Dissertation

Mandibular Corpus Distraction Osteogenesis:

An additional Approach for adult Patients with Retrognathic Mandible

submitted by

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Declaration

I hereby declare that this thesis is my own original work and I have fully acknowledged by name all those individuals and organisations that have contributed to the research for this thesis. Due acknowledgement has been made in the text to all other material used. Throughout this thesis and in all related publications, I followed the, “Guidelines of the Medical University of Graz on Good Scientific Practice.”

Graz, November 2022 Dr. med. Dent. Herwig Köstenberger

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Relapse rate and magnitude of relapse after mandibular distraction osteogenesis (MDO) in adult retrognathic patients

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All co-authors have approved the use of the data for the publication of this thesis.

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"Everything will be fine – Everything is fine."

quoted freely from BW and HK

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Abbreviations and Definitions

AHI	Apnoe-Hypopnoe-Index
Ar	Articulare
BSSO	Bilateral Sagittal Split Osteotomy
CBCT	Cone Beam Computer Tomography
Cond	Condylion
C4	4th Cervical Vertebra
DO	Distraction Osteogenesis
DVT	Digitale Volumentomographie
EBO	European Board of Orthodontics
FH	Frankfort Horizontal
Gn	Gnation
Go	Gonion
ICC	Interclass Correlation Coefficient
IAN	Inferior Alveolar Nerve
MBL	Mandibular Body Length
MDO	Mandibular Distraction Osteogenesis
Me	Menton
mm	Millimetre
MPA	Mandibular Plane Angle
MUL	Mandibular Unit Length
Na	Nasion
OSA	Obstructive Sleep Apnea
PAV	Pharyngeal Airway Volume

Pog	Pogonion
S	Sella
SD	Standard deviation
SNA	Sella-Nasion-Point A Angle
SNB	Sella-Nasion-Point B Angle
SN-Pog	Sella-Nasion-Pogonion Angle
T0	Measure point: preoperatively
T1	Measure point: after the active distraction phase
T2	Measure point: 12 months after surgery
T3	Measure point: later than 12 months after surgery
TMD	Temporomandibular disorder
TMJ	Temporomandibular joint
y	Years

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Zusammenfassung

Ziel: Das Ziel dieser Studie ist es, die skelettale Stabilität, die Rezidivrate, die Verletzungsrate des Nervus alveolaris inferior und die Volumenänderung der oberen Atemwege nach mandibulärer Distraktionsosteogenese (MDO), unter Verwendung von kephalometrischen und 3- dimensionalen Messungen, zu ermitteln.

Material und Methoden: Es wurden digitale Volumentomographien (DVTs) von 74 Patienten (56 Frauen, 18 Männer), Durchschnittsalter 23,3 Jahre (± 8,4) untersucht. Alle wurden zwischen 2010 und 2021 mittels MDO operiert. Die Daten stammen aus den Patientenakten und aus den DVTs: präoperativ (T0), nach aktiver Distraktionsphase (T1), 12 Monate nach Operation (T2) und optional, später als 12 Monate nach Operation (T3). Kephalometrische Längen- und Winkelmessungen, sowie 3-dimensionale Überlagerungs- und 3-dimensionale Oropharynx-Volumenanalysen wurden durchgeführt.

Ergebnisse: Im Durchschnitt betrug die Zunahme durch Distraktion der „Mandibular Body Length“ (MBL) 10,31 mm (± 3,44), der „Mandibular Unit Length“ (MUL) 7,91 mm (± 2,53) und des SN-Pog Winkels 3,96° (± 3,17). 13,39 Monate nach der Operation (T2) nahm MUL um 0,45 mm (± 1,62, p = 0,02) und MBL um 0,12 mm (± 2,01, p = 0,597) ab. 43,17 Monate nach der Operation (T3) nahm MUL um 0,59 mm (± 1,64, p = 0,224) und MBL um 0,60 mm (± 1,35, p = 0,079) ab. Eine positive moderate Korrelation zwischen dem Ausmaß der Distraktion und dem Ausmaß des Rezidivs wurde für T2 beobachtet (MBL p = 0,242; MUL p = 0,001), jedoch nicht für T3. Patienten mit einem mandibular Basiswinkel (> 38°) zeigten größere Rezidivwerte im Vergleich zur Gruppe mit niedrigem bis normalem mandibular Basiswinkel (≤ 38°). Es wurde keine Korrelation zwischen dem Ausmaß des Rezidivs im Vergleich mit Geschlecht, der Indikation, dem Zeitpunkt der Entfernung des Verbindungselements des Distraktors und dem Alter gefunden. Die Rezidivrate (SN-Pog-Verringerung ≥1°) betrug 13,4 % (n = 10) bzw. bei SN-Pog-Verringerung ≥2° 6,7 % (n = 5). Das Volumen der oberen Atemwege wurde um 38,85 % vergrößert. Es wurde keine Verletzung des Nervus Alveolaris inferior aufgezeichnet.

Schlussfolgerung: MDO ist eine sichere und stabile Methode zur Korrektur einer Unterkieferrücklage bei Erwachsenen und um die oberen Atemwege zu erweitern. MDO ist keine ersetzende Operationstechnik, sondern ist eine Ergänzung zur konservativen chirurgischen Behandlung der Unterkieferrücklage.

Abstract

Purpose: The objective of the present study was to analyse skeletal stability, relapse rate, rate of inferior alveolar nerve (IAN) injury, and the effect on the subregion oropharynx of the upper airway after mandibular distraction osteogenesis (MDO) using cephalometric and 3-dimensional measurements.

Material and Methods: The sample comprised cone-beam computed tomography (CBCT) data from 74 patients (56 women, 18 men), mean age 23.3 years (± 8.4), who underwent MDO between 2010 and 2021. Data were collected from patients records and CBCTs recorded preoperatively (T0), after active distraction phase (T1), 12 months after surgery (T2), and optionally, if available, more than 12 months after surgery (T3). Two-dimensional cephalometry measurements and 3-dimensional superimposing- and 3-dimensional oropharynx volume analyses were performed.

Results: The mean cephalometric advancement was for Mandibular Body Length (MBL) 10.31 mm (± 3.44), for Mandibular Unit Length (MUL) 7.91 mm (± 2.53), and for SN-Pog 3.96° (± 3.17). 13.39 months after surgery (T2), MUL decreased by 0.45 mm (± 1.62, $p = 0.02$), and MBL by 0.12 mm (± 2.01, $p = 0.597$). 43.17 months after surgery (T3), MUL decreased by 0.59 mm (± 1.64, $p = 0.224$), and MBL by 0.60 mm (± 1.35, $p = 0.079$). Positive moderate correlation between the amount of distraction and the amount of skeletal instability was identified for the short-term follow-up T2 (MBL $p = 0.242$; MUL $p = 0.001$) but not for the long-term T3. High-angle patients (MPA > 38°) showed a correlation with greater amounts of relapse comparing to normal-to-low angle group (MPA ≤ 38°). No correlation was found between the amount of skeletal relapse compared to gender, the chief complaint for surgery, appointment of removing of the connection element of the distractor, and age. The relapse rate (SN-Pog decrease ≥1°) was 13.4% (n = 10) and for SN-Pog angle reduction ≥2° 6.7% (n = 5) respectively. The pharyngeal airway volume was improved by 38.85% from its original size. No IAN injury was recorded.

Conclusion: MDO is a highly stable method of advancing the mandible and the pharyngeal airway in retrognathic adult patients. MDO should not be considered as an all-in-one-solution. It is an addendum to other surgical options.

Introduction

"It is now time that we should earnestly endeavour to free ourselves from blind and empiric custom, and discover the means of lengthening the tissues to their greatest possible extent, while compatible with the maintenance of their physiologic functions." (1)

Allessandro Codivilla, born in 1861 and died in 1912 in Bologna, Italy, was a famous surgeon and medical scientist. Codivilla published more than 190 scientific papers, and he is considered to be the creator of Italian orthopaedics and the first one to bring orthopaedics to the operating room (2). His beginnings were in the field of general surgery. His work influenced fundamental aspects of visceral surgery, and he performed in 1898 the first documented pancreatoduodenectomy (2). Since 1900, his scientific focus was limited exclusively to orthopaedics. The above written statement comes from one of his main publications, "On the means of lengthening in the lower limbs, the muscles, and tissues which are shortened through deformity," in 1905 (1). This was not only the first publication in the field of lengthening bones, but it is a report where Codivilla also stated the key aspects of this discipline. His concern was not about the bone itself. Main subjects for skeletal stability and treatment success are the surrounding tissues and by them the generated forces counter-directing the lengthening direction (1). Over the decades, lengthening tubular bones became a settled method in traumatology and orthopaedics and found its way into the field of maxillofacial surgery. Mile steps were Ilizarovs' research in the second half of the 20th century in distraction osteogenesis (DO), the first time, rate and rhythm of distraction was considered important (3-5). In 1991, McCarthy established this technique to the human craniofacial skeleton, to irregular bones (6). Nowadays, mandibular distraction osteogenesis (MDO) is recognized as a treatment option for congenital hypoplasia of the mandible in children but not fully established as a way of advancing the retrognathic mandible in adults. *"The evolution of craniofacial distraction continues,"* is the conclusion output of Hopper et al. (2020) in their continuing education article on craniofacial distraction osteogenesis (7).

One century after, Codivilla asked to focus on the technique itself and to free from empiric, the focal point to take this evolution further needs to be on evaluating the technique of MDO.

Genesis and growth of bones

Bones, teeth, and depending on the author cartilages belong to hard tissues. Growth arises in small parts by hypertrophy and hyperplasia of cells. The main growth results from secretion and mineralization of extracellular material. Mineralized extracellular matrix restricts interstitial growth, which is the characteristic growth for soft tissues. Two essential processes, intramembranous and endochondral ossification, create bones. Intramembranous ossification is the direct deposition of bone on the surface of existing bones induced from fibrous membranes like the bone covering periosteum. This surface growth leads to shaping and increasing of thickness of the bone. Intramembranous ossification is typical for bones of the skull, flat bones of the face, and the clavicles. Endochondral ossification involves the replacement of cartilage with bony tissue. Blood, vascular elements, and osteoblasts are the source for centres of ossification to create. From this, centre ossification continues to the end of bones. Cartilage in the epiphyses continues to grow until the rate of maturation exceeds the rate of proliferation. Diaphysis and the epiphysis merge and length growth is completed. Further physiologic growth is not possible. Endochondral ossification is typical for long bones, which are most of the bones of the skeleton. These two essential processes predominantly take place during fetal development, but growth in length continues until the end of adolescence. After the peak of adolescence, growth spurt further and increase of bone mass cannot be expected. Deviations in the extent of bone growth are common, especially in the jaws. The mandible is at higher risk to be affected by abnormal growth, deformities, and acquired deficiencies.

Causes of mandibular abnormalities

Congenital:

- Hemifacial microsomia
- Craniofacial microsomia
- Congenital micrognathia associated with Robin sequence, velocardiofacial syndrome, cerebral palsy, Treacher-Collins syndrome, Nager syndrome, Goldenhar syndrome, Mobius syndrome and others
- Trauma leading to ankyloses of the temporomandibular joints and asymmetry development
- Juvenile idiopathic arthritis

- Mandibular retrognathia related to growth deficiency/hypoplasia without associated syndromes

Acquired:

- Continuity defects resulting from traumata (gunshot injury)
- Continuity defects resulting from oncologic resections (malignant oral tumours)
- Continuity defects resulting from osteonecrosis, infections, and benign lesions
- Segmental defects from trauma or infections
- Mandibular retrognathia aggravated by environmental factors such as finger sucking, allergies, poor respiratory function, atypical swallowing, and chronic mouth breathing

Hemifacial deformities and mandibular continuity defects can generally be considered by their location and extent but do not follow a classifiable algorithm. There is no ideal system of classification and therapy planning; the choice of reconstruction mainly depends on surgeon experience and the associated tissues to reconstruct (8).

Bilateral, more symmetric hypoplasia of the mandible, independent of its cause, are easier to classify and therefore to rate. Mandibular retrognathia is a common malocclusion, and the severity of this malocclusion defines the need and the therapeutic strategy.

Classification of mandibular retrognathia

The Angle classification of occlusion differentiates normal occlusion, Classes I, II and III malocclusions, based on the relationship of the first molar teeth. Normal occlusion and Class I malocclusion demonstrate "*the mesiobuccal cusp of the upper first molar is received in the sulcus between the mesial and distal buccal cusps of the lower.*" (9) Class II describes a lower molar more distal, and Class III a lower molar more mesial. It is a dental based classification, it can, but does not automatically show the underlying jaw relationship. In the permanent dentition, Class I has the highest prevalence in global distribution with 74.7 % followed by Class II with 19.56 % and Class III with 5.93 %. According to geographical location, there is a wide range of Class II malocclusion from 1.6 % in Nigeria to 63 % in Belgium. The European continent shows the highest prevalence of Class II with 33.51 %. The Caucasian population has a Class II prevalence of 22.9% (10).

The Angle classification terminology is widely used, and it is also taken over for classification of skeletal jaw relationship. Retrognathia describes a distal orientated jaw relationship (Class II), prognathia a mesial orientated relationship (Class III) and eugnathia, according to dental normal occlusion, a normal relationship of upper and lower jaw. To achieve normal dental occlusion an eugnathic jaw relationship is required.

Normal occlusion is desirable and should be the aim of every orthodontic treatment. It allows oral functions to operate properly, is helpful in the prevention of diseases, and provides the best aesthetics.

Approximately 10% of the whole population shows significant overjet. Approximately 5% of this group requires surgery for optimal correction (11).

Approaches to correction mandibular retrognathia

There are different concepts in the correction of a retrognathic mandible depending on age, maturity, severeness, and compliance of the patient. Treatment concepts in chronologic order:

Removeable myofunctional appliances

These appliances are prescribed when the permanent incisors and first molars have erupted, in certain circumstances, treatment can be suggested at an earlier stage (12). Removeable myofunctional appliances are non-invasive and highly depending on patient compliance to wear. Dental hygiene is possible without circumstances. The Class II correction before puberty with removable myofunctional appliances is mostly confined to the dentoalveolar level (13). In most cases, further therapy with fixed appliances to a later stage is needed (two-step treatment). Examples are Activator appliance, Bionator appliance, Twin Block appliance, Frankel 2 appliance and many more.

Fixed myofunctional appliances

Prior to or during the adolescence growth spurt (boys between 11 and 14, girls between 10 and 13), when the patient is in late mixed or permanent dentition, correction of the retrognathic mandible with fixed myofunctional appliances should start (12). Levelling and aligning the lower and upper arch have to be finished prior to the mandibular advancement. The fixed myofunctional appliances (springs or rigid appliances, examples: Forsus™ Class II Correction System, 3M; Twin Force® Bite Corrector Device; Henry Schein® Orthodontics, BioBiteCorrector®; BBC-Orthotec, and many more) are attached to the bands or braces or directly cemented to the teeth (example: the original Herbst appliance). One-step treatment decreases total treatment time and is less depending on patient compliance, and dental hygiene is possible with greater effort.

Orthognathic surgery

Also known as jaw surgery or corrective jaw surgery, orthognathic surgery is appropriate after growth stops (usually around ages 16 for females and 18 to 21 for males). Surgery becomes necessary if treatment of a less severe malocclusion did not occur or was not successful during adolescence or if the skeletal discrepancy was too severe for functional appliances. Jaw surgery always requires orthodontic treatment with fixed appliances. Different timing for the management of skeletal imbalances is possible. In the conventional approach or also known as surgery late approach, mandibular advancement surgery is performed after a period of preoperative orthodontic alignment, levelling, and decompensation followed by postoperative occlusal refinement (14). The surgery first or surgery early approaches turn a dentoskeletal malocclusion into a dental malocclusion at an early stage of treatment, per definition without preoperative orthodontic preparation, followed by postoperative dental alignment (14). The surgery-first approach is not versatile, but it is an alternative (15). It is a concept of minimizing the duration of orthodontic treatment and early facial aesthetics optimization (16). For advancement of the retrognathic mandible, two surgery techniques are currently applied. Bilateral sagittal split osteotomy (BSSO) is the conventional technique applied since 1953, (17) and mandibular distraction osteogenesis (MDO) is the innovative alternative applied since 1991 (6).

Bilateral sagittal split osteotomy (BSSO)

Mandibular osteotomies have been performed since the beginning of the 20th century. These osteotomies were mostly done through an extraoral approach and a bilateral horizontal ramus osteotomy to advance the mandible. The first transoral sagittal splitting procedure was performed by Hugo L. Obwegeser in 1993 at the Maxillofacial Unit of the Dental School of the University of Graz in Austria (17). Incision is placed in the mucosa laterally to the first molar and extended to the base of the coronoid process. The periosteum is elevated, and the ascending ramus is exposed on the lingual and buccal side. The medial ramus osteotomy is done above the lingula all the way back to the posterior border. The buccal osteotomy of the mandibular body directs from the second molar region toward the angle. Both cuts are connected along the anterior boarder of the ascending ramus. Positioning and fixation of the condyle in the glenoid fossa is the most important step. Fixation can be done by using bone clamp or holding wire. Splitting of the mandible using a splitter and an osteotome is done. Unfavourable splits can be prevented by carefully following the surgical steps. The teeth are brought into occlusion. The condyles are positioned accurately, stabilized, and the fragments are fixed by means of bicortical screws and/or plate fixation. Wounds are closed, and intermaxillary elastics are placed (17,18).

Mandibular distraction osteogenesis (MDO)

As mentioned above, mandibular distraction osteogenesis was first documented by McCarthy in 1991 (6). MDO is a controlled surgical procedure that it is based on Ilizarov´s Law of tension-stress principle, which claims that tissues subjected to slow and steady traction become metabolically activated (19). Mechanical strains enhance the biological responses to create new bone (20). Both, the proliferative and biosynthetic cellular functions get stimulation (3). Bone growth in the distraction gap is called regenerate and is gradually distracted. It forms under the influence of tension-stress and has features of endochondral and intramembranous ossification (4). For mandibular distraction osteogenesis corticotomies are applied. A corticotomy removes the cortical bone that strongly resists traction force by avoiding damaging the neurovascular complex. The osteotomy can be seen as an artificial created epiphyseal plate, and the external distraction force as the tension stress, usually created by cartilage proliferation. The combination of both ossification processes makes the distraction regenerated bone unique. Endochondral ossification occurs during early stages and intramembranous bone formation in later stages. Second, it is the predominant mechanism of ossification. A third form, transchondroid ossification is usually observed at the level of the periosteum, not in the distraction gab (21).

The first distractor devices were sufficiently large and required extraoral application. Residual cutaneous scars along the cheeks resulting from the surgical incisions were consequences. During activation of extraoral distractors, the vector can be easily controlled and if necessary, modified (22). Three years after the invention of MDO, McCarthy investigated a miniaturized unidirectional bone lengthener for intraoral placement along the buccal surface of the mandible (23). Advantages of intraoral devices are avoiding scars, reducing proneness the device get traumatized, reducing perceptible mobility between the proximal, and distal segments of bone, and minimizing limitation in social life; therefore, they are well tolerated by patients and allow for a long consolidation period (24,25). Most of the planed surgical movements are a combination of translation and rotation. Unidirectional devices failed to completely restore them, and multidirectional or curvilinear distractors were invented with the disadvantage of being bigger in size (26). The distractor has to be activated by following a strict distraction protocol done manually by patients. Automated and continuous distraction devices are expected soon (27).

The basic distractor is a tram with some sort of attachment to the bone. Extraoral devices are non-submerged and attached directly to the bone with pins. Multidirectional vectors can be applied easier with extraoral devices. The appliance is placed further away from the ideal centre of distraction. Asymmetric movements of the segments are more likely (25). Intraoral distractors have submerged footplates on each site of the osteotomy. Screws attach the footplates to the bone, and the unit footplate and screws is called distractor anchor. The distal and proximal anchor are connected by a tram exiting through oral mucosa, which expands. The tram is also called the distraction unit or the connecting element. Anchors can be located on both sides directly next to the osteotomy, or the distal anchor can be placed more mesial in canine area. This greater distance between the anchors allows a distraction unit with greater extent needed for multidirectional devices. The distraction unit is closer to the ideal centre of distraction than in extraoral devices. A more controlled distraction vector can be applied. The footplates need to be adapted to the contour of the skeletal surface by bending, while keeping the proposed direction of the distraction. Ideally a stereolithographic model of the mandible facilitates adaptation through footplate bending prior surgery. It is difficult to perform adaptation at the operation site, partly due to the limited surgical area (28). Firm fixation of the footplates to the contour of the bone rises anchor stability. The device itself has to guarantee a stable configuration with maximum distraction to lead to direct osteogenesis without intervening cartilage formation (5). The latest generation of distractor devices are fully CAD/CAM-based customized offering an assembly system with customized bone plates including positioning guides (28). Techniques like virtual treatment planning and computer-guided distraction osteogenesis are already subject of research (29).

The process of MDO is divided into several stages:

1) **MDO-Surgery**: Corticotomies and distraction devices are applied to the mandible. Incisions are placed in the mucosa in retromolar region and periosteum is elevated lingually and buccally extending to the inferior boarder of the mandibular body. Depending on the distractor device, further incisions, and periosteum elevation in

canine area are needed for placing the distal anchor. Osteotomy is made at the prior defined location. The osteotomy directs circular from the upper to the lower boarder of the mandibular body. The course of the osteotomy, in more vertical or horizontal direction towards the mandibular angle, and distractor device position will define the distraction vector, special attention is required (6,30). The distractor device is orientated perpendicular to the osteotomy and fixed with screws. The distractor gets activated and deactivated to ensure proper function and sufficient mobility of the segments. The mucoperiosteal flaps are repositioned and wounds are closed in layers.

2) **Latency phase**: It is the interval between osteotomy and beginning with lengthening, no distraction is performed. This stage usually lasts 7–10 days and allows the initial trauma response to take place. The latency phase starts immediately after osteotomy and extends until the onset of active distraction. A hematoma is formed at the bone gab and primary inflammatory processes start. Recruitment of mesenchymal stem cells and periosteal callus and cartilage formation are basically the same processes as to the beginning of normal fracture healing (21).

3) **Distraction phase**: In this stage, lengthening of the mandible occurs. Tensile forces are applied to regenerate. A specific rate and rhythm of activations stretch the callus and forms a central fibrous interzone. Chondrocyte-like, fibroblasts and differentiating osteoblasts migrate and the cartilage, formed during latency phase, resorbs, and gets replaced by bone (endochondral ossification). In the central fibrous interzone, fibroblast cells and collagen fibres are aligned parallelly to the vector of lengthening. Neo-angiogenesis develops between the collagen fibre bundles. Collagen fibres are structural proteins crucial in wound healing and a key component of the structural support of the body. Osteoblasts are recruited and arranged along the blood vessels. New bone columns are formatted (intramembranous ossification) (21). The distraction protocol defines timing and extent of activation, generally, twice per day each time 0.5 mm resulting in 1 mm length gain every day (22). Depending on surgeon preferences and patient-specific factors the distraction protocol can vary. Daily lengthening less than 0.5 mm can cause premature consolidation because osteogenesis overtook the speed of distraction (4). Distraction rates higher than 2 mm can lead to exuberant periosteal bone formation, retarded osteogenesis, detrimental changes in the surrounding soft tissues or fibrous non-union (31).

4) **Consolidation phase**: The time from the end of distraction until bony union. The desired length is achieved, distraction ceases, and bone columns interconnect (21). During this stage, the distractor acts as a rigid fixation device. The new formed bone is held in length. After the second week of consolidation, a first radiographic mineralization is visible. Corticalization begins not before week eight of consolidation and is one of the last stages of regeneration and indicates that the device can be removed (32). Osteoclasts are recruited, and remodelling process starts. The cross-section of the new formed bone is frequently smaller than the cross-section of the bone at the osteotomy (33).

5) **Retention phase**: The time after distraction device removal with undefined end point. During this time, orthodontic treatment occurs until final occlusion is fixed. About 12 months after surgery a clinical and radiographic follow-up enables assessment of distraction stability, which can be assessed separately by skeletal stability and occurrence of relapse. Retention phase does not automatically stop after orthodontic treatment goals are achieved. Changes can always arise over time, albeit with decreasing frequency.

MDO for congenital craniomaxillofacial deformities

Craniofacial distraction osteogenesis and especially mandibular distraction osteogenesis became powerful surgical tools and enabled managing congenital craniomaxillofacial deformities (22,34,35). Surgeons can achieve results that were not previously attainable (36). Mandibular distraction osteogenesis offers another option in infants who are considering a tracheotomy (33,37). Facial and mandibular deficiency are quite variable in the clinical presentation and often manifests asymmetrically (30). Conventional techniques often cannot fulfil all needs for correcting or reconstructing asymmetrical deficiency. Severe skeletal discrepancies, exceeding 20 mm can be corrected by distraction osteogenesis (36). Distraction osteogenesis can be applied to different locations of the maxillofacial complex. Lengthening of the mandibular body, of the mandibular ramus, the mandibular ramus condylar unit, or mandibular symphysis are possible. For the maxilla, distraction osteogenesis can be applied at the Le Fort I, II and III level, and as monobloc to distract the cranial vault.

Hemifacial microsomia and congenital related micrognathia are the main concern in MDO-research in the last decades. In moderate to severe cases, hemifacial microsomia affects the ascending ramus. Horizontal osteotomies for vertical ramus distraction are needed (38). The relapse for vertical ramus lengthening is greater than for the horizontal body lengthening (39). 74% of all unilateral MDOs, the primary diagnosis was hemifacial microsomia (35). Craniofacial DO has had an enormous impact in the treatment of congenital and acquired deformities of the craniofacial skeleton (40). In 1991, McCarthy et al. first published a serious case of four young patients (between 2 and 10-year-old boys). Three patients, suffering from hemifacial microsomia, underwent unilateral distraction and one patient, suffering from Nager`s syndrome, underwent bilateral distraction. The average length? of distraction was 20 mm. No attempt was made to quantify changes radiographically. They used extraoral devices, and the consolidation phase was 9 weeks. One patient showed a clinical relapse of 5 mm (6). Huang et al. lengthened the ascending ramus of five patients with hemifacial microsomia. The chin tended to move downward more than forward, and the mandibular length could be adequately maintained 1 year after distraction (41). In another related case report, Marquez et al. showed that 2 years after unilateral distraction, the 15 mm ramus lengthening reduced by 13 mm. Occlusion and chin projection remained significantly improved, but not excellent 2 years after distraction (42). In a more recent retrospective study, Peacock et al. examined 26 patients who underwent MDO during the primary or mixed dentition period. Primary diagnosis for MDO was craniofacial microsomia. They could show that after distraction and after a period of relapse, mandibular growth continued but below published norms for mandibular size at each time point. 88% of patients in this study had adverse effects on the dentition. Directly by the osteotomy, damaged second and third molars germs were not likely to become functional teeth (39). MDO eliminates the need for bone grafting and blood transfusions and therefore the associated morbidity with this procedure (11,43). No definitive conclusion about permanent size increase in the mandible, stability, and predictability for MDO during growth can be given (44).

The clinical presentation of syndromic patients is heterogeneous, and symptoms vary greatly in their severity. Management of craniofacial deformities varies in accordance with the degree of disease severity. Young patients often require multiple surgeries and lifelong treatment and assistance (45). The outcome and success definition for these surgeries are improved in function and facial aesthetics. Full recovery in a single-surgery setting is rare. MDO became a powerful tool, and the results previously not attainable can be achieved. Every deformity is unique and comparison is difficult, or even impossible.

MDO for advancing a retrognathic mandible

Less data exists about MDO as a treatment approach for adults with middle-to-severe mandibular retrognathia, isolated without congenital malformation syndromes (40). Mandibular advancement shows a positive correlation with the risk of relapse (46,47). Greater extend of mandibular advancement can be achieved with MDO then with BSSO (48). In severe cases where? 20 or more mm mandibular lengthening is needed, MDO is accepted as the only option for mandibular advancement (7). BSSO-advancement over 15 mm is difficult because of resistance of the soft tissues and maintaining adequate bony contact for fixation and healing (49). MDO offers the possibility of obtaining results that simply cannot be achieved with conventional techniques (11). If the mandible was advanced by 8 mm or less, no differences in occlusal stability was found comparing to bilateral sagittal split osteotomy and mandibular distraction osteogenesis (11). BSSO weighs in favour, the second needed surgery and higher cooperation and costs do not stand for MDO in those cases (50,51). Moderate deficiencies, in the range of 8 to 12 mm, are in the focus of much debate (11). For this group, the decision between BSSO or MDO is influenced by further criteria in addition to deficiency. For moderate advancements around 10 mm significant stability differences were found, with stability demonstrated following MDO (52).

Craniofacial DO was found to be an approach with low preoperative and postoperative morbidity (40,43,53). One of the main benefits of MDO is the tension stress effect (5). This effect leads to gradual stretching of the overlying soft tissue envelope, less periosteal stripping and having the osteotomy mesial to the pterygo-masseteric sling. MDO creates a bidirectional force across an osteotomy. Although, the desired effect is for the tooth-bearing segment to move away from the skull base. There is an equal and opposite force that is transmitted through to the temporomandibular joint (TMJ) (7). The gradual stretching may result in decreased abnormal loading on the temporomandibular joint and might not promote condylar resorption (11,51).These factors are considered beneficial to soft tissue adaptation resulting in low relapse rates (22,54,55).

MDO limits the amount of acute manipulation and stretching of the branches of facial and inferior alveolar nerves (IAN) during surgery (50). The simpler and more predictable split of the bone segments result in a decrease of occurrence of neurosensory abnormalities (51). The distractor fixation is usually monocortical, thereby minimizing the risk of surgery-related nerve disturbances. Since the use of mainly intraoral devices, skin scarring caused by translation of transcutaneous fixation pins are avoided (56).

Due to less manipulation during surgical procedure, hospital stays have been drastically reduced. Most patients undergo MDO as a walk in and out at the same-day experience (11,57,58).The minimal immobilization of the jaws allows patients to resume daily activities sooner (57). Normal mouth opening is possible during all stages of distraction (55). Intraoral devices enable invisible distraction of the mandible, thus eliminating frequent monitoring and limitation on social life (59).

Distraction vector control is highly depending on device placement and course of osteotomy (11,48). Attaining the predicted occlusion using MDO has been much more difficult and requires the distractors perfectly positioned to provide the appropriate vector to obtain the desired outcome (50). Inappropriate vector is the most troublesome complication and leads to laterognathism, malocclusion, and the need of device replacement (60). With the use of multidirectional devices and preoperative planning of distractor placement and distraction vector, it was possible to overcome the limitation to simple and pure anterior-posterior movements (43).

Mandibular distraction osteogenesis can be done during orthodontic therapy, in a surgery first or even in a pre-surgery setting. Most importantly, at least six months before the planned MDO surgery, third lower molars, if present, have to be removed. MDO is according to the patient not an uncomfortable experience and no major discomfort was noted (55).

The less invasive approach and the consistent improvements in aesthetics and function obtained through MDO has widely encouraged the adoption of the procedure in modern maxillofacial surgery (3).

The most obvious disadvantage of MDO is the second needed surgical procedure, including all the risks involved to remove the distractor devices (11,61). After surgery, patients should be seen in weekly intervals during active distraction stage by the surgeon. Up to 3 times the number of visits is required by the patients than with BSSO (11). MDO has been associated with increased costs of 36%, due to the second needed surgery and mainly due to the price of the distractor devices (58). Device failure including breakage and dislodgement are possible complications most common in patients undergoing external distraction (60). Loose pins could be resulting of micromovements during the retention period or due to the distraction process itself (55). Most anchors are fixed with several pins, where single pin loosening is not related to complications. Other reasons for loose pins can be poor bone quality, trauma, and pin-tract infections (60). Minor local infection not requiring removal of devices can be treated easily with local or systemic application of antibiotics. Osteomyelitis and deep infections are possible but much less common (60).

Fibrous non-union or premature consolidation are troublesome fusion errors. Premature consolidation is caused by incomplete osteotomy, distraction rates inferior to 1 mm per day, excessive latency period, and/or device failure (40,60). Fibrous non-union occurs due to a truncated latency period and excessive frequent daily distraction rate and rhythm (53,60).

The frequency of each complication varies based on the surgeon experience (60). MDO has been used for an obviously much shorter period of time and many surgeons don’t have the experience with this approach (11). However, as for every new technique, the rate of complications decreases substantially as the experience of the surgeon increases (19).

One factor, influencing the stability of MDO is Mandibular Plane Angle (MPA) prior surgery. High-angle patients (MPA ≥38°) are at risk of relapsing. Van Strijen et al. showed in 2004 in a retrospective study on fifty patients that for normal-to-low angle patients, MDO is a safe and predictable procedure (relapse rate one year after surgery: 8.3%). The high-angle group showed a relapse rate (≥2 mm) of 57% (52). In another study from van Strijen et al., fourteen young growing patients (age between 12 and 15), who had failed to respond to initial functional orthodontic treatment, were treated with MDO. Six patients showed relapse within the first six months. It was concluded that young patients can be treated effectively by means of distraction osteogenesis without going further into detail about the high relapse rate (55). Baas et al. compared the postoperative stability of the mandible after BSSO (n= 17 patients) and after MDO (n= 18 patients). They used Point B changes to estimate relapse. 46 to 95 months after advancement of the mandible, neither group showed significant differences (49). One of the rare randomized clinical trials on MDO on adults was conducted by Baas et al. in 2015. In this trial they compared postoperative stability after mandibular advancement in non-syndromal class II patients. 66 patients were included, and BSSO and MDO stability were compared. Both approaches gave similar stable results in advancement of the mandible up to 10mm. The magnitude of advancement, Mandibular Plane Angle, gender, and age were not identified as independent risk factors (61).

Advancing a retrognathic mandible not only improves occlusion and facial aesthetic but repositioning of the skeletal framework also expanded or diminished the soft tissue envelope, creating volumetric changes in the pharyngeal airway (62). Bimaxillary and isolated mandible (BSSO) or maxilla (LeFort I) surgery can lead to an initial immediate upper airway gain of 36%: however, 10% volumetric relapse has to be expected after a follow-up of 12 months (8). This volumetric relapse can be related to the fact of measuring a space, which depends on function, adaptation, and skeletal stability (8).

Ow and Cheung performed in 2007 an evidence-based review comparing skeletal stability and complications of bilateral sagittal split osteotomy and mandibular distraction osteogenesis. Based on the 34 articles relating to stability, patients undergoing MDO or BSSO (advancement between 6 and 10mm) showed similar mean skeletal relapse of 17.1% and 15.0%. Results stand for the first 6 to 12 postoperative months. Based on the 49 articles relating to complications, MDO showed a lower incidence of persistent inferior alveolar nerve disturbance (2.9%) and condylar resorption (1.4%). In BSSO, the incidence for persistent inferior alveolar nerve disturbance was 27.8% and for condylar resorption was 6.1% (51).

Nine years later, Rossini et al. conducted another systematic review based on eight relevant publications. The aim was to analyse the available evidence on the skeletal and soft tissue effects of MDO. The quality of the collected evidence was low to moderate. In the vertical plane a considerable relapse (2.5 mm) occurred, while in the sagittal plane no values were mentioned. Significant skeletal relapse was reported; however, not worsening the results of treatment significantly (63).

Relapse and skeletal stability

Relapse is defined as the gradual recurrence over time of the abnormality for which distraction was performed. In other words, as any increase in post-distraction overjet from the immediate postoperative sagittal overbite measurement, following MDO (60,64). The aetiology of relapse after mandibular advancement is multifactorial and associated with the temporomandibular joint through condylar distraction, rotation of the ramus segment, morphological changes in the condyle, the accuracy of the surgery, occlusion stability, proper seating of the condyles and upper jaw, remaining growth and remodelling activity, muscle pull, soft tissue contraction, gravitational displacement, and the amount of advancement (47). In contrast to skeletal stability, relapse has less to do with the distracted bone itself but is a change in mandibular position. Relapse is the most common complication in MDO and BSSO procedures (65). The frequency is greatly variable depending on the anatomic location of DO perform (33). The position of the condyle is affected during different stages of the surgical approach. Minimizing changes in the position of the condyle to ensure normal mandibular movement and temporomandibular joint (TMJ) function is the main objective of orthognathic surgery (66). Intraoperative loosening of condyle fixation in proper position and condyle rotation due to segmental fixation are the main reasons for improper postoperative occlusion. Improperly positioned condyles are considered a major factor contributing to the development of temporomandibular disorder (TMD) after orthognathic surgery (66). If relapse occurs in the first weeks after surgery, most likely the causes can be attributed to loss of segment fixation and tensional imbalances of the muscles and surrounding tissues (50). Late relapse is associated with significant morphologic changes of the condyle and bone remodelling (67). Morphologic postoperative changes of the condyles may occur in cases in which the altered mechanical load exceeds the intrinsic adaptive capability of the joints (68). Symptoms for relapse can be clinically an increased overjet and worsening of profile and radiographically by decreased Sella-Nasion-Point B (SNB) and Sella-Nasion-Pogonion (SN-Pog) angel.

Reduction of the Mandibular Body Length after BSSO or MDO is resulting from a lack in skeletal stability. Forces generated from the surrounding soft tissues, especially from the muscles can lead to changes at the osteotomy sites through inter-segmental movements. Inflammation and infection of the regenerated unstable fixation during the consolidation phase and advancements crossing the physiological boundaries are further possible reasons for skeletal instability. Ilizarov already summarized in 1990 the main characteristics for successful bone lengthening and skeletal stability. He asked for *“maximum preservation of extraosseous and medullary blood supply; stable fixation; a delay prior to distraction; a distraction rate of 1 mm per day in frequent small steps; a period of stable neutral fixation after lengthening; and physiologic use of the elongating limb.”* (5) Skeletal instability might be observed in the short-term and is validated by decrease in radiographic mandibular body and unit length measurements.

Justification of the research question

A low number of studies focused on adult patients undergoing mandibular distraction osteogenesis. No definite conclusion about skeletal stability and relapse rate has been reached on adult retrognathia patients. Most data have also been described through case presentation and anecdotal evidence. There is simply not sufficient evidence provided through long-term controlled studies that show the increased stability when measured by the same traditional yardsticks used to evaluate traditional mandibular advancement. Heterogeneous groups of patients with respect to age and indication were treated during the last decades. Distraction related procedures were not performed uniformly. Bias related to different types of surgical management is likely. MDO has casuistic features within individual therapeutic concepts. The risks and benefits of the new technique must be compared with commonly used surgical procedures. For this, basic data from homogeneous groups treated with a stable concept by one experienced surgeon are needed.

Aims of the dissertation

The primary aim of this retrospective study is to evaluate the skeletal changes after mandibular distraction osteogenesis over short and long-term in adult retrognathia patients. Skeletal stability and relapse rate were chosen to show changes over time of a group of patients treated by one, high experienced surgeon.

The secondary aims of this study are as follows:

- To identify upper airway volume changes caused by mandibular distraction osteogenesis
- To identify differences in terms of skeletal stability and relapse rate among males and females
- To identify differences in terms of skeletal stability and relapse rate among different indications for mandibular distraction osteogenesis
- To identify correlation in terms of skeletal stability and relapse rate among further patients' characteristics

Hypotheses

For this purpose, the following null hypothesis and respective alternative hypotheses have been identified:

Null-Hypothesis

H_0: There are statistically significant postoperative changes regarding skeletal stability and mandibular position in patients undergoing mandibular distraction osteogenesis in short-term and long-term.

Alternative hypothesis

H_1: There are upper airway volume changes caused by mandibular distraction osteogenesis.

H_2: There are no postoperative statistically significant gender-specific differences regarding skeletal stability and mandibular position in patients undergoing MDO.

H_3: There are no postoperative statistically significant indication-specific differences regarding skeletal stability and mandibular position in patients undergoing MDO.

H_4: There are no correlations in terms of skeletal stability and relapse rate among further patients' characteristics.

Material and Methods

Study Design and Variables

The current study was conducted retrospectively as a reuse of health-related personal data in medical research. All consecutive patients, independent from gender and age, who underwent MDO surgery at pyramid clinic of Zürich, Switzerland between 2010 and 2021 were eligible for this study.

The inclusion criteria were following:

1) Angle class II mandibular retrognathia

2) full dataset, which consist of CBCTs recorded

T0 - preoperatively

T1 - after the active distraction phase

T2 - 12 months after surgery

T3 - later than 12 months after surgery (if available)

The exclusion criteria were the following:

1) additional mandibular surgery, like genioplasty or wing-osteotomy, between T1 and T2

2) those who did not consent

Primary outcome

Measuring the amount of distraction in mm and of the skeletal changes after surgery.

Determination of relapse rate.

Secondary outcome

Determination of statistical relevant corelations between amount of relapse and amount of distraction, gender, age, Mandibular Plane Angle, and time of the connection element of the distractor in situ.

Determination of volume changes of the oropharynx pre- and postoperatively.

Surgical Intervention

All patients went through the following procedure:

6 months before surgery

- first consultation and briefing
- removing of lower third molars, if present

3 months before surgery

- informed consent discussion to treatment
- CBCT T0

days before surgery

- intraoral and extraoral photographs, casts
- printing the 3-dimensional mandibular model
- surgical planning including defining of distraction vector and amount of distraction, device position and adjusting the anchors to the bone surface (Figure 1-3)

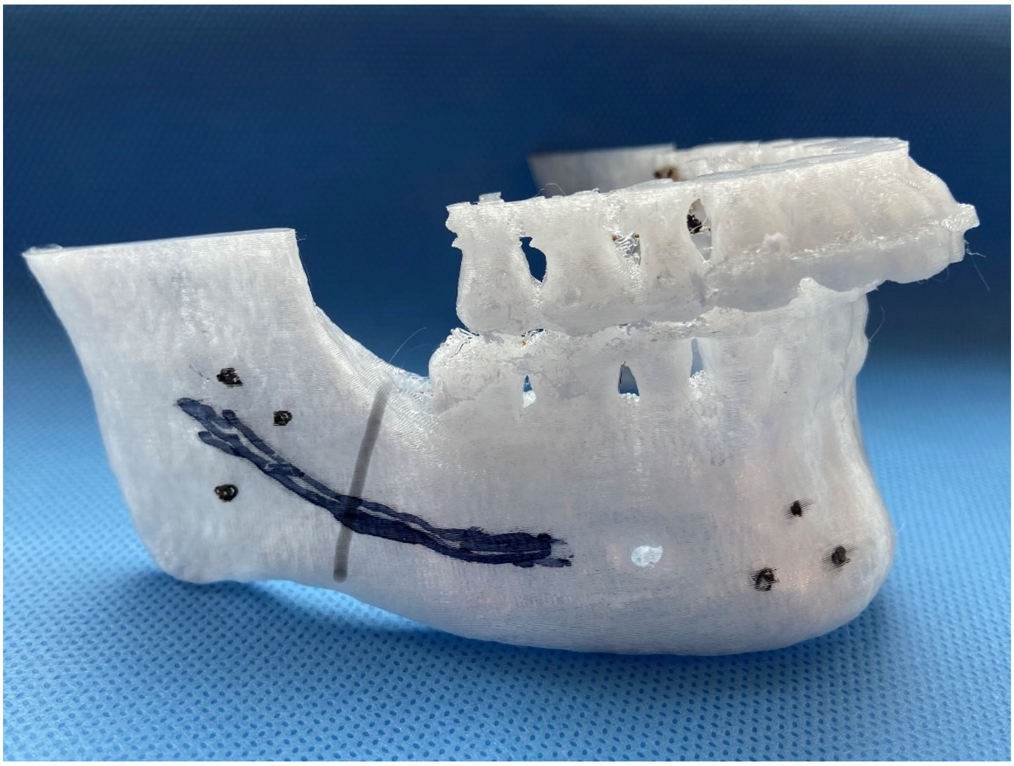

Figure 1: 3D-printed jaw model; with marked device and osteotomy position and intrabony IAN course

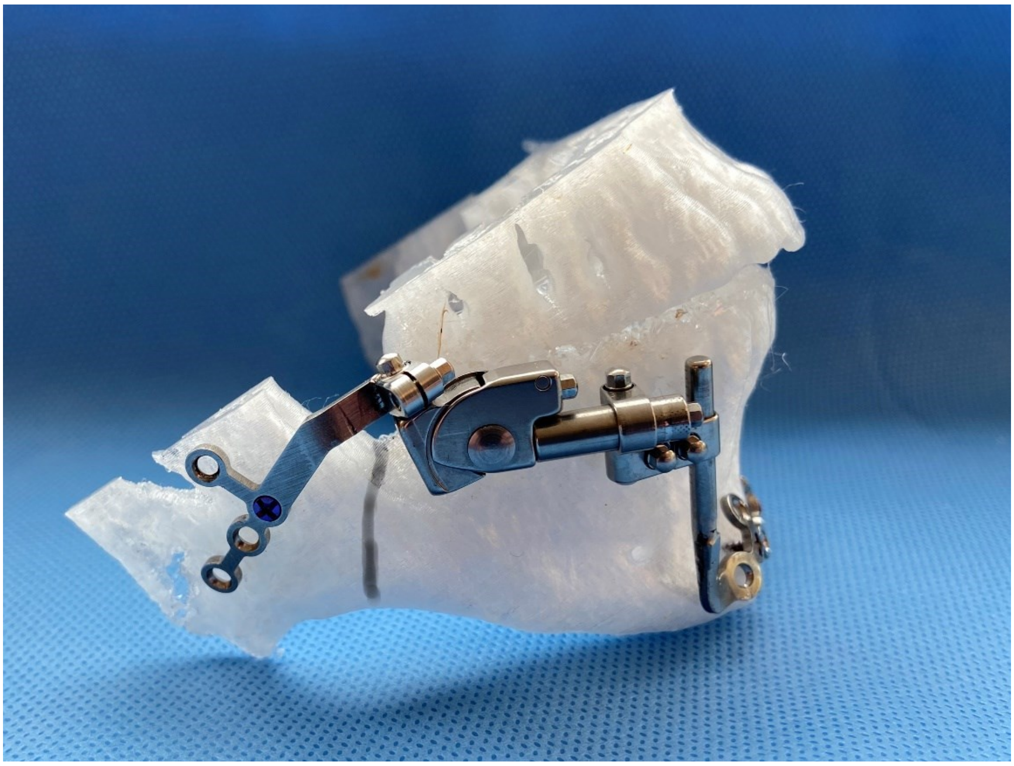

Figure 2: 3D-printed jaw model; with marked osteotomy position and anchors adaptation (lateral view)

Figure 3: 3D-printed jaw model; with marked osteotomy position and anchors adaptation (frontal view)

Day of surgery

Preparation:

- general anaesthesia through nasal intubation
- patient positioned on his back and head is slightly hyperextended

Surgery procedure:

- distractor device placement and anchors fixation on patient's right side:
    - intraoral vestibular mucosal incision in retromolar area (2.5 cm) (Figure 4)
    - buccal subperiosteal mobilisation extending from the molars to the ascendant mandibular ramus and the inferior boarder of mandibular body
    - lingual subperiosteal mobilisation continued to the inferior boarder of mandibular body
    - marking the osteotomy-line according to the operation planning protocol
    - cortectomies buccal and lingual
    - placing and fixation of proximal anchor with 3 monocortical screws (Figure 5)
    - Intraoral vestibular gingival incision in canine area (1.5 cm)
    - subperiosteal mobilisation
    - placing and fixation of the distal anchor with 3 monocortical screws (Figure 6)
    - placing the connecting element of the distractor and marking the position on the distal anchor (Figure 7)
    - removing the connecting element of the distractor and controlled fracture to complete cortecotomy (Figure 8)
    - replacing connection element of the distractor at marked position (Figure 9)
- distractor device placement and anchors fixation on patients left side
- pre- and de-activation to conform proper distractor function and to check osteotomy
- suture and wound management

The whole procedure lasts about 60 minutes (± 30).

After post-operative physical examination, patients are allowed to leave hospital.

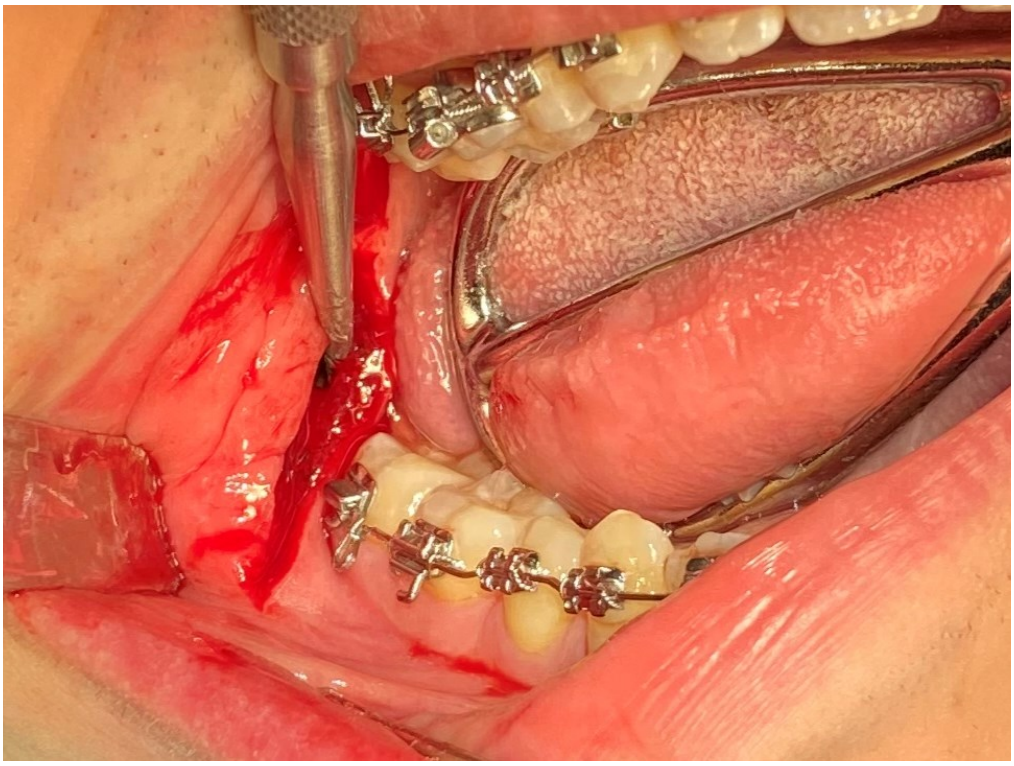

Figure 4: Vestibular mucosal incision in retromolar area

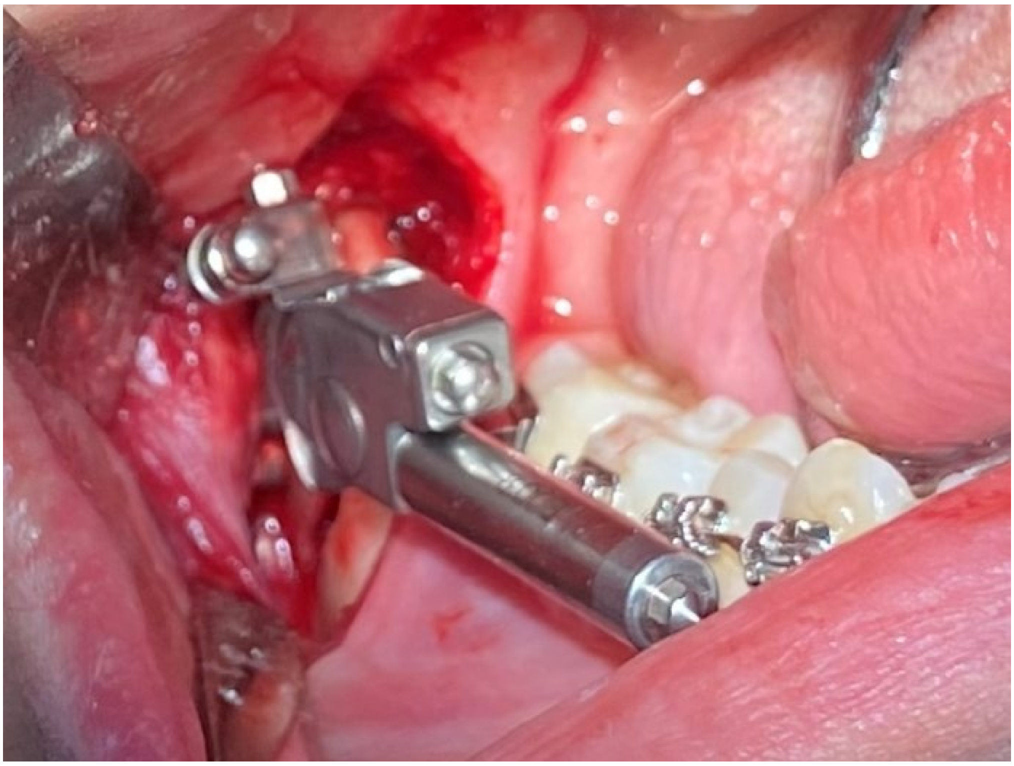

Figure 5: Placing and fixation of proximal anchor with 3 monocortical screws

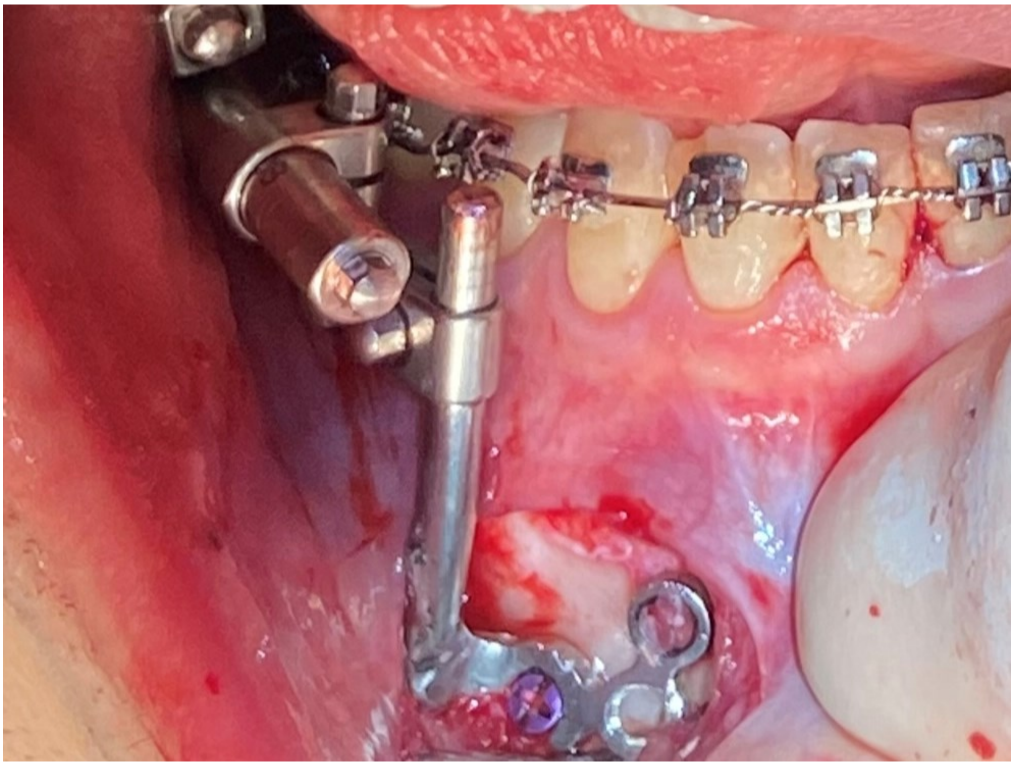

Figure 6: Placing and fixation of the distal anchor with 3 monocortical screws

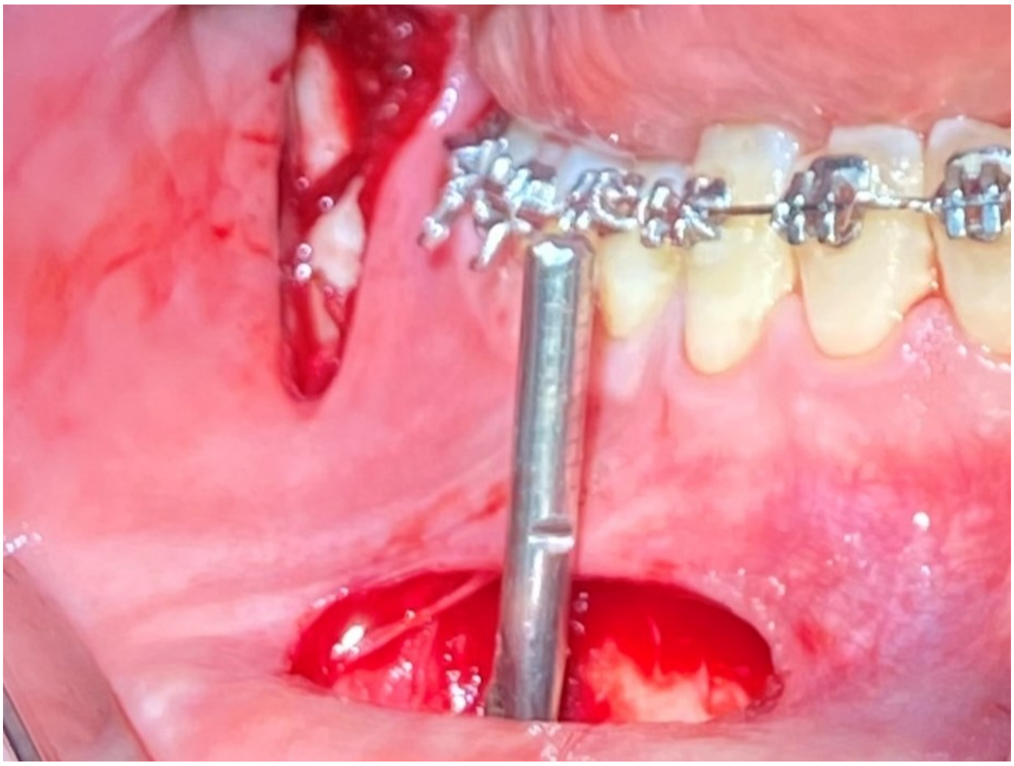

Figure 7: Marked position for the connection element on the distal anchor

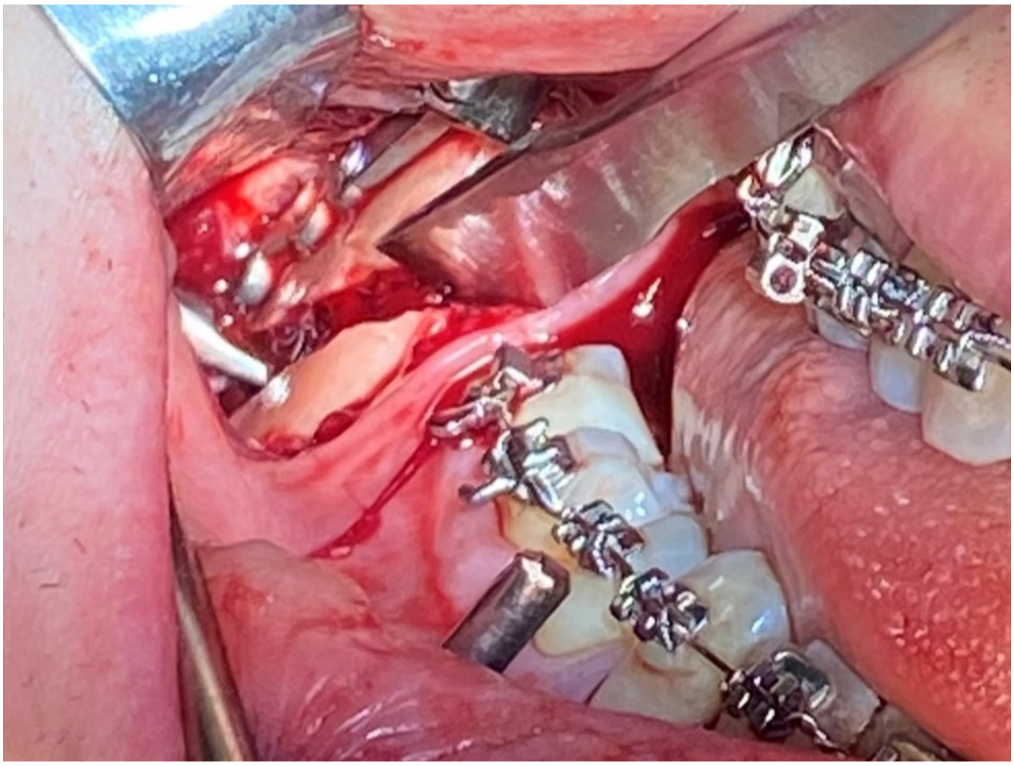

Figure 8: Controlled fracture to complete cortecotomy

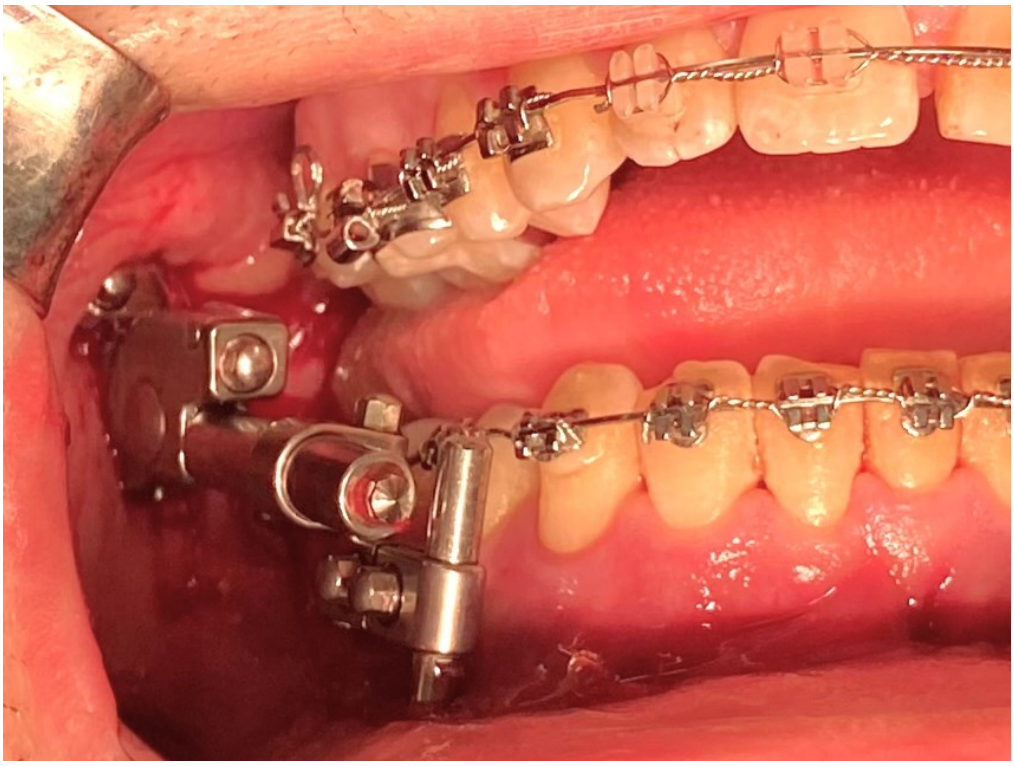

Figure 9: Distractor in place

7 Days after surgery:

- first examination after latency phase
- introduction to the distraction procedure
  activation 3 times a day, every 8 hours one turn

weekly after surgery

- virtual examination and control of the distraction procedure and adjustments

1 month after surgery

- second physical examination final adjustment for final occlusion
- start of retention phase with connection element in situ

3 months after surgery:

- removing of the connection elements

6 months after surgery:

- removing of the anchors in total anaesthesia
- additional maxillofacial surgery if indicated

12 months after surgery

- CBCT T2

Later than 12 months after surgery

- further check-ups, CBCT T3 if indicated

All mandibular distraction osteogenesis related procedures like planning, surgery, activation, consolidation, and material removal were performed by the same surgeon (AT).

For all CBCT scans a KaVo 3D Exam Cone Beam (Germany) CBCT machine was used. The parameters for every scan were:

- scan time 8.9 sec.
- isotropic voxel of 0.4 mm
- field of view 16 x 13 cm

Measurements

2-Dimensional Cephalogram Measurements

To get a cephalogram out of the 3-dimensional CBCT datasets, Planmeca Romexis TM software 6.1.0.997 (Helsinki, Finland) was used. The software calculates a 2-dimensional cephalogram out of the 3-dimensional CBCT dataset, which can be manually adjusted in head position. Double contours, often seen on classic cephalograms, can be avoided.

To analyse the cephalogram, the Image Instrument, OnyxCeph 3TM 2D Pro software 3.2.157 (Chemnitz, Germany), was applied for measurements. A customized analysis was compiled from elements from different standardized cephalogram analysis listed in the OnyxCeph analysis bibliography. Table 1 shows the landmarks, abbreviations, and landmark definitions used for the customized analysis according to Wiliam R. Proffit (69). Figure 10 shows a cephalogram calculated out of a CBCT including the landmarks defined for the customized cephalometric analysis used in this study.

Landmark	Abbreviation	Landmark definition
Nasion	Na	The anterior point of the intersection between the nasal and frontal bones
Sella	S	The midpoint of the cavity of sella turcica
Condylion	Cond	The most superior point of the condyle
Articulare	Ar	The point of intersection between the shadow of the zygomatic arch and the posterior border of the mandibular ramus
Gonion	Go	The midpoint of the contour connection the ramus and body of the mandible
Menton	Me	The most inferior point on the bony chin
Gnation	Gn	The most inferior and anterior point on the mandibular symphysis
Pogonion	Pog	The most anterior point on the contour of the bony chin

Table 1: Landmarks, abbreviation, and landmark definitions used for the customized analysis

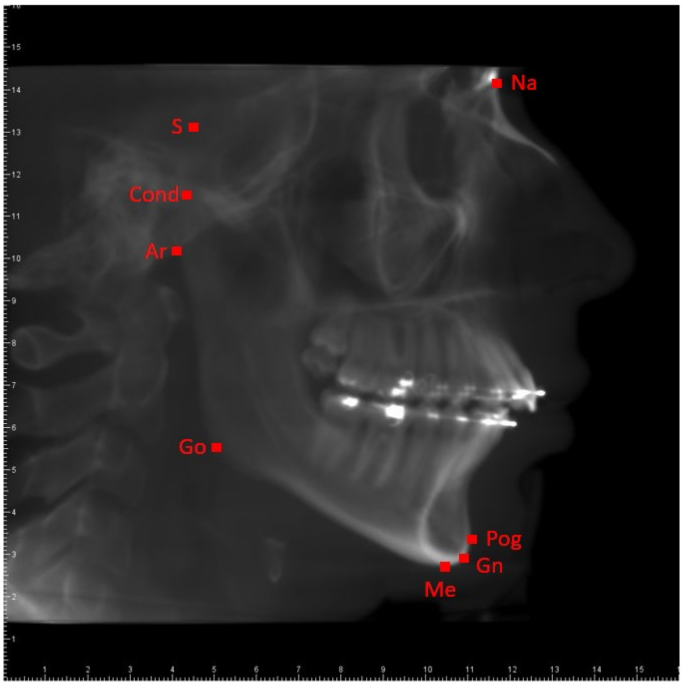

Figure 10: Cephalometric landmarks; Na Nasion, S Sella, Cond Condylon, Ar Articulare, Go Gonion, Me Menton, Gn Gnation, Pog Pogonion

Out of this landmarks, three angular measurements and two linear distance measurements, were calculated for each cephalogram to demonstrate the changes during distraction (T0-T1) and retention period (T1-T2 and if available T1-T3). Table 2 shows the characteristics of each element of the customized cephalometric analysis and from which original cephalometric analysis the element was taken from.

Name	Abbreviation	Landmarks	Measurement	Origin
Mandibular Body Length	MBL	Gonion to Pogonion	Distance (mm)	Bonn University
Mandibular Unit Length	MUL	Condylon to Gnathion	Distance (mm)	Mc Namara
Mandibular Plane Angle	MPA	Sella/Nasion-Gonion/Gnathion	Angle (°)	EBO
SN-Pog Angle	SN-Pog	Sella-Nasion-Pogonion	Angle (°)	EBO
Gonion Angle	Go-Angle	Articulare-Gonion-Menton	Angle (°)	Burstone

Table 2: Characteristics of the elements used for the customized cephalometric analysis; EBO European Board of Orthodontics

The elements were chosen to measure and interpret the following:

MBL and MUL: Amount of distraction was defined as the increase in length from T0 to T1 in mm. Relapse was defined as the loss of length from T1 to T2, if available from T1 to T3 in mm. All landmarks for these measurements refer to mandibular only; changes in these values present skeletal stability.

MPA: Mandibular Plane Angle was used to divide patients into a high Mandibular Plane Angle group (MPA > 38°) and a normal-to-low Mandibular Plane Angle group (MPA ≤ 38°).

SN-Pog: The angle defined by the landmarks sella, nasion, and pogonion was used to measure mandibular retrognathia and relapse. Relapse was defined as a negative changing of the SN-Pog value from T1 to T2 and if available from T1 to T3 in degrees. This measurement shows the mandibular position in relation to the anterior cranial base.

Go-Angle: The angle defined by the landmarks articulare, gonion, and menton was measured to show the direction of the distraction. Positive changes from T0 to T1 are defined as a vertical direction, while negative or no changes as a horizontal distraction direction.

Figures 11-14 shows the distance measurements and the angle measurements used for this study.

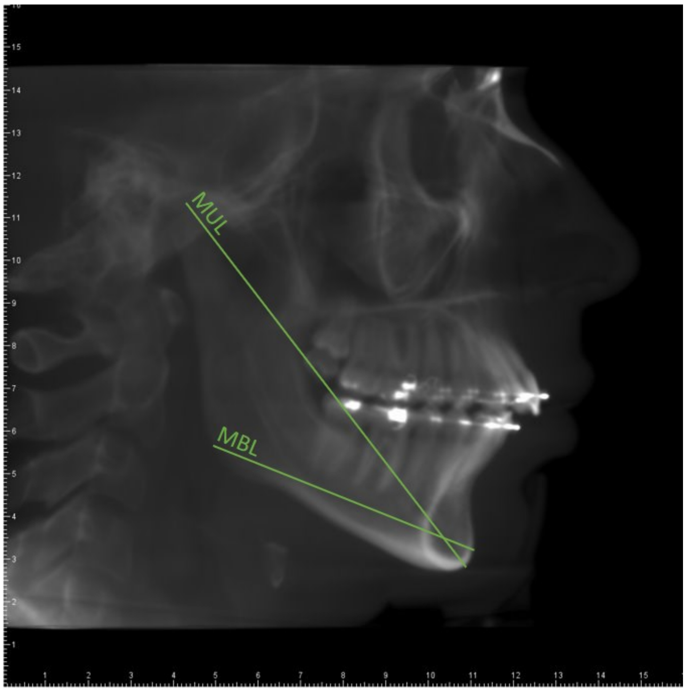

Figure 11: Distance measurements; MUL Mandibular Unit Length, MBL Mandibular Body Length

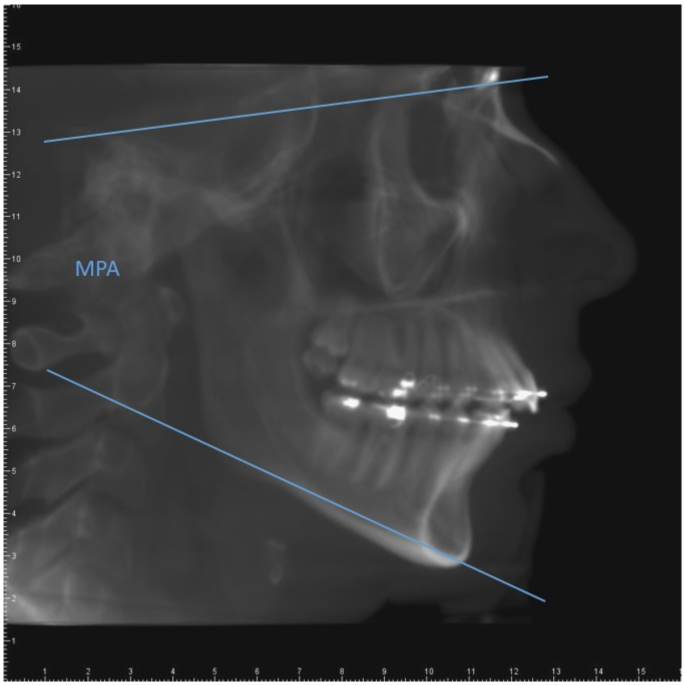

Figure 12: Angle-measurement: MPA Mandibular Plane Angle

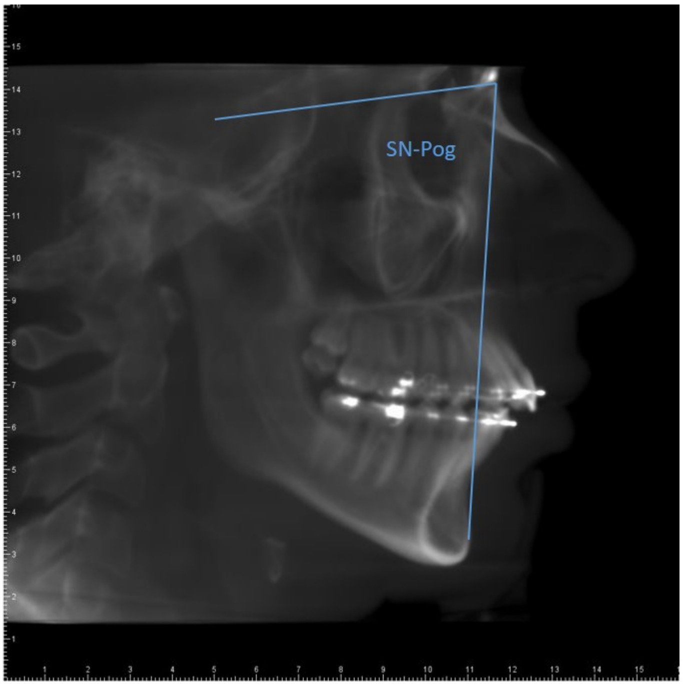

Figure 13: Angle-measurement: SN-Pog angle

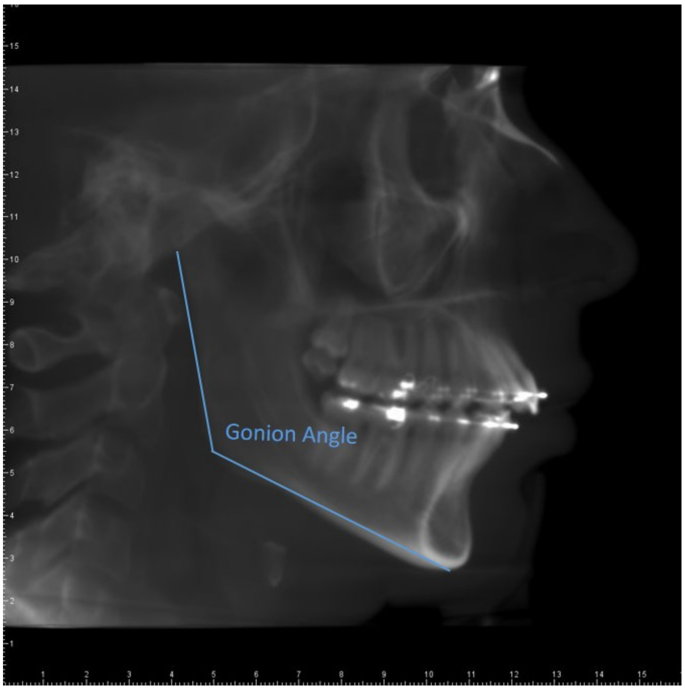

Figure 14: Angle-measurement: Go-Angle

Measurement procedure

Values from cephalometric analysis are highly depending on subjective landmark interpretation. To get independent from subjective interpretation, all measurements were carried out separately by two experienced operators (HK and SM), both from the department of oral surgery and orthodontics of the dental clinic of the medical university of Graz, finished in the postgraduate education in orthodontics. After a period of 4 weeks, cephalograms of 5 randomly selected patients were retraced. The intercorrelation coefficient was calculated to check inter- and intra-examiner reliability.

3-Dimensional CBCT Superimposition Measurements

To superimpose, a CBCTs Planmeca Romexis TM software 6.1.0.997 (Helsinki, Finland) was used. Measurements were done on superimposed CBCTs from T0 with T1 and T1 with T2 and, if available, T1 and T3 of each patient. CBCT T1 of each case was defined as the standard volume and was positioned corresponding to Frankfort Horizontal. The plane extends from the upper border of the external auditory canal (porion) to the upper border of the lower orbital rim (orbitale) (69). Fitting of the corresponding CBCTs (T1 with T0, T1 with T2, and if available T1 with T3) was done semiautomated. Selection of three common corresponding points in both volumes were defined and the software calculated the best fit. After the automated superimpose procedure, fitting was controlled and manually adjusted if needed. The anterior cranial base has been used for superimposition. It is considered as a stable structure for superimposition and also other traditional superimposition methods, such as superimposing of cephalograms, which uses the anterior cranial base (70). Figure 15 shows superimposed CBCTs from T0 and T1 in X-Axis (sagittal).

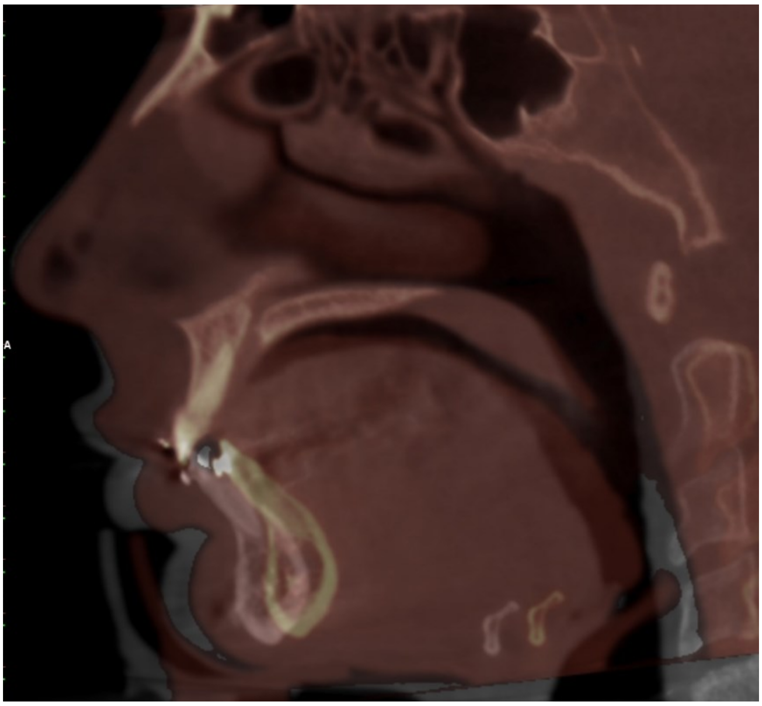

Figure 15: Superimposition of CBCT T0 (green) and T2 (red)

Measurement procedure

In Romexis the sagittal view, (X-Axis) was set to the midsagittal plane, so the incisive canal could be seen, and the axial view (Z-Axis) was positioned for the first measurement at pogonion and for the second measurement at Point B. Table 3 shows the landmarks, abbreviations and landmark definitions used for this analysis according to Wiliam R. Proffit

(69). In these layers, the distance between the two anterior cortical contours was measured with the distance measuring tool provided by the Romexis TM software. Due to resolution accuracy, the minimum distance between the two points had to be 0.6 mm, every difference smaller than 0.6 mm could not be measured and was defined as no changing. Figure 16 shows the X-Axis (sagittal plane) and Z-Axis (axial plane) view with the measuring of the amount of distraction at pogonion and Figure 17 at point B respectively.

Landmark	Abbreviation	Landmark definition
Point B	Point B	the innermost point on the contour of the mandible between the incisor tooth and the bony chin
Pogonion	Pog	The most anterior point on the contour of the bony chin

Table 3: Landmarks, abbreviation, and landmark definitions used for these measurements

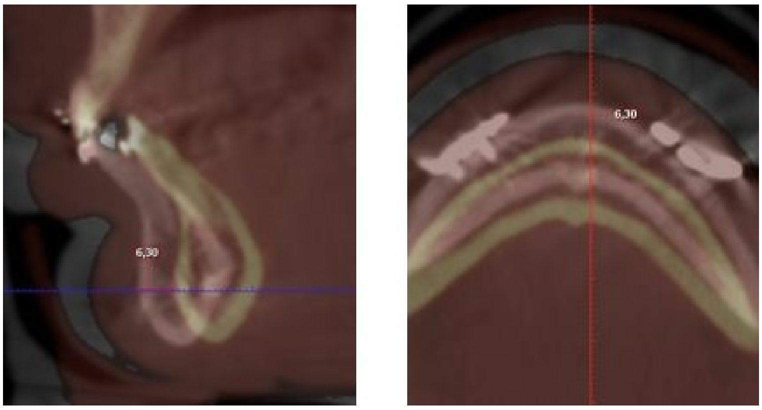

Figure 16: X-Axis and Z-Axis view with distance measurement at pogonion

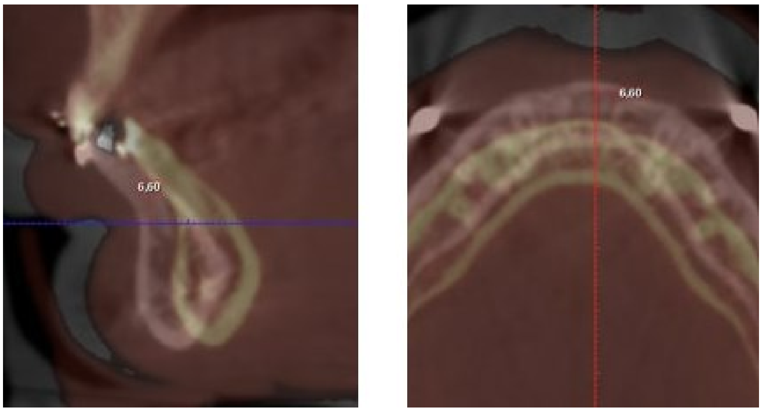

Figure 17: X-Axis and Z-Axis view with distance measurement at point B

Because anterior cranial base was used as reference for superimposition, measurements at point B and Pogonion were sensitive for vertical mandibular position changings. If patients underwent additional craniofacial surgery, like Le Fort I Osteotomy during the period T1 to T2, the mandible changed in the vertical position, mostly in a counter clockwise direction. Pogonion and point B respectively therefor chanced in vertical but also in sagittal position. These patients had to be excluded from these measurements.

After 4 weeks of latency period, 10 Patients were randomly selected, reimposed, and remeasured by the principal investigator to check inter-observer reliability.

3-Dimensional Oropharynx Volume Measurements

The pharyngeal airway consists of three sections, the nasopharynx, oropharynx, and the hypopharynx. For this study the oropharynx was examined, and the boundaries were defined as the following (71,72):

- Superior: a line parallel to the Frankfort Horizontal (FH) from the posterior nasial spine extended to the soft tissue pharyngeal wall contour
- Inferior: a line parallel to the superior boundary from the anterior-superior edge of the 4th cervical vertebra (C4)

The anterior-superior edge of C4 consists of the position of the epiglottis in general (73). If C4 was not visible on the CBCT, patients were excluded from this evaluation. Planmeca Romexis TM software 6.1.0.997 (Helsinki, Finland) includes an airway analysis tool to automatically calculate the pharyngeal airway volume (PAV). Endpoints for this volume calculation has to be selected manually. Four weeks after the original investigation, 15 randomly selected cases were re-evaluated to check intra-observer reliability. Figure 18 shows the defined boundaries of the oropharynx and Figure 19 the volume calculation respectively.

Figure 18: Oropharynx with superior (S) and inferior (I) boundary parallel to Frankfort Horizontal (FH)

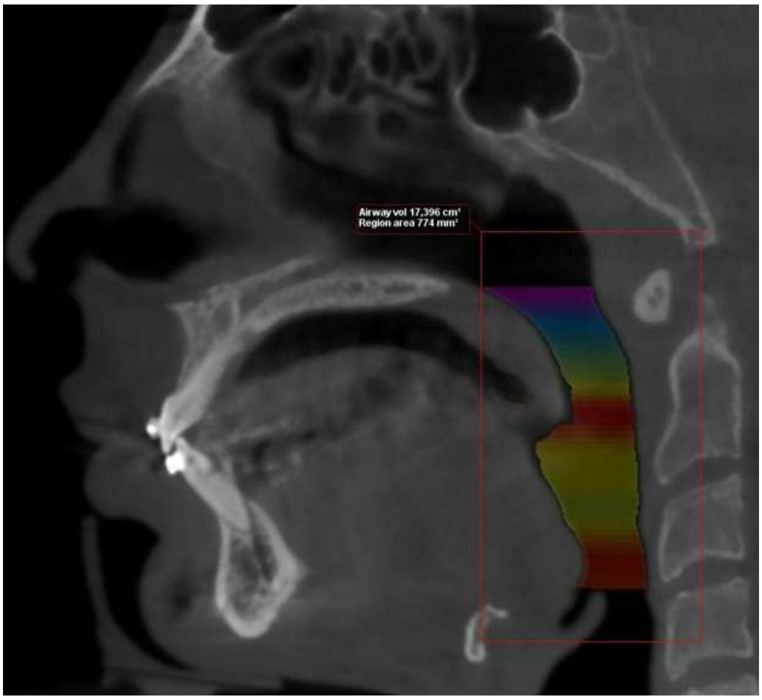

Figure 19: Pharyngeal airway volume (PAV) of the oropharynx

Data Management and Statistical Analysis

Statistical analyses were done using IBM SPSS Statistics 26 (Armonk, NY; IBM Corp). The intraclass correlation coefficient (ICC) was determined to assess the reproducibility through measurements inter- and intra-operator. Descriptive statistics were used to show changings in length, degrees, and volume during and after distraction phase.

One Sample T-test was used for the values from the cephalometric and superimposition measurements. Paired Sample T-test was used to test airway volume changes. Correlation between variables (age, gender, MBA, amount of distraction, amount of relapse and appointment of removing of the connection element) was calculated by means of the Pearson´s correlation coefficient.

The p-value was set as the cut-off for statistical significance at 0.05.

Ethical Approval

Approval from the ethics committee of the medical university of Graz (34-055 ex 21/22 1494-2021) and ethics committee of Zürich (2021-01218) were obtained for this study.

Results

Sample Characterization

A total of 124 records were assessed for this study, of which 74 fulfilled the inclusion criteria. The final sample consisted of 56 women (76%) and 18 men (24%). The mean age on the day of surgery was 23.3 years (± 8.4). 46 patients (62.2%) had a normal-to-low mandibular plane angel (MPA ≤ 38°), and 28 patients (37.8%) were defined as high Mandibular Plane Angle (MPA > 38°). The SN-Pog angle was on average 77.0° (± 5.0) preoperatively, men had 81.2° (± 5.0) higher values for SN-Pog than women with 75.6° (± 4.1). The characteristics of the final sample are summarized in table 4 and 5. Table 6 shows the absolute and relative distribution of the chief complaint for surgery.

	n	Age (y)	SD	SN-Pog	SD
Male	18	23.6	7.8	81.2	5.0
Female	56	23.2	8.7	75.6	4.1
Total	74	23.3	8.4	77.0	5.0

Table 4: Sample characteristics; y years, SD standard deviation

	MPA > 38°	%	MPA ≤ 38°	%
Male	2	2.7	16	21.62
Female	26	35.14	30	40.54
Total	28	37.84	46	62.16

Table 5: Normal-to-low and high MPA; MPA Mandibular Plane Angle

	n	%
OSA symptoms	11	14.9
TMJ symptoms	43	58.1
Trauma	3	4.1
Post-surgery	5	6.8
Congenital micrognathia	12	16.1
Total	74	100

Table 6: Absolute and relative distribution of the chief complaint for surgery

The CBCT T0 was taken preoperatively and shows the origin values of the skeletal misalignment. The day of surgery was set as “day 0”, which was used as the reference to calculate time. The connecting element of the distractor was removed on average 4.28 months (± 0.67) after surgery. During this period, the active bone distraction and the bone maturation process of the new generated callus took place. CBCT T1 was taken 4.37 month (± 2.24) after surgery and represents the values of the amount of distraction. The CBCT T2 for the short-term follow-up was taken on average 13.39 months (± 5.43) after surgery, and CBCT T3 for the long-term follow-up was taken 43.17 months (± 22.13) after surgery. Figure 20 shows a graphical representation of the timeline.

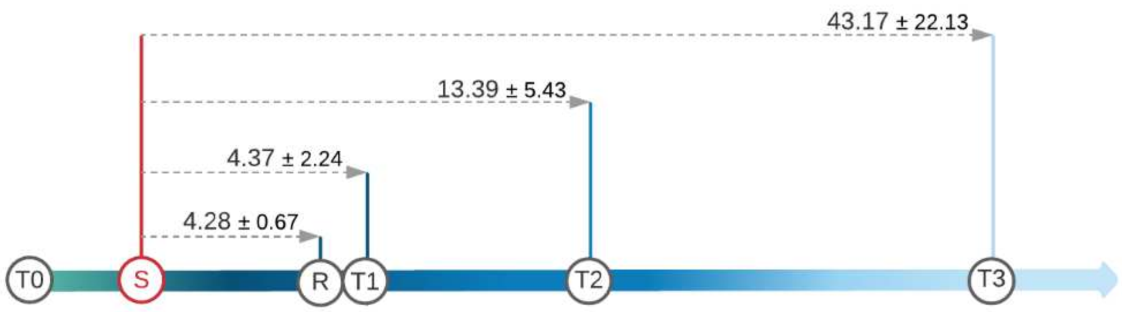

Figure 20: Timeline in months; S surgery, R removing of the connection element

2-Dimensional Cephalogram Measurements

Figure 21: Flow diagram showing numbers of patients included in measurement

All patients fulfilled the inclusion criteria and therefor the dataset consists of 74 patients at T2 and additional 22 patients had a CBCT at T3, which as the foundation to analyse long-term stability (Figure 21).

The ICC for the cephalometric measurements was between 0.9 and near the maximum of one for both, inter and intra-examiner's reliability in almost all measurements except for Mandibular Body Length (MBL) at T1 intra-examiner (0.71 and 0.75). The difference between operator 1 and 2 was between 0.60° and 1.39° for the angle measurements and 0.76 mm and 1.26 mm for the distance measurements. Table 7 shows ICC-values and mean differences between measurements from operator 1 and 2 for all 2-dimensional cephalometric measurements.

ICC	Inter-operator	Intra-operator 1 (HK)	Intra-operator 2 (SM)	Mean difference	SD
T0 SN-Pog	0.993	0.993	0.995	0.60°	0.56
T0 MPA	0.994	0.992	0.991	1.04°	0.87
T0 Go-Angle	0.985	0.976	0.984	1.28°	0.99
T0 MUL	0.995	0.986	0.989	0.82 mm	0.72
T0 MBL	0.992	0.994	0.994	0.90 mm	0.66
T1 SN-Pog	0.991	0.997	0.993	0.69°	0.56
T1 MPA	0.991	0.997	0.994	0.98°	0.80
T1 Go-Angle	0.978	0.987	0.992	1.39°	1.61
T1 MUL	0.995	0.983	0.985	0.76 mm	0.71
T1 MBL	0.985	0.710	0.750	1.26 mm	0.83
T2 SN-Pog	0.986	0.994	0.983	0.82°	0.65
T2 MPA	0.990	0.990	0.984	1.13°	0.94
T2 Go-Angle	0.981	0.978	0.985	1.38°	1.06
T2 MUL	0.995	0.958	0.998	0.94 mm	0.64
T2 MBL	0.990	0.758	0.983	0.96 mm	0.73
T3 SN-Pog	0.974	-	-	-	-
T3 MPA	0.977	-	-	-	-
T3 Go-Angle	0.981	-	-	-	-
T3 MUL	0.996	-	-	-	-
T3 MBL	0.977	-	-	-	-

Table 7: ICC for the 2-dimensional cephalogram measurements; ICC Interclass Correlation Coefficient, SD standard deviation

During distraction ∆T1 (T0 vs T1) the Mandibular Unit Length (MUL) increased by 7.91 mm (± 2.53, p = < 0.001) and MBL by 10.31 mm (± 3.44, p = < 0.001). This corresponds to an increase in length of +7.51 % for MUL and +15.01% for MBL of the original length. SN-Pog increased during distraction by 3.96° (± 3.17, p = < 0.001), MPA and Go-Angle increased by 0.39° (± 3.78) and 0.68° (± 4.16) respectively but were not statistically significant (p = 0.374 and p = 0.165).

The short-term follow-up ΔT2 (T1 vs T2) was done 13.39 months (± 5.43) after surgery. Decreases in distance are defined as relapse in skeletal stability and increases of length has to be accepted as measurement artifacts. MUL decreased statistically significant by 0.45 mm (± 1.62, p = 0.02) and MBL decreased without statistically significance by 0.12 mm (± 2.01, p = 0.597). Go-Angle increased with a statistically significance by 1.27° (± 2.18, p = < 0.001), SN-Pog and MPA increased by 0.27° (± 1.57) and 0.07° (± 2.47) respectively but were not statistically significant (p = 0.139 and p = 0.796).

The measurement T3 was recorded 43.17 months (± 22.13) after surgery. Throughout the period from T2 to T3, long-term follow-up ΔT3 (T2 vs T3) and progressive changings could be measured. According to the short-term follow-up ΔT2, decreases in distance are defined as relapse in skeletal stability, and increases of length has to be accepted as measurement artifacts. MUL decreased by 0.59 mm (± 1.64) and MBL increased by 0.60 mm (± 1.35), both values were without statistically significance (p = 0.107 and p = 0.051). Go-Angle increased without statistically significance by 0.44° (± 1.78, p = 0.257), SN-Pog did not show a changing (0.00°, ± 1.58, p = 0.989) and MPA increased by 0.13° ± 2.30 (p = 0.791) respectively. Both not statistically relevant.

The relapse rate, SN-Pog angle reduction ≥1°, was 13.4% (n = 10) and for SN-Pog angle reduction ≥2° 6.7% (n = 5) respectively.

Analyses were also done for the whole follow-up period ΔT4 (T1 vs T3) to check overall skeletal stability. MUL decreased over time by 0.55 mm (± 2.08), and MBL increased by 0.60 mm (± 1.35). Both values without statistically significance (p = 0.224 and p = 0.079 respectively). SN-Pog and MBA increased by 0.49° (± 1.68, p = 0.185) and 0.23° (± 2.33, p = 0.652) respectively. Go-Angle increased with statistically significance by 1.00° (± 2.15, p = 0.042). Figures 22-28 show the changings of the individual values at terms of time.

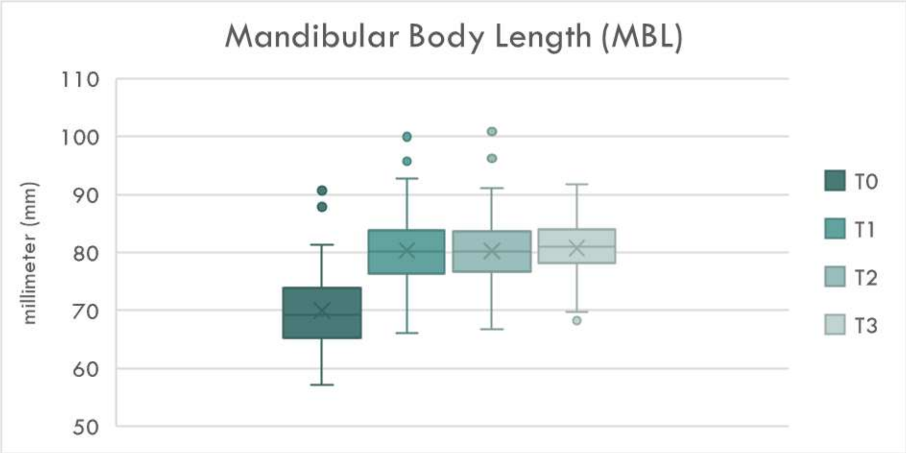

Figure 22: Mandibular Body Length: Changes in length in terms of time

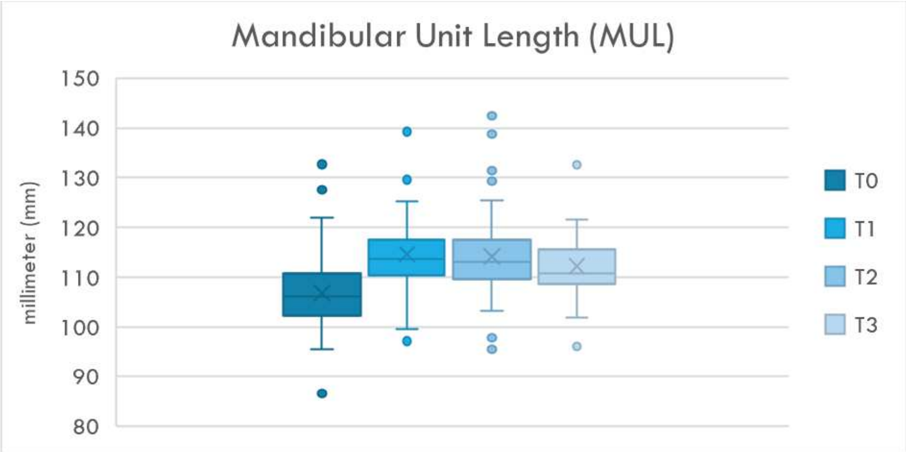

Figure 23: Mandibular Unit Length: Changes in length in terms of time

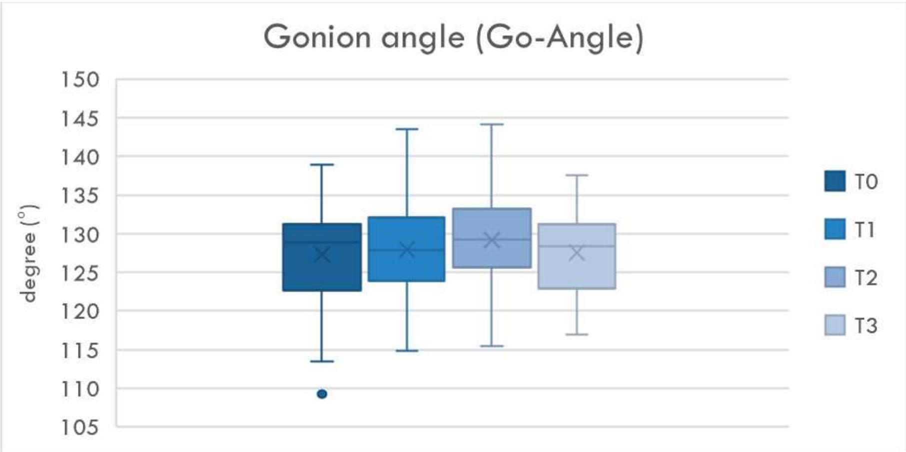

Figure 24: Gonion angle: Changes in degree in terms of time

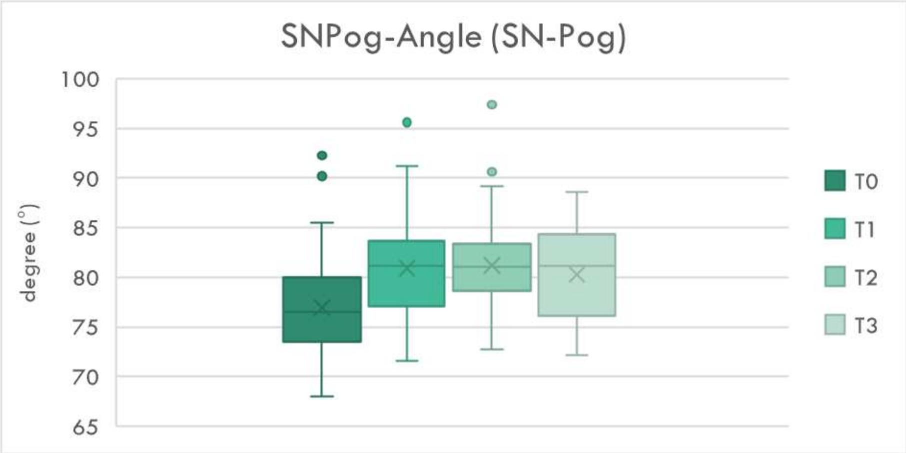

Figure 25: SN-Pog Angle: Changes in degree in terms of time

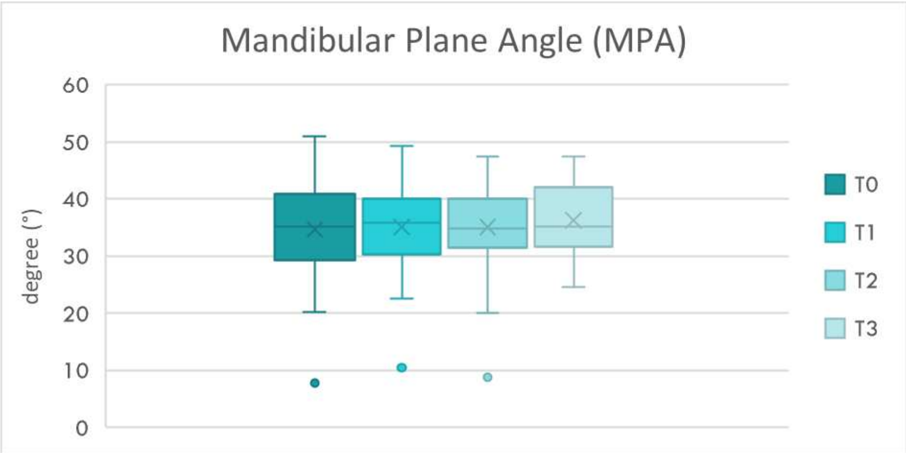

Figure 26: Mandibular Plane Angle: Changes in degree in terms of time

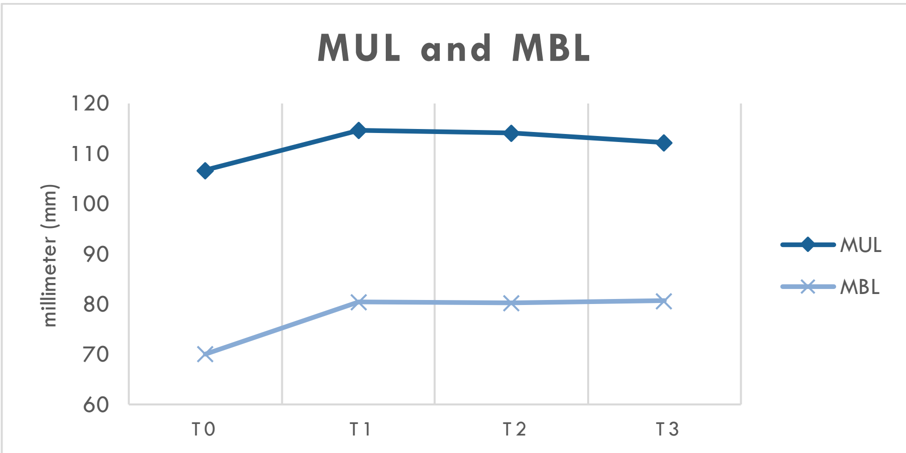

Figure 27: Means of distance measurements: Changes in length in terms of time

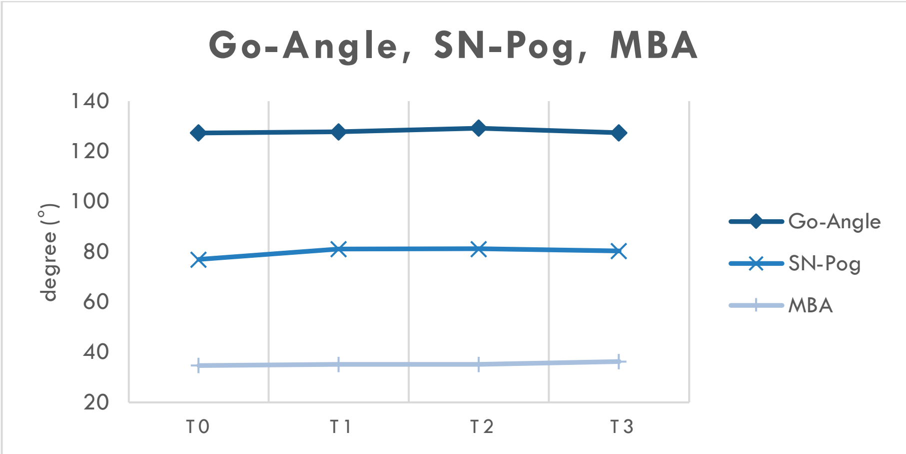

Figure 28: Means of angular measurements: Changes in length in terms of time

When comparing the amount of distraction ΔT1 (T0 vs T1) with the amount of relapse at short-term follow-up ΔT2 (T1 vs T2), a positive statistically significant correlation could be found. For MBL the p-value is 0.037 with a moderate Pearson´s correlation of 0.242 and for MUL a p-value of 0.001 with a moderate Pearson´s correlation of 0.367. For the long-term follow up ΔT3 (T2 vs T3), no statistically significant Pearson´s correlation could be found between the amount of distraction and amount of relapse (MBL $r = 0.274$, $p = 0.216$ and MUL $r = 0.138$, $p = 0.539$).

High-angle patients (MPA > 38°) showed at the t-test for independent variables a correlation ($r = 0.53$, $p = 0.028$) with greater amounts of relapse comparing to normal-to-low angle group (MPA ≤ 38°) at MBL at the short-term follow-up ΔT2 ($p = 0.028$) and at long-term follow-up ΔT3 ($p = 0.003$).

No correlation was found between the amount of skeletal relapse at short-term follow-up ΔT2 (T1 vs T2) and long-term follow-up ΔT3 (T2 vs T3) compared to gender, the chief complaint for surgery, appointment of removing of the connection element of the distractor, and age.

3-Dimensional CBCT Superimposition Measurements

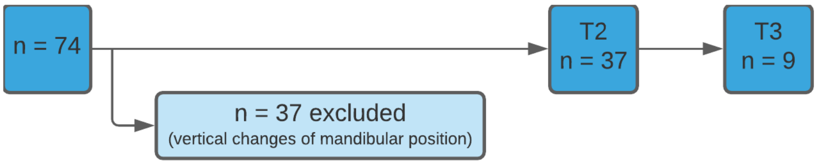

Figure 29: Flow diagram showing numbers of patients included in measurement

Half of the patients (n = 37) showed a vertical displacement of the mandible at T2. Those had to be excluded for this measurement. The vertical displacement of the mandible and therefore also sagittal moving of the symphysis was a consequence of additional maxillofacial surgery (Le Fort I osteotomies) during the follow-up period. Measurements could not be taken in the defined sagittal and horizontal direction. From the remaining 37 patients, 9 had an additional CBCT T2 for the long-term follow-up measurements (Figure 29).

ICC showed a high intra-examiner reliability (0,996).

After distraction, pogonion and Point B advanced in sagittal direction by 8.66 mm (± 2.96) and 8.81 mm (± 2.73) respectively. Both changings were statistically and clinically relevant ($p = < 0.001$). At short-term follow-up ∆T2 (T1 vs T2), 89 % of the patients (n = 33) did not show any changing. For the remaining 11 % (n = 4) both values decreased. Point B decreased by 0.21 mm (± 0.65), which was not statistically relevant ($p = 0.063$), and pogonion had a decrease by 0.19 mm (± 0.57) which was statistically relevant with a p-value of 0.046. Although, 0.19 mm relapse can be seen as clinically not relevant. Form the 9 patient who could be included to the long-term follow-up ∆T3 (T2 vs T3), 66 % did not show any changings. In 33 % of those 9 patients (n = 3) values decreased at T3 compared to T2. Two of the patients had an ongoing decrease and one decrease occurred during the period T2 to T3. For these 3 patients Point B decreased by 0.62 (± 0.96) and pogonion by 0.58 (± 0.87) both statistically relevant ($p < 0.001$). Figures 30 and 31 show the changings of the individual values at terms of time.

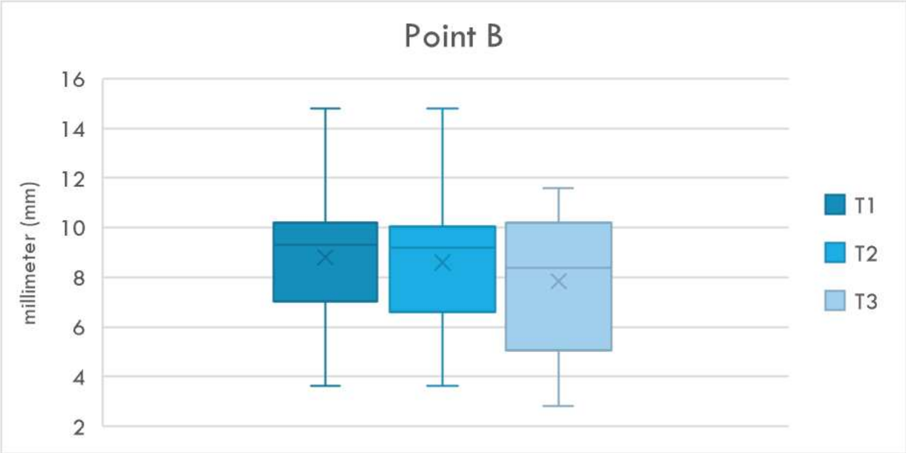

Figure 30: Point B: Changes in length in terms of time

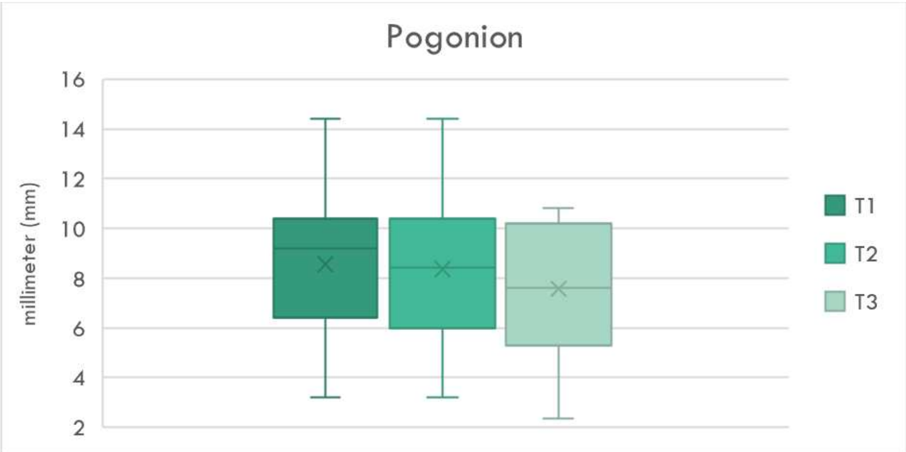

Figure 31: Pogonion: Changes in length in terms of time

No correlations were identified for age, gender, the chief complaint for surgery, MBA, amount of distraction or appointment of removing connection element with occurrence, and amount of relapse.

3-Dimensional Oropharynx Volume Measurements

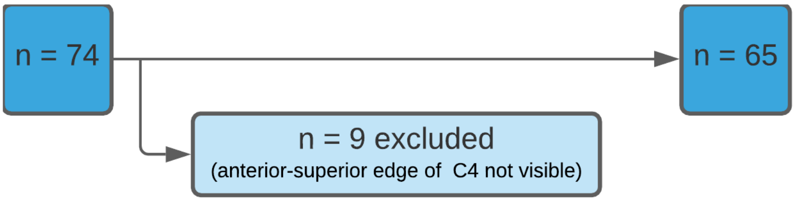

Figure 32: Flow diagram showing numbers of patients included in measurement

From the calculation of the oropharynx, 9 cases had to be excluded because the anterior-superior edge of the 4th cervical vertebra (C4) was not visible on the CBCT (Figure 32). The intraclass correlation coefficient was 0.998 for the measurements preoperatively (T0) and 0.993 for the measurements at T2, which makes a cumulative ICC of 0.997 for oropharynx measurements. For the remaining 65 patients, the oropharynx volume had preoperatively an average size of 15.7 cm^3 (± 6.7). At T2, 13.39 months (± 5.43) after surgery, the oropharynx volume significantly increased by 21.8 cm^3 (± 8.1, 95% CI: 38.15 to 68.49 %; $p < 0.001$), which is a total volume gain of 38.85 % (Figure 33).

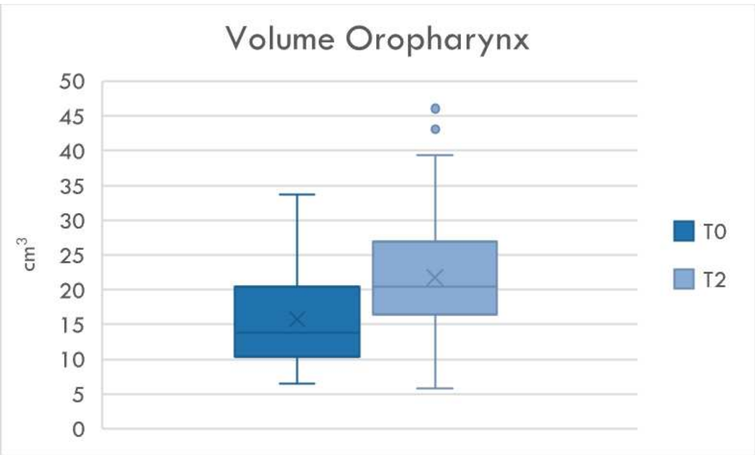

Figure 33: Oropharynx volume at T0 and T2 in cm^3

Discussion

The purpose of the present study was to evaluate the skeletal changes after mandibular distraction osteogenesis over short and long-term in adult retrognathia patients. The specific aim was to measure skeletal stability and relapse rate to show changes of a group of patients treated by one, high-experienced surgeon. The results of this retrospective study have shown that no clinical nor statistically significant skeletal changes occur after short-term or long-term. The relapse rate is 13.4 % (SN-Pog angle reduction ≥1°).

Further aims of this study were to measure the volume changes of the upper airway caused by mandibular distraction osteogenesis and the rate of neurosensory disturbances of the inferior alveolar nerve. Oropharynx increases by 38,85 %, and no neurosensory disturbances were recorded.

Based on the existing literature and the wide variation in the practice, the research revealed that the MDO of the craniofacial skeleton cannot be considered yet as evidence-based care (74). The complication rate for mandibular distraction osteogenesis is high with 26-87% (41,42,44,75). There is a lack of homogeneity among the studies regarding patients' chief complaint, measurements, and term definitions. The literature on MDO is sometimes confusing regarding the terms, "corticotomy/osteotomy", "relapse/skeletal stability", and "micrognathia/retrognathia." Corticotomy is frequently used, while a complete division of the bone is performed (40). Relapse and skeletal stability are often used as synonyms and many different methods of defining and measuring relapse or skeletal stability exist. Micrognathia in most cases are found in growing patients with different congenital disorders. Mandibular retrognathia is found in non-growing patients without developmental deformities.

Unilateral craniofacial microsomia is the second most common congenital head and neck malformation after cleft lip and palate (75). Many studies include a small sample size with heterogeneous deformities and a wide range in ages. This lack of uniformity creates difficulties in identifying characteristics that can be attributed to various problems (62). The deformity can be mild to severe depending on the degree of genetic expression. The ''ideal age to perform MDO'' was considered to be between 7 and 14 years-old for hemifacial micrognathia (74). The continued mandibular growth in childhood would certainly affect the corrections over time, a phenomenon that cannot be examined in short-term studies (62). Relapse is due to the inherently retarded growth of the mandible relative to the natural progression of maxillary growth. Relapse is the most reported complication of MDO in the skeletally immature patient, particularly in skeletally immature syndromic children (60). The affected side always grew at a slower rate than the contralateral side after the distraction process was complete (75,76). It is highly possible that subsequent asymmetric growth of the mandible may necessitate serial distraction (76,77). Early MDO can improve the quality of life by minimizing facial asymmetry and helping craniofacial microsomia patients overcome some of the barriers of social integration during their developmental years (78). In adult patients with mandibular asymmetry, MDO creates significant aesthetic improvements (79). In the present study, patients were on average 23.3 (± 8.4) years-old on the day of surgery. No residual growth can be expected for this group.

For treatment of severe mandibular deficiencies, such as those over 12 mm, MDO is an appropriate and excepted approach. Low abnormalities of less than 8 mm deficiency are best treated with routine surgical correction using BSSO (11). 16.1 % (n = 12) of the patients in this study had a mandibular deficiency over 12 mm. Moderate deficiencies, in the range of 8 to 12 mm, are in the focus of much discussion. 83.9 % (n = 62) of the patients in this study were in the moderate deficiency group. For those patients, the decision between BSSO or MDO is influenced by further criteria in addition to deficiency. Patients including those exhibiting temporomandibular joint (TMJ) symptoms or at elevated risk of developing temporomandibular disorders (TMD), patients after facial traumata, after conventional maxillofacial surgery, or with tendency to or manifested obstructive sleep apnoea can benefit from the MDO approach, even if the efforts and costs exceed those of BSSO. The difference in procedure time of 37% and cost of 36% mainly due to the price of the distractors make MDO a more expensive procedure when compared to BSSO (57,58). The shorter hospital stays, one day less then with BSSO and minimal immobilization of the jaws after distraction allow patients to resume daily activities sooner (57). During active distraction phase, up to 3-times more visits are required compared to BSSO therapy needs (11).

MDO is associated with a broad variety of minor and major complications. All can be mostly avoided with accurate planning and technique. The prevalence of each complication serves as a mean across all surgeons. However, the frequency may vary based on surgeons' experience (60). MDO is compared to the traditional orthognathic surgery method BSSO, a new technique that is not yet well-known among surgeons (11). Mofid et al. showed that surgeons with the highest general complication rate (55.6%) performed less than 10 distraction cases, whereas those performing greater number reported incrementally lower rates (64). Also, the long-term stability is probably related to this learning curve effect. More postoperative infections of the distraction site are possibly leading to prolonged bone formation and more relapse (49). In our study we could assess the skeletal stability and relapse rate from patients treated by one highly experienced surgeon.

Relapse is the most common complication in any MDO procedure, although its frequency is greatly variable (33). Because of the slow expansion of the soft tissue envelope, it is claimed that gradual adaptation occurs over the distraction and consolidation period resulting in less postsurgical change. However, it is impossible to compare MDO with traditional orthognathic surgical treatment of mandibular deficiencies due to the lack of published studies evaluating the stability after MDO in large numbers of patients.

We defined every change in mandibular position relative to anterior cranial base as relapse irrespective of the origin (SN-Pog ≥1°) (47). Relapse in our study occurred in 13.4% of all cases. If we put the cut-off value for relapse at 2°, relapse occurred in 6.7 % of all cases.

Shrinking of bone after distraction is one possible cause of relapse and is defined as skeletal instability. It must be emphasized that the remodelling of the condyle and gonion (the key cephalometric reference points) gives an exaggerated representation of skeletal stability (75). Our results show that MDO is a highly stable procedure. On average, the MBL was advanced by 10.31 mm (± 3.44) or 15.01 % of the original length and MUL by 7.91 mm (± 2.53) or 7.51%. After distraction, pogonion and Point B advanced in sagittal direction by 8.66 mm (± 2.96) and 8.81 mm (± 2.73) respectively. Twelve months later, MBL decreased by 0.12 mm (± 2.01) and MUL by 0.45 mm (±1.62), which was for MUL statistically significant but not clinically. These results are in line with those of other authors. Baas et al. assessed an advancement mean of 7.3 mm (range 5-12) and a horizontal relapse of 0.324 mm (61). Aizenbud et al. reported a horizontal distraction of 6.8 to 7.61 mm with a relapse of 0.5 to 2.5 mm (59). Al-Moraissi et al. stated in their meta-analysis a mean of 8.41 mm advancement in the MDO group and a at least equal, perhaps more stable, skeletal stability for MDO than BSSO (50).

For BSSO the mean postoperative relapse is according to Xi et al. 0.71 mm = 15.5% of the surgical advancement in the middle range (68). In conclusion there is no clear preferences for either procedure in terms of skeletal stability in small to moderate (<10mm) advancements (49,50,61,80).

In these moderate advancements (≥ 8 mm) the relapse appears to be multifactorial and related in some degree to the amount of advancement (11,47). With more advancement needed, the risk of relapse increases (46). The results of our study go in line and show a positive moderate correlation (for MBL 0.242 and for MUL 0.367) between the amount of distraction and the amount of relapse. Baas et al. could not confirm the relationship between the magnitude of advancement and relapse (61).

Another influencing factor is the presurgical MPA. In our study 37.8% of the patients showed a presurgical high MPA (>38°). We found a correlation between the presurgical MPA and relapse. Patients with a high MPA showed a slightly higher risk for relapse ($r = 0.53$, $p = 0.028$) compared to patients with a moderate-to-low MPA ($r = 0.52$, $p = 0.028$). Bass et al. did not find any correlation depending on MPA in short or long-term (49,61). Van Strijen et al. controversy assessed that Class II non-syndrome patients with high MPA showed a much higher relapse rate (57%) after MDO than patients with a low MPA (8.3%) (52). This can be explained because of the differences in the surgical procedure and population. Strijen et al. assessed mostly growing patients at mean age of 14.7 yearold who had the distractor device removed after 6 weeks (52). Longer consolidation periods may be required for high-angle cases to allow adequate maturity of the distraction regeneration in the context of resisting paramandibular soft-tissue forces (51). In our study, patients showed skeletal maturity and the connecting element of the distractor, which serves as splint for the new formed bone that has been removed on average 18 weeks after surgery. Swennen et al. revealed in a review of the literature that 6–8week consolidation phase was the most appropriate for all mandibular lengthening (40). In general, they showed in the review that all patients with mandibular retrognathia had data on the obtained distraction distance varying from 6.8 to 28 mm. But no data regarding follow-up and relapse were reported in the mandibular retrognathia sample (40).

There are other mechanisms and time slots, which are related to relapse and two mechanisms are specific for BSSO: postoperative malocclusion caused by condylar malposition and relapse due to loss of fixation within the first weeks (46,50). Since the introduction of the hybrid technique (4 monocortical and 1 bicortical screw) for fixation of the osteotomy, relapse rate (>1 mm or > 1°) could be reduced (47). Relapse that occurs months later, after osseous healing has finished, is likely related to condylar remodelling, degeneration, and/or osteolysis (50). This can be seen in both, BSSO and MDO.

Orthognathic surgical procedure can directly affect TMJ disfunctions. Patients with pre-existing TMJ dysfunction may experience a significant improvement or resolution of temporomandibular disorders signs and symptoms. However, a new onset of minor temporomandibular disorders signs and symptoms is possible in patients previously not affected by such disorders, especially in the early postoperative phase with a subsequent gradual improvement (81). Condylar displacement, caused by surgery within a clinically acceptable range (<1 mm linear changes) is not associated with postoperative TMJ pain and sound (66). MDO improves postoperative position of the condylar head compared with conventional BSSO (82). MDO results in gradual stretching of the bone and the adjacent soft tissue. Theoretically this may result in decreased abnormal loading on the joint. Rapid and/or large movement might benefit condylar resorption in MDO and osteotomy patients. The correlation between MDO on the temporomandibular joint remains unclear (11). The incidence of condylar resorption reported by this review was only 6.1% after BSSO (51). Condylar changes with mandibular distraction, although recognized, remain poorly understood (83).

Repositioning of the skeletal framework expands or diminishes the soft tissue envelope creating volumetric changes in the pharyngeal airway volume (PAV). Measurement and analysis of the three-dimensional airway from CBCT data using a semi-assisted software program became fast, accurate, and reliable (84). Although measurements are depending on the impact of head position, soft tissue resilience, respiration phase, influence of tongue position, mandible morphology, and other influences (72). Every taken image of this functional space, no matter if 2-dimensional or 3-dimensional, is always static. The oropharynx compared to the nasopharynx and hypopharynx is the most enlarged area after surgery owing to the impact of both maxillary and mandibular bones and therefore probably the most relapse-prone area (85). Schendel et al. assessed for the age group of 18-50 years old, 610 unselected orthodontic patients (including Class I, II and III) an average oropharynx volume between 14.07 – 15.59 cm^3 (73). This corresponds with the results (15.7 cm^3 ± 6.7) of our population before MDO. Giralt-Hernando et al. measured an initial increase of oropharynx volume of 29.7% after monomandibulary surgery, of 28.9% after monomaxillary surgery and of 43.2% after bimaxillary surgery. The total PAV gain for BSSO was 29.7% for the oropharynx (85). Our measurements show a mean increase of PAV of 8.1 cm^3, which is equivalent to 38.85 %.

Before performing the surgery, it is necessary to assess how the pharyngeal soft tissues will respond to the skeletal movements. However, the mechanism by which skeletal advancement affects the musculoskeletal system and achieves improvement of the airway remains unclear (86). Several software packages showed high reliability for the measurements of oropharynx and minimum cross-sectional area (87). Do Vale et al. indicated that mandibular advancement surgery is a viable option to achieve widening of the posterior superior airway space in Class II skeletal patients (88). The required magnitude and direction of surgery-induced movements for each patient needs to be individualised. For a mean of 10 mm maxillomandibular advancement Giralt-Hernando et al. measured an initial increase in the PAV after surgery of 7.35 cm^3 and over the long-term of 12 months, 10% relapse can be expected (85). This 10 mm value has become the gold standard and the minimum amount of mandibular advancement that providers should strive to achieve in patients with obstructive sleep apnoea (OSA). Ubaldo et al. found no evidence of a linear relationship between greater amounts of mandibular advancement and improvement of OSA. Patients with less than 10 mm advancement had successful objective short-term and subjective long-term OSA reduction (89). The correlation between the amounts of surgical advancement and long-term reduction of sleep apnoea remains unclear. There were insufficient data to support a relation between improvement in sleep apnoea and changes in the upper airway and surrounding structures because of the contradictory results and poor- quality of most studies (90).

MDO has the advantage that patient sleep parameters can be controlled during distraction phase and the needed amount of advancement can be easily recognized and achieved during active distraction phase. Extensively maxillo-mandibular advancement advances (maxilla mean 7.3–9.2 mm and mandible mean 10.2–12.5 mm), raises the hyoid (mean 3–11.3 mm), provides good success rates in Apnoe-Hypopnoe-Index (AHI), and reduces (mean 65–100%) (90). Stipa et al. revealed the existence of a relationship between OSA severity and the cephalometric measurements (soft palate length and vertical position of the hyoid bone) (91).

The AHI is negatively correlated with the horizontal position of landmark points posterior nasial spine (PNS), lower central incisor point, B point, pogonion, and the angular measurement of SNA and SNB. The horizontal positions of A point and B point were the two factors that were most correlated with airway dimensions at all levels with no evidence of a linear relationship (89). Therefore, the greater Sella-Nasion-Point A (SNA) and Sella-Nasion-Point B (SNB) angle, the greater the volume gain, the greater the corresponding AHI reduction (92). Sella-Nasion-B point angle can be used as a guidance in achieving normalized AHI after surgery (86). A significant relationship was detected between Mandibular Body Length and OSA severity. The smaller the area of the mandibular enclosure, the more severe the OSA symptoms. Mandibular advancement surgery has a good therapeutic effect for OSA patients with short mandibular body (93). Tsui et al. stated in 2019 that BSSO and MDO show no statistical differences in the OSA cure rate (88.9% and 77.8%). This prospective study was terminated early after severe complication in the MDO group (n = 9). One out of 9 MDO patients developed hospital-acquired pneumonia, other two patients showed non-union of the mandible, and one non-union of maxilla. Post-operative infection was mentioned in 6 out of 9 MDO patients and 2 out of 9 BSSO patients (94). No other study showed such a high rate of severe complications.

One of the major disadvantages of BSSO is the resulting neurosensory deficit. The inferior alveolar nerve is at risk from the osteotomy itself, whereas its distal continuation, the mental nerve, may be at risk during intraoral incision. The osteotomy should always be performed carefully to prevent inferior alveolar nerve transection. When making a retromandibular incision, the marginal mandibular branch of the facial nerve is also at risk, so the incision should be placed 1 cm inferior to the inferior border of the angle of the mandible (33). MDO decreases the occurrence of neurosensory deficits by decreasing the amount of acute manipulation and stretching during surgery (11,61). Two possible complications induced by mandibular distraction osteogenesis are transient hypesthesia of the inferior alveolar nerve and transient paraparesis of the muscles innervated by the recurrent marginalis branch of the facial nerve (60). Total facial nerve palsy/paresis is a rare complication from MDO that has scarcely been reported and is often in small case series without a complete review of the literature. The mechanism of injury to the facial nerve also varies widely. The large majority resolves with a combination of time and steroids (95). Verlinden et al. stated in a review on complications of MDO that neurosensory disturbances of the inferior alveolar nerve or mental nerve were seen in 6.5% of the patients (96). The relative risk of neurosensory deficit of the inferior nervous alveolaris decreases dramatically by using MDO for mandibular advancement compared to BSSO (50). In our study, incidence of IAN injury was assessed from the patients' records. No note about incidence of IAN injury after surgery was found.

Not only skeletal stability defines the success of the orthognathic surgery technique, also it defines if the preoperatively desired position of the mandible can be achieved. A pure and simple anterior-posterior movement is rare to correct mandibular deficiency (11). Uniplanar and multiplanar devices can be used in treating a three-dimensional mandibular deficiency if one pays careful attention to accurate vector planning and device placement (30). The biological and mechanical forces determined by the osteotomy and the position of the pins related to the positioning of the distraction appliances are key elements for the distraction vector (6). Correction of abnormalities that requires multidirectional movement can be extremely difficult with MDO (43). To avoid a prolonged post-distraction orthodontic therapy or even additional surgical correction to improve final occlusion, vector flexibility can support getting into the desired position. Therefore, a distractor device, which can be activated in all 3 dimensions was used. This needs a high patient compliance and up to 3-times more visits during active distraction phase compared to BSSO therapy (11).

Laterognathism is represented as a sagittal rotation of the mandibular midline. This occurs typically in patients undergoing unilateral MDO. The mandibular midline rotates towards the non-distracted side. In the absence of an orthodontic appliance, laterognathism can lead to malocclusion consisting of a closed lateral bite and crossbite, condylar displacement and/or condylar resorption. This possible complication shows the importance of adjuvant orthodontic management throughout the the period of active distraction (60).

After surgical correction of mandibular deficiency, it is much more difficult to obtain a predictable and refined occlusal relationship. As previously stated, asymmetric and/or vertical rotations may occur resulting in the need for prolonged and intensive orthodontic treatment post surgically (11).

In 2012, Goldwaser et al., stated that automated continuous devices for MDO would eliminate the need for patient participation in the distraction process. Significant problems remained in automated continuous device design. Motor-driven, spring-mediated, and hydraulic devices were tested and showed promising results. None of the devices could fulfil all key features of a clinically useful distractor device. Key features are: small size, easily implantable, fully buried, biocompatible, sufficient force generation and maintenance, ability to measure force used, robust enough to withstand in vivo environments, simple design and activation, adjustability of rate, rhythm, and vector once treatment begins, automated with little patient involvement; predictability of distraction endpoint, ability to noninvasively and accurately measure progress of lengthening, need for few additional procedures after implantation (27). Ten years later, automated continuous devices are not in the focus of research anymore. Advances in manufacturing techniques have facilitated the availability of distractors of various shapes and designs. Most craniofacial defects are three-dimensional and linear distractors failed to completely restore them. Multidirectional or curvilinear distraction is often appreciated, but these distractors are often large in size (24). It is difficult to perform placement and directional control of the device at the operation site, partly due to the limited surgical area (28). Virtual surgical simulation allows to accurate determine the skeletal discrepancy and to determine desired distraction-vector. Device position and the position and angulation of the osteotomy cuts define the planned movement. Treatment simulation allows altering the position and angulation of the device and cuts until the desired result is achieved (24). CAD-CAM fabricated templates, and splints increase the accuracy of transferring the virtual treatment plan of mandibular distraction osteogenesis into the surgical theatre with an acceptable margin of error and without injury to any vital structures (29). During surgery, the main challenge arises from the necessary customization process. Bending and contouring of a factory-produced distractor with a flat plate surface to meet the curve bone surface, while keeping the proposed direction of the distraction. A new distraction osteogenesis assembly system, which comprises of a fully customized CAD/CAM-based fixation unit and ready-made distraction unit were introduced 2020 by Kang et al. (28). The incorporation of new diagnostic and treatment planning tools have improved the predictability of outcomes, and like in medicine, generally the trend goes into fully customized treatment. Vale et al. elaborated in 2021 a new custom-manufactured dental-anchored distractor anchored in the first molar and lower canine. Corticotomies were performed between the lower premolars. They stated that the use of dental-anchored distractor allows its placement and removal without demanding surgery, and it should be considered as a new treatment option for mandibular retrognathia (97). In order to achieve better MDO treatment, Sensoy et al. developed a concept to computationally determine the location of the osteotomy line and the distractor´s position (98).

The major limitation of this study is the retrospective study design and the resulting usual biases. All distraction related procedures were performed uniformly by the same surgeon, so that bias resulting from different types of surgical management is unlikely. The relationship between patients' sleep parameters (AHI) and PAV change was not assessed in our study. Preoperative and postoperative polysomnography would have been necessary to show improvement of the clinical symptoms of obstructive sleep apnoea. From patients' records and statements, we can say that OSA symptoms improved. For more controlled results, a prospective study design is needed.

In our study-design, we planned to measure relapse rate with a CBCT superimposition technique. During the conduct of the study, problems arose with this measurement technique. The idea was to measure mandibular position changes in strictly sagittal plane. Due to a Le Fort I osteotomy during T1 and T2 and inclination changes of the front teeth, vertical position of the mandibular changed and could not be interpreted anymore. The vertical position change included also change of the landmarks Pogonion and Point B in the sagittal plane. We could only include 37 patients for the CBCT assessment. Another problem was the superimposition of CBCTs is highly depending on the operator, even if the ICC showed high reliability. Minimal not recognizable superimposition differences at the cranial base leads to different outcomes at Point B and Pogonion. From the resolution of the CBCTs, it is indistinguishable whether landmarks are superimposed or directly next to each other. These minimal position changes along the anterior cranial base provide relevant changes at point B and Pogonion. These two landmarks have a greater distance from centre of rotation for superimposition, which is somewhere close to sella turcica. The operator sees both sides, anterior cranial base and the origin of interest (Point B and Pogonion) at one time. Bias in interpretation of ideal superimposition can be expected. Another factor was the minimum difference of 0.6 mm is necessary for distance measurement because of software resolution reasons. We decided to measure the relapse rate via SN-Pog change over time. SN-Pog is, according to SNB, an established method to measure relapse.

Conclusion

MDO is a powerful surgical tool and enables surgeons to achieve results not previously attainable (36). MDO is now considered the gold-standard treatment for symptomatic micrognathia seen in patients with congenital syndromes (22). Timing of surgical intervention may contribute to an increased risk for relapse. It is often performed in a group of patients generally considered to be difficult, with respect to age and surgical diagnosis (64). Complications for MDO for congenital deformities are highly case depending (99).

Consequently, MDO should not be considered as an all-in-one-solution. The technique should probably better be seen as an addendum to other surgical options. The technique represents a powerful tool within individually tailored therapeutic concepts for the surgical correction of craniofacial anomalies to improve quality of life in patients who are affected by congenital or acquired craniofacial anomalies.

Haas Junior et al. proposed in 2019, based on an overview of systematic reviews, a hierarchical pyramid to assess the stability of orthognathic surgery. They categorized a surgical procedure as highly stable if relapse is between 0% and 24.9% of the magnitude of surgical movement (100). BSSO with bicortical screws was considered as highly stable with a magnitude of relapse of 14.7%. According to this pyramid, we can consider MDO procedure with a relapse rate (SN-Pog reduction ≥2°) of 6.7 % as highly stable. This pyramid is an additional tool for helping surgeons to choose the technique with the best surgical outcomes and for reducing skeletal and volumetric relapse to a certain degree (100).

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