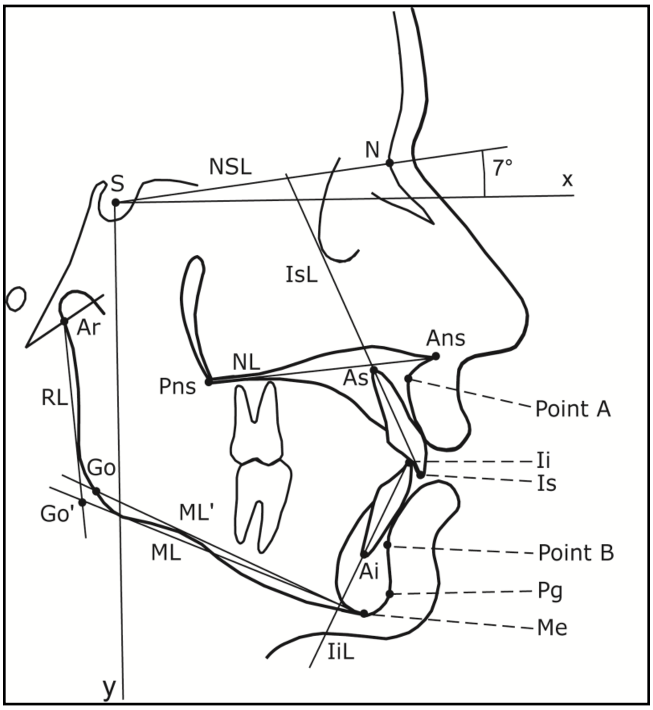

Figure 1. *Reference points and lines used in the cephalometric analysis. The coordinate system had its origin at point S (sella), and its x-axis formed an angle of 7° with the reference line NSL. S, sella; NSL, nasion–sella-line; N, nasion; x, horizontal reference plane; NL, nasal line; ILs, upper incisal line; Ar, articulare; RL, ramus line; Ans, anterior nasal spine; Pns, posterior nasal spine; As, apex superior; point A; Ii, incision inferior; Is, incision superior; Go, gonion; Go', gonion prime; ML', mandibular line prime; ML, mandibular line; Ai, apex inferior; point B; Pg, pogonion; Me, menton; and y, vertical reference plane. The Holdaway ratio is the distance between Ii vertical to N–B-line minus distance Pg vertical to N–B-line and the Jarabak ratio is the distance from S to Go'/distance N to Me.*

Conventional cephalometric variables and the coordinates of the reference points (Table 1) were calculated by the computer program.

Table 1. *Random errors (Si) in mm or degrees of the cephalometric variables.*

Variable	Si	Variable	Si	Reference point	Si (mm)	
					X	*Y*
SNA (°)	1.14	IiL-N-Point B (°)	1.14	Incision sup.	0.48	0.21
SNB (°)	0.82	IiL-N-Point B (mm)	0.24	Incision inf.	0.58	0.55
ANB (°)	0.48	IiL-A-Pg (°)	1.29	Apex inf.	0.54	0.18
NSL/NL (°)	0.86	IiL-A-Pg (mm)	0.49	Point B	0.28	0.45
NSL/ML' (°)	1.01	Holdaway ratio	0.47	Asab	0.35	0.25
NL/ML' (°)	0.84	IsL/IiL (°)	1.63	Pogonion	0.37	1.19
Jarabak ratio	1.15	Overjet	0.36	Menton	0.89	0.45
IsL/NSL (°)	1.52	Overbite	0.53	Gonion'	2.48	1.14
IsL/NL (°)	1.31					
IiL/ML' (°)	1.39					

Asab, alveolar surgical anterior base

The coordinate system had its origin at point S (sella), and its X-axis formed an angle of 7° with the reference line NSL (Fig. 1). Overjet and overbite were calculated from the coordinates of the points Is (incision superior) and Ii (incision inferior). The lateral cephalograms of T2 were only used to locate the cephalometric point alveolar surgical anterior base (Asab) before postoperative distraction of the alveolar process was carried out. Asab is the most anterior and inferior point of the lower anterior segment resulting from the surgical osteotomy (Fig. 2). This cephalometric point was introduced to evaluate the movement (rotation versus translation) of the lower anterior segment base in comparison to the lower incisors as ratio (Ii [*x* value; T3 - T2]/Asab [*x* value; T3 - T2]).

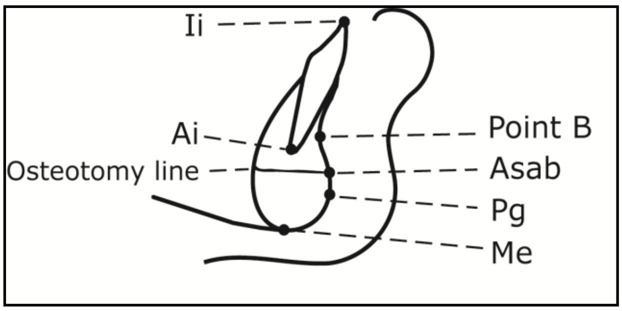

Figure 2. *Reference points used in the cephalometric analysis of the lower apical base in DOGpatients. Ii, incision inferior; point B; Ai, apex inferior; Asab, apical surgical anterior base; Pg, pogonion; and Me, menton. Asab is the most anterior and inferior point of the lower anterior segment resulted by the surgical osteotomy. This cephalometric point was introduced to evaluate the movement (rotation versus translation) of the lower anterior segment base in comparison to the lower incisors (Ii) as the ratio Ii (x value)/Asab (x value).*

3.2.2 Error of the method

To determine the error of the method, 21 randomly selected cephalograms were retraced and re-analysed after a 2-week interval. Horizontal (*x* values) and vertical (*y* values) linear measurements were reobtained by superimposing the tracings of the different stages (T2, T3, and T4) on the first radiograph (T1). The error of the method (si) was calculated with the formula: $\text{si} = \sqrt{\frac{\sum d^2}{2n}}$

where *d* is the difference between the repeated measurements and *n* is the number of duplicate determinations.[3] The random errors are presented in Table 1. No systematic errors were found when the values were evaluated with a paired *t* test.

3.2.3 Statistical analysis

Statistical analyses were conducted using SPSS software (version 13.0, SPSS Inc., Chicago, IL, USA). Normal distribution was confirmed with the Kolmogorov–Smirnov test. The effect of treatment, determined as the differences between the variables and co-ordinates at T3 and T1 (T3 and T2 for Asab), T4 and T1 (T4 and T2 for Asab), T4 and T3 was tested with a paired *t* test. The relationships between skeletal variables, age, and gender were analysed with the Pearson's product moment correlation coefficient.

3.3 Results

Table 2 shows the selected variables before surgery (T1) and at 2-year follow-up (T4). The mean changes, standard deviations, and ranges for the selected cephalometric parameters before surgery and during the subsequent observation periods are given in Tables 3 and 4. Negative values imply a backward, and positive values a forward, movement of the point in the horizontal plane. In the vertical plane, negative values imply an upward and positive values a downward movement of the point.

Table 2. *Values of selected cephalometric variables at T1 (before surgery) and T4 (2.0 years after surgery).*

	T1			T4		
	Mean	SD	Range	Mean	SD	Range
SNA (°)	80.5	3.7	73.1-88.0	80.2	4.0	72.8-92.1
SNB (°)	76.2	4.1	68.8-85.4	77.2	4.4	69.9-90.1
ANB (°)	4.3	2.0	0.3-8.0	3.0	2.2	-1.4-6.6
NSL/NL (°)	7.6	4.2	-1.9-15.0	7.9	4.1	0-14.6
NSL/ML' (°)	33.7	7.3	16.3-53.7	34.8	7.3	13.9-53.2
NL/ML' (°)	26.0	6.4	13.9-44.8	26.9	6.3	12.4-45.4
Gonion angle (°)	124.9	7.4	112.7-145.8	124.7	7.9	107.5-142.9
Jarabak ratio	64.8	6.3	49.2-80.9	63.9	6.1	50.2-83.8
IsL/NSL (°)	106.8	8.7	81.7-120.5	105.3	8.0	92.1-125.0
IsL/NL (°)	114.4	8.4	91.0-126.7	113.2	7.3	100.8-126.4
IiL/ML' (°)	91.1	7.3	77.2-104.6	95.4	8.2	78.3-111.3
IiL-N-Point B (°)	20.9	7.5	6.2-36.3	27.5	7.1	14.5-46.8
IiL-N-Point B (mm)	4.3	3.2	-1-12.9	7.1	3.4	2.7-16.7
IiL-A-Pg (°)	20.4	6.8	5.5-31.3	25.2	6.6	9.0-38.5
IiL-A-Pg (mm)	-0.4	3.5	-7.0-9.0	4.5	2.9	-0.1-13.7
Holdaway ratio	0.2	5.2	-10.2-13.6	6.0	4.5	-2.8-19.4
IsL/IiL (°)	128.5	12.4	106.9-157.3	124.5	10.6	100.1-145.6
Overjet (mm)	7.4	2.4	4.1-14.3	2.4	0.8	0.9-4.1
Overbite (mm)	4.0	2.0	0.7-7.5	1.7	1.6	-0.7-5.4

3.3.1 Horizontal changes

The mean advancement of the anterior alveolar process immediately following DOG (T3 - T1) was 4.2 mm at point B, 2.9 mm at Asab (T3 - T2), and 6.4 mm at incision inferior (all p = 0.000). Mean relapse (T4 - T3) was -0.8 mm or 19.0% at point B, -1.2 mm or 41.4% at Asab (T4 - T2), and -1.6 mm or 25.0% at incision inferior of the initial surgical advancement. Figures 3 and 4 show the surgical changes (T3 - T1) and the amount of relapse (T4 - T3) of point B and OJ.

Regarding the ratio Ii [*x* value; T3 - T2]/Asab [*x* value; T3 - T2], the alveolar segment moved as a result of the DOG in a rotational way in all but six patients if the ratio between 0.8 and 1.2 was taken as translational movement. That means, that in 27 patients the incisal edges of the lower incisors (Ii) were more advanced than their alveolar surgical anterior base (Asab). In five patients the ratio was negative; that means that point Asab was even set back whilst point Ii was advanced by the DOG.

3.3.2 Correlations

No significant correlations were found between relapse (T4 - T3, *x* value) of point B, Ii, or Asab with gender and age of the patients. No correlations were found for the amount of advancement (T3 - T1) and relapse (T4 - T3) at Ii, point B and Asab. The type of advancement (rotational versus translational; Ii [*x* value; T3 - T2]/Asab [*x* value; T3 - T2]) had no influence on relapse (T4 - T3) at point B (*x* value) and Asab (*x* value).

Table 3. *Changes (mm or degree) in the variables and coordinates of the mandible and lower incisors as the immediate (T3 - T1) and final (T4- T1) result of DOG surgery.*

	Variable or coordinate	T3-T1[1]				T4-T1[2]			
		Mean	*p*	SD	Range	Mean	*p*	SD	Range
Horizontal	Point B	4.2	***	2.4	-0.21-11.6	3.4	***	2.3	0.1-11.8
(*X*-value [mm])	Asab	2.9	***	2.3	-1.1-6.7	1.6	***	2.2	-2.1-7.1
	Pogonion	0.0	ns	1.1	-3.7-1.8	0.6	*	1.5	-3.2-4.5
	Go'	-0.5	ns	2.5	-4.6-5.3	0.3	ns	2.4	-5.5-5.9
	Incision sup.	1.3	***	1.6	-1.3-5.4	0.1	ns	2.1	-3.6-6.5
	Incision inf.	6.4	***	2.5	-0.5-13.1	4.8	***	2.9	-0.9-10.4
	Apex inf.	4.7	***	2.2	1.7-10.8	3.7	***	2.4	0.1-13.1
Vertical									
(*Y*-value [mm])	Point B	1.7	***	2.3	-1.6-6.6	0.6	ns	2.4	-5.2-6.0
	Asab	-0.5	ns	1.6	-5.4-2.3	0.2	ns	1.5	-3.6-3.3
	Pogonion	0.3	ns	2.0	-5.1-4.8	0.3	ns	2.5	-4.6-5.4
	Menton	0.1	ns	0.7	-0.7-2.7	0.0	ns	1.1	-3.4-3.3
	Go'	-0.4	ns	2.0	-6.6-4.7	-0.4	ns	1.7	-4.0-2.8
	Incision sup.	-1.7	***	1.6	-6.7-0.4	-0.7	**	1.4	-4.1-1.4
	Incision inf.	1.6	***	2.1	-2.3-5.7	1.3	**	2.3	-4.0-5.8
	Apex inf.	0.5	ns	1.7	-2.8-4.5	0.6	ns	1.7	-3.1-4.6
Angular (°), linear measurements (mm), and ratios									
	SNA (°)	-0.2	ns	1.0	-3.0-1.7	-0.3	ns	1.6	-3.9-4.1
	SNB (°)	1.4	***	1.4	-0.6-4.1	1.0	***	1.7	-2.3-4.7
	ANB (°)	-1.6	***	1.1	-4.0-0.9	-1.4	***	1.2	-3.9-0.5
	Wits (mm)	-3.7	***	2.0	-8.0-0.4	-3.1	***	2.3	-7.1-3.4
	NSL/NL (°)	0.2	ns	1.2	-2.4-2.9	0.2	ns	1.5	-2.8-3.6
	NSL/ML' (°)	1.3	***	1.4	-1.0-4.8	1.1	**	1.9	-2.9-4.0
	NL/ML' (°)	1.1	***	1.6	-2.0-4.7	0.9	***	1.3	-1.9-3.3
	Gonion angle (°)	-2.1	***	2.7	-8.0-1.9	-0.2	ns	3.8	-6.3-8.9
	Jarabak ratio	-0.7	*	1.6	-4.0-2.2	-0.9	*	2.0	-4.2-4.1
	IsL/NSL (°)	0.7	ns	4.8	-7.2-22.0	-1.5	ns	5.8	-16.3-11.5
	IsL/NL (°)	0.9	ns	4.4	-7.6-20.1	-1.2	ns	5.6	-14.2-10.5
	IiL/ML' (°)	6.5	***	5.3	-6.5-15.7	4.3	***	7.1	11.8-19.2
	IiL-N-Point B (°)	9.1	***	4.5	-4.2-17.1	6.5	***	6.7	-6.3-21.5
	IiL-N-Point B (mm)	3.2	***	1.5	-1.7-5.2	2.8	***	2.7	-1.6-9.0
	IiL-A-Pg (°)	5.5	***	4.6	-4.9-15.6	4.8	***	6.8	-11.7-19.2
	IiL-A-Pg (mm)	6.4	***	1.9	0.5-11.5	4.8	***	2.8	-0.7-12.6
	Holdaway ratio	8.6	***	2.8	1.4-16.4	5.9	***	3.3	-0.9-13.7
	IsL/IiL (°)	-8.5	***	6.7	-31.4-4.9	-4.0	*	9.5	-28.3-10.5
	Overjet (mm)	-5.3	***	1.8	-9.4- -1.1	-4.9	***	2.3	-11.8- -1.5
	Overbite (mm)	-3.4	***	1.7	-7.1-0.1	-2.2	***	2.2	-6.8-2.2
	Ii/Asab	441.87		15.4	-66.2-42.3				

T1, before surgery; T3, 24.4 days after surgery; T4, 2.0 years after surgery.
** $p \le 0.05$.*
*** $p \le 0.01$.*
**** $p \le 0.001$.*
[1]T3 T2 for Asab, Ii (x value; T3 T2)/Asab (x value; T3 T2) instead of mean value the median was taken for this ratio and no paired t-test was possible because measured on a single occasion. [2]T4-T2 for Asab.Negative values imply a backward and positive values a forward movement of the point in the horizontal plane. In the vertical plane, negative values imply an upward and positive values a downward movement of the point.

Table 4. *Changes (mm, degree or ratio) in the variables and coordinates of the mandible and lower incisors as the relapse (T4 T3) of DOG surgery.*

	Variable or coordinate	T4-T3			
		Mean	*p*	SD	Range
Horizontal	Point B	-0.8	***	1.2	-3.2-1.7
(X-value [mm])	Asab[1]	-1.2	***	1.5	-4.2-1.6
	Pogonion	0.7	***	1.0	-1.2-3.7
	Go'	0.8	ns	2.9	-6.4-4.9
	Incision sup.	-1.2	***	1.6	4.7-1.2
	Incision inf.	-1.6	***	2.1	-6.2-2.6
	Apex inf.	-1.1	***	1.6	-4.2-2.3
Vertical					
(Y-value [mm])	Point B	-1.1	*	2.4	-6.5-2.9
	Asab[1]	0.7	*	1.6	-3.0-4.5
	Pogonion	-0.1	ns	2.3	-5.4-5.0
	Menton	-0.1	ns	1.0	-3.0-2.0
	Go'	0.0	ns	1.9	-3.9-3.9
	Incision sup.	1.0	***	1.3	-1.5-3.1
	Incision inf.	-0.3	ns	2.2	-4.7-4.5
	Apex inf.	-0.1	ns	2.2	-4.1-5.8
Angular (°), linear measurements (mm), and ratios					
	SNA (°)	-0.2	ns	1.4	-2.9-4.7
	SNB (°)	-0.4	ns	1.2	-2.7-3.2
	ANB (°)	0.2	ns	1.0	-2.1-1.6
	Wits (mm)	0.5	ns	2.0	-3.5-4.7
	NSL/NL (°)	0.0	ns	1.2	-2.5-2.0
	NSL/ML' (°)	-0.2	ns	2.1	-5.4-3.6
	NL/ML' (°)	-0.2	ns	1.7	-4.0-2.8
	Gonion angle (°)	1.9	**	3.3	-5.4-9.5
	Jarabak ratio	-0.2	ns	2.2	-4.5-5.0
	IsL/NSL (°)	-2.2	*	5.9	-13.4-12.8
	IsL/NL (°)	-2.2	*	5.9	-12.2-11.3
	IiL/ML' (°)	-2.1	ns	7.7	-17.0-22.2
	IiL-N-Point B (°)	-2.6	*	7.1	-15.5-18.1
	IiL-N-Point B (mm)	-0.4	ns	2.5	-4.6-5.1
	IiL-A-Pg (°)	-0.7	ns	7.5	-13.4-20.5
	IiL-A-Pg (mm)	-1.5	***	2.2	-5.1-4.5
	Holdaway ratio	-2.7	***	2.1	-6.7-1.8
	IsL/IiL (°)	4.5	**	9.3	-25.2-21.7
	Overjet (mm)	0.3	ns	2.1	-4.8-5.5
	Overbite (mm)	1.1	**	2.2	-3.1-6.7

T3, 24.4 days after surgery; T4, 2.0 years after surgery.
** $p \leq 0.05$.*
*** $p \leq 0.01$.*
**** $p \leq 0.001$.*
Negative values imply a backward and positive values a forward movement of the point in the orizontal plane. In the vertical plane, negative values imply an upward and positive values a downward movement of the point.

A larger gonial angle (T1) was significantly correlated with a smaller relapse (T4 - T3) at the *x* values of point B (p = 0.042; R = 0.356). A larger NL/ML' angle (T1) showed significant correlations with a smaller relapse (T4 - T3) at the *x* values of point B (p = 0.006; R = 0.470) and Abas (p = 0.011; R = 0.438). The same was seen for a larger NSL/ML' angle (T1) and a smaller relapse (T4 - T3) at the *x* value of point B (p = 0.041; R = 0.357). A larger Jarabak ratio (T1) was significantly correlated with a larger relapse (T4 - T3) at the *x* values of point B ($p = 0.016$; $R = 0.418$).

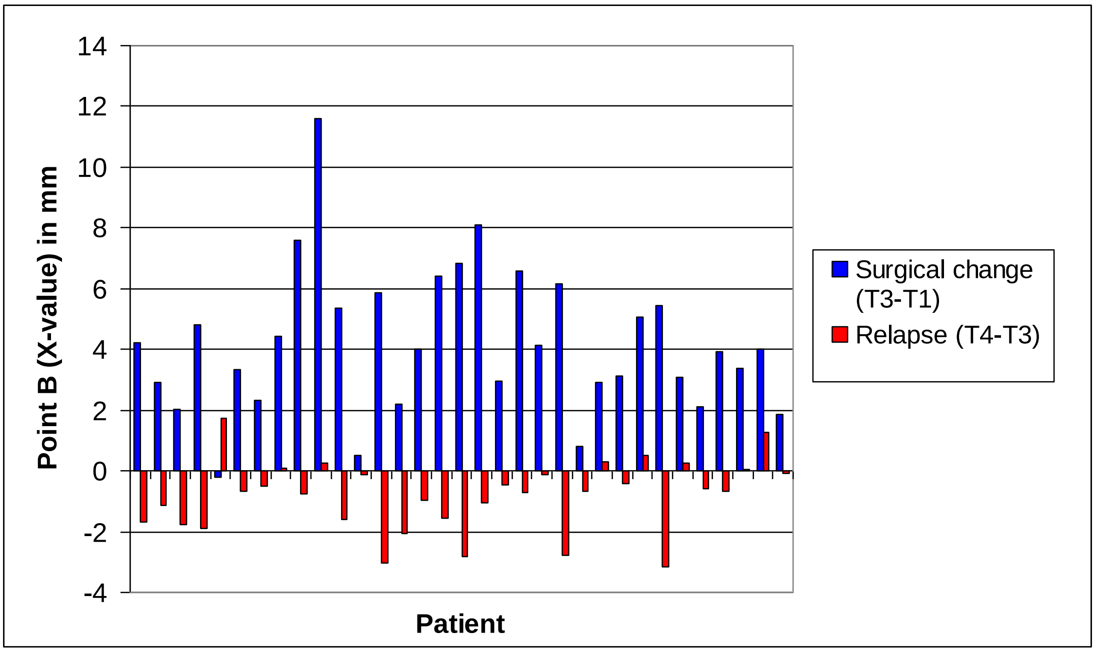

Figure 3. *Surgical change (T3 - T1) and amount of relapse (T4 - T3) of point B (x value in mm) in individual patients (n = 33).*

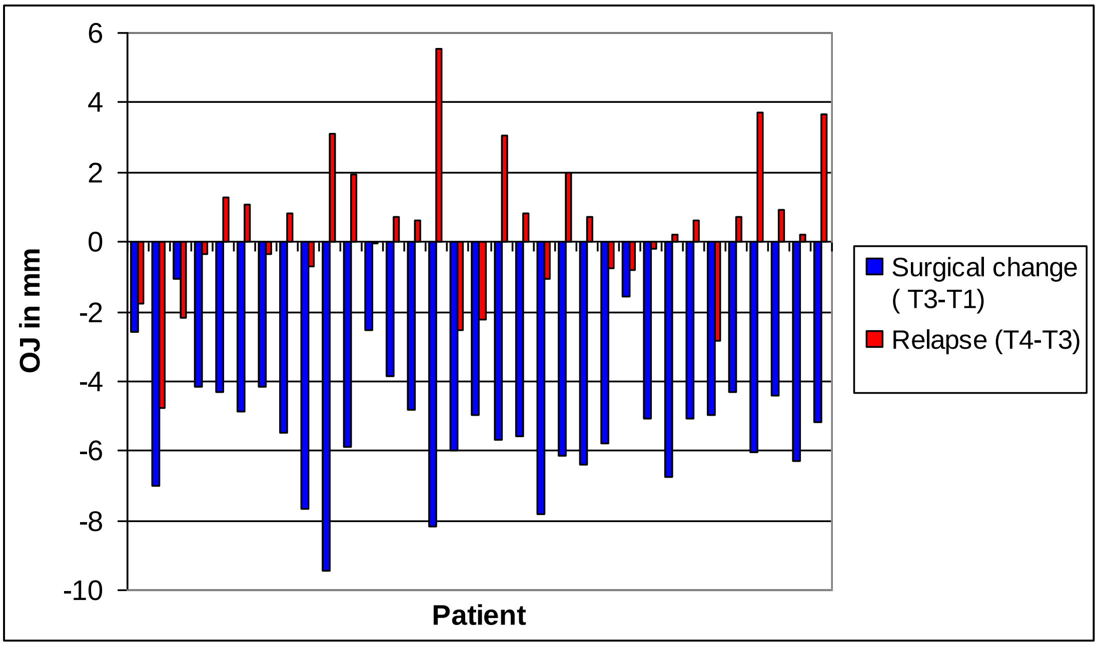

Figure 4. *Surgical change (T3 - T1) and amount of relapse (T4 - T3) of OJ (in mm) in individual patients (n = 33).*

3.4 Discussion

This study was undertaken to investigate the amount of skeletal relapse and remodeling in patients undergoing DOG of the mandibular anterior alveolar process. Additional surgical procedures on the mandible (e.g. genioplasty and BSSO) and maxilla were excluded to provide a uniform patient sample. This permits the examination of alveolar segmental DOG without the influence of other confounding surgical procedures.

About one quarter of this sample was male. This predominance of female over male patients (27 versus 6) is often found in maxillofacial surgery and adult orthodontics, because more females than males seek treatment. This meant that it was not possible to investigate possible gender differences.

The amount of advancement (T3 - T1) had no influence on the amount of relapse (T4 - T3) at point B, at Ii, and Asab. Smaller advancements with DOG did not show less relapse than larger advancements. In BSSO such a positive correlation was found between the amount of relapse and the amount of mandibular advancement. Advancements in the range of 6–7 mm or more predispose to horizontal relapse.[6] It was a surprising finding that a larger NL/ML' and NSL/ML' angles (T1) were significantly correlated with a smaller relapse (T4 - T3) for the *x* values of point B in this patient sample. This is in contrast to relapse patterns after a BSSO for mandibular advancement where a large mandibular plane angle (NL/ML') is often correlated with increased horizontal relapse.[6] It is possible that patients with a hyperdivergent facial pattern have a lower perioral muscular tonus and thus fewer relapses.

7 patients had mandibular advancement due to DOG of more than 6.0 mm and the mean advancement at point B was 4.2 mm in this study. The amount of relapse at point B is 19% after 2.0 years. A reason for this amount of skeletal relapse could be the overcorrection achieved by the distraction where an edge-to-edge incisal position or negative OJ at T3 had to be corrected with Class III elastics in 11 patients. A systematic review on relapse rates in BSSO for mandibular advancement with bicortical screws shows a large variability from 2 to 50% in long-term

relapse (>1.5 years) at point B.[6] Pseudarthrosis at the osteotomy sites occurred in none of the 33 patients examined.

The higher relapse rate at Ii of 25% could be due to the fact that the DOG creates space distally of the canines whilst crowding is still present in the incisor region. Incisor alignment is carried out in this newly generated space to prevent further proclination or round trips not until the distraction will be accomplished. For this reason, it is possible that Ii moves further posteriorly by orthodontic forces.

To the authors' knowledge, there are no published studies that evaluate skeletal stability of DOG of the mandibular anterior alveolar process, which makes a direct comparison of the present data impossible. Recently, VOS *et al*.[21] could not show retrospectively any significant difference in non-syndromic adult patients treated for mandibular advancement either with DOG (BSSO type) or BSSO 10–49 months after surgery. The mean lengthening of 7.23 mm in BSSO and 7.81 mm in DOG was comparable. Skeletal relapse was -0.5 mm (7%) in BSSO and -1.1 mm (14%) in DOG.

The movement of distraction (translation versus rotational) was defined by the type of distraction appliance chosen. The hinge plate allows a more rotational and the base-distractor a more translational movement of the anterior mandibular alveolar segment. The idea behind the introduction of two newly defined skeletal points (alveolar surgical anterior base and alveolar surgical prominence) was to evaluate the movement of the surgical base independently and to evaluate bone remodeling at the surgical site. A comparison between the movements of Ii, point B, and lower incisor apex makes it possible to study whether DOG created predominantly a rotation or translation of the alveolar process, especially when considering the ratio Ii (x value; T3 T2)/Asab (x value; T3 T2). A ratio of 1 signifies that a pure translation of the segment was taking place. The higher the ratio is above 1, the more the centre of rotation is located at the lower incisor apex or at Asab, respectively, and the contrary for values below 1. Five of the 33 patients had a negative ratio indicating a set back of point Asab whilst point Ii was advanced. Only six patients had a ratio between 0.8 and 1.2 which could be described as translation movement. That means that 27 patients had a more or less accentuated rotational movement of the distracted segment. Some proclination of the lower incisors however was certainly related to the orthodontic treatment which could have biassed the assessment of that ratio.

The interface of the surgical section of the anterior aspect of the symphysis is highly susceptible to resorption and bony remodelling. This has been confirmed by McDonell *et al.*,[8] when evaluating the surgical borders of advancement genioplasties where osseous remodelling was highest. In the present study, this was seen especially at point Asab. The border of the segment needs to be remodelled to smooth the contour and aspect of the anterior symphysis. This may explain why the relapse rate of 41% at Asab is so high. Triaca *et al.*[18] noted that DOG of the mandibular alveolar process can be applied in specific cases: skeletal Class II patients with crowding to reduce the required sagittal distance to be achieved by an advancement BSSO; skeletal Class III patients to create space for decompensation of the lower incisor inclination; skeletal Class I with dental Class II patients to create space of one premolar width and overjet normalization; and in skeletal and dental Class I patients with crowding to avoid extraction and the often resulting unfavourable profile. It could also be argued that DOG of the mandibular anterior alveolar segment might be beneficial to prevent the biomechanical side effects on the mandibular condyle that can occur after BSSO or mandibular DOG.[11] This could prevent progressive condylar resorption which is related to long-term relapse and impaired mandibular function. The target groups for condylar resorption are young women with a high mandibular plane angle.[5,13] 7% of all BSSO advancement patients appear to undergo progressive condylar resorption.[12] Further research is needed to elucidate whether condylar resorption is less in cases treated with DOG of the mandibular alveolar process.

In conclusion, DOG of the mandibular anterior alveolar process resulted in a mainly rotational rather than translational advancement of the tooth-bearing alveolar segment. Two years after treatment, 19% of the original skeletal advancement and 26% of the dental advancement have vanished. Considering the amount of skeletal relapse, the procedure could be an alternative to BSSO for mandibular advancement in selected cases.

3.5 Acknowledgement

This article is dedicated to the memory of Dr Michele Antonini who passed away in September 2009. He will always be remembered for his contribution to orthodontics.

3.6 Ethical approval

Ethical approval was admitted by the Ethic Committee of the Kanton Zürich, Switzerland, number 593.

3.7 References

1. Björk A, Skieller V. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. *Br J Orthod* 1975;4:53–64.
2. Chiapasco M, Lang NP, Bosshardt DD. Quality and quantity of bone following alveolar distraction osteogenesis in the human mandible. *Clin Oral Implants Res* 2006;17:394–402.
3. Dahlberg G. Statistical methods for medical and biological students. New York: Interscience Publications; 1940.
4. Guerrero CA, Bell WH, Contasti GI, Rodriguez AM. Mandibular widening by intraoral distraction osteogenesis. *Br J Oral Surg* 1997;35:383–92.
5. Hoppenreijs TJ, Freihofer HP, Stoelinga PJ, Tuinzing DB, van't Hof MA. Condylar remodelling and resorption after Le Fort I and bimaxillary osteotomies in patients with anterior open bite. A clinical and radiological study. *Int J Oral Maxillofac Surg* 1998;27:81–91.
6. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg* 2009;67:301–13.
7. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. *Plast Reconstr Surg* 1992;89:1–8. Discussion 9–10.

8. McDonnell JP, McNeill RW, West RA. Advancement genioplasty: a retrospective cephalometric analysis of osseous and soft tissue changes. *J Oral Surg* 1977;35:640–7.
9. Meazzini MC, Mazzoleni F, Caronni E, Bozzetti A. Le Fort III advancement osteotomy in the growing child affected by Crouzon’s and Apert’s syndromes: presurgical and postsurgical growth. *J Craniofac Surg* 2005;16:369–77.
10. Meazzini MC, Mazzoleni F, Gabriele C, Bozzetti A. Mandibular distraction osteogenesis in hemifacial microsomia: long-term follow-up. *J Craniomaxillofac Surg* 2005;33:370–6.
11. Peltomaki T. Stability, adaptation and growth following distraction osteogenesis in the craniofacial region. *Orthod Craniofac Res* 2009;12:187–94.
12. Scheerlinck JPO, Stoelinga PJW, Blijdorp PA, Brouns JJA, Nijs MLL. Sagittal split advancement osteotomies stabilized with miniplates: a 2–5-year follow-up. *Int J Oral Maxillofac Surg* 1994;23:127–31.
13. Sesenna E, Raffaini M. Bilateral condylar atrophy after combined osteotomy for correction of mandibular retrusion. A case report. *J Maxillofac Surg* 1985;13:263–6.
14. Shetye PR, Grayson BH, Mackool RJ, McCarthy JG. Long-term stability and growth following unilateral mandibular distraction in growing children with craniofacial microsomia. *Plast Reconstr Surg* 2006;118:985–95.
15. Stucki-McCormick SU. Reconstruction of the mandibular condyle using transport distraction osteogenesis. *J Craniofac Surg* 1997;8:48–52. discussion 53.
16. Swennen G, Colle F, De May A, Malevez C. Maxillary distraction in cleft lip palate patients: a review of six cases. *J Craniofac Surg* 1999;10:117–22.
17. Swennen G, Schliephake H, Dempf R, Schierle H, Malevez C. Craniofacial distraction osteogenesis: a review of the literature: Part 1: Clinical studies. *Int J Oral Maxillofac Surg* 2001;30:89–103.
18. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001;59:26–34. Discussion 34–5.
19. Triaca A, Minoretti R, Merz B. Treatment of mandibular retrusion by distraction osteogenesis: a new technique. *Br J Oral Maxillofac Surg* 2004;42:89–95.
20. van Strijen PJ, Perdijk FB, Becking AG, Breuning KH. Distraction osteogenesis for mandibular advancement. *Int J Oral Maxillofac Surg* 2000;29:81–5.

21. Vos MD, Baas EM, de Lange J, Bierenbroodspot F. Stability of mandibular advancement procedures: bilateral sagittal split osteotomy versus distraction osteogenesis. *Int J Oral Maxillofac Surg* 2009;38:7–12.

Chapter 4

Soft tissue stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up

C.U. Joss
A. Triaca
M. Antonini
S. Kiliaridis
A.M. Kuijpers-Jagtman

Int. J. Oral Maxillofac. Surg. 2012;41:560–5

Summary

This study evaluated soft tissue changes in adult patients treated with distraction osteogenesis (DOG) of the anterior mandibular alveolar process and related it to different parameters. 33 patients (27 females; 6 males) were analysed retrospectively before surgery at T1 (17.0 days), after surgery at T2 (mean 6.5 days), at T3 (mean 24.4 days), and at T4 (mean 2.0 years). Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated. Statistical analysis was carried out using Kolmogorov–Smirnov test, paired *t*-test, Pearson's correlation coefficient, and linear backward regression analysis. 2 years postoperatively (T4), the net effect of the soft tissue at point B' was 100% of the advancement at point B whilst the lower lip (labrale inferior) followed the advancement of incision inferior to 46%. Increased preoperative age was correlated ($p < 0.05$) with more horizontal backward movement (T4–T3) for labrale superior and pogonion'. Higher NL/ML' angles were significantly correlated ($p < 0.05$) with smaller horizontal soft tissue change at point B'. Gender and the amount of skeletal and dental advancement were not correlated with postoperative soft tissue changes (T4–T3). DOG of the anterior mandibular alveolar process is a valuable alternative for mandibular advancement regarding soft tissue change and predictability.

4.1 Introduction

The early 21st century saw a paradigm shift in the treatment goal for orthodontic patients. The emphasis on skeletal and dental relationships is changing towards greater consideration of the facial soft tissues.[16] The combination of orthodontic treatment with maxillofacial surgery aims for optimal function and the best aesthetic results. Commonly, when orthognathic surgery is planned, the skeletal tissues are used to determine the amount of change necessary to provide an appropriate soft tissue profile change. The clinician needs precise information to increase the ability to predict the surgical effect of skeletal displacement on the patient's overlying soft tissue profile.

The changes in shape and position of the overlying soft tissues in retrognathic patients has been evaluated mainly for bilateral sagittal split osteotomy (BSSO) with mandibular advancement[2,5,8,13,15,18] and less frequently for mandibular distraction osteogenesis (DOG).[1,12] Until now, the evaluation of the soft tissue profile and its change in DOG of the lower anterior mandibular alveolar segment has not been carried out, whereas skeletal relapse has been examined recently.[9] DOG of the lower anterior mandibular alveolar segment was introduced by TRIACA *et al*.[19,20] They noted that DOG of the anterior mandibular alveolar process can be applied in the following specific cases: skeletal Class II patients with crowding to reduce the required sagittal distance to be achieved by an advancement BSSO; skeletal Class III patients to create space for the decompensation of the lower incisor inclination; skeletal Class I with dental Class II patients to create space of one premolar width and overjet normalization; and skeletal and dental Class I patients with crowding to avoid extraction and the often resulting unfavourable profile.

The aim of the present study was to evaluate the soft tissue changes in adult patients treated with DOG of the anterior mandibular alveolar process and to relate them to different parameters.

4.2 Material and methods

The sample consisted of 33 Caucasian patients (27 females; 6 males); aged 16.5–56.0 years (mean 30.3 years, SD 10.7). They were treated orthodontically by one orthodontist (MA) and underwent DOG of the mandibular anterior alveolar process to correct a skeletal Class II and large overjet, with or without incisor crowding, from 1998 to 2004.[9] The female patients had a mean age of 30.8 years (16.8–56.0 years, SD 10.9 years) and the male patients 28.3 years (16.5–43.7 years, SD 10.5 years). The surgical procedure was performed by one experienced maxillofacial surgeon (AT); the technique has been published previously.[19,20] Patients receiving other surgical procedures simultaneously on the mandible and maxilla, such as genioplasty, BSSO, and Le Fort were excluded. Syndromic or medically compromised patients were excluded. Ethical approval was obtained from the ethics committee of the Kanton Zürich, Switzerland, number 593. All subjects signed written, informed consent.

Four cephalograms were taken: the first, on average, 17.0 days before surgery (T1); the second (T2) between 0 and 12 days (mean 6.5 days) after the osteotomy and before any distraction was carried out; the third (T3) between 13 and 92 days (mean 24.4 days); and the fourth (T4) between 0.9 and 3.7 years (mean 2.0 years) after distraction of the mandibular anterior alveolar process. The distraction was completed at T3 and the orthodontic treatment at T4. All patients were debonded before T4 and the retention of the lower incisors was achieved with a bonded canine-tocanine retainer.

4.2.1 Cephalometric analysis

The soft tissue changes were evaluated on profile cephalograms taken with the teeth in the intercuspal position, and including a linear enlargement of 1.2%. The cephalograms were taken with the subject standing upright with a natural head position and with relaxed lips. The same X-ray machine and the same settings were used to obtain all cephalograms.

The lateral cephalograms of each patient were scanned and evaluated with the program Viewbox 3.1® (dHal software, Kifissia, Greece). The conventional cephalometric analysis for T1, T2, T3, and T4 was carried out by one author (CUJ) and included the reference points and lines shown in Fig. 1.

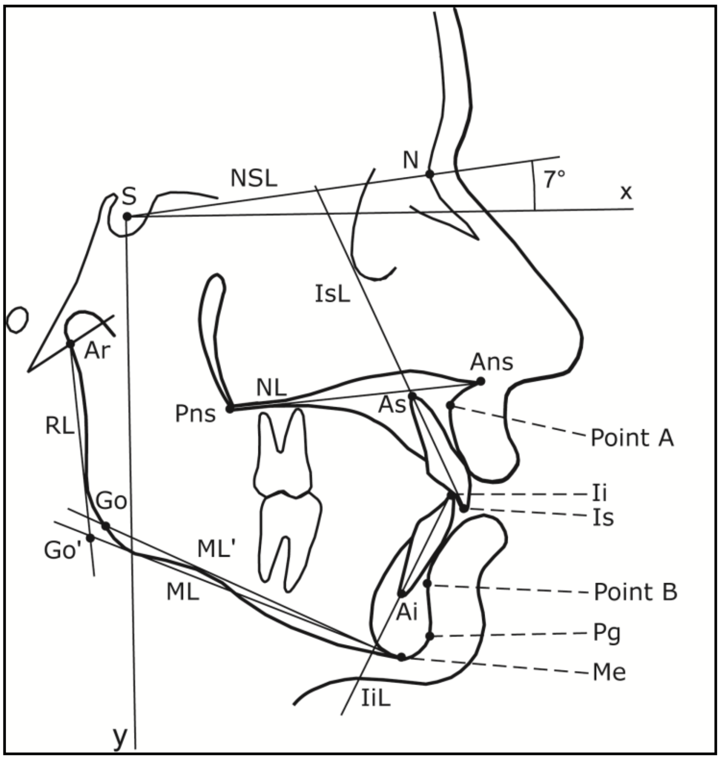

Figure 1. *Reference points and lines used in the cephalometric analysis. The coordinate system had its origin at point S (sella), and its x axis formed an angle of 7° with the reference line NSL. G, glabella; S, sella; NSL, nasion-sella-line; N, nasion; x, horizontal reference plane; NL, nasal line; Cm, columella; Sn, subnasale; ILs, upper incisal line; Ans, anterior nasal spine; Pns, posterior nasal spine; As, apex superior; point A; point A’, soft tissue point A; Ls, labrale superior; Ss, stomion superior; Ii, incision inferior; Is, incision superior; Si, stomion inferior; Li, labrale inferior; Go, gonion; ML', mandibular line prime; Ai, apex inferior; point B; point B', soft tissue point B; Pg, pogonion; Pg', soft tissue pogonion; Me, menton; Me', soft tissue menton; S-line; and y, vertical reference plane.*

Horizontal (*x* values) and vertical (*y* values) linear measurements were obtained by superimposing the tracings of the different stages (T2, T3, and T4) on the first radiograph (T1), and the reference lines were transferred to each consecutive tracing. During superimposition, particular attention was given to fitting the tracings of the cribriform plate and the anterior wall of the sella turcica which undergo minimal remodeling.[3] A template of the outline of the mandible of the preoperative cephalogram (T1) was made to minimize errors for superimposing on subsequent radiographs.

Conventional cephalometric variables as well as the coordinates of the reference points were calculated by the computer program. The coordinate system had its origin at point S (sella), and its x axis formed an angle of 78 with the reference line NSL (Fig. 1). Overjet and overbite were calculated from the coordinates of the points Is (incision superior) and Ii (incision inferior).

The lateral cephalograms of T2 were only used to locate the cephalometric point, called the alveolar surgical anterior base (Asab) before postoperative distraction of the alveolar process was carried out. Asab is the most anterior and inferior point of the lower anterior segment resulting from the surgical osteotomy (Fig. 2). This cephalometric point was introduced to evaluate the movement (rotation versus translation) of the lower anterior segment base in comparison with the lower incisors as ratio (Ii [*x* value, T3–T2]/Asab [*x* value, T3–T2]).

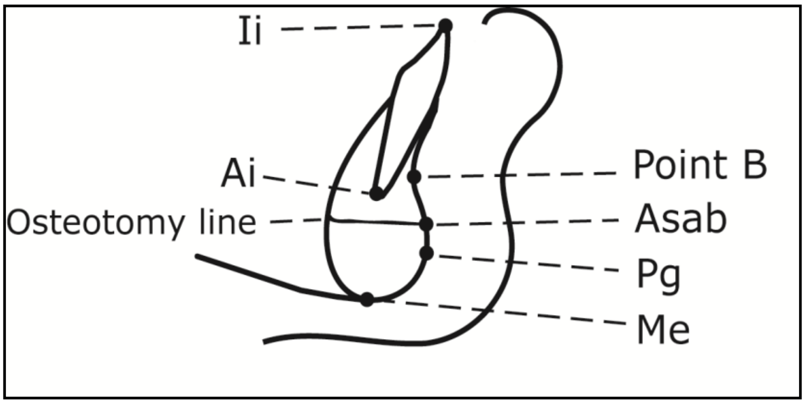

Figure 2. *Reference points used in the cephalometric analysis of the lower apical base in DOG patients. Ii, incision inferior; point B; Ai, apex inferior; Asab, apical surgical anterior base; Pg, pogonion; and Me, menton. Asab is the most anterior and inferior point of the lower anterior segment resulted by the surgical osteotomy. Asab was introduced to evaluate the movement (rotation versus translation) of the lower anterior segment base in comparison to the lower incisors (Ii); for the ratio see the text.*

4.2.2 Error of the method

To determine the error of the method, 21 randomly selected cephalograms were retraced and re-analysed after a 2-week interval. Horizontal (*x* values) and vertical (*y* values) linear measurements were reobtained by superimposing the tracings of the different stages (T2–T4) on the first radiograph (T1). The error of the method (si) was calculated with the formula: $\mathrm{si} = \sqrt{\frac{\sum d^2}{2n}}$

where d is the difference between the repeated measurements and n is the number of duplicate determinations.[4]

The random errors are presented in Table 1. The measurement of the nasiolabial angle (Cm–Sn–Ls) and menton (x value) were excluded owing to the increased random error. No systematic errors were found when the values were evaluated with a paired t test.

Table 1. *Random errors (si) of the cephalometric analysis.*

Variable	Si	Variable	Si	Reference point	Si (mm)	
					X	*Y*
SNA (°)	1.14	Overjet (mm)	0.36	Incision sup.	0.48	0.21
SNB (°)	0.82	Overbite (mm)	0.53	Incision inf.	0.58	0.55
ANB (°)	0.48	Cm-Sn-Ls (°)	3.32	Point B	0.28	0.45
NSL/NL (°)	0.86	G-Sn-Pg' (°)	1.14	Asab	0.35	0.25
NSL/ML' (°)	1.01	Ls/Cm-Pg' (mm)	0.67	Pogonion	0.37	1.19
NL/ML' (°)	0.84	Li/ Cm-Pg' (mm)	0.49	Menton	0.89	0.45
IsL/NSL (°)	1.52			Labrale sup.	0.78	1.30
IsL/NL (°)	1.31			Stomion sup.	1.68	0.99
IiL/ML' (°)	1.39			Labrale inf.	1.07	1.01
IsL/IiL (°)	1.63			Stomion inf.	1.15	0.85
				Point B'	1.20	1.10
				Pogonion'	1.19	1.15
				Menton'	3.07	1.21

Table 2. *Cephalometric variables at T1 (before surgery) and T4 (2 years after surgery).*

T1	Mean	SD	Range	T4	Mean	SD	Range
SNA (°)	80.5	3.7	73.1-88.0		80.2	4.0	72.8-92.1
SNB (°)	76.2	4.1	68.8-85.4		77.2	4.4	69.9-90.1
ANB (°)	4.3	2.0	0.3-8.0		3.0	2.2	-1.4-6.6
NSL/NL (°)	7.6	4.2	-1.9-15.0		7.9	4.1	0-14.6
NSL/ML' (°)	33.7	7.3	16.3-53.7		34.8	7.3	13.9-53.2
NL/ML' (°)	26.0	6.4	13.9-44.8		26.9	6.3	12.4-45.4
IsL/NSL (°)	106.8	8.7	81.7-120.5		105.3	8.0	92.1-125.0
IsL/NL (°)	114.4	8.4	91.0-126.7		113.2	7.3	100.8-126.4
IiL/ML' (°)	91.1	7.3	77.2-104.6		95.4	8.2	78.3-111.3
IsL/IiL (°)	128.5	12.4	106.9-157.3		124.5	10.6	100.1-145.6
Overjet (mm)	7.4	2.4	4.1-14.3		2.4	0.8	0.9-4.1
Overbite (mm)	4.0	2.0	0.7-7.5		1.7	1.6	-0.7-5.4
Facial convexity (°)	14.9	6.5	4.2-32.0		12.2	6.0	-2.5-25.5
Upper lip to S-line (mm)	-2.8	2.5	-8.8-2.4		-4.8	2.9	-10.4-1.5
Lower lip to S-line (mm)	-2.2	3.6	-11.2-3.2		-2.6	3.3	-8.3-5.1

Facial convexity, G–Sn–Pg'; upper lip to S-line, Ls/Cm–Pg'; lower lip to S-line, Li/Cm–Pg'.

4.2.3 Statistical analysis

Statistical analyses were conducted using SPSS software (version 13.0, SPSS Inc., Chicago, IL, USA). Normal distribution was confirmed with the Kolmogorov–Smirnov test. The effect of treatment (i.e. the differences between the variables and co-ordinates at T3 and T1, T4 and T1, T4 and T3) was tested with a paired *t*-test. The relationships between soft tissue and skeletal variables, age, and gender were analysed with the Pearson's product moment correlation coefficient and linear backward regression analysis.

Table 3. *Changes (mm or degree) in the variables and coordinates of the mandible and lower incisors as the immediate (T3–T1) and final (T4–T1)result of DOG surgery.*

Variable or coordinate		Short term change (T3-T1)[1]				Long term change (T4-T1)[2]			
		Mean	*p*	SD	Range	Mean	*p*	SD	Range
Horizontal									
x-value (mm)	Incision sup.	1.3	***	1.6	-1.3-5.4	0.1	ns	2.1	-3.6-6.5
	Incision inf.	6.4	***	2.5	-0.5-13.1	4.8	***	2.9	-0.9-10.4
	Point B	4.2	***	2.4	-0.21-11.6	3.4	***	2.3	0.1-11.8
	Asab	2.9	***	2.3	-1.1-6.7	1.6	***	2.2	-2.1-7.1
	Pogonion	0.0	ns	1.1	-3.7-1.8	0.6	*	1.5	-3.2-4.5
	Labrale sup.	1.0	***	1.5	-1.3-5.3	-0.1	ns	1.8	-3.7-5.6
	Labrale inf.	4.3	***	2.8	-1.6-11.2	2.2	***	2.6	-3.8-8.0
	Point B'	5.9	***	2.6	-0.5-11.4	3.4	***	2.3	0.7-10.0
	Pogonion'	4.9	***	1.9	1.5-8.6	3.0	***	2.0	-0.3-7.4
Vertical									
y-value (mm)	Labrale sup.	1.2	**	2.4	-4.2-6.2	-0.1	ns	1.8	-2.8-4.1
	Stomion sup.	-0.7	*	1.8	-4.5-2.5	0.3	ns	1.2	-2.2-3.0
	Labrale inf.	0.9	ns	3.2	-5.9-9.6	0.9	ns	3.0	-4.2-9.4
	Stomion inf.	0.9	ns	3.1	-4.1-10.2	1.1	*	2.4	-4.2-8.3
	Point B'	3.8	***	4.0	-5.0-10.5	3.8	***	3.4	-2.4-16.1
	Pogonion'	1.0	ns	3.5	-6.9-9.1	2.3	**	4.4	-6.4-17.7
	Menton'	1.3	**	2.3	-3.9-7.1	1.9	***	2.8	-2.3-12.9
Angular (°) and linear measurements (mm)									
	Facial convexity	-3.1	***	3.0	-7.8-3.7	-2.7	***	3.0	-11.5-4.6
	Ls to S-line	-1.3	***	1.7	-7.0-2.4	-2.0	***	2.0	-5.9-1.1
	Li to S-line	0.6	ns	2.3	-4.3-6.6	-0.4	ns	2.1	-5.6-5.7
	Ii/Asab	1.87		15.4	-66.2-42.3				

T1, before surgery; T3, 24.4 days after surgery; T4, 2.0 years after surgery. Facial convexity, G–Sn–Pg'; upper lip to S-line, Ls/Cm–Pg'; lower lip to S-line, Li/Cm'–Pg'.
[1] *T3–T2 for Asab, Ii (x value, T3–T2)/Asab (x value, T3–T2) instead mean value the median was taken for this ratio and no paired t-test was possible because measured on a single occasion.*
[2] *T4–T2 for Asab.*
* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$.

4.3 Results

4.3.1 Horizontal and vertical changes

Table 2 shows the selected variables at T1 and T4. The mean changes, standard deviations, and ranges for the selected cephalometric parameters (horizontal and vertical direction) before surgery and during the subsequent observation periods are given in Tables 3 and 4.

Negative values imply a backward, and positive values a forward, movement of the point in the horizontal plane. Negative values imply an upward, and positive values a downward, movement of the point in the vertical plane.

4.3.2 Soft to hard tissue ratios

The net effect (T4–T1) in labrale inferior was 46% of the advancement in Ii. The corresponding values for point B' to point B was 100% and for labrale superior to Ii 2%.

4.3.3 Correlations and backward linear regression

In the period T4–T3, an increase in the patient's age was significantly correlated with a downward movement of the vertical, or *y* values, of stomion inferior ($p = 0.023$; $R = 0.395$), point B' ($p = 0.012$; $R = 0.431$), pogonion' ($p = 0.011$; $R = 0.439$), and menton' ($p = 0.014$; $R = 0.422$). Increased patient age was significantly correlated with a backward movement of the horizontal, or *x* values, of labrale superior ($p = 0.035$; $R = 0.368$) and pogonion' ($p = 0.006$; $R = 0.466$) in the period (T4–T3).

The amount of advancement (T3–T1, *x* values) at point B and Ii was not significantly correlated with the amount of change (T4–T3, *x* and *y* values) measured at soft tissue points. A higher ratio (Ii [*x* value, T3–T2]/Asab [*x* value, T3–T2]), i.e. a more rotational than translational distraction of the alveolar process, was significantly correlated ($p = 0.012$; $R = 0.433$) with a forward movement of labrale superior in the period (T4–T3). A preoperative larger NL/ ML' angle (T1) was significantly correlated ($p = 0.036$; $R = 0.366$) with a smaller horizontal change at point B' (T4–T3, *x* value). No significant correlations were found between the change at T4–T3 of all soft tissue points and gender.

Correlations were significant between horizontal (*x* value) hard to soft tissue movements for point B and point B' (T3–T1: p = 0.000; R = 0.648; T4–T3: p = 0.003; R = 0.503), for Ii and labrale inferior (T3–T1: p = 0.000; R = 0.720; T4–T3: p = 0.000; R = 0.647), for Ii and labrale superior (T3–T1: p = 0.001; R = 0.539; T4–T3: p = 0.005; R = 0.482).

Table 4. *Changes (mm, degree or ratio) in the variables and coordinates of the mandible and lower incisors as the relapse (T4–T3) of DOG surgery.*

		T4-T3			
	Variable or coordinate	Mean	*p*	SD	Range
Horizontal					
x-value (mm)	Incision sup.	-1.2	***	1.6	4.7-1.2
	Incision inf.	-1.6	***	2.1	-6.2-2.6
	Point B	-0.8	***	1.2	-3.2-1.7
	Asab	-1.2	***	1.5	-4.2-1.6
	Pogonion	0.7	***	1.0	-1.2-3.7
	Labrale sup.	-1.1	***	1.6	-4.4-2.7
	Labrale inf.	-2.0	***	1.8	-7.0-1.7
	Point B'	-2.4	***	1.7	-6.0-1.2
	Pogonion''	-1.9	***	2.0	-6.3-3.1
Vertical					
y-value (mm)	Labrale sup.	-1.3	**	2.4	-7.8-2.4
	Stomion sup.	1.0	**	1.8	-1.8-5.2
	Labrale inf.	0.0	ns	3.6	-8.7-7.0
	Stomion inf.	0.1	ns	3.5	-9.3-6.2
	Point B'	0.0	ns	3.7	-8.5-8.0
	Pogonion'	1.3	*	3.2	-4.1-8.6
	Menton'	0.5	ns	2.8	-6.2-8.0
Angular (°) and linear measurements (mm)					
	Facial convexity	0.4	ns	2.2	-5.6-3.6
	Ls to S-line	-0.7	*	1.8	-4.0-2.5
	Li to S-line	-1.0	*	2.1	-4.8-3.5

T3, 24.4 days after surgery; T4, 2.0 years after surgery.
** $p \leq 0.05$.*
*** $p \leq 0.01$.*
**** $p \leq 0.001$.*

Table 5. *Backward linear regression. Dependent variable: point B' (x value) T4–T3.*

Model	*B*	*95% Confidence Interval for B*		*Significance*	*R*	R^2
		Lower Bound	*Upper Bound*			
(Constant)	*3.873*	*-2.704*	*10.450*	*.238*		
Age	*-.057*	*-.105*	*-.008*	*.024*		
IiL/ML' at T1	*-.044*	*-.115*	*.028*	*.224*	*0.649*	*0.421*
	-.015	*-.053*	*.022*	*.401*		
Point B (x-value) T4-T3	*.787*	*.314*	*1.261*	*.002*		

Results for the backward linear regression analysis are shown in Tables 5 and 6.

Table 6. *Backward linear regression. Dependent variable: labrale inf. (x value) T4–T3.*

Model	B	95% Confidence Interval for B		Significance	R	R^2
		Lower Bound	Upper Bound			
(Constant)	-1.483	-4.267	1.301	.285	0.719	0.517
Age	-.021	-.068	.026	.369		
NL/ML' at T1	.047	-.033	.126	.238		
Incision inf. (*x*-value) T4-T3	.491	.242	.741	.000		
Incision sup. (*x*-value) T4-T3	.261	-.069	.592	.117		

4.4 Discussion

This research is a continuation of the authors' previous study[9] on the skeletal relapse rate in patients undergoing DOG of the anterior mandibular alveolar process. Additional surgical procedures on the mandible (e.g. genioplasty, BSSO) and maxilla were excluded to ensure a uniform patient sample. This allows the examination of DOG of the anterior mandibular alveolar process to be studied without the influence of other confounding surgical procedures. All patients were skeletally mature (mean age 30.3 years, SD 10.7) which excludes the effect of growth as a confounding factor.

Lateral cephalograms can only reproduce a two-dimensional preoperative and postoperative situation. There has been a recent trend to quantify soft tissue profile changes using three-dimensional evaluation (i.e. optical laser surface scanners,[14] stereophotogrammetry with cameras,[6] or computed tomography assisted imaging[17]).

To the authors' knowledge, soft tissue ratios and changes in DOG of the anterior mandibular alveolar segment have not previously been investigated. In the present study, point B' followed point B to 100% and lower lip (labrale inferior) the advancement of Ii to 46%. There are no data on adult patients after DOG available in the literature for comparison. Research on soft tissue compared with skeletal changes after DOG for mandibular elongation is only available for children with hypoplastic mandibles evaluated on lateral cephalograms[12] or photographs combined with postero-anterior cephalograms.[1] MELUGIN *et al*.[12] found that point B' followed point B and pogonion' to pogonion to 90% at post-consolidation in 27 paediatric patients. The magnitude of the advancement, and the age, and sex of the patients had no effect on these ratios.

JOSS *et al*.[7] systematically reviewed the effect of BSSO with rigid internal fixation (RIF) or wire fixation (WF) for mandibular advancement on soft tissue ratios. Short- and long-term ratios for lower lip to lower incisor in RIF or WF can be described as 50%. No difference between short- and long-term ratios for point B' to point B and pogonion' to pogonion could be observed. It could be characterised as a 1 to 1 ratio. The exception was that pogonion' to pogonion with RIF tended to be higher than a 1 to 1 ratio in long-term results. The upper lip mainly showed retrusion but high variability. There is almost no difference in the ratios for the lower lip and point B' when comparing the present data to the data found in this review on BSSO for mandibular advancement in RIF and WF.

The influence of gender on soft tissue change has only limited validity because there was a predominance of female patients (27 versus 6 males) in this study. This is often found because more females seek orthodontic treatment combined with maxillofacial surgery.[10,11] Another possibility is that the total number of patients included was too small to determine any difference. Nevertheless, no significant correlations were found between gender and the change T4–T3 in all described soft tissue points.

The amount of skeletal and dental advancement (T3–T1, x values) at point B and Ii seems to have no influence on the amount of soft tissue change (T4–T3) measured at all described soft tissue points. These two findings are in accordance with the results of JOSS *et al*.[8] in their long-term study on hard and soft tissue changes in patients with BSSO for mandibular advancement and RIF.

RIF, in the form of miniplates in the present study, adds more volume on the labial surface of the chin bone, which has an impact on the soft tissue profile and limits the exact location of cephalometric landmarks. Miniplates were present at T2 and T3 but surgically removed before T4 in all but one patient. The removal of the miniplates could have led to a slight increase in soft tissue change (T4–T3) of point B'.

The interface of the surgical section of the anterior aspect of the symphysis was also more susceptible to resorption and bony remodeling.[9] In addition to the new soft tissue position of the lower face, an important short-term effect of maxillofacial surgery and confounding variable is postoperative swelling (oedema from retraction, irritation and inflammation). Thus, the immediate short-term soft tissue profile changes measured on lateral cephalogram are always in addition to the surgery, swelling, and thickness of the orthodontic brackets.[7]

2 years postoperatively, correlations were found between the patient's age and changes (T4–T3, *x* and *y* values) of different soft tissue points. Significant positive correlations were seen for vertical soft tissue change (*y* values) of stomion inferior, point B', pogonion', and menton'. That means that increased preoperative age showed more downward movement, and younger age more upward movement in these points. Significant negative correlations were found for horizontal change (*x* values) for labrale superior and pogonion'. In other words, the older the patient, the more horizontal backward movement was seen for labrale superior and pogonion'. It is possible that soft tissue strength was reduced by further ageing.

The same patient population examined earlier for skeletal relapse did not show any significant correlations between age and amount of relapse (T4–T3) measured at Ii or point B.[9] Interesting research questions, such as associations between soft tissue change and gender, preoperative age, low and high angle patients, and the amount of advancement have not yet been addressed in other studies for DOG or BSSO on mandibular advancement[7] with one exception. Joss & Thuer[8] could not find any correlations between soft tissue changes and preoperative age, gender, and the amount of advancement in their long-term study on BSSO for mandibular advancement. It is possible that larger patient samples are able to show a difference between genders.

In selected cases, DOG of the anterior alveolar process is a valuable alternative to BSSO for mandibular advancement regarding soft tissue change and predictability.

4.5 Acknowledgement

This article is dedicated to the memory of Dr. med. dent. Michele Antonini who passed away in September 2009. He will always be remembered for his contribution to orthodontics.

4.6 Ethical approval

Yes. Ethical approval was admitted by the Ethic Committee of the Kanton Zürich, Switzerland, number 593.

4.7 References

1. Altug-Atac AT, Grayson BH, McCarthy JG. Comparison of skeletal and soft-tissue changes following unilateral mandibular distraction osteogenesis. *Plast Reconstr Surg* 2008;121:1751–9.
2. Alves PV, Mazucheli J, Vogel CJ, Bolognese AM. How the lower face soft tissue changes after mandibular advancement or setback. *J Craniofac Surg* 2008;19:593–8.
3. Björk A, Skieller V. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. *Br J Orthod* 1975;4:53–64.
4. Dahlberg G. Statistical Methods for Medical and Biological Students. New York: Interscience Publications; 1940.
5. Dolce C, Hatch JP, Van Sickels JE, Rugh JD. Five-year outcome and predictability of soft tissue profiles when wire or rigid fixation is used in mandibular advancement surgery. *Am J Orthod Dentofacial Orthop* 2003;124:249–56. quiz 340.

6. Hajeer MY, Ayoub AF, Millett DT. Threedimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery. *Br J Oral Maxillofac Surg* 2004;42:396–404.
7. Joss CU, Joss-Vassalli IM, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue profile changes following bilateral sagittal split osteotomy for mandibular advancement: a systematic review. *J Oral Maxillofac Surg* 2010;68:2792–801.
8. Joss CU, Thuer UW. Stability of the hard and soft tissue profile after mandibular advancement in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2008;30:16–23.
9. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Skeletal and dental stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:553–9.
10. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy setback surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg* 2008;66:1634–43.
11. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg* 2009;67:301–13.
12. Melugin MB, Hanson PR, Bergstrom CA, Schuckit WI, Gerard Bradley T. Soft tissue to hard tissue advancement ratios for mandibular elongation using distraction osteogenesis in children. *Angle Orthod* 2006;76:72–6.
13. Mobarak KA, Espeland L, Krogstad O, Lyberg T. Soft tissue profile changes following mandibular advancement surgery: predictability and long-term outcome. *Am J Orthod Dentofacial Orthop* 2001;119:353–67.
14. Nkenke E, Vairaktaris E, Kramer M, Schlegel A, Holst A, Hirschfelder U, Wiltfang J, Neukam FW, Stamminger M. Three-dimensional analysis of changes of the malar-midfacial region after LeFort I osteotomy and maxillary advancement. *Oral Maxillofac Surg* 2008;12:5–12.
15. Pangrazio-Kulbersh V, Berger JL, Kaczynski R, Shunock M. Stability of skeletal Class II correction with 2 surgical techniques: the sagittal split ramus osteotomy and the total mandibular subapical alveolar osteotomy. *Am J Orthod Dentofacial Orthop* 2001;120:134–43.
16. Proffit WR, Fields HW, Sarver DM. In: Louis St., editor. Malocclusions and dentofacial deformity in contemporary society. Missouri: Mosby Elsevier; 2007 Number of 1–23.

17. Terajima M, Yanagita N, Ozeki K, Hoshino Y, Mori N, Goto TK, Tokumori K, Aoki Y, Nakasima A. Three-dimensional analysis system for orthognathic surgery patients with jaw deformities. *Am J Orthod Dentofacial Orthop* 2008;134:100–11.
18. Thüer U, Ingervall B, Vuillemin T. Stability and effect on the soft tissue profile of mandibular advancement with sagittal split osteotomy and rigid internal fixation. *Int J Adult Orthod Orthognath Surg* 1994;9:175–85.
19. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001;59:26–34. [discussion 34-25].
20. Triaca A, Minoretti R, Merz B. Treatment of mandibular retrusion by distraction osteogenesis: a new technique. *Br J Oral Maxillofac Surg* 2004;42:89–95.

Chapter 5

Neurosensory and functional evaluation in distraction osteogenesis of the anterior mandibular alveolar process

C.U. Joss
A. Triaca
M. Antonini
A.M. Kuijpers-Jagtman
S. Kiliaridis

Int. J. Oral Maxillofac. Surg. 2013;42:55–61

Summary

Neurosensory status and craniomandibular function of 19 patients (mean age 35.2 years, range 17.8–58.8 years) treated by combined surgical orthodontic treatment with distraction osteogenesis of the mandibular anterior alveolar process (DO group) was compared with that in 41 orthodontically treated patients (mean age 22.9 years, range 15.1–49.0 years; control group). Clinical examination took place on average 5.9 years (DO group) and 5.4 years (control group) after treatment ended. Neurosensory status was determined by two-point discrimination (2-pd) and the pointed and blunt test. Lateral cephalograms evaluated advancement of the mandibular alveolar process and possible relapse. There was no significant difference in craniomandibular function and neurosensory status between the groups. Age was significantly correlated with 2-pd at the lips (DO: $p = 0.01$, $R = 0.575$; control group: $p = 0.039$, $R = 0.324$) and chin (DO: $p = 0.029$, $R = 0.501$; control group: $p = 0.008$, $R = 0.410$). Younger patients had smaller 2-pd values. Gender, age, the amount of advancement, and relapse at point B or incision inferior show no correlation with craniomandibular function and neurosensory impairment. DO of the mandibular anterior alveolar process is a valuable and safe method with minor side effects regarding neurosensory impairment.

5.1 Introduction

The principles of distraction osteogenesis (DO) were first described by Codivilla[1] and widely applied and refined by Ilizarov.[2] In 1972 Snyder *et al*.[3] applied the technique of DO to lengthen a canine mandible and in 1989 the first human mandibular distraction was performed by McCarthy *et al*.[4]

Segmental intra-alveolar DO of the anterior mandibular alveolar process was first introduced by Triaca *et al*.[5] The goal was the creation of space and to reduce anterior crowding of the mandibular arch as a result of distraction of the anterior mandibular alveolar process. Segmental alveolar DO is an alternative to extraction orthodontic therapy which can often cause a compromised facial profile, dental stripping, or mandibular arch expansion to resolve dental crowding and its high risk of periodontal problems, such as root exposure. It allows the correction of Class II skeletal problems instead of a bilateral sagittal split osteotomy (BSSO). In skeletal Class III patients the anterior mandibular dentition could be decompensated and the sagittal step for further orthognathic surgery (Le Fort I surgery) increased.[5,6] Recently, changes in skeletal stability, and soft tissue profile were analysed after DO of the anterior alveolar process.[7,8]

Besides the clinical benefits of DO, complications such as neurosensory disturbances of the inferior alveolar nerve are possible. Neurosensory changes in the alveolar nerve were evaluated mainly in animal studies after DO of the whole mandible.[9–12] The nerve tissue seems to have the ability to adapt to the gradual stretching due to DO within physiological limits. A distraction rate of 1 mm/day appears to be relatively safe for the inferior alveolar nerve[9,10] whereas rapid distraction may cause serious damage such as demyelination, axonal swelling, decrease of the number of axons, and axoplasmic darking.[10] Others[12] related the high incidence of nerve injuries tested by using sensory nerve action potentials to the device construction and osteotomy technique. Apart from these results, based on osteotomies in a BSSO surgical approach for mandibular distraction, no clinical data have been published on craniomandibular function and neurosensory impairment in patients who have osteotomy anterior of the foramen mandibulae to distract the anterior mandibular alveolar process only.

The aim of the present research was to analyse the neurosensory status and craniomandibular function of patients treated by DO of the anterior mandibular alveolar process and to compare the data with a control group of non-surgically treated orthodontic patients.

5.2 Subjects and methods

The DO group consisted of 19 patients (mean age 35.2 years, range 17.8–58.8 years) who had orthodontic treatment in combination with DO of the anterior mandibular alveolar process as described by Triaca *et al*.[5] No additional mandibular surgery (genioplasty, BSSO) was performed. In 16 patients, the osteotomy for the DO was between the lower canine and first premolar, and in the remaining 3 patients it was between lower lateral and canine. Additional maxillary surgery was accepted and performed in 5 patients. Two patients had an additional one piece Le Fort I osteotomy, two others a surgically assisted rapid maxillary expansion (SARME), and one a distraction of the maxillary anterior alveolar segment in the DO group. No syndromes, clefts, traumas, or other abnormalities were accepted. The DO group was examined on average 5.9 years (range 2.7–8.4 years) after DO of the anterior alveolar mandibular process and completion of orthodontic treatment. 15 patients were female (mean age 37.7 years, range 17.8–58.8 years) and 4 male (mean age 25.9 years, range 19.6–37.8 years) and the mean age at surgery was 29.3 years (range 12.3–56.1 years).

The control group comprised 41 orthodontically treated patients (mean age 22.9 years, range 15.1–49.0 years) without any concomitant maxillofacial surgery. Orthodontic treatment had finished a mean of 5.4 years previously (range 0.2–12.9 years). 21 patients were female (mean age 22.9 years, range 15.3–49.0 years) and 20 were male (mean age 22.9 years, range 15.1–41.8 years).

All patients were treated by the same orthodontist (MA) with a straight wire appliance and for mandibular anterior alveolar DO by the same maxillofacial surgeon (AT) at the Pyramide Clinic in Zürich, Switzerland. The patients were clinically examined in the private practice by one of the authors (CJ) in Zürich, Switzerland. All clinical examinations and analysis of the radiographic data were carried out by the same clinician (CJ).

Ethical approval was accomplished and admitted by the ethic committee of the Kanton Zürich, Switzerland, number 593. All patients provided written, informed consent.

5.2.1 Surgical procedure

The DO procedure was performed as described by Triaca *et al*.[5] and illustrated in Figs. 1 and 2. Prior to surgery, the interroot space of the teeth next to the vertical osteotomies is increased by tipping them orthodontically. The desired new anterior position of the anterior alveolar segment has to be defined by the orthodontist and surgeon, from which the required position of the hinge axis is derived. The surgery can be performed under local or general anaesthesia. A horizontal incision is made from canine to canine 1 cm from the attached gingiva. The osteotomy is made about 5 mm inferior to the apices of the teeth with the help of a thin burr-type bone cutter (Cutter E0540, Maillefer, Ballaigues, Switzerland). After the horizontal osteotomy is completed, incomplete vertical osteotomies are made mostly between the canine and first premolars (less often between the lateral incisors and canines). When creating the osteotomies, care must be taken to maintain the lingual periosteum and mucosa largely intact. A joint plate is loosely fixed with screws before completion of the vertical osteotomies. The vertical osteotomies are completed, the segment is mobilized with a chisel, and the screws holding the plate are tightened. The free rotation of the anterior bone segment is confirmed, and the wound is closed, and sutured. After 5 days of healing, the orthodontic appliance to distract the anterior alveolar segment is activated for 0.5 mm/day. After the desired position is reached, the segment is held in position for 6 weeks with the help of the activation appliance, which is locked in the final position.[5]

Figure 1. *The horizontal osteotomy is made about 5 mm inferior to the apices of the teeth. A joint plate is loosely fixed with screws before completion of the vertical osteotomies.*

Figure 2. *After the horizontal osteotomy is completed, incomplete vertical osteotomies are made mostly between the canine and first premolars. The vertical osteotomies are then completed, the mandibular anterior alveolar segment is then mobilized with a chisel, and the screws holding the plate are tightened.*

5.2.2 Neurosensory test

The examiner first asked the patient to describe their perceptions in the lower lip and the chin. The function of the inferior alveolar nerve was tested by examination of the innervation of the mental nerve by distinguishing two regions of the lip and chin: the lower lip and the region between the vermilion border of the lower lip and the lower border of the chin. The following tests were carried out.

First, the pointed and blunt test. A ball burnisher and a pointed dental probe were pressed lightly and randomly on the skin to check the ability to differentiate between pointed and blunt objects.

Second, the two point touch test (two point discrimination, 2-pd). The patient's ability to discriminate between two points was measured with a sliding calliper. The two pointed, but not sharp, tips of the calliper touched the skin simultaneously with light pressure while the patient's eyes were closed. The separation of the two points was gradually reduced from 20 mm at the chin and 10 mm at the lips to the moment where the patient could feel one point only. The minimum separation at which two points could be reported was recorded. The mean of two measurements was used.

5.2.3 Craniomandibular function

Signs of craniomandibular dysfunction concerning mandibular function, clickings, crepitus, and pain in the temporomandibular joint (TMJ) and muscles (temporalis and masseter) were evaluated by palpation.

Clinical findings on function were recorded as follows. The maximum opening capacity was measured with a steel ruler to the nearest 0.5 mm as the distance between the edges of the maxillary and mandibular central incisors with the addition of overbite. The mean of the two measurements was recorded as the maximum opening capacity. Maximum lateral movement was measured as follows: a vertical line was drawn on the incisors at maximum intercuspation from one maxillary incisor to the corresponding mandibular incisor. The patient then moved the mandible to either side as far as possible, opening the mouth just as far as necessary to disclose the teeth. The maximum side-shift capacity was measured with a ruler, and the mean of two measurements each to the right and the left was used. Overjet was measured with a steel ruler for maximum protrusion. The patient was asked to advance the mandible as far as possible. The distance between the labial surfaces of the maxillary and mandibular incisors was measured at maximum intercuspation and maximum protrusion. The sum of the two measurements is the maximum protrusion. The mean of two measurements was used. Deviations to the left or right during maximum opening were recorded on a threepoint scale: 0 = 0–2 mm; 1 = 3–4 mm, and 2 = >5 mm. The patients were examined for audible or palpable TMJ sounds (clicking and crepitus). The antero-posterior and lateral distances between the retruded contact position (RCP) and the intercuspal position (ICP) of the mandible were measured with a ruler to the nearest 0.5 mm.[13]

The first cephalogram was taken at a mean of 34.5 days before surgery (T1), the second (T2) at a mean of 11.2 days, T3 at a mean of 34.3 days, and clinical follow-up (T4) at a mean of 5.9 years. The skeletal tissue changes were evaluated on profile cephalograms taken with the teeth in the intercuspal position, and including a linear enlargement of 1.2%. The cephalograms were taken with the subject standing upright in the natural head position and with relaxed lips. The same X-ray machine and the same settings were used to obtain all cephalograms. The lateral cephalograms of each patient were scanned and evaluated with the program Viewbox 3.1® (dHal software, Kifissia, Greece). The cephalometric analysis was carried out by one author (CJ) and included the reference points and lines shown in Fig. 3. Horizontal (*x*-values) and vertical (*y*-values) linear measurements were obtained by superimposing the tracings of the different stages (T2, T3, and T4) on the first radiograph (T1), and the reference lines were transferred to each consecutive tracing. During superimposition, particular attention was given to fitting the tracings of the cribriform plate and the anterior wall of the sella turcica which undergo minimal remodelling.[14] A template of the outline of the mandible of the preoperative cephalogram (T1) was made to minimize errors for superimposing on subsequent radiographs.

Conventional cephalometric variables as well as the coordinates of the reference points were calculated by the computer program.

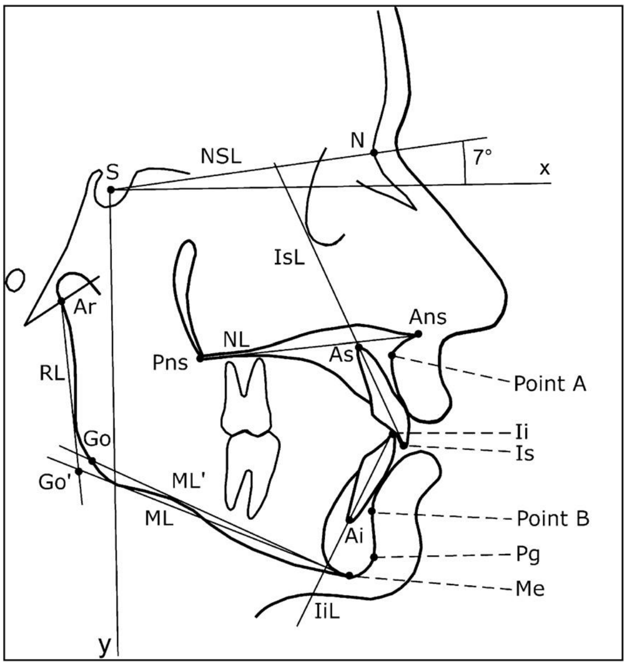

Figure 3. *Reference points and lines used in the cephalometric analysis. The coordinate system had its origin at point S (sella), and its x-axis formed an angle of 7 degrees with the reference line NSL. S, sella; NSL, nasion-sella-line; N, nasion; x, horizontal reference plane; NL, nasal line; ILs, upper incisal line; Ar, articulare; RL; ramus line; Ans, anterior nasal spine; Pns, posterior nasal spine; As, apex superior; point A; Ii, incision inferior; Is, incision superior; Go, gonion; Go', gonion prime; ML', mandibular line prime; ML, mandibular line; Ai, apex inferior; point B; Pg, pogonion; Me, menton; and y, vertical reference plane.*

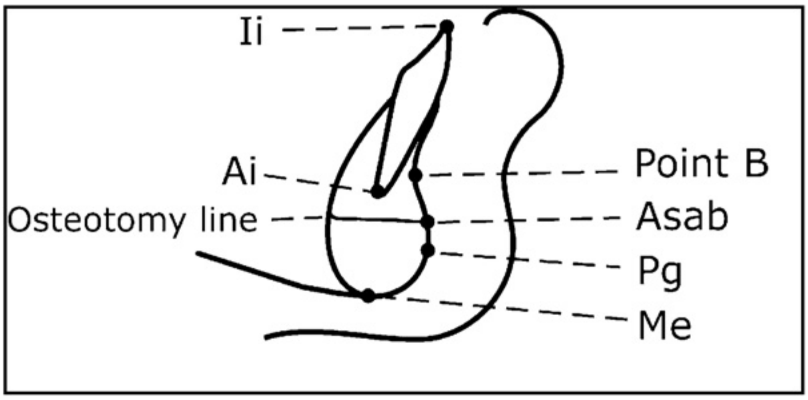

Figure 4. *Reference points used in the cephalometric analysis of the lower apical base in DO patients. Ii, incision inferior; point B; Ai, apex inferior; Asab, apical surgical anterior base; Pg, pogonion; and Me, menton. Asab is the most anterior and inferior point of the lower anterior segment resulted by the surgical osteotomy. This cephalometric point was introduced to evaluate the movement (rotation vs translation) of the lower anterior segment base in comparison to the lower incisors (Ii) as the ratio: Ii(x-value; T3-T1)/Asab(x-value; T3-T2).*

The coordinate system had its origin at point S (sella), and its *x*-axis formed an angle of 78 with the reference line NSL (Fig. 3).

The lateral cephalograms of T2 were only used to locate the cephalometric point alveolar surgical anterior base (Asab) before postoperative distraction of the alveolar process was carried out. Asab is the most anterior and inferior point of the lower anterior segment resulting from the surgical osteotomy (Fig. 4). This cephalometric point was introduced to evaluate the movement (rotation vs. translation) of the lower anterior segment base in comparison to the lower incisors as the ratio: Ii(*x*-value; T3-T1)/Asab(*x*-value; T3-T2). The cephalometric values of the same groups were recently published.[7,8]

5.2.4 Statistical methods

Statistical analyses were conducted using SPSS software (version 19.0, SPSS Inc., Chicago, IL, USA). Normal distribution was confirmed with the Kolmogorov–Smirnov test. The paired *t*-test was used for comparisons between the right and left sides of the face. The unpaired *t*-test was used for inter-group comparisons in analysis of neurosensory status and craniomandibular function. The relationships between cephalometric variables, age, and gender were analysed with the Pearson's product moment correlation coefficient. To determine the error of the method, 21 initial lateral cephalograms were selected randomly after 2 weeks and reanalyzed (Table 1).

Table 1. *Random errors (si) in mm or degrees of the cephalometric variables.*

Variable	*si*	Variable	*si*	Reference point	Si (mm)	
					x	*y*
SNA (°)	1.14	IiL-N-Point B (°)	1.14	Incision sup.	0.48	0.21
SNB (°)	0.82	IiL-N-Point B (mm)	0.24	Incision inf.	0.58	0.55
ANB (°)	0.48	IiL-A-Pg (°)	1.29	Apex inf.	0.54	0.18
NSL/NL (°)	0.86	IiL-A-Pg (mm)	0.49	Point B	0.28	0.45
NSL/ML' (°)	1.01	Holdaway ratio	0.47	Asab	0.35	0.25
NL/ML' (°)	0.84	IsL/IiL (°)	1.63	Pogonion	0.37	1.19
Jarabak ratio	1.15	Overjet	0.36	Menton	0.89	0.45
IsL/NSL (°)	1.52	Overbite	0.53	Gonion'	2.48	1.14
IsL/NL (°)	1.31					
IiL/ML' (°)	1.39					

Asab, alveolar surgical anterior base

21 subjects were selected randomly after 2 weeks to measure the 2-pd of the lips (si = 0.6 mm) and chin (si = 0.7 mm). The error of the method (si) was calculated with the formula: $si = \sqrt{\frac{\sum d^2}{2n}}$
where *d* is the difference between the repeated measurements and *n* is the number of duplicate determinations.[15] No systematic errors were found when the values were evaluated with a paired *t*-test.

5.3 Results

5.3.1 Neurosensory status

Comparisons between the right and left side of the face regarding the 2-pd and pointed and blunt test showed no significant difference for the control and DO groups. For this reason, the right and left side each for the chin and for the lips were pooled together. No significant differences were found between the DO and control groups for the 2-pd at the lips and chin (Table 2). Only one patient in the DO group was unable to differentiate between sharp and blunt at the chin.

Table 2. *Minimum distance (mm) for two-point discrimination.*

	DOG-group (*n*=19)			Control group (*n*=41)			Unpaired *t*-test
	Mean	*SD*	Range	Mean	*SD*	Range	*P*
Lip	3.7	1.4	1-6	3.7	1.2	1-6	0.938
Chin	8.7	2.5	4-15	8.3	2.1	4-15	0.507

In the DO group, gender was significant correlated with the 2-pd at the lips (p = 0.021; R = 0.524) and chin (p = 0.026; R = 0.509). Women showed larger values for 2-pd than men, but there were significantly older female than male patients in the sample (p = 0.045; R = 0.464). Age was significantly correlated with 2-pd at the lips (p = 0.01; R = 0.575) and chin (p = 0.029; R = 0.501). Younger patients had smaller 2-pd values than older patients. The amount of advancement (T3-T1) and relapse (T4-T3) at point B, incision inferior, anterior surgical apical base, and Ii(*x*-value; T3-T1)/Asab(*x*-value; T3-T2) were not correlated with the 2-pd at the lips or chin. Gender, age, the amount of advancement (T3-T1), and relapse (T4-T3) at point B, incision inferior, anterior surgical apical base, and Ii(*x*-value; T3-T1)/ Asab (*x*-value; T3-T2) were not correlated with the maximum mouth opening, laterotrusion, and protrusion. One exception was that patients with more horizontal relapse (T4-T3) at incision inferior showed significantly less maximum protrusion ($p = 0.018$; $R = 0.536$).

In the control group, gender did not show any significant correlations but a higher age was significantly correlated with an increase in 2-pd at the lips ($p = 0.039$; $R = 0.324$) and chin ($p = 0.008$; $R = 0.410$).

Multiple regression analysis was used to test the significance of age, gender and surgery on 2-pd of the lips and chin in both groups pooled together (Tables 3 and 4).

Table 3. *Multiple regression analysis to test the significance of age, gender and surgery on 2-pd of the lips.*

Independent variables	Coefficient *b*	Standard Error	Significance
Age	0.060	0.018	0.001
Gender	0.314	0.297	0.296
Surgery	0.806	0.370	0.034

Significance of the model: R = 0.453, R2 = 20.5%, p = 0.005.
Dependent variable (y): 2-pd of the lips.
Multiple regression analysis: y = 0.506 + b1age + b2gender + b3surgery.

Table 4. *Multiple regression analysis to test the significance of age, gender and surgery on 2-pd of the chin.*

Independent variables	Coefficient *b*	Standard Error	Significance
Age	0.130	0.032	0.000
Gender	-0.395	0.543	0.470
Surgery	1.084	0.677	0.115

Significance of the model: R = 0.481, R2 = 23.1%, p = 0.002.
Dependent variable (y): 2-pd of the chin.
Multiple regression analysis: y = 3.374 + b1age + b2gender + b3surgery.

5.3.2 Craniomandibular function

The objective examination on signs of craniomandibular dysfunction did not demonstrate any statistical difference between the DO and control groups (Table 5). Two patients (11%) in the DO group and three (7%) in the control group showed TMJ clicking. One patient in the DO group showed pain on palpation of the temporalis muscles whereas none did in the control group. The RCP-ICP sagittal distance tended to be larger than 0.5 mm in the control group with 6 patients (14%) compared to 1 patient (5%) in the DO group.

No statistical differences were found for the maximum opening capacity, laterotrusion, and protrusion between the two groups (Table 6). The mean values were similar. Patients with maximum mouth opening capacities of less than 40 mm were found in both groups: 1 patient with 38 mm (5%) in the DO group and 2 patients (5%) in the control group.

Table 5. *Number of patients with signs of craniomandibular dysfunction.*

	DOG-group (*n*=19)	Control group (*n*=41)
Deviation on opening		
0-2 mm (normal)	14 (74%)	37 (90%)
3-4 mm	4 (21%)	3 (7.5%)
≥ 5 mm	1 (5%)	1 (2.5%)
TMJ clicking total	3 (16%)	3 (7.5%)
Unilateral	2 (10.5%)	3 (7.5%)
Bilateral	1 (5.5%)	0
TMJ crepitus total	2 (10.5%)	2 (5%)
Unilateral	1 (5.5%)	2 (5%)
Bilateral	1 (5.5%)	0
Pain on palpation of TMJ from lateral total	0	0
Unilateral	0	0
Bilateral	0	0
Pain on palpation of TMJ from posterior position total	0	0
Unilateral	0	0
Bilateral	0	0
Pain on palpation of the temporalis muscles total	1 (5.5%)	0
From extraoral	0	0
From intraoral	1 (5.5%)	0
Pain on palpation of the masseter muscles total	0	0
From extraoral	0	0
From intraoral	0	0
RCP-ICP distance sagittal ≤ 0.5mm	18 (94.5%)	35 (85%)
RCP-ICP distance sagittal > 0.5mm	1 (5.5%)	6 (15%)
RCP-ICP distance lateral ≤ 0.5mm	18 (94.5%)	41 (100%)
RCP-ICP distance lateral > 0.5mm	1 (5.5%)	0

ICP, intercuspal position; RCP, retruded contact position.

Table 6. *Maximum movement capacity of the mandible (mm).*

	DOG-group (*n*=19)			Control group (*n*=41)			unpaired *t*-test
	Mean	SD	Range	Mean	SD	Range	*P*,
Max. mouth-opening capacity	51.6	6.6	38-61	52.8	6.6	33-65	0.520
Max. lateral movement capacity	9.2	2.9	5-15	9.5	2.3	2-15	0.656
Max. protrusion	8.6	2.1	6-14	8.5	1.8	4-12	0.860

5.4 Discussion

The present study could not find any differences between patients with DO of the anterior mandibular alveolar segment and control patients regarding neurosensory status and craniomandibular function.

A limitation of this study could be that the clinical data were collected on a longterm single occasion and approximately 5 years after DO or orthodontic treatment. The comparison of the surgically treated patients with a control group of orthodontically treated patients was chosen to overcome the disadvantage of missing presurgical and immediate post-surgical follow-ups. Nevertheless, this clinical evaluation and set-up allows the authors to draw some conclusions about the postsurgical situation in craniomandibular function and neurosensitivity regarding DO.

The present study is based on non-growing and healthy adult patients with no history of trauma or other types of mandibular surgery. There is a lack of human studies evaluating neurosensory status and cranimandibular function after DO in the literature. To the authors' knowledge this data on DO of the anterior alveolar segment is missing. In general, DO is mainly carried out in young patients with different syndromes[16] (hemifacial microsomia, Nager, and Treacher Collins) whereby presurgical neurosensory function and regenerative potential of the inferior alveolar nerve is questionable.

Whitesides and Meyer[17] followed 5 patients prospectively who underwent vertical posterior body osteotomy or BSSO with the application of a distraction device for advancement of the mandible of 10–14 mm. They concluded that all 10 nerves showed improvement of function as measured by 2-point discrimination, response to painful stimulus, and moving brush stroke identification 1 year after surgery.

Several publications on animals addressed the morphological and clinical changes of the inferior alveolar nerve after DO. Block *et al.*[9] performed nerve testing and histology on operated and non-operated sides in four dogs. They found only mild pathological changes on microscopic examination when the mandible was lengthened on average 5.5 mm, apart from one case that showed significant nerve degeneration resulting from acute laceration by an extraoral device. Makarov *et al.*[12] evaluated the inferior alveolar nerve in 12 dogs with mandibular distraction of 10 mm using sensory nerve action potentials. 12 of 24 nerves showed complete loss of evoked potentials after surgery without recovery. The high incidence was thought to be related to device construction and osteotomy technique.

In the present study, age was significantly correlated with 2-pd at the lips and chin in both the DO and control group with no significant difference between the groups. Younger patients had smaller 2-pd values than older patients. These findings are in accordance with the research of Brill *et al.*[18] which demonstrated a significant increase of 2-pd in older subjects. Joss and Thüer related the newly manifested increase 12.7 years postoperatively in 2-pd distance in patients with BSSO and mandibular advancement or setback to the normal human process of ageing.[19] It has been reported that the incidence or severity of neurosensory impairment after BSSO increases with age.[20–22]

The present study shows that neither the amount of advancement (T3-T1), nor the relapse (T4-T3) at point B, incision inferior, and anterior surgical apical base inferior or the type of movement of the distracted segment were correlated to the 2-pd at the lips or chin.

It has been demonstrated that stretching of the inferior alveolar nerve in BSSO with large mandibular advancement could result in increased loss of neurosensensory function.[22] The osteotomy design in the present patient population avoids stretching and direct contact with the inferior alveolar nerve, which seems to be the major reason for the absence of neurosensory problems after DO of the mandibular anterior alveolar segment. Vertical osteotomies are made mostly between the canine and first premolars (less often between the lateral incisors and canines) and therefore anteriorly to the exit of the inferior alveolar nerve. A horizontal osteotomy is made about 5 mm inferior to the apices of the teeth.[5]

Generally, 40 mm is considered an acceptable value for maximum mouth opening capacity.[23] One patient in the DO group and two patients in the control group were below this level.

BSSO for mandibular advancement aims, as does DO of the mandibular anterior process, for a sagittal correction of the mandible. Therefore these studies could be helpful for indirect comparisons with the present data. Joss and Thüer found a significant impairment in movement capacity 7.3 months after surgery which was still reduced but improved at 13.9 months. 12.7 years post-surgically, full restitution to pre-surgical values was shown.[19] Only minor changes were found in TMJ signs such as clicking or pain before and after surgery[19,24,25] whereas others found an improvement[26] or impairment.[27] 5 years after treatment, craniomandibular function, as measured in this study, was comparable to non-surgical controls. The range of mandibular motion, TMJ dysfunction such as clicking, crepitus, muscular pain, and deviation on opening were normal and similarly distributed in both groups.

It could also be argued that DO of the mandibular anterior alveolar process might be beneficial to prevent biomechanical side effects on the mandibular condyle that can occur after BSSO or mandibular DO. This could prevent progressive condylar resorption which is related to long-term relapse and impaired mandibular function. The target groups for condylar resorption are young women with a high mandibular plane angle.[28] It was showed that 7% of all BSSO advancement patients appear to undergo progressive condylar resorption.[29]

Mandibular widening by symphyseal distraction osteogenesis is another approach to resolve lower incisor crowding to gain space and prevent premolar extractions.[30] Histological findings in 9 monkeys showed morphological differences within the fibrous layer, cartilage layer or bone/cartilage interface. Specific areas of condylar compression due to rotation of the condyle around a vertical axis resulted from the symphyseal distraction. More degenerative changes would occur in an increased rate of midline distraction beyond the adaptive capacity of the condyles.[30] It was also speculated that adaptive potential is being lost with age and thereby rendering the mandibular condyles more susceptible to adverse changes.

In conclusion, no differences between orthodonically treated control subjects and patients with DO could be found. DO of the mandibular anterior alveolar segment is a valuable and safe method with minor side effect regarding craniomandibular function and neurosensory impairment.

5.5 Ethical approval

Ethical approval was admitted by the Ethic Committee of the Kanton Zürich, Switzerland, number 593.

5.6 References

1. Codivilla A. On the means of lengthening in the lower limbs, the muscles and tissues which are shortened through deformity. *Am J Orthop Surg* 1905;2:353–69.
2. Ilizarov GA. The possibilities offered by our method for lengthening various segments in upper and lower limbs. *Basic Life Sci* 1988;48:323–4.
3. Snyder CC, Levine GA, Swanson HM, Browne Jr EZ. Mandibular lengthening by gradual distraction. Preliminary report. *Plast Reconstr Surg* 1973;51:506–8.
4. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. *Plast Reconstr Surg* 1992;89. discussion 9–10.
5. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001;59:26–34. Discussion 34-35.
6. Triaca A, Minoretti R, Merz B. Treatment of mandibular retrusion by distraction osteogenesis: a new technique. *Br J Oral Maxillofac Surg* 2004;42:89–95.
7. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Skeletal and dental stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:553–9.
8. Joss CU, Triaca A, Antonini M, Kuijpers-Jagtman AM, Kiliaridis S. Soft tissue stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:560–5.

9. Block MS, Daire J, Stover J, Matthews M. Changes in the inferior alveolar nerve following mandibular lengthening in the dog using distraction osteogenesis. *J Oral Maxillofac Surg* 1993;51:652–60.
10. Hu J, Tang Z, Wang D, Buckley MJ. Changes in the inferior alveolar nerve after mandibular lengthening with different rates of distraction. *J Oral Maxillofac Surg* 2001;59:1041–5. discussion 1046.
11. Karp NS, Thorne CH, McCarthy JG, Sissons HA. Bone lengthening in the craniofacial skeleton. *Ann Plast Surg* 1990;24:231–7.
12. Makarov MR, Harper RP, Cope JB, Samchukov ML. Evaluation of inferior alveolar nerve function during distraction osteogenesis in the dog. *J Oral Maxillofac Surg* 1998;56:1417–23. discussion 1424-1415.
13. Helkimo M, Ingervall B, Carlsson GE. Comparison of different methods in active and passive recording of the retruded position of the mandible. *Scand J Dent Res* 1973;81:265–71.
14. Björk A, Skieller V. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. *Br J Orthod* 1975;4:53–64.
15. Dahlberg G. Statistical methods for medical and biological students. New York: Interscience Publications; 1940.
16. Swennen G, Schliephake H, Dempf R, Schierle H, Malevez C. Craniofacial distraction osteogenesis: a review of the literature. Part 1. Clinical studies. *Int J Oral Maxillofac Surg* 2001;30:89–103.
17. Whitesides LM, Meyer RA. Effect of distraction osteogenesis on the severely hypoplastic mandible and inferior alveolar nerve function. *J Oral Maxillofac Surg* 2004;62:292–7.
18. Brill N, Tryde G, Morgan G, Rees DA. Age changes in the two-point discrimination threshold in skin innervated by the trigeminal nerve. *J Oral Rehabil* 1974;1:149–57.
19. Joss CU, Thüer UW. Neurosensory and functional impairment in sagittal split osteotomies: a longitudinal and long-term followup study. *Eur J Orthod* 2007;29:263–71.
20. Essick GK, Phillips C, Kim SH, Zuniga J. Sensory retraining following orthognathic surgery: effect on threshold measures of sensory function. *J Oral Rehabil* 2009;36:415–26.
21. Westermark A, Bystedt H, von Konow L. Inferior alveolar nerve function after sagittal split osteotomy of the mandible: correlation with degree of intraoperative nerve encounter and other variables in 496 operations. *Br J Oral Maxillofac Surg* 1998;36:429–33.

22. Ylikontiola L, Kinnunen J, Oikarinen K. Factors affecting neurosensory disturbance after mandibular bilateral sagittal split osteotomy. *J Oral Maxillofac Surg* 2000;58:1234–9.
23. Helkimo M. Studies on function and dysfunction of the masticatory system. II. Index for anamnestic and clinical dysfunction and occlusal state. *Sven Tandlak Tidskr* 1974;67:101–21.
24. Magnusson T, Ahlborg G, Svartz K. Function of the masticatory system in 20 patients with mandibular hypo- or hyperplasia after correction by a sagittal split osteotomy. *Int J Oral Maxillofac Surg* 1990;19:289–93.
25. Smith V, Williams B, Stapleford R. Rigid internal fixation and the effects on the temporomandibular joint and masticatory system: a prospective study. *Am J Orthod Dentofacial Orthop* 1992;102:491–500.
26. Harper RP. Analysis of temporomandibular joint function after orthognathic surgery using condylar path tracings. *Am J Orthod Dentofacial Orthop* 1990;97:480–8.
27. Feinerman DM, Piecuch JF. Long-term effects of orthognathic surgery on the temporomandibular joint: comparison of rigid and nonrigid fixation methods. *Int J Oral Maxillofac Surg* 1995;24:268–72.
28. Hoppenreijs TJ, Freihofer HP, Stoelinga PJ, Tuinzing DB, van’t Hof MA. Condylar remodelling and bimaxillary osteotomies in patients with anterior open bite. A clinical and radiological study. *Int J Oral Maxillofac Surg* 1998;27:81–91.
29. Scheerlinck JPO, Stoelinga PJW, Blijdorp PA, Brouns JJA, Nijs MLL. Sagittal split advancement osteotomies stabilized with miniplates: a 2–5-year follow-up. *Int J Oral Maxillofac Sur*g 1994;23:127–31.
30. Harper RP, Bell WH, Hinton RJ, Browne R, Cherkashin AM, Samchukov ML. Reactive changes in the temporomandibular joint after mandibular midline osteodistraction. *Br J Oral Maxillofac Surg* 1997;35:20–5.

Chapter 6

Skeletal and dental stability of segmental distraction of the anterior mandibular alveolar process. A 5.5-year follow-up

C.U. Joss
A. Triaca
M. Antonini
S. Kiliaridis
A.M. Kuijpers-Jagtman

Int. J. Oral Maxillofac. Surg. 2013;42:337–44

Summary

17 patients (14 female; 3 male) were analysed retrospectively for skeletal and dental relapse before distraction osteogenesis (DO) of the mandibular anterior alveolar process at T1 (17.0 days), after DO at T2 (mean 6.5 days), at T3 (mean 24.4 days), at T4 (mean 2.0 years), and at T5 (mean 5.5 years). Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated. Skeletal correction (T5–T1) was mainly achieved through the distraction of the anterior alveolar segment in a rotational manner where the incisors were more proclined. The horizontal backward relapse (T5–T3) measured 0.3 mm or 8.3% at point B (nonsignificant) and 1.8 mm or 29.0% at incision inferior ($p < 0.01$). Age, gender, amount and type (rotational vs. translational) of advancement were not correlated with the amount of relapse. High angle patients (NL/ML'; $p < 0.01$) showed significant smaller relapse rates at point B. Overcorrection of the overjet achieved by the distraction could be a reason for dental relapse. Considering the amount of long-term skeletal relapse the DO could be an alternative to bilateral sagittal split osteotomy for mandibular advancement in selected cases.

6.1 Introduction

The principles of distraction osteogenesis (DO)[1] and its clinical application in maxillofacial surgery[2] have opened new horizons in the treatment of facial and skeletal disharmonies. Mandibular DO is still mainly used in patients with syndromes and congenital anomalies and less in nonsyndromic adult patients.[3] Many surgeons still prefer to advance the mandible in one step by bilateral sagittal split osteotomy (BSSO) in normal patients than in several steps by DO. Mandibular DO seems to show similar risk factors for skeletal relapse when compared with BSSO for mandibular advancement.[4]

Today there are new surgical approaches to correct mandibular deficiency. DO of the anterior alveolar mandibular process[5] and mandibular wing osteotomy for the correction of the mandibular plane6 are two of them. Triaca *et al*.[5] reported that DO of the mandibular alveolar process can be applied in several specific cases: in skeletal Class II patients with crowding to reduce the required sagittal distance to be achieved by an advancement BSSO; in skeletal Class III patients to create space for the decompensation of the lower incisor inclination; in skeletal Class I patients with a dental Class II to create space of one premolar width and overjet normalization, and in skeletal and dental Class I patients with crowding to avoid extraction and the resulting unfavorable profile that often results.

Few studies have been published on the results of DO on the anterior alveolar mandibular process.[5] Recently, the soft tissue, skeletal and dental stability, neurosensory and function after DO of the anterior alveolar process were examined 2.0 years postoperatively.[7–9] Skeletal relapse at point B was found in 19%. No correlation between the amount of skeletal relapse and the amount of advancement, patient’s age or gender could be demonstrated.[7] Studies on the long-term results of DO of the anterior alveolar process are still lacking. The aims of the present study were to evaluate the amount of skeletal changes and dental changes 5 years after treatment in patients treated with DO of the mandibular anterior alveolar process, and to identify factors related to skeletal and dental stability.

6.2 Materials and methods

This study reports the follow-up of an initial sample of 33 patients published previously.[7,8] Of the 33 patients, 17 patients were available for re-examination. The follow-up group (T1) consisted of 17 Caucasian patients (14 females and 3 males); aged 16.5–56.0 years (mean age 29.8 years, SD 11.9).

They were all treated orthodontically by one orthodontist (MA) and underwent DO of the mandibular anterior alveolar process to correct a skeletal Class II and large overjet with or without incisor crowding at the Pyramide Clinic in Zürich, Switzerland in the years 1998–2004. The female patients in the follow-up group had a mean age of 31.7 years (17.1–56.0 years, SD 12.0 years) and the male patients 21.5 years (16.5–31.4 years, SD 8.6 years) at T1. The surgical procedure was performed by one experienced maxillofacial surgeon (AT) and the technique has been published previously.[5,10] Patients receiving other surgical procedures simultaneously on the mandible and maxilla such as genioplasty, BSSO, and Le Fort were excluded. Syndromic or medically compromised patients were excluded.

Five cephalograms were taken: the first on average 17.0 days before surgery (T1); and the second (T2) between 0 and 12 days (mean 6.5 days) after the osteotomy and before any distraction was carried out. The third (T3) cephalogram was taken between 13 and 92 days (mean 24.4 days) when the distraction was completed; the fourth (T4) between 0.9 and 3.7 years (mean 2.0 years) at the end of orthodontic treatment; and the fifth (T5) between 2.7 and 8.3 years (mean 5.5 years) after distraction of the mandibular anterior alveolar process. Lower incisors were retained with a bonded canine to canine retainer. The DO procedure has been described previously.[5,10]

Ethical approval was given by the Ethic Committee of the Kanton Zürich, Switzerland, number 593. All subjects signed written, informed consent.

6.2.1 Cephalometric analysis

Skeletal changes were evaluated on profile cephalograms taken with the teeth in the intercuspal position, including a linear enlargement of 1.2%. The cephalograms were taken with the subject standing upright in the natural head position and with relaxed lips. The same X-ray machine and the same settings were used for all cephalograms.

The lateral cephalograms were scanned and evaluated with the program Viewbox 3.11 (dHal software, Kifissia, Greece). The cephalometric analysis for T1, T2, T3, T4 and T5 was carried out by one author (CUJ) and included the reference points and lines shown in Fig. 1.

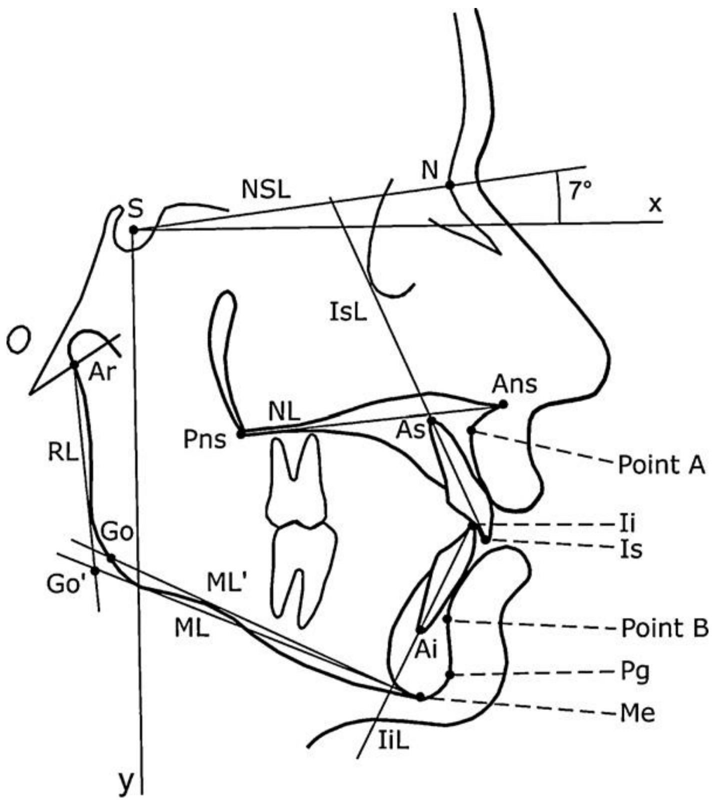

Figure 1. *Reference points and lines used in the cephalometric analysis. The coordinate system had its origin at point S (sella), and its X-axis formed an angle of 7° with the reference line NSL. S, sella; NSL, nasion-sella-line; N, nasion; X, horizontal reference plane; NL, nasal line; ILs, upper incisal line; Ar, articulare; RL; ramus line; Ans, anterior nasal spine; Pns, posterior nasal spine; As, apex superior; point A; Ii, incision inferior; Is, incision superior; Go, gonion; Go', gonion prime; ML', mandibular line prime; ML, mandibular line; Ai, apex inferior; point B; Pg, pogonion; Me, menton; and y, vertical reference plane. The Holdaway ratio is the distance between Ii vertical to N-B-line minus distance Pg vertical to N-B-line and the Jarabak ratio is the distance from S to Go'/distance N to Me.*

Horizontal (*X*-values) and vertical (*Y*-values) linear measurements were obtained by superimposing the tracings of the different stages (T2, T3, T4 and T5) on the first radiograph (T1), and the reference lines were transferred to each consecutive tracing. During superimposition, particular attention was given to fitting the tracings of the cribriform plate and the anterior wall of the sella turcica which undergo minimal remodelling.[11] A template of the outline of the mandible of the preoperative cephalogram (T1) was made to minimize errors for superimposing on subsequent radiographs.

Conventional cephalometric variables as well as the coordinates of the reference points (Table 1) were calculated by the computer program. The coordinate system had its origin at point S (sella), and its Xaxis formed an angle of 78 with the reference line NSL (Fig. 1). Overjet and overbite were calculated from the coordinates of the points Is (incision superior) and Ii (incision inferior).

Table 1. *Random errors (Si) in mm or degrees of the cephalometric variables.*

Variable	Si	Variable	Si	Reference point	Si (mm)	
					X	*Y*
SNA (°)	1.14	IiL-N-Point B (°)	1.14	Incision sup.	0.48	0.21
SNB (°)	0.82	IiL-N-Point B (mm)	0.24	Incision inf.	0.58	0.55
ANB (°)	0.48	IiL-A-Pg (°)	1.29	Apex inf.	0.54	0.18
NSL/NL (°)	0.86	IiL-A-Pg (mm)	0.49	Point B	0.28	0.45
NSL/ML' (°)	1.01	Holdaway ratio	0.47	Asab	0.35	0.25
NL/ML' (°)	0.84	IsL/IiL (°)	1.63	Pogonion	0.37	1.19
Jarabak ratio	1.15	Overjet	0.36	Menton	0.89	0.45
IsL/NSL (°)	1.52	Overbite	0.53	Gonion'	2.48	1.14
IsL/NL (°)	1.31					
IiL/ML' (°)	1.39					

See Fig. 1 for details of the variables.

The lateral cephalograms of T2 were only used to locate the cephalometric point alveolar surgical anterior base (Asab) before postoperative distraction of the alveolar process was carried out. Asab is the most anterior and inferior point of the lower anterior segment resulting from the surgical osteotomy (Figs 2 and 3). This cephalometric point was introduced to evaluate the movement (rotation vs. translation) of the lower anterior segment base in comparison to the lower incisors as the ratio (Ii [*X*-value; T3–T2]/Asab [*X*-value; T3–T2]).

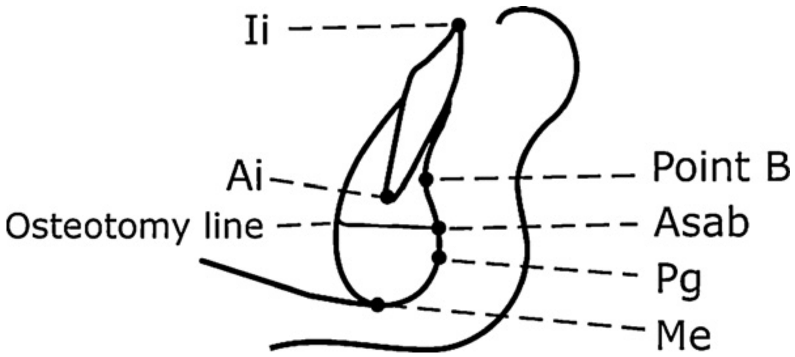

Figure 2. *Reference points used in the cephalometric analysis of the lower apical base in DO patients. Ii, incision inferior; point B; Ai, apex inferior; Asab, apical surgical anterior base; Pg, pogonion; and Me, menton. Asab is the most anterior and inferior point of the lower anterior segment formed by the surgical osteotomy. This cephalometric point was introduced to evaluate the movement (rotation vs. translation) of the lower anterior segment base in comparison to the lower incisors (Ii) as the ratio Ii (X-value)/Asab (X-value).*

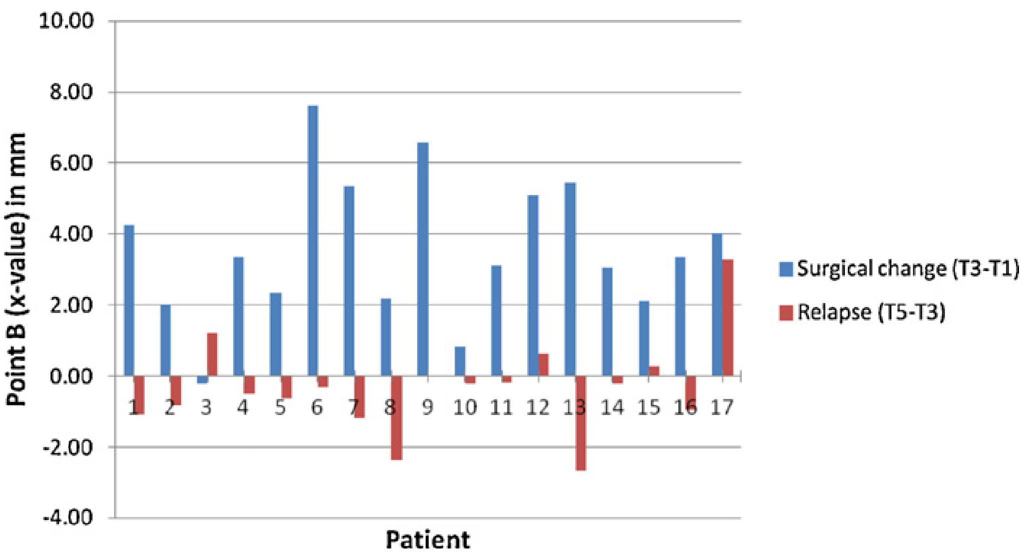

Figure 3. *Surgical change (T3–T1) and amount of relapse (T5–T3) of point B (X-value in mm) in individual patients (n = 17).*

6.2.2 Error of the method

To determine the error of the method, 21 randomly selected cephalograms were retraced and re-analysed after a 2-week interval. Horizontal (*X*-values) and vertical (*Y*-values) linear measurements were re-obtained by superimposing the tracings of the different stages (T2, T3, T4, and T5) on the first radiograph (T1). The error of the method (Si) was calculated with the formula $Si = \sqrt{\frac{\sum d^2}{2n}}$ where d is the difference between the repeated measurements and n is the number of duplicate determinations.[12]

The random errors are presented in Table 1. No systematic errors were found when the values were evaluated with a paired *t*-test. The drop-out analysis included the unpaired *t*-test to compare drop-outs with the remaining patients for age and cephalometric features at T1, T2, T3 and T4, and the $_x{}^2$ test for sex. Drop-out analysis showed that there were no significant differences between the drop-out and the remaining patients for age and cephalometric features at T1, T2, T3 and T4.

6.2.3 Statistical analysis

Statistical analyses were conducted using SPSS software (version 19.0, SPSS Inc., Chicago, IL, USA). Normal distribution was confirmed with the Kolmogorov–Smirnov test. The effect of treatment, i.e. the differences between the variables and co-ordinates at T3 and T1 (T3 and T2 for Asab), T5 and T1 (T5 and T2 for Asab), T5 and T4 were tested with a paired *t*-test. The relationships between skeletal variables, age, and gender were analysed with the Pearson's product moment correlation coefficient.

Table 2. *Values of selected cephalometric variables at T1 (before surgery) and T5 (5.5 years after surgery).*

	T1			T5		
	Mean	SD	Range	Mean	SD	Range
SNA (°)	80.9	3.7	73.1-85.7	80.0	2.8	74.0-84.4
SNB (°)	76.7	4.2	69.8-83.8	77.3	3.8	70.7-85.5
ANB (°)	4.2	2.2	0.3-7.1	2.7	3.0	-2.9-6.3
NSL/NL (°)	7.4	4.1	-1.9-15.0	7.6	3.7	0.1-13.0
NSL/ML' (°)	33.6	7.9	21.4-53.7	34.7	7.1	23.9-53.7
NL/ML' (°)	26.2	6.4	16.2-44.8	27.1	5.8	19.8-45.2
Gonion angle (°)	125.9	8.1	115.6-145.8	124.3	8.0	111.0-143.0
Jarabak ratio	64.5	6.5	49.2-75.7	63.6	5.4	49.9-72.5
IsL/NSL (°)	109.3	9.8	81.7-120.5	105.0	7.1	91.3-117.0
IsL/NL (°)	116.7	9.4	91.0-126.7	112.6	6.2	99.0-121.8
IiL/ML' (°)	91.0	6.8	77.2-104.6	96.5	6.6	81.5-108.3
IiL-N-Point B (°)	21.2	8.3	6.2-36.3	28.5	6.7	18.1-42.3
IiL-N-Point B (mm)	4.4	3.8	-1.0-12.9	7.3	3.7	2.5-15.6
IiL-A-Pg (°)	20.1	6.5	7.6-30.3	26.4	5.7	18.4-39.9
IiL-A-Pg (mm)	0.1	3.7	-5.3-9.0	4.8	2.7	1.3-11.9
Holdaway ratio	1.0	5.8	-6.1-13.6	6.3	4.9	-3.4-17.2
IsL/IiL (°)	126.2	14.0	106.9-157.3	123.8	6.6	81.5-108.3
Overjet (mm)	7.7	2.1	4.5-11.9	2.8	0.9	1.3-4.5
Overbite (mm)	4.4	1.7	1.0-7.3	3.0	1.5	0.2-5.5

See Fig. 1 for details of the variables.

Table 3. *Changes (mm or degree) in the variables and coordinates of the mandible and lower incisors as the immediate (T3–T1) and final (T5–T1) result of DO surgery.*

Variable or coordinate	T3-T1[1]				T5-T1[2]			
	Mean	*p*	SD	Range	Mean	*p*	SD	Range
Horizontal (*X*-value [mm])								
Point B	3.6	***	2.0	-0.21-7.6	3.2	***	2.3	-0.2-7.3
Asab	2.2	***	2.1	-1.1-5.4	1.2	*	2.1	-2.2-4.7
Pogonion	0.1	ns	1.0	-1.7-1.8	0.5	*	1.0	-0.8-2.4
Go'	-0.6	ns	2.4	-3.5-2.5	-0.4	ns	2.7	-5.7-2.8
Incision sup.	1.1	**	1.4	-1.3-3.2	-0.4	ns	1.9	-4.1-3.0
Incision inf.	6.2	***	2.5	-0.5-10.9	4.6	***	3.2	-1.6-11.5
Apex inf.	4.2	***	1.9	1.7-8.8	3.1	***	2.2	-0.6-6.7
Vertical (*Y*-value [mm])								
Point B	1.4	**	1.7	-1.6-4.8	0.0	ns	1.9	-6.0-2.3
Asab	-0.4	ns	1.4	-4.6-1.0	0.1	ns	1.3	-2.5-2.1
Pogonion	0.2	ns	2.4	-5.1-4.8	0.3	ns	1.8	-2.8-4.8
Menton	0.1	ns	0.5	-0.6-1.2	0.0	ns	1.0	-1.5-1.5
Go'	-0.3	ns	2.4	-3.5-2.5	-0.6	ns	1.9	-3.5-3.2
Incision sup.	-1.8	***	1.7	-6.7-0.4	-0.3	ns	1.4	-3.3-2.4
Incision inf.	1.3	**	1.9	-1.8-4.9	1.3	*	1.9	-1.7-4.9
Apex inf.	0.2	ns	1.2	-2.8-2.0	0.1	ns	1.8	-2.8-3.4
Angular (°), linear measurements (mm), and ratios								
SNA (°)	-0.4	ns	1.6	-3.0-1.7	-0.9	*	1.6	-3.2-2.2
SNB (°)	0.9	*	1.2	-0.6-3.9	0.6	ns	1.6	-1.7-3.3
ANB (°)	-1.3	***	1.0	-3.9-0.9	-1.5	***	1.2	-3.7-0.2
Wits (mm)	-3.1	***	1.5	-5.3-0.4	-2.9	***	2.2	-7.7-1.3
NSL/NL (°)	0.2	ns	1.3	-2.0-2.8	0.2	ns	1.3	-2.1-2.1
NSL/ML' (°)	1.3	***	1.3	-0.5-3.5	1.1	*	1.6	-2.8-3.8
NL/ML' (°)	1.1	**	1.5	-0.4-3.7	1.0	*	1.4	-1.6-3.6
Gonion angle (°)	-2.1	**	2.7	-7.0-1.9	-1.6	ns	3.7	-10.2-4.5
Jarabak ratio	-0.3	ns	1.6	-2.7-2.2	-0.9	ns	2.0	-4.0-3.4
IsL/NSL (°)	1.3	ns	5.9	-5.1-22.0	-4.3	**	6.0	-16.7-9.6
IsL/NL (°)	1.5	ns	5.3	-4.6-20.1	-4.1	**	5.7	-14.7-8.0
IiL/ML' (°)	7.2	***	4.9	-6.5-15.7	5.5	**	5.9	-5.7-16.1
IiL-N-Point B (°)	9.4	***	4.6	-4.2-16.1	7.2	***	6.1	-4.3-16.5
IiL-N-Point B (mm)	3.4	***	1.5	-1.7-5.2	2.9	ns	2.5	-1.4-7.8
IiL-A-Pg (°)	6.2	***	4.0	-4.9-13.4	6.3	***	5.7	-3.1-14.7
IiL-A-Pg (mm)	6.0	***	1.9	0.5-8.9	4.6	***	2.7	-0.5-11.4
Holdaway ratio	7.9	***	2.7	1.4-12.7	5.4	***	3.3	-1.2-13.3
IsL/IiL (°)	-9.7	***	7.9	-31.4-4.9	-2.4	ns	9.6	-21.9-14.5
Overjet (mm)	-5.1	***	1.7	-7.8- -1.1	-4.9	***	1.9	-9.2- -3.0
Overbite (mm)	-3.1	***	1.7	-6.4-0.1	-1.5	**	1.7	-5.3-1.1
Ii/Asab	1.8		7.5	-22.4-9.7				

*T1, before surgery; T3, 24.4 days after surgery; T5, 5.5 years after surgery; *, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$*
[1]T3-T2 for Asab, Ii (X-value, T3-T2) / Asab (X-value, T3-T2) instead mean value the median was taken for this ratio and no paired t-test was possible because measured on a single occasion;
[2]T5-T2 for Asab. Negative values imply a backward and positive values a forward movement of the point in the horizontal plane. In the vertical plane, negative values imply an upward and positive values a downward movement of the point.

6.3 Results

Table 2 shows the selected variables before surgery (T1) and at 5.5-year follow-up (T5). The mean changes, standard deviations, and ranges for the selected cephalometric parameters before surgery and during the subsequent observation periods are given in Tables 3 and 4.

Table 4. *Changes (mm, degree or ratio) in the variables and coordinates of the mandible and lower incisors as the relapse (T5–T3) and the longterm change (T5–T4) of DO surgery.*

Variable or coordinate	T5-T3				T5-T4			
	Mean	*p*	SD	Range	Mean	*p*	SD	Range
Horizontal (*X*-value [mm])								
Point B	-0.3	ns	1.3	-2.7-3.3	0.3	ns	0.7	-1.0-2.0
Asab	-1.0	***	0.9	-2.4-1.1	0.1	ns	0.6	-1.1-1.5
Pogonion	0.4	ns	1.0	-1.6-2.9	-0.1	ns	0.7	-1.0-2.0
Go'	0.2	ns	2.7	-6.4-4.7	-0.4	ns	2.5	-7.6-4.1
Incision sup.	-1.5	**	1.7	-5.4-1.2	0.1	ns	0.6	-1.6-0.9
Incision inf.	-1.8	***	1.9	-5.4-0.6	-0.2	ns	0.6	-1.6-1.4
Apex inf.	-1.1	*	1.7	-3.8-1.6	0.1	ns	1.4	-3.5-2.9
Vertical (*Y*-value [mm])								
Point B	-1.4	*	2.7	-7.9-2.7	-0.1	ns	1.7	-3.2-3.2
Asab	0.5	ns	1.0	-1.1-2.7	-0.1	ns	0.6	-1.9-0.9
Pogonion	0.1	ns	2.3	-3.7-3.3	0.4	ns	1.7	-4.6-3.0
Menton	-0.2	ns	0.6	-1.3-0.9	0.0	ns	0.6	-1.0-1.0
Go'	-0.3	ns	1.4	-2.9-2.4	-0.4	ns	1.5	-2.9-2.1
Incision sup.	1.4	***	1.5	-1.2-3.9	0.5	**	0.8	-0.6-1.8
Incision inf.	-0.1	ns	1.6	-4.3-2.8	-0.1	ns	0.7	-1.1-1.4
Apex inf.	0.3	ns	1.7	-2.5-3.0	-0.6	ns	1.5	-4.2-2.9
Angular (°), linear measurements (mm), and ratios								
SNA (°)	-0.5	ns	1.3	-2.9-2.4	0.2	ns	1.4	-2.6-2.4
SNB (°)	-0.3	ns	1.1	-1.9-1.9	0.4	ns	0.8	-1.0-1.8
ANB (°)	-0.2	ns	1.0	-2.2-1.8	-0.2	ns	1.0	-2.5-1.4
Wits (mm)	0.2	ns	1.8	-3.2-2.8	-0.2	ns	1.4	-2.1-2.2
NSL/NL (°)	0.0	ns	0.8	-1.3-1.4	-0.3	ns	0.9	-1.7-1.6
NSL/ML' (°)	-0.1	ns	1.4	-3.5-1.9	-0.6	ns	1.3	-3.5-1.6
NL/ML' (°)	-0.1	ns	1.2	-2.2-2.1	-0.3	ns	1.1	-1.9-1.8
Gonion angle (°)	0.6	ns	3.4	-7.3-6.7	-1-1	ns	3.6	-7.1-4.6
Jarabak ratio	-0.6	ns	1.7	-3.9-2.1	0.6	ns	1.6	-2.9-3.5
IsL/NSL (°)	-5.5	***	4.5	-12.4-0.1	-0.6	ns	2.7	-5.7-3.0
IsL/NL (°)	-5.5	***	4.6	-12.3-0.3	-1.0	ns	2.9	-5.4-3.2
IiL/ML' (°)	-1.7	ns	5.4	-11.5-9.0	0.0	ns	3.1	-5.1-7.8
IiL-N-Point B (°)	-2.1	ns	5.3	-12.2-10.1	-0.3	ns	3.4	-5.8-9.0
IiL-N-Point B (mm)	-0.5	ns	2.3	-4.8-4.0	-0.5	*	0.7	-2.1-0.7
IiL-A-Pg (°)	0.1	ns	5.9	-12.1-11.7	-0.2	ns	3.3	-5.6-8.1
IiL-A-Pg (mm)	-1.4	**	1.9	-5.5-2.5	-0.3	ns	1.0	-1.8-1.3
Holdaway ratio	-2.6	***	2.2	-6.0-1.2	-0.3	ns	0.9	-2.2-1.0
IsL/IiL (°)	7.3	***	6.3	-7.0-18.3	1.3	ns	4.0	-5.3-9.3
Overjet (mm)	0.1	ns	1.4	-2.6-2.4	0.3	*	0.5	-0.4-1.7
Overbite (mm)	1.7	***	1.7	-1.5-3.9	1.0	**	1.1	-0.5-4.0

See Fig. 1 for details of the variables. T3, 24.4 days after surgery; T4, 2.0 years after surgery; T5, 5.5 years after surgery. Negative values imply a backward and positive values a forward movement of the point in the horizontal plane. In the vertical plane, negative values imply an upward and positive values a downward movement of the point.
** $p \leq 0.05$.*
*** $p \leq 0.01$.*
**** $p \leq 0.001$.*

Negative values imply a backward and positive values a forward movement of the point in the horizontal plane. In the vertical plane, negative values imply an upward and positive values a downward movement of the point.

6.3.1 Horizontal changes

The mean advancement of the anterior alveolar process immediately following DO (T3–T1) was 3.6 mm at point B, 2.2 mm at Asab (T3–T2), and 6.2 mm at incision inferior (all p = .000). Mean relapse (T5–T3) was 0.3 mm or 8.3% at point B, 1.0 mm or 45.5% at Asab (T5–T2), and 1.8 mm or 29.0% at incision inferior of the initial surgical advancement. Figures 3 and 4 show the surgical changes (T3–T1) and the amount of relapse (T5–T3) of point B and overjet. Figure 5 shows the changes of point B and incision inferior over time from T1 to T5.

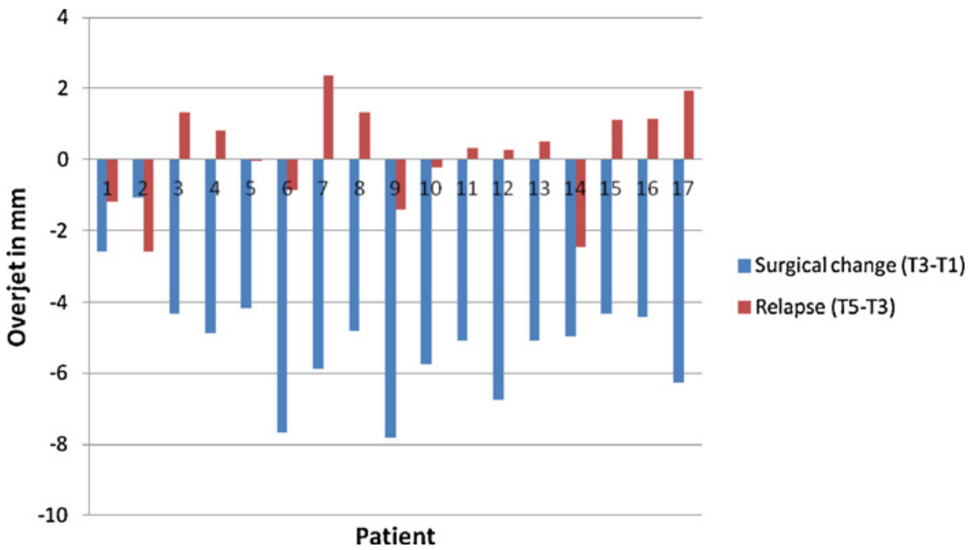

Figure 4. *Surgical change (T3–T1) and amount of relapse (T5–T3) of overjet (in mm) in individual patients (n = 17).*

Regarding the ratio Ii [*X*-value; T3-T2]/Asab [*X*-value; T3–T2], the alveolar segment moved as a result of the DO in a rotational way in all but one patient if the ratio between 0.8 and 1.2 was taken as translational movement. That means that in 13 patients the incisal edges of the lower incisors (Ii) were more advanced than their Asab. In three patients the ratio was negative; that means that point Asab was even set back while point Ii was advanced by the DO.

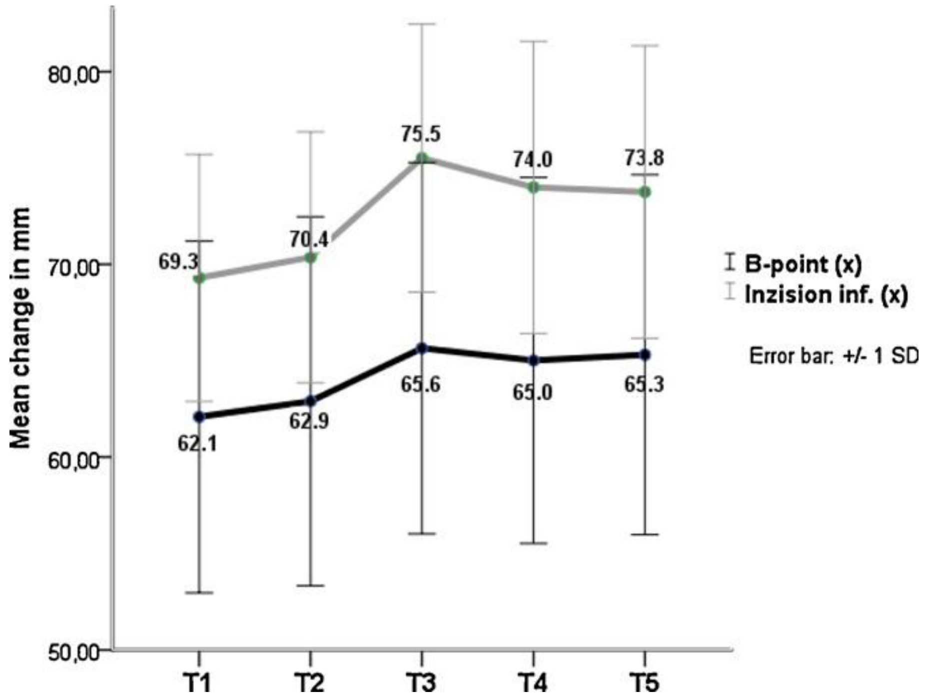

Figure 5. *Changes of point B and overjet from T1 to T5.*

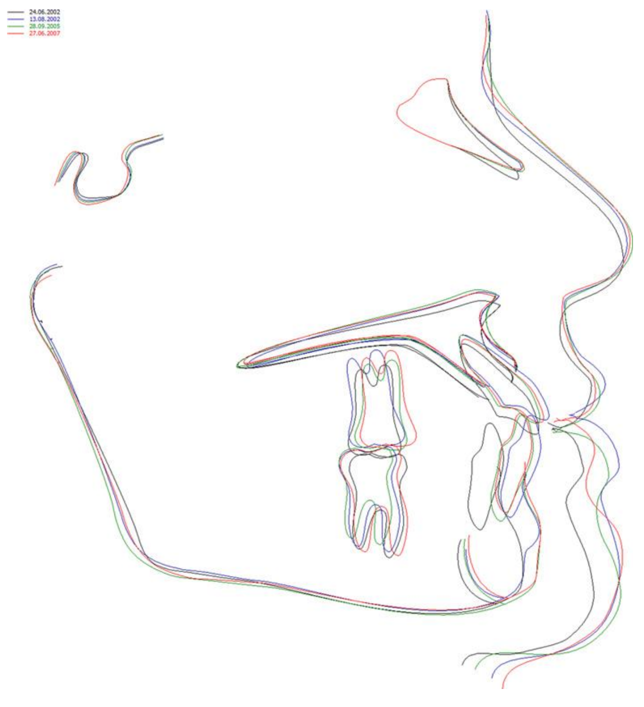

Figure 6. *Superposition of serial tracings (T1, T3, T4, and T5) in a male patient (number 12) with little skeletal and dental changes in long-term. Legend: T1 (24.06.2002), T3 (13.08.2002), T4 (28.09.2005), and T5 (27.06.2007).*

6.3.2 Correlations

No significant correlations were found between the amount of relapse (T5–T3 and T5–T4, *X*-value) at point B, Ii, Asab or pogonion with gender and age of the patients. No correlations were found for the amount of advancement (T3–T1) and long-term relapse (T5–T3) at Ii, point B and Asab. The type of advancement (rotational vs. translational; Ii [*X*-value; T3–T2]/Asab [*X*-value; T3–T2]) had no influence on relapse (T5–T3) at point B (*X*-value) and Asab (*X*-value).

A larger gonial angle (T1) was significantly correlated with a smaller relapse (T5–T3) at the *X*-values of pogonion (p = 0.024; R = 0.544). A larger NL/ML' angle (T1) showed significant correlations with a smaller relapse at the *X*-values of point B (T5–T3: p = 0.006; R = 0.633; T5-T4: p = 0.015; R = 0.576) and pogonion (T5–T3: p = 0.000; R = 0.773; T5–T4: p = 0.013; R = 0.588). The same was seen for a larger NSL/ML' angle (T1) and a smaller relapse (T5–T3) at the *X*-value of point B (p = 0.047; R = 0.487) and pogonion (p = 0.012; R = 0.596). A larger Jarabak ratio (T1) was significantly correlated with a larger relapse (T5–T3) at the *X*-values of point B (p = 0.026; R = 0.538) and pogonion (p = 0.014; R = 0.586).

No correlation was seen between the advancement of point B (T3–T1) and the vertical relations at T1 of NSL/ML', NL/ML', and Jarabak ratio. Relapse as a pure geometric correlation between vertical and sagittal relationship was thus excluded.

6.4 Discussion

The present study was undertaken to investigate long-term dental and skeletal changes in patients undergoing DO of the mandibular anterior alveolar process. In a previous paper on skeletal and dental stability 2 years after DO of the anterior alveolar process the authors reported a 19% amount of relapse at point B.[7] To the authors' knowledge, no other study on DO of the mandibular anterior alveolar process has been published, which makes a direct comparison of the present data impossible for the moment. For the present study a uniform group of

17 patients was obtained due to the exclusion of additional surgical procedures on the mandible (genioplasty, BSSO) and maxilla. An examination of alveolar segmental DO without the influence of other confounding surgical procedures on the hard tissue was thus possible. An inherent problem of long-term studies is the loss of patients for follow-up examinations. Only 17 of 31 patients initially evaluated[7] could be re-examined. The drop-out analysis showed that there was no significant difference between the drop-out and the remaining patients for cephalometric parameters, age and sex. Even though the percentage of skeletal relapse in this sample is 8.3% which is smaller than the 19% reported 2 years after DO of the anterior alveolar process. Figures 6 and 7 illustrate long-term skeletal and dental changes from T1 to T5 in two different patients. The number of re-examined patients is comparable to the 18 patients receiving DO in the long-term study by Baas *et al.*[13]

Although there are no studies on DO of the mandibular anterior alveolar process there are some comparing mandibular advancement with DO or by a BSSO. Vos *et al.*[14] could not show retrospectively any significant skeletal differences in nonsyndromic adult patients treated for mandibular advancement either with DO (BSSO type) or BSSO 10–49 months after surgery. Recently, in a follow-up study Baas *et al.*[13] could still not show any difference 46–95 months after surgery on the same but reduced patient samples while the mean distance of advancement was comparable in both groups. No difference in relapse between patients with high or normal to low mandibular plane was found. In contrast to the study of Baas *et al.*,[13] high angle patients (NL/ML') examined in the present study showed significantly smaller relapse rates at point B ($p < 0.01$) and pogonion ($p < 0.001$). This was a surprising finding when compared to relapse patterns after a BSSO for mandibular advancement where a large mandibular plane angle (NL/ML') is often correlated with increased horizontal relapse.[15] It is possible that patients with a hyperdivergent facial pattern have a lower perioral muscular tonus and thus fewer relapse.[7]

It could also be argued that DO of the mandibular anterior alveolar segment might be beneficial to prevent biomechanical side effects on the mandibular condyle that can occur after BSSO or mandibular DO.[16] This could prevent progressive condylar resorption which is related to long-term relapse and impaired mandibular function. The target groups for condylar resorption are young women with a high mandibular plane angle.[17,18] It was shown that 7% of all BSSO advancement patients appear to undergo progressive condylar resorption.[19] Further research is needed to elucidate whether condylar resorption is less in cases treated with DO of the mandibular alveolar process. Recently, Joss *et al.*[9] showed that DO of the mandibular anterior alveolar process is a valuable and safe method with minor side effect regarding neurosensory impairment and craniomandibular function. No significant difference in craniomandibular function and neurosensory status between a DO group and an orthodontically treated control group could be found.

In the present study the amount of advancement (T3–T1) had no influence on the amount of relapse (T5–T3) at point B, at Ii, and Asab. Smaller advancements with DO did not show less relapse than larger advancements even though the mean advancement at point B (X-value) was rather low with 3.6 mm. This is in accordance with the findings of the authors' previous study 2.0 years after DO of the anterior alveolar segment.[7] In contrast, in BSSO a positive correlation between the amount of relapse and the amount of mandibular advancement is often seen.

Advancements in the range 6–7 mm or more predispose to horizontal relapse.[15] Only two of 17 of the patients had advancements larger than 6 mm at point B. The amount of relapse at point B was 8.3% 5.5 years after DO of the anterior alveolar segment. Nevertheless, the amount of relapse at point B was 19.0% after 2.0 years.[7] Reasons for this improvement regarding the relapse rate at point B could be the missing data from the 16 patients which could not be re-examined for this 5.5 year follow-up. The systematic review on BSSO for mandibular advancement of Joss and Vassalli[15] showed a large variability from 2 to 50.3% in long-term relapse (>1.5 years) at point B.

A reason for the amount of dental relapse of 29.0% at incision inferior to the initial surgical advancement could be the overcorrection achieved by the distraction where an edge-to-edge incisal position or negative overjet at T3 had to be corrected with Class III elastics postsurgically. Furthermore, the DO creates space distal of the canines while crowding is still present in the incisor region. Incisor alignment is carried out in this newly generated space to prevent further proclination or round tripping. For this reason, it is possible that incision inferior moves further posteriorly by orthodontic forces.[7]

The distraction vector (translation vs. rotational) was defined by the type of distraction appliance chosen, whereas pseudarthrosis at the osteotomy sites occurred in none of the 17 patients examined. The hinge plate allows a more rotational and the base-distractor a more translational movement of the anterior mandibular alveolar segment. The introduction of the newly defined skeletal points (Asab) permits the evaluation of the movement of the surgical base independently and the bone remodeling at the surgical site.[7] A comparison between the movements of Ii, point B, and lower incisor apex can determine whether DO created predominantly a rotation or translation of the alveolar process, especially when considering the ratio Ii (X-value, T3–T2)/Asab (X-value, T3–T2). A ratio of 1 signifies that a pure translation of the segment had taken place. The higher the ratio over 1 the more the centre of rotation is located at the lower incisor apex or at Asab, respectively, and the opposite for values below 1.

Three of the 17 patients had a negative ratio indicating a setback of point Asab while point Ii was advanced. Only one patient had a ratio between 0.8 and 1.2 which could be described as translation movement, that means that 13 patients had a more or less accentuated rotational movement of the distracted segment. Some proclination of the lower incisors was related to the orthodontic treatment which could have biased the assessment of that ratio.

In this study, the relapse rate at Asab (45.5%) was quite large. This could be due to remodeling of the border of the segment to smooth the contour and aspect of the anterior symphysis. The interface of the surgical section of the anterior aspect of the symphysis is highly susceptible to resorption and bony remodeling. This has also been shown at the surgical borders of advancement genioplasties where osseous remodeling was highest.[20]

In summary, this long-term follow-up found that no change in further relapse was seen between 2.0 years and 5.5 years postoperatively regarding point B and the incision of the lower incisors. DO of the mandibular anterior alveolar process resulted in a mainly rotational rather than translational advancement of the tooth bearing alveolar segment. 5 years after treatment 8.3% of the original skeletal advancement and 29% of the dental advancement has vanished. Considering the amount of long-term skeletal relapse the procedure could be an alternative to BSSO for mandibular advancement in selected cases.

6.5 Ethical approval

Yes. Ethical approval was admitted by the Ethic Committee of the Kanton Zürich, Switzerland, number 593.

6.6 References

1. Codivilla A. On the means of lengthening in the lower limbs, the muscles and tissues which are shortened through deformity. *Am J Orthop Surg* 1905;2:353–69.
2. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. *Plast Reconstr Surg* 1992;89:1–8. [discussion 9–10].
3. Swennen G, Schliephake H, Dempf R, Schierle H, Malevez C. Craniofacial distraction osteogenesis: a review of the literature: Part 1: clinical studies. *Int J Oral Maxillofac Surg* 2001;30:89–103.
4. Ow A, Cheung LK. Skeletal stability and complications of bilateral sagittal split osteotomies and mandibular distraction osteogenesis: an evidence-based review. *J Oral Maxillofac Surg* 2009;67:2344–53.
5. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001;59:26–34. [discussion 34–25].
6. Triaca A, Minoretti R, Saulacic N. Mandibula wing osteotomy for correction of the mandibular plane: a case report. *Br J Oral Maxillofac Surg* 2010;48:182–4.

7. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Skeletal and dental stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:553–9.
8. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:560–5.
9. Joss CU, Triaca A, Antonini M, Kuijpers-Jagtman AM, Kiliaridis S. Neurosensory and functional evaluation in distraction osteogenesis of the anterior mandibular alveolar process. *Int J Oral Maxillofac Surg* 2012 Jul 19.
10. Triaca A, Minoretti R, Merz B. Treatment of mandibular retrusion by distraction osteogenesis: a new technique. *Br J Oral Maxillofac Surg* 2004;42:89–95.
11. Björk A, Skieller V. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. *Br J Orthod* 1975;4:53–64.
12. Dahlberg G. Statistical methods for medical and biological students. New York: Interscience Publications; 1940.
13. Baas EM, Pijpe J, de Lange J. Long term stability of mandibular advancement procedures: bilateral sagittal split osteotomy versus distraction osteogenesis. Int *J Oral Maxillofac Surg* 2011;41:137–41.
14. Vos MD, Baas EM, de Lange J, Bierenbroodspot F. Stability of mandibular advancement procedures: bilateral sagittal split osteotomy versus distraction osteogenesis. *Int J Oral Maxillofac Surg* 2009;38:7–12.
15. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg* 2009;67:301–13.
16. Peltomaki T. Stability, adaptation and growth following distraction osteogenesis in the craniofacial region. *Orthod Craniofac Res* 2009;12:187–94.
17. Hoppenreijs TJ, Freihofer HP, Stoelinga PJ, Tuinzing DB, van't Hof MA. Condylar remodelling and resorption after Le Fort I and bimaxillary osteotomies in patients with anterior open bite. A clinical and radiological study. *Int J Oral Maxillofac Surg* 1998;27:81–91.
18. Sesenna E, Raffaini M. Bilateral condylar atrophy after combined osteotomy for correction of mandibular retrusion. A case report. *J Maxillofac Surg* 1985;13:263–6.
19. Scheerlinck JPO, Stoelinga PJW, Blijdorp PA, Brouns JJA, Nijs MLL. Sagittal split advancement osteotomies stabilized with miniplates: a 2-5-year follow-up. *Int J Oral Maxillofac Surg* 1994;23:127–31.

20. McDonnell JP, McNeill RW, West RA. Advancement genioplasty: a retrospective cephalometric analysis of osseous and soft tissue changes. *J Oral Surg* 1977;35:640–7.

Chapter 7

Soft tissue stability after segmental distraction of the anterior mandibular alveolar process: a 5.5 year follow-up

C.U. Joss
A. Triaca
M. Antonini
S. Kiliaridis
A.M. Kuijpers-Jagtman

Int. J. Oral Maxillofac. Surg. 2013;42:345–51

Summary

Soft tissue changes were analysed retrospectively in 17 patients following distraction osteogenesis (DO) of the mandibular anterior alveolar process. Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated at T1 (17.0 days), after DO at T2 (mean 6.5 days), at T3 (mean 24.4 days), at T4 (mean 2.0 years), and at T5 (mean 5.5 years). Statistical analysis was carried out using Kolmogorov–Smirnov test, paired *t*-test, Pearson's correlation coefficient, and linear backward regression analysis. 5.5 years postoperatively, the net effect for the soft tissue at point B' was 88% of the advancement at point B while the lower lip (labrale inferior) followed the advancement of incision inferior to 24%. Increased preoperative age was correlated ($p < 0.05$) with more horizontal backward movement (T5–T3) for labrale inferior and pogonion'. Higher NL/ML' angles were significantly correlated ($p < 0.05$) to smaller horizontal soft tissue change at labrale inferior (T5–T3). The amount of advancement at point B was significantly correlated with an upward movement (T5–T3) of labrale inferior ($p < 0.01$) and stomion inferior ($p < 0.05$). It can be concluded that further change in soft tissues occurred between 2.0 and 5.5 years postoperatively. The physiological process of ageing and loss of soft tissue elasticity should be considered as possible reasons.

7.1 Introduction

The combination of orthodontic treatment and maxillofacial surgery aims to provide optimal function and the best aesthetic results for the patient. The clinician needs precise information to increase his ability to predict the surgical effect of skeletal displacement on the patient's overlying soft tissue profile. Commonly, in a twodimensional analysis the amount of change necessary to provide appropriate soft tissue profile change by maxillofacial surgery is determined by the use of ratios between the soft tissues and the underlying skeletal and dental base.

Little is known about the effect of mandibular DO on the change in shape and position of the soft tissue profile[1–3] when compared with bilateral sagittal split osteotomy (BSSO) for mandibular advancement.[4–9] Commonly used lateral cephalograms can only reproduce a twodimensional pre- and postoperative situation whereas in recent years there has been a trend in quantifying soft tissue profile changes using three-dimensional evaluation (i.e. optical laser surface scanners,[10] stereophotogrammetry with cameras,[11] or computed tomography assisted imaging[12]).

Recently, skeletal and soft tissue changes 2 years after DO of the anterior mandibular alveolar segment have been examined.[2,13,14] The net effect of the soft tissue at point B' was 100% of the advancement at point B while the lower lip (labrale inferior) followed the advancement of incision inferior to 46% examined 2.0 years postoperatively.[13] Skeletally, 5.5 years after DO the horizontal backward relapse measured 0.3 mm or 8.3% at point B and 1.8 mm or 29.0% at incision inferior.[14] To the authors' knowledge, evaluation of the soft tissue profile and its change in the long-term is lacking. The aim of the present study was to evaluate soft tissue changes 5 years after treatment in adult patients treated with DO of the anterior mandibular alveolar process and to relate it to different parameters.

7.2 Materials and methods

The study represents a follow-up of an initial sample of 33 patients published previously.[2,13] The initial patient sample consisted of 33 Caucasian patients (27 females and six males) aged 16.5–56.0 years (mean age 30.3 years, SD 10.7). Of these 33 patients, 17 patients could be re-examined. The follow-up group (T1) consisted of 17 Caucasian patients (14 females and three males); aged 16.5–56.0 years (mean age 29.8 years, SD 11.9). Ethical approval was obtained from the ethic committee of the Kanton Zürich, Switzerland (number 593). All subjects gave written, informed consent.

All patients were treated orthodontically by one orthodontist (MA) and underwent DO of the anterior mandibular alveolar process to correct a skeletal Class II and large overjet with or without incisor crowding at the Pyramide Clinic in Zürich, Switzerland in the years 1998–2004. The female patients in the follow-up group had a mean age of 31.7 years (17.1–56.0 years, SD 12.0 years) and the male patients 21.5 years (16.5–31.4 years, SD 8.6 years) at T1. The surgical procedure was performed by one experienced maxillofacial surgeon (AT); the technique has been published previously.[15,16] Patients receiving other surgical procedures simultaneously on the mandible and maxilla, such as genioplasty, BSSO, and Le Fort, were excluded. Syndromic or medically compromised patients were excluded. Five cephalograms were taken: the first on average 17.0 days before surgery (T1); the second (T2) between 0 and 12 days (mean 6.5 days) after the osteotomy and before any distraction was carried out; the third (T3) between 13 and 92 days (mean 24.4 days); the fourth (T4) between 0.9 and 3.7 years (mean 2.0 years), and the fifth (T5) between 2.7 and 8.3 years (mean 5.5 years) after distraction of the anterior mandibular alveolar process. The distraction was completed at T3 and the orthodontic treatment at T4. The position of the lower incisors was retained with a bonded only on canine to canine retainer. The DO procedure has been described previously.[15,16]

7.2.1 Cephalometric analysis

Soft tissue changes were evaluated on profile cephalograms taken with the teeth in the intercuspal position, and including a linear enlargement of 1.2%. The cephalograms were taken with the subject standing upright in the natural head position and with relaxed lips. The same X-ray machine and the same settings were used to obtain all cephalograms.

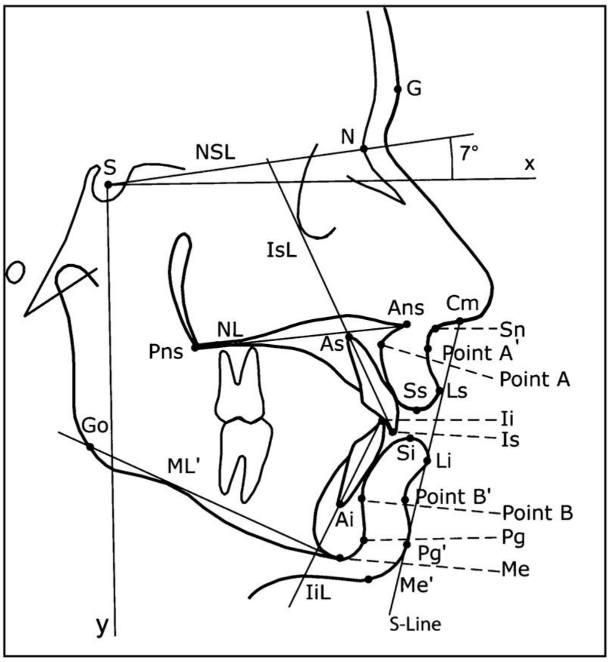

Figure 1. *Reference points and lines used in the cephalometric analysis. The coordinate system had its origin at point S (sella), and its x-axis formed an angle of 7° with the reference line NSL. G, glabella; S, sella; NSL, nasion-sella-line; N, nasion; x, horizontal reference plane; NL, nasal line; Cm, columella; Sn, subnasale; ILs, upper incisal line; Ans, anterior nasal spine; Pns, posterior nasal spine; As, apex superior; point A; point A', soft tissue point A; Ls, Labrale superior; Ss, stomion superior; Ii, incision inferior; Is, incision superior; Si, stomion inferior; Li, labrale inferior; Go, gonion; ML', mandibular line prime; Ai, apex inferior; point B; point B', soft tissue point B; Pg, pogonion; Pg', soft tissue pogonion; Me, menton; Me', soft tissue menton; S-Line; and y, vertical reference plane.*

The lateral cephalograms were scanned and evaluated with the Viewbox 3.11 program (dHal software, Kifissia, Greece). The conventional cephalometric analysis for T1, T2, T3, T4, and T5 was carried out by one author (CUJ) and included the reference points and lines shown in Fig. 1. Horizontal (*x*-values) and vertical (*y*-values) linear measurements were obtained by superimposing the tracings of the different stages (T2, T3, T4 and T5) on the first radiograph (T1), and the reference lines were transferred to each consecutive tracing. During superimposition, particular attention was given to fitting the tracings of the cribriform plate and the anterior wall of the sella turcica which undergo minimal remodelling.[17] A template of the outline of the mandible of the preoperative cephalogram (T1) was made to minimize errors for superimposing on subsequent radiographs.

Conventional cephalometric variables as well as the coordinates of the reference points were calculated by the computer program. The coordinate system had its origin at point S (Sella), and its x-axis formed an angle of 78 with the reference line NSL (Fig. 1). Overjet and overbite were calculated from the coordinates of the points Is (incision superior) and Ii (incision inferior).

The lateral cephalograms of T2 were only used to locate the cephalometric point, called the alveolar surgical anterior base (Asab) before postoperative distraction of the alveolar process was carried out. Asab is the most anterior and inferior point of the lower anterior segment resulting from the surgical osteotomy (Fig. 2). This cephalometric point was introduced to evaluate the movement (rotation vs. translation) of the lower anterior segment base in comparison to the lower incisors as the ratio $\frac{\text{Ii}(x\text{-value, T3}-\text{T2})}{\text{Asab}(x\text{-value, T3}-\text{T2})}$

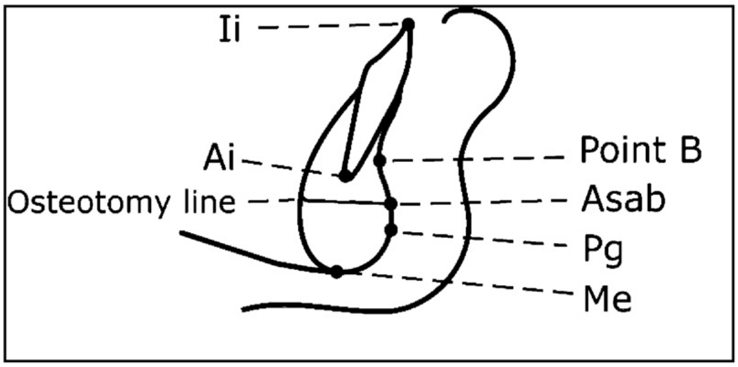

Figure 2. *Reference points used in the cephalometric analysis of the lower apical base in DOpatients. Ii, incision inferior; point B; Ai, apex inferior; Asab, apical surgical anterior base; Pg, pogonion; and Me, menton. Asab is the most anterior and inferior point of the lower anterior segment resulted by the surgical osteotomy; the reason for its introduction is given in the text.*

7.2.2 Error of the method

To determine the error of the method, 21 randomly selected cephalograms were retraced and re-analysed after a 2 week interval. Horizontal (*x*-values) and vertical (*y*-values) linear measurements were reobtained by superimposing the tracings of the different stages (T2, T3, T4 and T5) on the first radiograph (T1). The error of the method (si) was calculated with the formula $si = \sqrt{\sum d^2/2n}$
where *d* is the difference between the repeated measurements and *n* is the number of duplicate determinations.[18]

7.2.3 Statistical analysis

Statistical analyses were conducted using SPSS software (version 19.0, SPSS Inc., Chicago, IL, USA). Normal distribution was confirmed with the Kolmogorov–Smirnov test. The effect of treatment (i.e. the differences between the variables and co-ordinates at T3 and T1, T5 and T1, T5 and T3, T5 and T4) was tested with a paired *t*-test. The relationships between soft tissue and skeletal variables, age, and gender were analysed with the Pearson's product moment correlation coefficient and linear backward regression analysis. The drop-out analysis included the unpaired *t*-test to compare drop-outs with the remaining patients for age and cephalometric features at T1, T2, T3 and T4, and the χ^2 test for gender and age.

7.3 Results

7.3.1 Error of the method and drop-out analysis

The random errors are presented in Table 1. The measurement of the nasiolabial angle (Cm–Sn–Ls) and menton' (*x*-value) were excluded due to the increased random error. No systematic errors were found when the values were evaluated with a paired *t*-test.

No significant differences were found between the drop-outs and the remaining patients for age, gender and cephalometric features at T1, T2, T3 and T4.

Table 1. *Random errors (Si) of the cephalometric landmarks and variables.*

Variable	Si	Variable	Si	Reference point	Si (mm) X	Si (mm) Y
SNA (°)	1.14	Overjet (mm)	0.36	Incision sup.	0.48	0.21
SNB (°)	0.82	Overbite (mm)	0.53	Incision inf.	0.58	0.55
ANB (°)	0.48	Cm-Sn-Ls (°)	3.32	Point B	0.28	0.45
NSL/NL (°)	0.86	G-Sn-Pg' (°)	1.14	Asab	0.35	0.25
NSL/ML' (°)	1.01	Ls/Cm-Pg' (mm)	0.67	Pogonion	0.37	1.19
NL/ML' (°)	0.84	Li/ Cm-Pg' (mm)	0.49	Menton	0.89	0.45
IsL/NSL (°)	1.52			Labrale sup.	0.78	1.30
IsL/NL (°)	1.31			Stomion sup.	1.68	0.99
IiL/ML' (°)	1.39			Labrale inf.	1.07	1.01
IsL/IiL (°)	1.63			Stomion inf.	1.15	0.85
				Point B'	1.20	1.10
				Pogonion'	1.19	1.15
				Menton'	3.07	1.21

7.3.2 Horizontal and vertical changes

Table 2 shows the descriptive statistics for the selected cephalometric variables at T1 and T5. The mean changes, standard deviations, and ranges (horizontal and vertical direction) before surgery and during the subsequent observation periods are given in Tables 3 and 4.

Negative values imply a backward, and positive values a forward, movement of the point in the horizontal plane. Negative values imply an upward, and positive values a downward, movement of the point in the vertical plane.

Table 2. *Values of selected cephalometric variables at T1 (before surgery) and T5 (5.5 years after surgery).*

Variable	T1 Mean	T1 SD	T1 Range	T5 Mean	T5 SD	T5 Range
SNA (°)	80.9	3.7	73.1-85.7	80.0	2.8	74.0-84.4
SNB (°)	76.7	4.2	69.8-83.8	77.3	3.8	70.7-85.5
ANB (°)	4.2	2.2	0.3-7.1	2.7	3.0	-2.9-6.3
NSL/NL (°)	7.4	4.1	-1.9-15.0	7.6	3.7	0.1-13.0
NSL/ML' (°)	33.6	7.9	21.4-53.7	34.7	7.1	23.9-53.7
NL/ML' (°)	26.2	6.4	16.2-44.8	27.1	5.8	19.8-45.2
IsL/NSL (°)	109.3	9.8	81.7-120.5	105.0	7.1	91.3-117.0
IsL/NL (°)	116.7	9.4	91.0-126.7	112.6	6.2	99.0-121.8
IiL/ML' (°)	91.0	6.8	77.2-104.6	96.5	6.6	81.5-108.3
IsL/IiL (°)	126.2	14.0	106.9-157.3	123.8	6.6	81.5-108.3
Overjet (mm)	7.7	2.1	4.5-11.9	2.8	0.9	1.3-4.5
Overbite (mm)	4.4	1.7	1.0-7.3	3.0	1.5	0.2-5.5
Facial convexity (°)	15.3	6.9	6.4-32.0	13.2	6.6	-3.3-29.0
Upper lip to S-line (mm)	-2.3	2.7	-8.0-2.4	-5.0	3.1	-9.6-0.8
Lower lip to S-line (mm)	-1.9	3.7	-8.5-3.2	-3.4	3.3	-7.7-3.6

Facial convexity, G–Sn–Pg'; upper lip to S-line, Ls/Cm–Pg'; lower lip to S-line, Li/Cm–Pg'.

Table 3. *Changes (mm or°) in the variables and co-ordinates of the mandible and lower incisors as the immediate (T3–T1) and final (T5–T1) result of DO surgery.*

Variable or coordinate		T3-T1[1]				T5-T1[2]			
		Mean	*p*	SD	Range	Mean	*p*	SD	Range
Horizontal									
x-value (mm)	Incision sup.	1.1	**	1.4	-1.3-3.2	-0.4	ns	1.9	-4.1-3.0
	Incision inf.	6.2	***	2.5	-0.5-10.9	4.6	***	3.2	-1.6-11.5
	Point B	3.6	***	2.0	-0.21-7.6	3.2	***	2.3	-0.2-7.3
	Asab	2.2	***	2.1	-1.1-5.4	1.2	*	2.1	-2.2-4.7
	Pogonion	0.1	ns	1.0	-1.7-1.8	0.5	*	1.0	-0.8-2.4
	Labrale sup.	0.9	*	1.4	-1.3-3.8	-0.5	ns	1.3	-2.8-1.7
	Labrale inf.	3.8	***	2.6	0.1-8.7	1.1	ns	2.2	-2.4-5.7
	Point B'	5.4	***	2.1	1.9-10.5	2.8	***	2.2	-1.1-7.7
	Pogonion'	4.9	***	1.9	1.5-8.6	3.0	***	2.3	-0.6-7.3
	Menton'	4.6	***	2.9	-0.3-8.6	3.8	***	2.7	-0.7-8.8
Vertical									
y-value (mm)	Labrale sup.	1.4	*	2.1	-2.6-6.2	-0.6	ns	1.5	-2.9-1.9
	Stomion sup.	-0.6	ns	1.7	-4.5-1.7	0.8	*	1.3	-1.1-2.9
	Labrale inf.	0.7	ns	2.1	-2.8-4.2	-0.2	ns	2.3	-4.8-3.4
	Stomion inf.	0.5	ns	2.2	-3.6-7.2	0.3	ns	1.6	-3.8-2.6
	Point B'	3.5	***	3.3	-3.5-8.2	2.6	**	3.3	-2.8-7.3
	Pogonion'	0.2	ns	3.3	-6.9-5.8	0.2	ns	4.6	-9.7-8.5
	Menton'	0.9	ns	2.2	-3.9-4.7	0.5	ns	2.6	-3.6-5.5
Angular (°) and linear measurements (mm)									
	Facial convexity	-3.3	***	3.3	-7.8-3.7	-2.0	***	2.0	-7.2-0.9
	Ls to S-line	-1.1	**	1.4	-4.2-1.2	-2.6	***	1.5	-5.4-0.2
	Li to S-line	0.8	ns	2.1	-2.5-4.4	-1.5	**	1.7	-4.0-1.5
	Ii/Asab	1.8		7.5	-22.4-9.7				

Negative values imply a backward and positive values a forward movement of the point in the horizontal plane. In the vertical plane, negative values imply an upward and positive values a downward movement of the point.
T1, before surgery; T3, 24.4 days after surgery; T5, 5.5 years after surgery.
[1] *T3–T2 for Asab, Ii (x-value, T3–T2)/Asab (x-value, T3–T2) instead mean value the median was taken for this ratio and no paired t-test was possible because measured on a single occasion.*
[2] *T5–T2 for Asab.*
* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$.

7.3.3 Soft to hard tissue ratios

The net effect (T5–T1) in labrale inferior was 24% of the advancement in incision inferior. The corresponding value for point B' to point B was 88% and for labrale superior to incision inferior 11%.

7.3.4 Correlations and linear regression

In the period T5–T3, an increase in the patient's age was significantly correlated with a downward movement of the vertical or *y*-value of pogonion' (p = 0.014; R = 0.538). Increased patient's age was significantly correlated to a backward movement of the horizontal or *x*-values of labrale inferior (p = 0.045; R = 0.492) and pogonion' (p = 0.036; R = 0.512) in the period T5–T3.

Table 4. *Changes (mm, degree or ratio) in the variables and coordinates of the mandible and lower incisors as the relapse (T5-T3) and the long-term change (T5-T4) of DO surgery.*

	Variable or coordinate	T5-T3				T5-T4			
		Mean	*p*	SD	Range	Mean	*p*	SD	Range
Horizontal									
x-value (mm)	Incision sup.	-1.5	**	1.7	-5.4-1.2	0.1	ns	0.6	-1.6-0.9
	Incision inf.	-1.8	***	1.9	-5.4-0.6	-0.2	ns	0.6	-1.6-1.4
	Point B	-0.3	ns	1.3	-2.7-3.3	0.3	ns	0.7	-1.0-2.0
	Asab	-1.0	***	0.9	-2.4-1.1	0.1	ns	0.6	-1.1-1.5
	Pogonion	0.4	ns	1.0	-1.6-2.9	-0.1	ns	0.7	-1.0-2.0
	Labrale sup.	-1.3	**	1.8	-4.5-2.9	-0.2	ns	0.7	-1.4-1.7
	Labrale inf.	-2.7	***	2.0	-9.2- -0.4	-0.6	ns	1.2	-72.9-1.4
	Point B'	-2.7	***	1.4	-5.0-0.6	-0.3	ns	0.9	-1.9-1.0
	Pogonion'	-1.9	***	1.8	-6.8-1.5	-0.1	ns	1.1	-2.1-2.1
	Menton'	-0.8	ns	2.5	-7.9-2.9	0.5	ns	2.6	-4.2-4.8
Vertical									
y-value (mm)	Labrale sup.	-2.0	***	1.8	-5.2-1.1	-1.0	*	1.6	-3.3-2.2
	Stomion sup.	1.4	***	1.4	-0.6-5.1	0.7	*	1.1	-1.6-3.0
	Labrale inf.	-0.9	ns	2.5	-6.3-2.5	-1.0	ns	2.9	-6.4-4.2
	Stomion inf.	-0.2	ns	2.4	-5.4-2.6	-0.4	ns	2.2	-5.8-3.1
	Point B'	-1.0	ns	2.0	-5.3-2.3	-0.5	ns	2.1	-5.9-2.6
	Pogonion'	0.0	ns	3.1	-6.0-8.0	-0.5	ns	2.8	-5.4-4.4
	Menton'	-0.4	ns	1.9	-3.6-3.8	-0.6	ns	2.2	-4.4-3.4
Angular (°) and linear measurements (mm)									
	Facial convexity	1.3	ns	2.9	-5.3-4.8	0.3	ns	2.4	-3.3-3.9
	Ls to S-line	-1.5	**	1.7	-4.8-1.1	-0.4	ns	1.2	-3.3-2.1
	Li to S-line	-2.3	***	2.0	-6.6-0.0	-1.4	**	1.7	-5.2-0.9

Table 5. *Linear regression. Dependent variable: Point B' (x-value) T5-T3.*

Model	B	95% Confidence Interval for B		Significance	R	R^2
		Lower Bound	Upper Bound			
(Constant)	5.578	-1.801	12.956	.125	0.791	0.626
Age	-.022	-.067	.024	.324		
IiL/ML' at T1	-.082	-.165	.001	.053		
$\frac{Ii(X-value, T3-T2)}{Asab(X-value, T3-T2)}$	-.015	-.051	.020	.358		
Point B (*x*-value) T5-T3	.618	.169	1.066	.011		

Table 6. *Linear regression. Dependent variable: labrale inf. (x-value) T5–T3.*

Model	B	95% Confidence Interval for B		Significance	*R*	R^2
		Lower Bound	Upper Bound			
(Constant)	.328	-2.098	2.754	.773	0.721	0.520
Age	-.070	-0.148	.008	.075		
NL/ML' at T1	.013	-.717	.742	.971		
Incision inf. (*x*-value) T5-T3	.049	-.573	.671	.866		
Incision sup. (*x*-value) T5-T3	.599	-.098	1.296	.086		

The amount of advancement (T3–T1, *x*-value) at point B was significantly correlated to an upward movement of the *y*-values of labrale inferior (p = 0.006; R = 0.637) and stomion inferior (p = 0.019; R = 0.561). The amount of advancement (T3–T1, *x*-value) at incision inferior and the ratio $\frac{\text{Ii}(x\text{-value, T3}-\text{T2})}{\text{Asab}(x\text{-value, T3}-\text{T2})}$ was not significantly correlated to the amount of change (T4–T3, *x*- and *y*-values) measured at soft tissue points.

A preoperative larger NL/ML' angle (T1) was significantly correlated (p = 0.044; R = 0.494) with a smaller horizontal change at labrale inferior (T5–T3, *x*-value). No significant correlations were found between the change at T5–T3 of all soft tissue points and gender.

Correlations were significant between horizontal (*x*-value) hard to soft tissue movements for point B and point B' (T3–T1: p = 0.003; R = 0.681; T5–T3: p = 0.017; R = 0.569), for incision inferior and labrale inferior (T3–T1: p = 0.005; R = 0.649; T5–T3: p = 0.092; R = 0.422), for incision inferior and labrale superior (T3–T1: p = 0.067; R = 0.454; T5–T3: p = 0.012; R = 0.592).

Results for the linear regression analysis are shown in Tables 5 and 6.

7.4 Discussion

This research represents the continuation of the authors' previous studies[2,13] on soft tissue changes in patients undergoing DO of the anterior mandibular alveolar process. A uniform group of 17 patients was obtained as patients with additional surgical procedures of the mandible (genioplasty, BSSO) and maxilla were excluded. An evaluation of alveolar segmental DO without the influence of other confounding surgical procedures was thus possible. The effect of growth as a confounding factor was excluded by examining only skeletally mature patients (mean age 30.3 years, SD 10.7). An inherent problem of long-term studies is the loss of patients for follow-up examinations. The authors performed a drop-out analysis for all patients for whom they had no records at T5 by comparing their cephalometric variables at all other time points with the remaining patients. The analysis showed that the dropouts and the remaining patients were comparable, minimizing the risk of bias due to patients lost to follow-up.

In the present study on 17 patients, point B' followed point B to 88% and lower lip study on facial growth Forsberg[19] reported that from the age of 24 to 34 years the nose grew forward, the lips retruded, and soft tissue pogonion moved backwards. This agrees with the authors' findings when comparing their long-term data for 5.5 years with that found earlier at 2.0 years after surgery. The net effect of point B' and the labrale inferior decreased over time. Another reason for the difference in point B' and labrale inferior could be the missing data from the 16 patients who could not be re-examined for the 5.5 year follow-up.

5.5 years postoperatively, correlations were found between patient's age and changes (T5–T3) of different soft tissue points. An increase in the patient's age was significantly correlated with a downward movement of the vertical or y-value of pogonion' ($p < 0.05$) and to a backward movement of the horizontal or x-values of labrale inferior and pogonion' (both $p < 0.05$). Thus it is possible that soft tissue strength was reduced in this patient sample by further ageing.

To the authors' knowledge, there is no other published data on adult patients after DO of the anterior mandibular alveolar process which makes a direct comparison of the data impossible. Soft tissue changes compared to skeletal changes were reported after DO for mandibular elongation in children with hypoplastic mandibles evaluated on lateral cephalograms[3] or photographs combined with posteroanterior cephalograms.[1] Melugin *et al*.[3] found in 27 paediatric patients that point B' followed point B and pogonion' to pogonion to 90% at post-consolidation. The magnitude of the advancement, and age, and sex of the patients had no effect on these ratios. In contrast, Joss *et al*.[20] systematically reviewed the effect of BSSO with rigid internal fixation (RIF) or wire fixation (WF) for mandibular advancement on soft tissue ratios. Short- and long-term ratios for lower lip to lower incisor in RIF or WF can be described as 50%. No difference between short- and long-term ratios for point B' to point B and pogonion' to pogonion could be observed. It could be characterized as a 1 to 1 ratio. The exception was that pogonion' to pogonion with RIF tended to be higher than a 1 to 1 ratio in long-term results. The upper lip showed mainly retrusion but high variability. The ratios for the lower lip and point B' found in that review on BSSO for mandibular advancement in RIF and WF2 are in accordance with the present authors' earlier data 2.0 years after surgery. The data from the present study show that point B' followed point B not in a 1 to 1 ratio but only to 80% and labrale inferior only to 24%.

The amount of advancement (T3–T1, *x*-value) at point B was significantly correlated with an upward movement of the *y*-values of labrale inferior ($p < 0.01$) and stomion inferior ($p < 0.05$). Joss *et al*.[6] could not show any correlation between the relapse in soft tissue and the amount of advancement at point B in their long-term study on hard and soft tissue change in patients with BSSO for mandibular advancement and RIF. It is interesting to note that the amount and type (rotational vs. translational) of advancement in the same patient population examined earlier were not correlated with the amount of skeletal relapse measured at incision inferior or point B.[2,14]

An important short-term effect of maxillofacial surgery and a confounding variable is postoperative swelling (oedema from retraction, irritations, and inflammation). For this reason, the immediate shortterm soft tissue profile changes measured on lateral cephalograms always include swelling and thickness of the orthodontic brackets.[20] Furthermore, RIF in the form of the miniplates used in the present study adds more volume to the labial surface of the chin bone which affects the soft tissue profile and limits the exact location of the cephalometric landmarks. Miniplates were present at T2 and T3 but surgically removed before T4 in all but one patient. The removal of the miniplates could have led to a slight increase in soft tissue change (T4–T3) of point B'.[13] In addition, the interface of the surgical section of the anterior aspect of the symphysis was more susceptible to resorption and bony remodelling.[2,14]

In conclusion, this long-term follow-up of 5.5 years found that further change in soft tissues occurred between 2.0 and 5.5 years postoperatively regarding point B' and labrale inferior. The physiological process of ageing and loss of soft tissue elasticity should be considered as possible reasons.

7.5 Acknowledgements

This article is dedicated to the memory of Dr. Med. Dent. Michele Antonini who passed away in September 2009. He will always be remembered for his contribution to orthodontics.

7.6 Ethical approval

Yes. Ethical approval was admitted by the Ethic Committee of the Kanton Zürich, Switzerland, number 593.

7.7 References

1. Altug-Atac AT, Grayson BH, McCarthy JG. Comparison of skeletal and soft-tissue changes following unilateral mandibular distraction osteogenesis. *Plast Reconstr Surg* 2008;121:1751–9.
2. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Skeletal and dental stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:553–9.
3. Melugin MB, Hanson PR, Bergstrom CA, Schuckit WI, Gerard Bradley T. Soft tissue to hard tissue advancement ratios for mandibular elongation using distraction osteogenesis in children. *Angle Orthod* 2006;76:72–6.

4. Alves PV, Mazucheli J, Vogel CJ, Bolognese AM. How the lower face soft tissue changes after mandibular advancement or setback. *J Craniofac Surg* 2008;19:593–8.
5. Dolce C, Hatch JP, Van Sickels JE, Rugh JD. Five-year outcome and predictability of soft tissue profiles when wire or rigid fixation is used in mandibular advancement surgery. *Am J Orthod Dentofacial Orthop* 2003;124:249–56. [quiz 340].
6. Joss CU, Thuer UW. Stability of the hard and soft tissue profile after mandibular advancement in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2008;30:16–23.
7. Mobarak KA, Espeland L, Krogstad O, Lyberg T. Soft tissue profile changes following mandibular advancement surgery: predictability and long-term outcome. *Am J Orthod Dentofacial Orthop* 2001;119:353–67.
8. Pangrazio-Kulbersh V, Berger JL, Kaczynski R, Shunock M. Stability of skeletal Class II correction with 2 surgical techniques: the sagittal split ramus osteotomy and the total mandibular subapical alveolar osteotomy. *Am J Orthod Dentofacial Orthop* 2001;120:134–43.
9. Thüer U, Ingervall B, Vuillemin T. Stability and effect on the soft tissue profile of mandibular advancement with sagittal split osteotomy and rigid internal fixation. *Int J Adult Orthodon Orthognath Surg* 1994;9:175–85.
10. Nkenke E, Vairaktaris E, Kramer M, Schlegel A, Holst A, Hirschfelder U, et al. Threedimensional analysis of changes of the malar-midfacial region after LeFort I osteotomy and maxillary advancement. *Oral Maxillofac Surg* 2008;12:5–12.
11. Hajeer MY, Ayoub AF, Millett DT. Threedimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery. *Br J Oral Maxillofac Surg* 2004;42:396–404.
12. Terajima M, Yanagita N, Ozeki K, Hoshino Y, Mori N, Goto TK, et al. Three-dimensional analysis system for orthognathic surgery patients with jaw deformities. *Am J Orthod Dentofacial Orthop* 2008;134:100–11.
13. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:560–5.
14. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Skeletal and dental stability of segmental distraction of the anterior mandibular alveolar process. A 5.5-years follow-up. *Int J Oral Maxillofac Sur*g 2012, http://dx.doi.org/10.1016/j.ijom.2012.10.019.

15. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001;59:26–34. [discussion 34-25].
16. Triaca A, Minoretti R, Merz B. Treatment of mandibular retrusion by distraction osteogenesis: a new technique. *Br J Oral Maxillofac Surg* 2004;42:89–95.
17. Björk A, Skieller V. Growth of the maxilla in three dimensions as revealed radiographically by the implant method. *Br J Orthod* 1975;4:53–64.
18. Dahlberg G. Statistical methods for medical and biological students. New York: Interscience Publications; 1940.
19. Forsberg CM. Facial morphology and ageing: a longitudinal cephalometric investigation of young adults. *Eur J Orthod* 1979;1:15–23.
20. Joss CU, Joss-Vassalli IM, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue profile changes after bilateral sagittal split osteotomy for mandibular advancement: a systematic review. *J Oral Maxillofac Surg* 2010;68:1260–9.

Chapter 8

General discussion

8.1 Introduction

Mandibular lengthening by gradual distraction takes advantage of the patient's innate physiological healing and growth potential.[1] The initial expectations were that not only the skeleton but also the surrounding soft tissue and musculature would be positively affected by the DO. The expected volumetric increase of soft tissue and musculature would benefit mostly syndromic patients where an inherent lack of soft tissue and musculature is present. However, it seems that the muscular changes associated with DO are largely characterized by adaptation and regeneration rather than hyperplasia or volumetric increase.[2]

Since the clinical introduction of DO in the field of maxillofacial surgery by McCarthy and co-workers in 1998[1] on patients with syndroms, the field of indication has markedly increased. In 2001 and 2004, surgical guidelines of DO of the anterior mandibular alveolar process were first published by Triaca *et al.*[3,4] but a scientific basis of the outcome was missing up to now.

The aim of the research project described in this thesis was to gain deeper insight into the outcome and possible secondary effects of distraction osteogenesis (DO) of the anterior mandibular alveolar process. Different surgical and non-surgical approaches are known in literature to correct Class II malocclusions at different ages. We mainly focused on a new surgical concept of DO of the anterior mandibular alveolar process in adult patients. The patients consisted of consecutively treated patients by the same orthodontist and maxillofacial surgeon.

In this general discussion, we will discuss the results of these studies in a wider perspective, especially the short- and long-term changes at the level of the hard and soft tissues. The chapter ends with directions for future research.

8.2 Outcome measurement

In order to evaluate clinically the treatment outcome and possible side effects, only consecutive patients with skeletal Class II malocclusion and large overjet with or without incisor crowding who underwent DO of the anterior mandibular alveolar process were included. Patients simultaneously receiving other surgical procedures on the mandible and maxilla, such as genioplasty and bilateral sagittal split osteotomy (BSSO), as well as syndromic or medically compromised were excluded.

8.2.1 Skeletal and dental changes and stability

Skeletal and dental relapse is an unfavourable side effect of maxillofacial surgery leading to a partial or very rarely to a complete setback of the distracted segment. Furthermore, the delivery of a surgical intervention depends on different characteristics by the surgeon such as skill, personal preferences and knowledge. Both, chapter 3 and 7 investigated the skeletal and dental changes and stability as well as factors influencing the outcome after DO of the anterior mandibular alveolar process.

It was reassuring to find out that the amount of skeletal relapse at point B was rather small with 8% 5.5 years after DO, which was less than the 19% reported 2 years after DO. Even though the drop-out analysis showed that there was no significant difference between the drop-out and the remaining patients regarding cephalometric parameters, age and sex it cannot be excluded that the loss of patients from initially n=33 to n=17 partially contributed to that fact. A possible reason for skeletal relapse could be that point B is next to the interface of the surgical section of the anterior aspect of the symphysis. It was reported that parts next to surgical osteotomies are highly susceptible to resorption and bony remodeling.[5] Anyhow, the border of the segment needs to be remodelled to smooth the contour and aspect of the anterior symphysis.

The skill of the surgeon in maxillofacial surgery has often been emphasized as an important, yet extremely difficult to measure, element affecting the outcome of a surgical intervention.[6] In this thesis, the same experienced surgeon operated on all evaluated patients of the same ethnic group (Caucasians). The present patients have all been treated by the same orthodontist to reduce bias in patient selection, surgical and orthodontic treatment procedures, and orthodontic treatment modalities such as torque control, intrusion and extrusion of lower incisors. Furthermore, the evaluation bias could be limited as the researcher was not involved at any stage in treatment of the patients, while the surgeon and orthodontist were not involved in the evaluation. However, blinding of the investigator and patient to the type of intervention was not possible and is a source of additional bias.

Unfortunately, the present cohort treatment outcome could only be evaluated on the basis of 2D cephalometry. The only 3D records were plaster dental casts. This resulted from an unavailability of 3D alternatives when the first records were taken from the years 1998 to 2004. Possible improvements in study design and limitations for further research are addressed at the end of this chapter.

We could not compare our results with others as, to our knowledge, there are no studies published on DO of the mandibular anterior alveolar process on stability. There are some comparing conventional mandibular advancement with a BSSO with DO. Vos *et al.*[7] could not show retrospectively any significant skeletal differences in nonsyndromic adult patients treated for mandibular advancement either with DO (BSSO type) or BSSO 10–49 months after surgery. Recently in a follow-up on the same patients, Baas *et al.*[8] also did not find any difference between the two groups 46-95 months post-operatively in their study.

Interesting is the comparison with the skeletal relapse rate found in our studies with those found in alternative treatment options such as the BSSO. A systematic review on BSSO for mandibular advancement[6] showed a large variability in long-term relapse (>1.5 years) at point B with bicortical screw fixation from 2 to 50.3% and with miniplates between 1.5 and 8.9%. It can be concluded that skeletal relapse rate after DO of the mandibular anterior alveolar process is at least comparable if not better than those values published on BSSO for mandibular advancement.

The amount of dental relapse at incision inferior was quite high with 29% 5 years after DO and 25% reported 2 years after DO. Overcorrection of the overjet achieved by the DO could be an important reason for dental relapse. An edge-to-edge incisal position or negative overjet immediately after DO had to be corrected with Class III elastics and retroclination of the incisors post-surgically. Furthermore, the DO creates space distal of the canines while crowding is still present in the incisor region. Incisor alignment is carried out in this newly generated space to prevent further proclination or round tripping. For this reason, it is possible that incision inferior moves further posteriorly by orthodontic movement.

Two different types of distractors were used in these studies to influence the vector of distraction (rotational vs. translational movement). The hinge plate allows a more rotational and the base-distractor a more translational movement of the anterior mandibular alveolar segment. A ratio was created between the tip of the lower incisor and a newly defined point at the antero-caudal base of the surgical segment to elucidate the type of distraction of all patients. Out of the 33 patients examined, a translation movement of the anterior mandibular process was seen in 6 and a rotational movement in the 27 patients.

The distraction procedure of the present patients included in this thesis has been performed using a dental-borne device whereas the molars were used as anchorage teeth, while the front teeth had to transmit the distraction forces to the alveolar segment. In fact, it would be preferable to have less rotational movement to reduce lower incisor proclination and possible “overloading” of the periodontal tissue. A promising strategy would be to improve the design of a bone-born base distractor to have it more suitable for patients with impaired periodontal health or a very thin symphysis.

A new innovation of a bone born-distractor was recently described to reduce the risk of increased dental tipping after DO.[9] It was the object to find a more accurate prediction of the centre of rotation to determine the final inclination of the front-block segment at the end of the distraction process. Since the first publications of Triaca *et al.* 3 other surgical concepts have been presented to enhance the DO procedure of the anterior mandibular alveolar process.[10,11] Zeeman *et al.*[10] introduced their concept of “hybrid distraction” of the anterior mandibular process where in a first step the apical base of the alveolar front-block segment is positioned anteriorly to reduce the inclination of the lower incisors and canines. The gaps are then grafted with an allogenic hydroxyapatite cancellous bone block. In a second step, the anterior mandibular alveolar process was distracted after a latency phase of 11 days. However, the similar one-stage approach of the anterior mandibular apical base augmentation without any additional DO was reported already in 2005 by Brusati and Giannì.[12]

The amount and type of surgical advancement had no influence on the amount of skeletal and dental relapse 2 years and 5.5 years after DO. This could be an advantage when comparing to the BSSO for mandibular advancement. In BSSO a positive correlation between the amount of mandibular advancement and the amount of relapse is normally seen. It was demonstrated that advancements of more than 6-7 mm predispose to horizontal relapse.[6] The gradual distraction of the alveolar process with its surrounding soft tissue envelope instead of one-step correction by BSSO could thus be beneficial to prevent short- and long-term skeletal and dental relapse. Even though larger advancements by DO of the anterior mandibular alveolar process are possible, the majority of the patients had skeletal advancements of about 4 to 6mm measured at point B. From an orthodontic point of view, we should keep in mind that at the end of DO the occlusion also has to fit again. The canines will occlude in an Angle Class I and the first molars should stay in an Angle Class II occlusion. Spaces created by larger advancements need to be closed by implant placement what increases the costs of the whole treatment.

In contrast to relapse patterns after a BSSO for mandibular advancement where a large mandibular plane angle (NL/ML') is often correlated with increased horizontal relapse,[6] it was surprising to find that in our patients with DO a larger mandibular plane angle was significantly correlated with a smaller relapse. It is possible that patients with a hyperdivergent facial pattern have a lower muscular tonus and thus fewer relapses.

The proper seating and control of the proximal segment is an important factor in the immediate relapse in BSSO but does not play a role in DO of the anterior mandibular alveolar process. Progressive condylar resorption is a possible side effect of the TMJ after mandibular surgery and is related to long-term relapse. Target groups for condylar resorption are young women with a high mandibular plane angle.[13,14] DO of the mandibular anterior alveolar process could be a valid alternative and might be of great benefit to prevent the biomechanical side effects on the mandibular condyle that can occur after BSSO or mandibular DO.

8.2.2 Soft tissue profile changes

An accurate prediction of the postoperative facial profile is an essential step in the treatment planning process for combined surgical orthodontic therapy.[15] Besides the conventional lateral cephalogram for 2-dimensional analysis, newer methods for quantifying the soft tissue profile, such as optical laser surface scanners,[16,17] stereophotogrammetry with 2 or more cameras,[18,19] or computer tomography-assisted imaging,[20,21] exist for 3-dimensional analysis. Anyhow, most clinicians in daily practice still use the 2-dimensional approach to predict the effect of maxillofacial surgery on the soft tissue profile as it is presented in chapters 3 and 5.

Calculating ratios between the movement of the hard tissue and soft tissue is a simple and effective method to quantify soft tissue profile changes after surgery. These ratios are the basis of prediction software programs used to guide the surgeon, orthodontist, and patient in their decision-making process. 2.0 and 5.5 years post-operatively, the net effect of the soft tissue at point B' was 100% and 88% of the advancement at point B whilst the lower lip (labrale inferior) followed the advancement of incision inferior to 46% and 24%, respectively. This shows that the soft tissues continued to change between 2.0 and 5.5 years postoperatively. An important short-term effect of maxillofacial surgery and a confounding variable is post-operative swelling (oedema from retraction, irritations, or inflammation). For this reason, the immediate short-term soft tissue profile changes measured on lateral cephalograms always include swelling and thickness of the orthodontic brackets.[22] Rigid internal fixation in the form of the miniplates used in our studies adds more volume to the labial surface of the chin bone which affects the soft tissue profile and limits the exact location of the cephalometric landmarks immediately after DO. However, miniplates were no more present 2.0 and 5.5 years post-operatively.

The physiological process of ageing and loss of soft tissue elasticity were considered as possible reasons for the decrease in soft tissue net effects in long-term. This could be illustrated by the fact that increased preoperative age was correlated with more horizontal backward movement for labrale inferior and pogonion' at 5.5 years post-operatively.

In his longitudinal survey on facial growth Forsberg[23] already reported that from the age of 24 to 34 years the nose grew forward, the lips retruded, and soft tissue pogonion moved backwards.

The evaluations in this thesis present the first results published for DO of the anterior mandibular alveolar process. The changes in shape and position of the overlying soft tissues in patients with Class II malocclusions has been evaluated mainly for BSSO with mandibular advancement[24-28] and less frequently for mandibular DO.[29,30]

In our systematic review[22] on soft tissue changes after BSSO for mandibular advancement, short- and long-term ratios for lower lip to lower incisor in rigid internal fixation (RIF) or wire fixation (WF) can be described as 50%, i.e. the lower lip only follows half the surgical advancement of the mandible measured at the tip of the lower incisor No difference between short- and long-term ratios for point B' to point B and pogonion' to pogonion could be observed. It could be characterised as a 1 to 1 ratio. The upper lip mainly showed retrusion but high variability.[22] It was interesting to see that there is almost no difference in the ratios for the lower lip and point B' when comparing the ratios of DO of the anterior mandibular alveolar process to the ratios found in this review on BSSO for mandibular advancement at 2.0 years post-operatively. However, the net effect of point B' and the labrale inferior decreased over time from 2.0 to 5.5 years post-operatively.

8.2.3 Craniomandibular function and neurosensory disturbances

Besides the clinical benefits of DO complications such as TMJ problems and neurosensory disturbances of the inferior alveolar nerve might be possible. Chapter 7 addressed the possible side effects on craniomandibular function and neurosensory disturbances after DO of the mandibular anterior alveolar process An overview of possible side effects after DO of the anterior mandibular alveolar process is given in Table 1.

Initial concerns on the TMJ after DO of the mandible was that the compressive force of the distraction leads to posterior displacement of the condyle and thus to TMJ pathology. McCormick *et al*.[31] could show in a canine model that a DO induces a minimal amount of condylar flattening with thinning of the condylar cartilage. This morphological change was transient and completely reversible. Clinically, it was shown in craniofacial anomalies with bilateral and unilateral mandibular DO that the expanded condyles had a nearly normal shape, size and configuration. The contralateral condyles did not show any deformational changes.[32] Up to now it was not known if the DO of the anterior mandibular alveolar process is a safe method.

Table 1. *Overview of possible side effects after DO of the anterior mandibular alveolar process.*

Possible side effect	Comment
Neurosensory disturbances of the inferior alveolar nerve (Chapter 5).	Not confirmed by this thesis.
Craniomandibular function and TMJ disorders (Chapter 5).	Not confirmed by this thesis.
Skeletal relapse and post-operative changes (Chapters 3 and 6).	The long-term backward skeletal relapse at point B is 8.3%. DO showed to be a stable maxillo-facial procedure.
Soft tissue relapse and post-operative changes (Chapters 4 and 7).	The long-term net effect of point B' was 88% and of the lower lip 24%. The physiological process of ageing and loss of soft tissue elasticity are a possible reason for further changes in soft tissue.
Gingival recessions of lower incisors due to surgical proclination of the alveolar process.	To be examined in the future.
Gingival recessions and periodontal problems of teeth adjacent to the osteotomy side.	To be examined in the future.
Root damage and resorption of teeth adjacent to the osteotomy side.	To be examined in the future.
Devitalisation and ankylosis of teeth adjacent to the osteotomy side.	To be examined in the future.

Our retrospective study design contained a comparison of the surgically treated DO patients with a control group of orthodontically treated patients to overcome the disadvantage of missing presurgical and immediate post-surgical follow-ups. Craniomandibular function was comparable to non-surgical controls: the range of mandibular motion, TMJ dysfunction such as clicking, crepitus, muscular pain, and deviation on opening were normal and similarly distributed in both groups.

In general, a direct comparison with studies evaluating the side effects after DO of the mandible is difficult. Unfortunately, studies examining healthy non-syndromatic patients are still rare in literature. Presurgical neurosensory and craniomandibular function or regenerative potential of the inferior alveolar nerve in patients with syndroms (hemifacial microsomia, Nager, and Treacher Collins) are questionable.[33]

Nevertheless a comparison with studies on BSSO for mandibular advancement is possible. Minor changes were found in TMJ signs such as clicking or pain before and after BSSO surgery[34-36] whereas others found an improvement[37] or impairment.[38] The DO of the anterior mandibular alveolar process does seem to be neither more advantageous nor disadvantageous regarding this comparison with the BSSO. However, it can be argued that DO of the anterior mandibular alveolar process might be beneficial to prevent biomechanical side effects on the mandibular condyle as it was shown after BSSO for mandibular advancement and progressive condylar resorptions.[13,14]

Neurosensory changes in the alveolar nerve were evaluated mainly in animal studies after DO of the whole mandible.[39-42] A distraction rate of 1 mm/day appears to be relatively safe for the inferior alveolar nerve and the nerve tissue seems to have the ability to adapt to the gradual stretching due to DO within physiological limits.[39,40]The main problem and question seems to be more the site and technique of the osteotomy for distraction to prevent nerve injuries.

The osteotomy design presented by Triaca *et al*.[3] avoids stretching and direct contact with the inferior alveolar nerve, which seems to be the major reason for the absence of neurosensory problems after DO of the mandibular anterior alveolar segment. Vertical osteo-tomies are made mostly between the canine and first premolars (less often between the lateral incisors and canines) and therefore anteriorly to the exit of the inferior alveolar nerve. A horizontal osteotomy is made about 5 mm inferior to the apices of the teeth to prevent devitalisation.

Neither gender nor age, the amount of advancement, and relapse at point B or incision inferior did show any correlation with craniomandibular function and neurosensory impairment.

In a prospective study on 5 patients who underwent vertical posterior body osteotomy or BSSO for mandibular distraction, Whitesides and Meyer concluded that all 10 nerves showed improvement of function as measured by 2-point discrimination, response to painful stimulus, and moving brush stroke identification 1 year after surgery.[43]

The DO of the anterior mandibular alveolar process seems to be advantageous regarding neurosensory impairment when compared to the findings after BSSO for mandibular advancement. It has been demonstrated that stretching of the inferior alveolar nerve in BSSO with large mandibular advancement could result in increased loss of neurosensensory function.[44]

8.3 Clinical relevance and perspectives for future orthodontic research

In general, the findings of this thesis were very promising regarding overall stability and secondary effects after DO of the anterior mandibular alveolar process. It could be shown in this thesis that this new concept is a safe possibility to correct surgically retrognathic mandibles. A continuation of this surgical approach is preferable. However, we should continue to ponder on the earlier discussed changes in distractor design to decrease the proclination of the incisors and to improve the advancement of the base of the anterior alveolar segment. Considering the methodological problems faced by researchers, it is likely that future research will not be able to assess outcomes through a randomized controlled clinical trial (RCT).

RCT are generally considered the gold standard to establish today the efficacy of an intervention. The advantage of an RCT is that compared groups are balanced regarding various types (known and unknown factors) of biases influencing the outcome. For this reason, RCTs are relatively rarely performed in surgery in comparison with other medical fields.[45] Nevertheless, RCT assessing surgical interventions are challenging to undertake because of the random allocation of participants, the masking of the patients and maxillo-facial surgeon which is often difficult or impossible.[46]

Alternatively, it is preferable for further research on DO of the anterior mandibular alveolar process to establish prospective cohort study design when an RCT cannot be performed.[47] However, one of the methodological shortcomings of this design would be the lack of randomization of patients into groups with and without surgery or extraction of premolars, respectively.

The tendency of evaluating hard and soft tissue before and after surgery is heading towards a three-dimensional analysis. Permanent efforts were and are undertaken to enhance the clinical utilisation and to combine the cone beam computed tomography (CBCT) applications with other 3D applications to finally result in a virtual 3D patient head. Further technical developments and refinements in CBCT devices and software programs aim to reduce the radiation dose and eliminating artefacts in the part of the CBCT scan containing the teeth. An increasing availability and number of CBCT on the market and in daily practice indicates this trend.

CBCT was first described in 1978[48] and it took twenty more years, in 1998, to have it finally introduced into the oral and maxillo-facial region[49] whereby it expanded the diagnostic possibilities for the orthodontic and maxillo-facial patient. On the other hand, there is still little evidence that the use of CBCT in orthodontics offers better treatment planning or results in better treatment outcome than do conventional imaging modalities.[50] However, patients where disturbed facial growth is present such as extreme Class II and III malocclusions, craniofacial syndroms or clefts of the lip and palate might particularly benefit from further 3D diagnostic tools.

Nevertheless, it would be very interesting for further research to have finally the third dimension taken into account when evaluating the hard and soft tissue outcome after DO of the anterior mandibular alveolar process. It is possible that the only records needed for the orthodontic patient's treatment planning and treatment simulation will be a CBCT scan with a colour 3D photograph of the patients face. CBCT and three dimensional (3D) stereophotogrammetry were already used to compare the 3D skeletal and soft tissue changes caused by BSSO one year after a mandibular advancement.[19] 3-dimensional CBCT constructed and superimposed models were successfully tested for accuracy and reproducibility[51] or used to evaluate soft tissue changes following surgically assisted rapid maxillary expansion (SARME).[52]

Besides the 3D analysis of the patient another up-coming topic is the change in prediction of the soft tissue profile. Predicting post-surgery soft tissue response after maxillo-facial surgery as a simple ratio between the underlying bone and the soft tissue will probably change more towards multivariate statistical methods of forming prediction equations such as the ordinary least squares method (OLS) and the partial least squares method (PLS).[53] The accuracy shows to improve when including as many predictors (independent variables) as possible into multiple regression analysis to increase the accuracy instead of using a simple proportional analysis or a simple regression analysis.[54] This statistical technique has been referred to as the conventional OLS method. The PLS method is a multivariate approach which involves multiple predictors and multiple response variables simultaneously taken into account that the soft tissue response at a specific point is highly dependent on its adjacent soft tissue behaviour.

Further research may hopefully proof the added benefit of 3D imaging on the planning of treatment procedures, its progression, the final outcome and long-term changes.

8.4 References

1. McCarthy JG, Schreiber J, Karp N, Thorne CH, Grayson BH. Lengthening the human mandible by gradual distraction. *Plast Reconstr Surg* 1992;89:1-8; discussion 9-10.
2. Proffit WR, White RP, Sarver DM. Maxillofacial distraction osteogenesis, in eds: St. Louis, Missouri: Mosby 2003:357-93.
3. Triaca A, Antonini M, Minoretti R, Merz BR. Segmental distraction osteogenesis of the anterior alveolar process. *J Oral Maxillofac Surg* 2001;59:26-34; discussion 34-25.
4. Triaca A, Minoretti R, Merz B. Treatment of mandibular retrusion by distraction osteogenesis: a new technique. *Br J Oral Maxillofac Surg* 2004;42:89-95.
5. McDonald WR, Stoelinga PJ, Blijdorp PA, Schoenaers JA. Champy bone plate fixation in sagittal split osteotomies for mandibular advancement. *Int J Adult Orthod Orthognath Surg* 1987;2:89-97.

6. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg* 2009;67:301-13.
7. Vos MD, Baas EM, de Lange J, Bierenbroodspot F. Stability of mandibular advancement procedures: bilateral sagittal split osteotomy versus distraction osteogenesis. *Int J Oral Maxillofac Surg* 2009;38:7-12.
8. Baas EM, Pijpe J, de Lange J. Long term stability of mandibular advancement procedures: bilateral sagittal split osteotomy versus distraction osteogenesis. *Int J Oral Maxillofac Surg* 2011;41:137-41.
9. Obwegeser JA, Metzler P, Jacobsen C, Zemann W. Innovation in anterior mandibular alveolar distraction osteogenesis: introduction of a new bone-borne distraction device and first clinical results. *J craniomaxillofac surg* 2012;40:e503-8.
10. Zemann W, Metzler P, Jacobsen C, Obwegeser JA. Hybrid distraction: a novel method for distraction osteogenesis of the alveolar process. *J Craniofac Surg* 2012;23:1642-4.
11. Matsushita K, Inoue N, Yamaguchi HO, Ooi K, Totsuka Y. Tooth-borne distraction of the lower anterior subapical segment for correction of class II malocclusion, subsequent to genioplasty. *Oral Maxillofac Surg* 2011;15:183-8.
12. Brusati R, Gianni AB. Anterior mandibular apical base augmentation in the surgical orthodontic treatment of mandibular retrusion. *Int J Oral Maxillofac Surg* 2005;34:846-50.
13. Sesenna E, Raffaini M. Bilateral condylar atrophy after combined osteotomy for correction of mandibular retrusion. A case report. *J Maxillofac Surg* 1985;13:263-6.
14. Hoppenreijs TJ, Freihofer HP, Stoelinga PJ, Tuinzing DB, van't Hof MA. Condylar remodelling and resorption after Le Fort I and bimaxillary osteotomies in patients with anterior open bite. A clinical and radiological study. *Int J Oral Maxillofac Surg* 1998;27:81-91.
15. Joss CU, Joss-Vassalli IM, Berge SJ, Kuijpers-Jagtman AM. Soft tissue profile changes after bilateral sagittal split osteotomy for mandibular setback: a systematic review. *J Oral Maxillofac Surg* 2010;68:2792-801.
16. Kau CH, Cronin A, Durning P, Zhurov AI, Sandham A, Richmond S. A new method for the 3D measurement of postoperative swelling following orthognathic surgery. *Orthod Craniofac Res* 2006;9:31-7.

17. Nkenke E, Vairaktaris E, Kramer M, Schlegel A, Holst A, Hirschfelder U, Wiltfang J, Neukam FW, Stamminger M. Three-dimensional analysis of changes of the malar-midfacial region after LeFort I osteotomy and maxillary advancement. *Oral Maxillofac Surg* 2008;12:5-12.
18. Hajeer MY, Ayoub AF, Millett DT. Three-dimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery. *Br J Oral Maxillofac Surg* 2004;42:396-404.
19. Maal TJ, de Koning MJ, Plooij JM, Verhamme LM, Rangel FA, Berge SJ, Borstlap WA. One year postoperative hard and soft tissue volumetric changes after a BSSO mandibular advancement. *Int J Oral Maxillofac Surg* 2012;41:1137-45.
20. Terajima M, Yanagita N, Ozeki K, Hoshino Y, Mori N, Goto TK, Tokumori K, Aoki Y, Nakasima A. Three-dimensional analysis system for orthognathic surgery patients with jaw deformities. *Am J Orthod Dentofacial Orthop* 2008;134:100-11.
21. Jung YJ, Kim MJ, Baek SH. Hard and soft tissue changes after correction of mandibular prognathism and facial asymmetry by mandibular setback surgery: three-dimensional analysis using computerized tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009;107:763-71 e768.
22. Joss CU, Joss-Vassalli IM, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue profile changes after bilateral sagittal split osteotomy for mandibular advancement: a systematic review. *J Oral Maxillofac Surg* 2010;68:1260-9.
23. Forsberg CM. Facial morphology and ageing: A longitudinal cephalometric investigation of young adults. *Eur J Orthod* 1979;1:15-23.
24. Alves PV, Mazucheli J, Vogel CJ, Bolognese AM. How the lower face soft tissue changes after mandibular advancement or setback. *J Craniofac Surg* 2008;19:593-8.
25. Dolce C, Hatch JP, Van Sickels JE, Rugh JD. Five-year outcome and predictability of soft tissue profiles when wire or rigid fixation is used in mandibular advancement surgery. *Am J Orthod Dentofacial Orthop* 2003;124:249-56; quiz 340.
26. Joss CU, Thuer UW. Stability of the hard and soft tissue profile after mandibular advancement in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2008;30:16-23.
27. Mobarak KA, Espeland L, Krogstad O, Lyberg T. Soft tissue profile changes following mandibular advancement surgery: Predictability and long-term outcome. *Am J Orthod Dentofacial Orthop* 2001;119:353-67.

28. Pangrazio-Kulbersh V, Berger JL, Kaczynski R, Shunock M. Stability of skeletal Class II correction with 2 surgical techniques: the sagittal split ramus osteotomy and the total mandibular subapical alveolar osteotomy. *Am J Orthod Dentofacial Orthop* 2001;120:134-43.
29. Altug-Atac AT, Grayson BH, McCarthy JG. Comparison of skeletal and soft-tissue changes following unilateral mandibular distraction osteogenesis. *Plast Reconstr Surg* 2008;121:1751-9.
30. Melugin MB, Hanson PR, Bergstrom CA, Schuckit WI, Gerard Bradley T. Soft tissue to hard tissue advancement ratios for mandibular elongation using distraction osteogenesis in children. *Angle Orthod* 2006;76:72-6.
31. McCormick SU, McCarthy JG, Grayson BH, Staffenberg D, McCormick SA. Effect of mandibular distraction on the temporomandibular joint: Part 1, Canine study. *J Craniofac Surg* 1995;6:358-63.
32. McCormick SU, Grayson BH, McCarthy JG, Staffenberg D. Effect of mandibular distraction on the temporomandibular joint: Part 2, Clinical study. *J Craniofac Surg* 1995;6:364-7.
33. Swennen G, Schliephake H, Dempf R, Schierle H, Malevez C. Craniofacial distraction osteogenesis: a review of the literature: Part 1: clinical studies. *Int J Oral Maxillofac Surg* 2001;30:89-103.
34. Joss CU, Thuer UW. Neurosensory and functional impairment in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod* 2007;29:263-71.
35. Magnusson T, Ahlborg G, Svartz K. Function of the masticatory system in 20 Patients with mandibular hypo- or hyperplasia after correction by a sagittal split osteotomy. *Int J Oral Maxillofac Surg* 1990;19:289-93.
36. Smith V, Williams B, Stapleford R. Rigid internal fixation and the effects on the temporomandibular joint and masticatory system: A prospective study. *Am J Orthod Dentofacial Orthop* 1992;102:491-500.
37. Harper RP. Analysis of temporomandibular joint function after orthognathic surgery using condylar path tracings. *Am J Orthod Dentofacial Orthop* 1990;97:480-8.
38. Feinerman DM, Piecuch JF. Long-term effects of orthognathic surgery on the temporomandibular joint: comparison of rigid and nonrigid fixation methods. *Int J Oral Maxillofac* Surg 1995;24:268-72.
39. Block MS, Daire J, Stover J, Matthews M. Changes in the inferior alveolar nerve following mandibular lengthening in the dog using distraction osteogenesis. *J Oral Maxillofac Surg* 1993;51:652-60.

40. Hu J, Tang Z, Wang D, Buckley MJ. Changes in the inferior alveolar nerve after mandibular lengthening with different rates of distraction. *J Oral Maxillofac Surg* 2001;59:1041-5; discussion 1046.
41. Karp NS, Thorne CH, McCarthy JG, Sissons HA. Bone lengthening in the craniofacial skeleton. *Ann Plast Surg* 1990;24:231-237.
42. 42. Makarov MR, Harper RP, Cope JB, Samchukov ML. Evaluation of inferior alveolar nerve function during distraction osteogenesis in the dog. J Oral Maxillofac Surg 1998;56:1417-23; discussion 1424-1415.
43. Whitesides LM, Meyer RA. Effect of distraction osteogenesis on the severely hypoplastic mandible and inferior alveolar nerve function. *J Oral Maxillofac Surg* 2004;62:292-7.
44. Ylikontiola L, Kinnunen J, Oikarinen K. Factors affecting neurosensory disturbance after mandibular bilateral sagittal split osteotomy. *J Oral Maxillofac Surg* 2000;58:1234-9.
45. Gelijns AC, Ascheim DD, Parides MK, Kent KC, Moskowitz AJ. Randomized trials in surgery. *Surgery* 2009;145:581-7.
46. Ergina PL, Cook JA, Blazeby JM, Boutron I, Clavien PA, Reeves BC, Seiler CM, Altman DG, Aronson JK, Barkun JS, Campbell WB, Feldman LS, Flum DR, Glasziou P, Maddern GJ, Marshall JC, McCulloch P, Nicholl J, Strasberg SM, Meakins JL, Ashby D, Black N, Bunker J, Burton M, Campbell M, Chalkidou K, Chalmers I, de Leval M, Deeks J, Grant A, Gray M, Greenhalgh R, Jenicek M, Kehoe S, Lilford R, Littlejohns P, Loke Y, Madhock R, McPherson K, Rothwell P, Summerskill B, Taggart D, Tekkis P, Thompson M, Treasure T, Trohler U, Vandenbroucke J. Challenges in evaluating surgical innovation. *Lancet* 2009;374:1097-104.
47. D'Agostino RB, Kwan H. Measuring effectiveness. What to expect without a randomized control group. *Medical care* 1995;33:AS95-105.
48. Smith KT, Solmon DC, Wagner SL, Hamaker C. Mathematical aspects of divergent beam radiography. *Proceedings of the National Academy of Sciences of the United States of America* 1978;75:2055-8.
49. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. *European radiology* 1998;8:1558-64.
50. van Vlijmen OJ, Kuijpers MA, Berge SJ, Schols JG, Maal TJ, Breuning H, Kuijpers-Jagtman AM. Evidence supporting the use of cone-beam computed tomography in orthodontics. *J Am Dent Assoc* 2012;143:241-52.

51. Nada RM, Maal TJ, Breuning KH, Berge SJ, Mostafa YA, Kuijpers-Jagtman AM. Accuracy and reproducibility of voxel based superimposition of cone beam computed tomography models on the anterior cranial base and the zygomatic arches. *PloS one* 2011;6:e16520.
52. Nada RM, van Loon B, Maal TJ, Berge SJ, Mostafa YA, Kuijpers-Jagtman AM, Schols JG. Three-dimensional evaluation of soft tissue changes in the orofacial region after tooth-borne and bone-borne surgically assisted rapid maxillary expansion. *Clin Oral Investig* 2013;17:2017-24.
53. Suh HY, Lee SJ, Lee YS, Donatelli RE, Wheeler TT, Kim SH, Eo SH, Seo BM. A more accurate method of predicting soft tissue changes after mandibular setback surgery. *J Oral Maxillofac Surg* 2012;70:e553-62.
54. Kneafsey LC, Cunningham SJ, Petrie A, Hutton TJ. Prediction of soft-tissue changes after mandibular advancement surgery with an equation developed with multivariable regression. *Am J Orthod Dentofacial Orthop* 2008;134:657-4.

Chapter 9

Summary

Chapter 1 introduces the topic of non-surgical and surgical modalities in orthodontics to treat Class II malocclusions. Epidemiologic surveys, incidence, etiologic factors, and treatment indications of Class II malocclusions are shortly discussed. Furthermore the features of Class II malocclusions are presented. Different treatment approaches are necessary if orthodontic treatment for Class II malocclusions is carried out in growing children and adolescences or in non-growing individuals. For growing individuals, various types of functional and other appliances as well as treatment principles to enhance mandibular growth are addressed in this chapter. Two basic treatment options are described in non-growing individuals: Orthodontic camouflage therapy (with or without additional genioplasty) and surgical correction of the dysgnathia in combination with orthodontic treatment. Finally, the bilateral sagittal split osteotomy for mandibular advancement (BSSO), the distraction osteogenesis (DO), and the DO of the anterior mandibular alveolar process are explored.

In **Chapter 2** the results of the study concerning the soft tissue changes after BSSO for mandibular advancement are presented. The purpose of the systematic review was to evaluate the soft tissue/hard tissue ratio in BSSO with rigid internal fixation (RIF) or wire fixation (WF) of the osteotomy segments. The databases PubMed, Medline, CINAHL, Web of Science, Cochrane Library, and Google Scholar Beta were searched. From the original 711 articles identified, 12 were finally included. Only 3 studies were prospective and 9 were retrospective. The postoperative follow-up ranged from 3 months to 12.7 years for RIF and 6 months to 5 years for WF. The short- and long-term ratios for the lower lip to lower incisor for BSSO with RIF or WF were 50%. No difference between the short- and long-term ratios for the mentolabial-fold to point B and soft tissue pogonion to pogonion could be observed. It was a 1:1 ratio. One exception was seen for the long-term results of the soft tissue pogonion to pogonion in BSSO with RIF; they tended to be greater than a 1:1 ratio. The upper lip mainly showed retrusion but with high variability. Despite a large number of studies on the short- and long-term effects of mandibular advancement by BSSO, the results of the present systematic review have shown that evidence-based conclusions on soft tissue changes are still unknown. This is mostly because of the inherent problems of retrospective studies, inferior study designs, and the lack of standardized outcome measures. Well-designed prospective studies with sufficient sample sizes that have excluded patients undergoing additional surgery (ie, genioplasty or maxillary surgery) are needed.

Chapter 3 describes a retrospective study on 33 patients (27 females; 6 males) analysed for skeletal and dental relapse before DO of the mandibular anterior alveolar process at T1 (17.0 days), after DO at T2 (mean 6.5 days), at T3 (mean 24.4 days), and at T4 (mean 2.0 years). Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated. Skeletal correction (T3-T1) was mainly achieved through the distraction of the anterior alveolar segment in a rotational manner where the incisors were more proclined. The horizontal backward relapse (T4-T3) measured -0.8 mm or 19.0% at point B ($p < 0.001$) and -1.6 mm or 25.0% at incision inferior ($p < 0.001$). Age, gender, amount and type (rotational versus translational) of advancement were not correlated with the amount of relapse. High angle patients (NL/ML'; $p < 0.01$) and patients with large gonial angle ($p < 0.05$) showed significantly smaller relapse rates at point B. Overcorrection of the overjet achieved by the distraction was seen in a third of the patients and could be a reason for relapse. Considering the amount of skeletal relapse the DO could be an alternative to bilateral sagittal split osteotomy for mandibular advancement in selected cases.

Chapter 4 presents the evaluation of soft tissue changes in adult patients treated with DO of the anterior mandibular alveolar process and related it to different parameters. 33 patients (27 females; 6 males) were analysed retrospectively before surgery at T1 (17.0 days), after surgery at T2 (mean 6.5 days), at T3 (mean 24.4 days), and at T4 (mean 2.0 years). Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated. Statistical analysis was carried out using Kolmogorov-Smirnov test, paired *t* test, Pearson’s correlation coefficient, and linear backward regression analysis. 2 years postoperatively (T4), the net effect of the soft tissue at point B' was 100% of the advancement at point B whilst the lower lip (labrale inferior) followed the advancement of incision inferior to 46%. Increased preoperative age was correlated ($p < 0.05$) with more horizontal backward movement (T4-T3) for labrale superior and pogonion'. Higher NL/ML' angles were significantly correlated ($p < 0.05$) with smaller horizontal soft tissue change at point B'. Gender and the amount of skeletal and dental advancement were not correlated with postoperative soft tissue changes (T4-T3). DO of the anterior mandibular alveolar process is a valuable alternative for mandibular advancement regarding soft tissue change and predictability.

Chapter 5 addresses the neurosensory status and craniomandibular function after DO. 19 patients (mean age 35.2 years, range 17.8-58.8 years) treated by combined surgical orthodontic treatment with DO of the anterior mandibular alveolar process (DO-group) were compared with a control-group of 41 orthodontically treated patients (mean age 22.9 years, range 15.1-49.0 years). Clinical examination took place on average 5.9 years (DO-group) and 5.4 years (control-group) after treatment ended. Neurosensory status was determined by two-point discrimination (2-pd) and the pointed and blunt test. Lateral cephalograms evaluated advancement of the mandibular alveolar process and possible relapse. There was no significant difference in craniomandibular function and neurosensory status between the groups. Age was significantly correlated with 2-pd at the lips (DO-group: $p = 0.01$, $R = 0.575$; control-group: $p = 0.039$, $R = 0.324$) and chin (DO-group: $p = 0.029$, $R = 0.501$; control-group: $p = 0.008$, $R = 0.410$). Younger patients had smaller 2-pd values. Gender, age, the amount of advancement, and relapse at point B or incision inferior show no correlation with craniomandibular function and neurosensory impairment. DO of the mandibular anterior alveolar process is a valuable and safe method with minor side effects regarding neurosensory impairment.

Chapter 6 describes 17 patients (14 female; 3 male) which were retrospectively analysed for skeletal and dental long-term relapse before DO of the mandibular anterior alveolar process at T1 (17.0 days), after

DO at T2 (mean 6.5 days), at T3 (mean 24.4 days), at T4 (mean 2.0 years), and at T5 (mean 5.5 years). Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated. Skeletal correction (T5-T1) was mainly achieved through the distraction of the anterior alveolar segment in a rotational manner where the incisors were more proclined. The horizontal backward relapse (T5-T3) measured -0.3 mm or 8.3% at point B (non-significant) and -1.8 mm or 29.0% at incision inferior ($p < 0.01$). Age, gender, amount and type (rotational vs. translational) of advancement were not correlated with the amount of relapse. High angle patients (NL/ML'; $p < 0.01$) showed significant smaller relapse rates at point B. Overcorrection of the overjet achieved by the distraction could be a reason for dental relapse. Considering the amount of long-term skeletal relapse the DO could be an alternative to bilateral sagittal split osteotomy for mandibular advancement in selected cases.

In **Chapter 7** long-term soft tissue changes of 17 patients following DO of the mandibular anterior alveolar process are presented. Lateral cephalograms were traced by hand, digitized, superimposed, and evaluated at T1 (17.0 days), after DO at T2 (mean 6.5 days), at T3 (mean 24.4 days), at T4 (mean 2.0 years), and at T5 (mean 5.5 years). Statistical analysis was carried out using Kolmogorov-Smirnov test, paired *t*-test, Pearson’s correlation coefficient, and linear backward regression analysis. 5.5 years postoperatively, the net effect for the soft tissue at point B’ was 88% of the advancement at point B while the lower lip (labrale inferior) followed the advancement of incision inferior to 24%. Increased preoperative age was correlated ($p < 0.05$) with more horizontal backward movement (T5-T3) for labrale inferior and pogonion'. Higher NL/ML' angles were significantly correlated ($p < 0.05$) to smaller horizontal soft tissue change at labrale inferior (T5-T3). The amount of advancement at point B was significantly correlated with an upward movement (T5-T3) of labrale inferior ($p < 0.01$) and stomion inferior ($p < 0.05$). It can be concluded that further change in soft tissues occurred between 2.0 and 5.5 years postoperatively. The physiological process of ageing and loss of soft tissue elasticity should be considered as possible reasons.

Chapter 8 is a general discussion of the clinical significance of the results of the different studies as well as the strengths and weakness are discussed. Methodological considerations, suggestions and trends for future research are presented.

Chapter 10

Samenvatting

In **hoofdstuk 1** wordt een inleiding gegeven op de chirurgische en niet-chirurgische behandelingsmogelijkheden van de Klasse II malocclusie. Epidemiologisch onderzoek, incidentie, etiologie en kenmerken van de Klasse II malocclusie worden besproken alsmede de behandelindicaties. Behandelplannen voor groeiende kinderen en adolescenten verschillen. In dit hoofdstuk wordt vooral ingegaan op behandelopties voor groeiende individuen, waaronder groeimodificatie van de onderkaak door middel van verschillende typen (functionele) apparatuur. De twee standaard behandelmogelijkheden voor uitgegroeide individuen zijn orthodontische camouflagetherapie (met of zonder kinplastiek) en orthodontisch-chirurgische correctie van de dysgnathie. Aan het einde van het hoofdstuk komen de bilaterale sagittale splijtingsosteotomie (BSSO) en distractie osteogenese (DO) van de mandibula alsmede DO van alleen het voorste segment van de processus alveolaris van de mandibula aan de orde.

In **hoofdstuk 2** worden de resultaten van het onderzoek naar veranderingen in de weke delen van het gelaat na voorwaartse verplaatsing van de mandibula door middel van een BSSO besproken. Het doel van dit systematisch literatuuronderzoek was de verplaatsing van de weke en benige delen te evalueren alsmede de verhouding tussen die twee bij toepassing van een BSSO met rigide fixatie (RIF) of draadfixatie (WF) van de osteotomiesegmenten. PubMed, Medline, CINAHL, Web of Science, Cochrane Library en Google Scholar Beta werden systematisch doorzocht. Van de 711 gevonden artikelen werden uiteindelijk 12 artikelen gebruikt. Hiervan beschreven 3 artikelen een prospectief onderzoek en 9 artikelen een retrospectief onderzoek. De postoperatieve follow-up varieerde van 3 maanden tot 12,7 jaar voor de RIF en 6 maanden tot 5 jaar voor de WF. Korte en lange termijn ratio's van de onderlip tot onderincisief waren zowel voor de BSSO met RIF als voor de WF 50%, dat wil zeggen dat de onderlip voor 50% de beweging van de onderincisieven volgt. Geen verschil werd gevonden tussen de korte en lange termijn ratio van de plica mentalis/B punt en van weke delen pogonion/benig pogonion. De ratio was voor beide 1:1. Een verschil werd wel gevonden voor het lange termijn resultaat bij de BSSO met RIF voor de weke delen pogonion/benig pogonion ratio; De ratio was groter dan de 1:1 ratio. Bij de bovenlip was vooral sprake van retrusie maar met een grote variabiliteit. Ondanks het grote aantal publicaties blijkt uit dit systematisch literatuuronderzoek dat evidence based conclusies over de verplaatsing van de weke delen –zowel korte als lange termijn - bij voorwaartse verplaatsing van de mandibula door middel van een BSSO nog moeilijk te trekken zijn. Dit komt doordat er veelal van retrospectief onderzoek sprake is, de onderzoeksmethoden ondeugdelijk zijn, en door gebrek aan gestandaardiseerde uitkomstmaten. Prospectief onderzoek met een onderzoekspopulatie van voldoende grootte is nodig waarbij patiënten met additionele chirurgie (kinplastiek, chirurgie van de maxilla) geëxcludeerd dienen te worden.

De resultaten van een retrospectief onderzoek naar skelettale en dentale relapse na segment-DO van het voorste deel van de processus alveolaris van de mandibula worden beschreven in **hoofdstuk 3**. Skelettale en dentale relapse werd geanalyseerd in 33 patiënten (27 vrouwen, 6 mannen). Laterale röntgenschedelprofielfoto’s waren beschikbaar op de volgende tijdstippen: vóór DO op T1 (17,0 dagen), na DO op T2 (gemiddeld 6,5 dagen), op T3 (gemiddeld 24,4 dagen) en op T4 (gemiddeld 2,0 jaar). De foto’s werden met de hand getraced, gedigitaliseerd, gesuperponeerd en geanalyseerd. Skelettale correctie (T3-T1) werd vooral bereikt door distractie met rotatie van het voorste alveolaire segment waarbij de onderincisieven meer geproclineerd werden. De horizontale achterwaartse relapse (T4-T3) was -0.8 mm (19.0%) bij B punt ($p < 0.001$) en -1.6 mm (25.0%) bij de incisale rand van de onderincisief ($p < 0.001$). Leeftijd, geslacht, hoeveelheid en type voorwaartse verplaatsing (translatie dan wel rotatie) waren niet gecorreleerd met de mate van relapse. High-angle casus (NL/ML'; $p < 0.01$) en patiënten met een grote gonion hoek ($p < 0.05$) hadden een significant kleinere mate van relapse bij punt B. Bij een derde van de patiënten was sprake van overcorrectie van de overjet door de distractie en dit zou een mogelijke verklaring voor de relapse kunnen zijn. Rekening houdend met de skelettale relapse zou DO van het voorste deel van de processus alveolaris van de onderkaak in specifieke gevallen een alternatief kunnen zijn voor de voorwaartse verplaatsing van de mandibula met een BSSO.

Hoofdstuk 4 beschrijft de verandering in de weke delen bij volwassen patiënten na DO van het voorste deel van de processus alveolaris van de mandibula en de correlatie met verschillende parameters. 33 patiënten (27 vrouwen, 6 mannen) werden retrospectief geanalyseerd vóór DO op T1 (17,0 dagen), na DO op T2 (gemiddeld 6,5 dagen), op T3 (gemiddeld 24,4 dagen) en op T4 (gemiddeld 2,0 jaar). Laterale röntgenschedel-profielfoto's werden met de hand getraced, gedigitaliseerd, gesuper-poneerd en geanalyseerd. Twee jaar na de operatie (T4) was het netto effect voor weke-delen-punt B' 100% van de voorwaartse verplaatsing van het skeletale punt B, terwijl de onderlip (labrale inferior) de voorwaartse verplaatsing van incision inferior maar voor 46% volgde. Een preoperatief hogere leeftijd was gecorreleerd met meer horizontale achterwaartse verplaatsing van de bovenlip (labrale superior) en pogonion' ($p < 0.05$) tussen T4-T3. Een grotere NL/ML' hoek was significant gecorreleerd ($p < 0.05$) met een kleinere horizontale verandering van de weke delen bij punt B'. De grootte van de skelettale en dentale voorwaartse verplaatsing en het geslacht van de patiënt waren niet gecorreleerd met postoperatieve veranderingen van de weke delen (T4-T3). DO van het voorste gedeelte van de processus alveolaris van de mandibula kan een waardevol alternatief zijn voor voorwaartse verplaatsing van de mandibula.

Hoofdstuk 5 gaat over neurosensorische veranderingen en cranio-mandibulaire (dis)functie na DO. 19 patiënten (gemiddelde leeftijd 35,2 jaar, range 17,8-58,8 jaar) die chirurgisch-orthodontisch behandeld waren met een DO van het voorste deel van de processus alveolaris van de mandibula werden vergeleken met een controlegroep van 41 patiënten die alleen orthodontisch behandeld werden (gemiddelde leeftijd 22,9 jaar, range 15,1-49,0 jaar). Klinisch onderzoek vond plaats ongeveer 5,9 jaar (DO-groep) en 5,4 jaar (controlegroep) na het einde van de behandeling. Aan de hand van laterale röntgenschedelprofielfoto's werden de voorwaartse verplaatsing en mogelijke relapse van de processus alveolaris van de mandibula gemeten. Er was geen significant verschil tussen beide groepen in craniomandibulaire functie en neurosensibiliteit. Leeftijd was significant gecorreleerd met de sensibiliteitstest van de lip (DO-groep: $p = 0.01$, $R = 0.575$; controlegroep: $p = 0.039$, $R = 0.324$) en de kin (DO-groep: $p = 0.029$, $R = 0.501$; controlegroep: $p = 0.008$, $R = 0.410$). Craniomandibulaire functie en neurosensorische veranderingen waren niet gecorreleerd met geslacht, leeftijd, grootte van de voorwaartse verplaatsing en relapse bij punt B of incision inferior. Geconcludeerd werd dat DO van het voorste deel van de processus alveolaris van de mandibula een veilige chirurgische methode is met geringe neveneffecten op de sensibiliteit.

In **hoofdstuk 6** worden de lange termijn skelettale en dentale relapse geanalyseerd bij 17 patiënten (14 vrouwen; 3 mannen) vóór DO op T1 (17,0 dagen), na DO op T2 (gemiddeld 6,5 dagen), op T3 (gemiddeld 24,4 dagen), op T4 (gemiddeld 2,0 jaar) en op T5 (gemiddeld 5,5 jaar). Laterale röntgenschedelprofielfoto's werden met de hand getraced, gedigitaliseerd, gesuperponeerd en geanalyseerd. Skelettale correctie (T5-T1) werd vooral bereikt door DO met rotatie van het voorste alveolaire segment waarbij de onderincisieven geproclineerd werden. De horizontale achterwaartse relapse (T5-T3) was -0,3 mm (8,3%) bij punt B ($p < 0.001$) en -1,8 mm (29,0%) bij de snijrand van de onderincisief ($p < 0.001$). Leeftijd, geslacht, hoeveelheid en type (translatie dan wel rotatie) voorwaartse verplaatsing waren niet gecorreleerd aan de hoeveelheid relapse. High-angle casus (NL/ML'; $p < 0.01$) hadden een significant kleinere mate van relapse bij punt B. Overcorrectie van de overjet tijdens de distractie zou een reden voor dentale relapse kunnen zijn. Rekening houdend met de skelettale relapse zou segment-DO in specifieke gevallen een alternatief kunnen zijn voor een BSSO.

In **hoofdstuk 7** worden de lange termijn veranderingen voor de weke delen beschreven na DO van het voorste deel van de processus alveolaris van de mandibula bij 17 patiënten (14 vrouwen; 3 mannen). Laterale röntgen-schedelprofielfoto's werden met de hand getraced, gedigitaliseerd, gesuperponeerd en geanalyseerd vóór DO op T1 (17,0 dagen), na DO op T2 (gemiddeld 6,5 dagen), op T3 (gemiddeld 24,4 dagen), op T4 (gemiddeld 2,0 jaar) en T5 (gemiddeld 5,5 jaar). Vijf jaar na de operatie (T5) was het netto effect op het weke delen punt B' 88% van de voorwaartse verplaatsing van het skelettale punt B, terwijl de onderlip (labrale inferior) de voorwaartse verplaatsing van de snijrand van de onderincisief maar voor 24% volgde. Een hogere preoperatieve leeftijd was gecorreleerd met meer horizontale achterwaartse verplaatsing tussen T5-T3 van de onderlip (labrale inferior) en pogonion' ($p < 0.05$). Een grotere NL/ML' hoek was significant gecorreleerd ($p < 0.05$) met een kleinere horizontale verplaatsing van de onderlip (labrale inferior). De grootte van de verplaatsing bij punt B was significant gecorreleerd aan een opwaartse beweging van de onderlip ($p < 0.01$) en van stomion inferior ($p < 0.05$). Geconcludeerd kan worden dat veranderingen in de weke delen tussen 2,0 en 5,5 jaar na behandeling nog plaatsvinden. Mogelijke verklaringen voor deze veranderingen zouden het fysiologisch verouderingsproces en verlies van elasticiteit van de weke delen kunnen zijn.

In de discussie in **hoofdstuk 9** wordt de klinisch betekenis van de resultaten besproken en worden de sterke en zwakke punten van het onderzoek bediscussieerd. Ook worden methodologische overwegingen en suggesties voor toekomstig onderzoek gepresenteerd.

Chapter 11

Zusammenfassung

Kapitel 1 gibt eine Einführung in das Thema der chirurgischen und nichtchirurgischen Behandlungsmöglichkeiten in der Kieferorthopädie zur Behandlung von Klasse II Malokklusionen. Epidemiologische Studien, Inzidenz, Ätiologische Faktoren und Behandlungsindikationen von Klasse II Malokklusionen werden kurz vorgestellt. Des Weiteren werden die charakteristischen Merkmale einer Klasse II Malokklusion beschrieben. Verschiedene Behandlungsmöglichkeiten zur Behandlung einer Klasse II Malokklusion bei Jugendlichen und Kindern in Wachstum oder beim Erwachsenen Patienten können zu Hilfe gezogen werden. Diverse Behandlungsarten funktionskieferorthopädischer und anderer Apparaturen für Patienten im Wachstum sowohl als auch deren Prinzipien zur Stimulation des Unterkieferwachstums werden in diesem Kapitel angesprochen. Es werden zwei grundsätzliche Behandlungsmöglichkeiten in Patienten mit abgeschlossenem Kieferwachstum beschrieben: zum einen die Möglichkeit der kieferorthopädischen Camouflage-Behandlung und zum anderen die kieferchirurgische Korrektur der Dysgnathie in Kombination mit der kieferorthopädischen Behandlung. Zum Abschluss kommen die bilaterale sagittale Spaltung (BSSO) zur mandibulären Vorverlagerung, die Distraktionsosteogenese (DO) und die DO des anterioren mandibulären Alveolarprozesses zur Sprache.

In **Kapitel 2** werden die Resultate der Studie zur Weichgewebeveränderung nach BSSO zur mandibulären Vorverlagerung vorgestellt. Das Ziel dieser systematischen Review war die Evaluation des Verhältnisses zwischen dem Weichgewebe und des knöchernen Skelets nach BSSO mit rigider interner Fixation (RIF) oder Drahtligierung (WF) der Osteotomiesegmente. Folgende Suchmaschinen wurden verwendet: PubMed, Medline, CINAHL, Web of Science, Cochrane Library und Google Scholar Beta. Aus 711 gefundenen Publikationen wurden schlussendlich 12 berücksichtigt. Davon waren nur 3 Studien prospektiv und 9 retrospektiv. Die post-operative Nachbetreuung bewegte sich zwischen 3 Monaten und 12.7 Jahren für RIF und zwischen 6 Monaten und 5 Jahren für WF. Das Kurz- und Langzeitverhältnis der Unterlippe zum Unterkieferinzision für BSSO mit

RIF oder WF war 50%. Kein Unterschied zwischen dem Kurz- und Langzeitverhältnis der Mentolabialfalte zum B-Punkt und Pogonion' zu Pogonion konnte festgestellt werden. Das Ganze verhielt sich in einem 1:1 Verhältnis. Eine Ausnahme stellte das Langzeitverhältnis von Pogonion' zu Pogonion nach BSSO mit RIF dar: eine Tendenz zu einem Verhältnis grösser als 1:1 war ersichtlich. Die Oberlippe zeigte hauptsächlich eine Retrusion jedoch auch grosse Variabilität. Es zeigte sich, trotz grosser Anzahl von Kurzzeit- und Langzeitstudien zur mandibulären Vorverlagerung durch BSSO, das evidenzbasierte Schlussfolgerungen nicht möglich sind. Dies ist hauptsächlich inhärenter Probleme retrospektiver Studien, niedrigerem Studiendesign und dem Mangel an standardisierten Messergebnissen zuzuschreiben. Gut konzipierte prospektive Studien mit einer genügend grossen Anzahl an Patienten ohne zusätzlicher kieferchirurgischen Eingriffe (z.B. Genioplastik oder maxillärer Chirurgie) sind in Zukunft notwendig.

Kapitel 3 beschreibt eine retrospektive Studie zum skelettalen und dentalen Rezidiv nach DO des anterioren mandibulären Alveolarprozesses mit 33 Patienten (27 Frauen und 6 Männer). Fernröntgenaufnahmen wurden erstellt vor DO zum Zeitpunkt T1 (17.0 Tage), und nach der DO zu den Zeitpunkten T2 (Mittelwert 6.5 Tage), T3 (Mittelwert 24.4 Tage) und T4 (Mittelwert 2.0 Jahre). Die Fernröntgenaufnahmen wurden von Hand durchgezeichnet, gescannt, überlagert und analysiert. Die skelettale Korrektur (T3-T1) wurde hauptsächlich durch eine Distraktion des anterioren mandibulären Alveolarprozesses in einer rotierenden Weise durchgeführt wobei die unteren Inzisiven stärker prokliniert wurden. Das horizontale rückwärtsgerichtete Rezidiv (T4-T3) betrug am B-Punkt -0.8 mm oder 19.0% ($p < 0.001$) und am Inzision inferior -1.6 mm oder 25.0% ($p < 0.001$). Das Alter und Geschlecht des Patienten sowie Umfang und Art (rotierend versus translatorisch) der Vorverlagerung des Unterkiefers waren nicht korreliert mit der Grösse des Rezidivs. Patienten mit vergrösserter Gesichtsdivergenz (NL/ML'; $p < 0.01$) und Patienten mit vergrössertem Gonion-Winkel ($p < 0.05$) zeigten eine signifikant kleinere Rezidivneigung am B-Punkt. Eine Überkorrektur des Overjets durch die

Distraktion fand sich in einem Drittel aller Patienten und könnte ein Rezidivgrund darstellen. Es wird schlussgefolgert, dass die DO des anterioren mandibulären Alveolarprozesses in Anbetracht der Grösse des skelettalen Rezidivs eine Alternative zur bilateralen sagittalen Spaltung (BSSO) in ausgesuchten Fällen darstellen könnte.

Kapitel 4 beschreibt die Evaluation der Weichgewebeveränderungen und deren Beziehung zu verschiedenen Parametern beim erwachsenen Patienten nach DO des anterioren mandibulären Alveolarprozesses vor. In 33 Patienten (27 Frauen und 6 Männer) wurden Fernröntgenaufnahmen vor DO zum Zeitpunkt T1 (17.0 Tage), und nach der DO zu den Zeitpunkten T2 (Mittelwert 6.5 Tage), T3 (Mittelwert 24.4 Tage) und T4 (Mittelwert 2.0 Jahre) erstellt. Die Fernröntgenaufnahmen wurden von Hand durchgezeichnet, gescannt, überlagert und analysiert. Die statistische Analyse wurde mit dem Kolmogorov–Smirnov Test, dem gepaarten *t*-Test, dem Pearson Korrelationskoeffizienten und der rückwärtsgerichteten Regressionsanalyse durchgeführt. Der Nettoeffekt der Weichgewebeveränderung 2 Jahre post-operativ (T4) war 100% an der Mentolabialfalte gemessen an der Vorverlagerung des B-Punktes während die Unterlippe (Labrale inferior) der Vorverlagerung des Inzision inferiores zu 46% folgte. Ein erhöhtes präoperatives Alter korrelierte ($p < 0.05$) mit mehr horizontaler Zurückverlagerung (T4-T3) des Labrale superior und Pogonion'. Ein vergrösserter NL/ML'-Winkel korrelierte signifikant ($p < 0.05$) mit einer kleineren horizontalen Weichgewebeveränderung an der Mentolabialfalte. Das Geschlecht und die Grösse der skelettalen und dentalen Vorverlagerung waren nicht korreliert mit den postoperativen Weichgewebeveränderungen (T4-T3). DO des anterioren mandibulären Alveolarprozesses ist eine nützliche Alternative zur mandibulären Vorverlagerung in Anbetracht der Stabilität der Weichgewebeveränderungen und ihrer Vorhersagbarkeit.

In **Kapitel 5** kommen die neurosensorischen Veränderungen und die Funktion des Kiefergelenks nach DO zur Sprache. Es wurden 19 Patienten (Mittelwert des Alters: 35.2 Jahre, Umfang: 17.8-58.8 Jahre), welche mittels DO des anterioren mandibulären Alveolarprozesses

(DO-Gruppe) und Kieferorthopädie behandelt wurden, mit 41 Patienten (Mittelwert des Alters: 22.9 Jahre, Umfang: 15.1-49.0 Jahre; Kontroll-Gruppe), welche eine reine kieferorthopädische Behandlung erhielten, verglichen. Die klinische Untersuchung fand im Mittel 5.9 Jahre (DO-Gruppe) und 5.4 Jahre (Kontroll-Gruppe) nach Abschluss der Behandlung statt. Der neurosensorische Status wurde mittels Zweipunktdiskrimination (2-pd) und einem spitz vs. stumpf Test bestimmt. Fernröntgenbilder wurden zur Evaluation der chirurgischen Vorverlagerung des anterioren mandibulären Alveolarprozesses und des möglichen Rezidives herangezogen. Es fanden sich keine signifikanten Unterschiede bezüglich der Funktion des Kiefergelenkes und des neurosensorischen Status im Vergleich der beiden Gruppen. Das Alter des Patienten war jedoch signifikant korreliert mit der 2-pd der Lippen (DO-Gruppe: $p = 0.01$, $R = 0.575$; Kontroll-Gruppe: $p = 0.039$, $R = 0.324$) und des Kinns (DO-Gruppe: $p = 0.029$, $R = 0.501$; Kontroll-Gruppe: $p = 0.008$, $R = 0.410$). Jüngere Patienten hatten kleiner Werte der 2-pd. Das Geschlecht, das Alter, die Grösse der Vorverlagerung und das Rezidiv gemessen am B-Punkt oder Inzision inferior zeigten keine Korrelationen mit der Funktion des Kiefergelenkes und dem neurosensorischen Status. Die DO des anterioren mandibulären Alveolarprozesses ist eine sichere Technik mit geringen Nebenwirkungen betreffend neurosensorischen Veränderungen.

Kapitel 6 beschreibt eine retrospektive Studie zum skelettalen und dentalen Rezidiv nach DO des anterioren mandibulären Alveolarprozesses mit 17 Patienten (14 Frauen und 3 Männer). Fernröntgenaufnahmen wurden erstellt vor DO zum Zeitpunkt T1 (17.0 Tage), und nach der DO zu den Zeitpunkten T2 (Mittelwert 6.5 Tage), T3 (Mittelwert 24.4 Tage), T4 (Mittelwert 2.0 Jahre) und T5 (Mittelwert 5.5 Jahre). Die Fernröntgenaufnahmen wurden von Hand durchgezeichnet, gescannt, überlagert und analysiert. Die skelettale Korrektur (T5-T1) wurde hauptsächlich durch eine Distraktion des anterioren mandibulären Alveolarprozesses in einer rotierenden Weise durchgeführt wobei die unteren Inzisiven stärker prokliniert wurden. Das horizontale rückwärtsgerichtete Rezidiv (T5-T3) betrug am B-Punkt -0.3 mm oder

8.3% (nicht signifikant) und am Inzision inferior -1.8 mm oder 29.0% ($p < 0.01$). Das Alter und Geschlecht des Patienten sowie Umfang und Art (rotierend versus translatorisch) der Vorverlagerung des Unterkiefers waren nicht korreliert mit der Grösse des Rezidivs. Patienten mit vergrösserter Gesichtsdivergenz (NL/ML'; $p < 0.01$) zeigten eine signifikant kleinere Rezidivneigung am B-Punkt. Eine Überkorrektur des Overjets durch die Distraktion könnte ein Grund für das dentale Rezidiv darstellen. Es wird schlussgefolgert, dass die DO des anterioren mandibulären Alveolarprozesses in Anbetracht der Grösse des skelettalen Rezidivs eine Alternative zur bilateralen sagittalen Spaltung (BSSO) in ausgesuchten Fällen darstellen könnte.

Kapitel 7 beschreibt die Evaluation der Weichgewebeveränderungen und deren Beziehung zu verschiedenen Parametern beim erwachsenen Patienten nach DO des anterioren mandibulären Alveolarprozesses vor. In 17 Patienten (14 Frauen und 3 Männer) wurden Fernröntgenaufnahmen vor DO zum Zeitpunkt T1 (17.0 Tage), und nach der DO zu den Zeitpunkten T2 (Mittelwert 6.5 Tage), T3 (Mittelwert 24.4 Tage), T4 (Mittelwert 2.0 Jahre) und T5 (Mittelwert 5.5 Jahre) erstellt. Die statistische Analyse wurde mit dem Kolmogorov–Smirnov Test, dem gepaarten *t*-Test, dem Pearson Korrelationskoeffizienten und der rückwärtsgerichteten Regressionsanalyse durchgeführt. Der Nettoeffekt der Weichgewebeveränderung 5.5 Jahre post-operativ (T5) war 88% an der Mentolabialfalte gemessen an der Vorverlagerung des B-Punktes während die Unterlippe (Labrale inferior) der Vorverlagerung des Inzision inferiores zu 24% folgte. Ein erhöhtes präoperatives Alter korrelierte ($p < 0.05$) mit mehr horizontaler Zurückverlagerung (T5-T3) des Labrale superior und Pogonion'. Ein vergrösserter NL/ML'-Winkel korrelierte signifikant ($p < 0.05$) mit einer kleineren horizontalen Weichgewebeveränderung an der Unterlippe (Labrale inferior, T5-T3). Die Grösse der skelettalen Vorverlagerung des B-Punktes war signifikant korreliert mit den postoperativen aufwärtsgerichteten Weichgewebeveränderungen (T5-T3) der Unterlippe (Labrale inferior, $p < 0.01$) und von Stomion inferior ($p < 0.05$). Eine weitere Weichgewebeveränderung konnte somit zwischen 2.0 und 5.5 Jahren post-operativ festgestellt werden. Der physiologische Alterungsprozess und die Abnahme der Gewebeelastizität könnten mögliche Gründe dazu darstellen.

Kapitel 8 stellt eine allgemeine Diskussion der klinischen Bedeutung der Resultate aus den verschiedenen Studien dar. Des Weiteren werden die Stärken und Schwächen der Studien diskutiert. Methodologische Erwägungen, mögliche Empfehlungen und Entwicklungsmöglichkeiten für zukünftige Studien werden aufgezeigt.

Everything comes finally to an end! I would like to take the opportunity to express my thanks to all those persons who helped me during this long scientific journey.

First and foremost, I would like to send my thanks and love to my wife **Isabella** and children **Alessia** and **Luca**. You had to renounce your daddy lots of time because of his scientific work. But do not forget: Alessia and Luca, your smile makes my world turning round again!

Isabella, I appreciate your good feedbacks and your positive scientific inputs. It is always a pleasure to discuss the different aspects of our work with you if we find the time amongst the daily familiar challenges!

My gratitude goes to my parents, **Urs** and **Rosita**, and my sister **Simone** for their constant support during all those years of hard study. Thanks mum to send me some of your aquarelle paintings to illustrate this thesis.

My deep appreciation goes to my supervisors Professor Stavros Kiliaridis and Professor Anne Marie Kuijpers-Jagtman.

Professor Stavros Kiliaridis, I thank you for your insightful comments, good ideas and the time we shared in long working conferences. I admire your dedication to the scientific world. You gave me the chance to do my 4 years specialty training in Geneva. We went through ups and downs during those years of scientific work. I hope that we created something positive to remember by this thesis. You helped me opening doors by introducing me to Dr. Albino Triaca and Dr. Michele Antonini – not a matter of course!

Professor Anne Marie Kuijpers-Jagtman, you gave me the opportunity to treat this project as a PhD thesis in a perfect environment. I really was amazed how fast I always got your good comments and the accuracy by correcting my manuscripts. You helped me sailing through the sometimes stormy and rough sea. It was an excellent experience and always a great pleasure to be one of your external faculty and to work with you throughout these years!

My thanks go to **Dr. Albino Triaca**. You are a fantastic and very enthusiastic surgeon! I thank you for giving me so much insight into the field of maxillo-facial surgery. It is notable how you still question your everyday practice. I hope that you still keep finding new ways and concepts in this field. I am already awaiting some of your new ideas!

Dear **Dr. Michele Antonini**, even though you are no more here on earth to read these lines and this thesis, I think that you would be happy to see that we brought this project finally to a good end. You were always a great source of inspiration together with Albino. All these new ideas which had to be tried out and tested! Thanks for giving me the opportunity to work with you!

I would like to send my thanks as well to the **staff members** of Albino's and Michele's offices. You did a great job helping me with calling up patients and finding documents.

My thanks go to my class mate **Mette Kuijpers**. Thanks for introducing me to so many people and to bring me to Nijmegen! Thanks to you my summary was finally translated into the Dutch language.

I made my first scientific experiences together with PD **Urs Thüer**. You gave me the possibility to re-examine two of your study groups for a long-term survey. Thanks to you I started to develop the passion for research and orthodontics! I wish you and your lovely family all the best for your retirement!

Bianca Scholz made the layout of this thesis. I would like to thank her for the great effort and her help.

Curriculum Vitae

The author of this thesis was born in Bern, Switzerland, on July first, 1977. In 1997, he completed his secondary education at the Gymnasium Lerbermatt in Köniz, Switzerland. During his secondary education in 1995, he profited from an exchange student program to improve his English knowledge at the Terrebonne High School in Houma, Louisiana, USA. Near to New Orleans, it was the right place to be for an amateur Jazz alto saxophone player. He passed years as voluntary worker at the Bern Jazz Festival to live his passion for Jazz and improvisation.

As a good Swiss citizen he had to pass his first education as recruit in the Swiss army before attending University in 1997. After the basic course at the Faculty of Medicine, University of Berne, Switzerland from 1997-1999, he started dental medicine at the Zahnmedizinische Kliniken (ZMK), University of Bern. He graduated in 2002 and finished his doctoral thesis in 2004.

Christof worked clinically as dentist in several offices in Fribourg and Payerne, Switzerland from 2002 to 2004. He started his four year orthodontic post-graduate training in 2004 at the orthodontic department, University of Geneva, Switzerland. He successfully defended his Master thesis in Oral Biology and finished his orthodontic training in 2008.

Christof won the best poster award of the European Orthodontic Society at the European Congress of Orthodontics in Lisbon, Portugal in 2008. He started his PhD at the Department of Orthodontics and Craniofacial Biology, Radboud University, Nijmegen Medical Center in 2010.

Christof lives in Lausanne together with his wife Isabella and his two children Alessia and Luca. Together with his wife, an orthodontist, he manages his own orthodontic office in Lausanne, Switzerland. He has a position of lecturer at the School for Education of Dental Assistants (EPSIC) in Lausanne, Switzerland.

Publications

1. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue stability after segmental distraction of the anterior mandibular alveolar process: a 5.5 year follow-up. *Int J Oral Maxillofac Surg* 2013;42:345-51.
2. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Skeletal and dental stability of segmental distraction of the anterior mandibular alveolar process. A 5.5-year follow-up. *Int J Oral Maxillofac Surg* 2013;42:337-44.
3. Joss CU, Triaca A, Antonini M, Kuijpers-Jagtman AM, Kiliaridis S. Neurosensory and functional evaluation in distraction osteogenesis of the anterior mandibular alveolar process. *Int J Oral Maxillofac Surg* 2013;42:55-61.
4. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Skeletal and dental stability of segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:553-9.
5. Joss CU, Triaca A, Antonini M, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue stability in segmental distraction of the anterior mandibular alveolar process. A 2-year follow-up. *Int J Oral Maxillofac Surg* 2012;41:560-5.
6. Joss CU, Joss-Vassalli IM, Bergé SJ, Kuijpers-Jagtman AM. Soft tissue profile changes after bilateral sagittal split osteotomy for mandibular setback: a systematic review. *J Oral Maxillofac Surg* 2010;68:2792-801.
7. Joss CU, Joss-Vassalli IM, Kiliaridis S, Kuijpers-Jagtman AM. Soft tissue profile changes after bilateral sagittal split osteotomy for mandibular advancement: a systematic review. *J Oral Maxillofac Surg* 2010;68:1260-9.
8. Joss-Vassalli IM, Joss CU, Gebauer U. Does hyoid bone resection according to Sistrunk influence normal craniofacial growth? A cephalometric study. *J Oral Maxillofac Surg*. 2009;67:2275-82.
9. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg*. 2009;67:301-13.
10. Joss CU, Thüer UW. Stability of hard tissue profile after mandibular setback in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod*. 2008;30:352-8.
11. Joss CU, Vassalli IM. Stability after bilateral sagittal split osteotomy setback surgery with rigid internal fixation: a systematic review. *J Oral Maxillofac Surg*. 2008;66:1634-43.

12. Joss CU, Vassalli IM, Thüer UW. Stability of soft tissue profile after mandibular setback in sagittal split osteotomies: a longitudinal and long-term follow-up study. *J Oral Maxillofac Surg*. 2008;66:1610-6.
13. Joss CU, Thüer UW. Stability of the hard and soft tissue profile after mandibular advancement in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod*. 2008;30:16-23.
14. Joss CU, Thüer UW. Neurosensory and functional impairment in sagittal split osteotomies: a longitudinal and long-term follow-up study. *Eur J Orthod*. 2007;29:263-71.