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**Cephalometric changes of maxillary molar distalization
using a non-compliance appliance**

Dissertation

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For my dear wife, my dear daughters

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1. Abstract

Introduction: The aim of this study was the evaluation of treatment outcomes using a mini-implant borne distalization appliance employing direct anchorage – the Beneslider.

Methods: Treatment of 51 patients (mean age 17.8 ± 9.6 years) was investigated retrospectively by means of pre- and post-treatment cephalograms. Patients were divided into three groups: 14 children with unerupted upper second molars (group 1), 23 adolescents with second molar in place (group 2) and 14 adults (group 3). Treatment changes were evaluated and tested statistically for significant differences.

Results: Class I molar relationship was achieved in all patients. All mini-implants remained stable during treatment. The mean distalization distance as measured by the displacement of the Trifurcation was 3.6 ± 1.9 mm (range: 1.2 to 8.5 mm depending on treatment needs). Since no significant tipping was found, the type of movement could be characterized as bodily movement. Mean overall distalization speed was 0.6 ± 0.4 mm per month. There were no statistical differences between the groups. In the analysis of skeletal vertical measurements, there were no significant changes of NSL-ML and NL-ML.

Conclusions: The Beneslider was found to be an effective appliance that enables bodily distalization in adequate treatment time. Its design provides a high degree of anchorage stability and also prevents bite opening.

2. Introduction

Class II malocclusion is the most frequent treatment problem in orthodontic practice. A Class II malocclusion can involve discrepancies of the craniofacial structures or dental Class II occlusion. In these cases, the increased overjet or the anterior crowding are caused by mesial migration. Especially for adult patients, extraction of premolars has been mainly chosen in the past. To avoid extraction therapy, distalization of the maxillary molars is regarded as the preferred method to create space and to establish a Class I molar relationship.^{1,17,21,31}

Over the past decades, various concepts, biomechanics, and appliances for maxillary molar distalization have been proposed to correct Class II malocclusion. One of the conventional approaches for distalization of molars was to apply an extraorally anchored headgear device.⁵ However, due to esthetic drawbacks and the duration of wear, compliance problems frequently occurred in the clinical application of these appliances.^{44,92,105}

In recent years, appliances independent of patient's compliance have become popular for maxillary molar distalization. These include intermaxillary appliances, such as Herbst appliance (Dentaurum, Ispringen, Germany), Jasper Jumper (American Orthodontics, Sheboygan, WI, USA), Forsus (3M Unitek, USA) and intramaxillary appliances employing repelling magnets, compressed coil springs, Jones jig (American Orthodontics, Sheboygan, WI, USA), Distal jet (American Orthodontics, Sheboygan, WI, USA), Pendulum appliance, Keles slider.

However, using conventional intra- and intermaxillary molar distalization devices unwanted side effects may occur in terms of e.g. distal tipping, extrusion and distal rotation of the maxillary molars as well anchorage loss in terms of mesial movement and proclination of the maxillary premolars.

One way to reduce these undesirable effects is the use of palatal acrylic pads, so called Nance buttons.⁴⁹ But the anchorage stability of any soft tissue element is questionable. These side effects vary among the different techniques and appliances, but they are always associated with maxillary molar distalization. Stable anchorage is the main prerequisite for successful maxillary molar distalization.⁸⁶

The development of skeletal anchorage has widened the possibilities of the maxillary molar distalization independent of patient's compliance and anchorage possibilities. Especially mini-implants have gradually attracted great attention, because they have a great versatility, minimal surgical invasiveness, and low costs.^{23,56,81} In recent years, various kinds of mini-implant borne distalization approaches have been described. However, there is still a lack of

well designed studies focusing on clinical efficacy.³⁴

As one of the non-compliance appliances used for the maxillary molar distalization, the Beneslider using skeletal anchorage has been developed.¹¹⁶ Various cases treated with the Beneslider have been reported, however, little is known in detail about cephalometric changes of maxillary molar distalization using this appliance.

The aim of this retrospective clinical study was to analyze the dentoalveolar and skeletal changes and to evaluate the treatment effects of the Beneslider used for the distalization of maxillary molars by means of lateral cephalograms.

3. Theoretical background

The following chapter gives an overview of previous studies and surveys on the subject of the maxillary molar distalization and the skeletal anchorage:

3.1 Maxillary molar distalization appliances

The current trend in orthodontics is toward the treatment of Class II malocclusion with non-extraction. Some of extraction treatments cause reopening of the extraction sites, excessive flattening of the facial profile and periodontal problems, and a tendency to deepen the overbite. One of the common strategies to treat Class II malocclusion without extraction is to distalize the maxillary molars aiming to establish Class I molar relationship.

In the past, researchers have developed numerous treatment modalities for maxillary molar distalization, including those that are patient-compliance dependent and those that are not. Distalization appliances can be classified on the basis of their anchorage commonly used for the correction of Class II malocclusions into extraoral, intermaxillary or intramaxillary devices.

3.1.1. Extraoral appliances

For years, one of the conventional approaches for distal movement of maxillary molars was the extraorally anchored headgear device (Fig 1).⁷² However, headgear is rejected by many patients because of esthetic and social concerns during treatment.³⁰ An effective and controlled use of the headgear for maxillary molar distalization requires consideration of the relationship of force application to the centre of resistance of the 1st molar.⁷³ Therefore, a predictable headgear effect is only achieved, if the force vector is orientated correctly to the centre of resistance. It is difficult that the outer bow has to be adjusted in such a that way the direction of force coincides with this vector. Another problem can be the extrusion of maxillary molars caused by the use of cervical extraoral headgear.¹⁶ In addition, there is also a risk of injury for the patient, when the facebow is attached or removed incorrectly.⁹⁸ The



Fig.1: Extraoral anchored appliance: headgear appliance.

difficulties of headgear wear, adjustment and dependence on patient cooperation stimulated many researchers to develop new non-compliance appliances and techniques for distal movement of maxillary molars.

3.1.2. Intermaxillary appliances

Over the past decade, non-extraction treatments with non-compliance therapies which include inter- and intramaxillary appliances have become popular in treating Class II malocclusions. Some intermaxillary appliances, known as fixed functional appliances, also distalize maxillary molars in Class II cases. The first fixed functional appliance was developed as long ago as in 1909 by Emil Herbst. In 1970's Pancherz re-



Fig.2: Intermaxillary anchored appliance: herbst appliance.

introduced the Herbst appliance and set it on its way to success (Fig 2).⁹³ In 1987 James J, Jasper developed the Jasper Jumper which has a flexible helical compression spring in a plastic cover.⁵² Bill Vogt made a new development, the so called Forsus Fatigue Resistant Device (FRD).¹¹⁰ Although such appliances can serve as intermaxillary appliances in case of non-compliance, they tend to produce some impairment of maxillary growth, some acceleration of mandibular growth, and flaring of the mandibular incisors.⁸⁷ As a consequence, they are mainly indicated in skeletal Class II patients without protrusion of lower incisors.⁵⁸

3.1.3. Intramaxillary appliances

Especially in cases with a dental Class II malocclusion, the distalization of the upper molars is indicated. A number of intramaxillary molar distalization appliances that do not depend on patient's compliance were designed.

Magnet modules

In 1978 Blechman and Smiley, in 1988 Gianelly et al, in 1992 and 1994 Bondemark and Kurol used magnets for maxillary molar distalization.^{4,6,8,41,42} Force application in these appliances relies on the repulsion between two repelling magnets. The mesial magnets are attached buccally to ribbon arches, the distal ones to the headgear tube of the first molar. Magnets create sufficient forces for molar distalization, but they are expensive and the force

drops considerably after a small amount of movement. As a consequence, patients must show up every 1 to 2 weeks to reactivate the appliance.

Coil springs

Miura et al. compared the mechanical properties of Japanese nickel titanium and stainless steel coils in closed and open springs. They found that nickel titanium springs exhibited superior springback and superelastic properties. The most important characteristic of these springs was their ability to exert a very long range of constant, light and continuous force.⁸² Nickel titanium coil springs have been ever since used in conjunction with various non-compliance appliances to achieve maxillary molar movement.^{18,40,47,84,95} In 1991, Gianelly and colleagues recommended placing super elastic nickel-titanium coil springs on stainless steel sectional wires from first premolar to first molar with a Nance appliance extending across the palate between the first premolars as an anchorage unit.⁴⁰ They reported that the 100gr coils can distalize maxillary molars by 1.5mm/month with approximately 20% anchorage loss. In 1997, Pieringer et al used Sentalloy coil springs (150-200g) and modified the Nance appliance, they reported of a maxillary molar distalization ranging from 1.8mm to 10.5mm associated with distal tipping of 5.2-22.2° and horizontal rotation of 5-27°. They concluded that complex three-dimensional movements occurred during distalization.⁹⁵

Jones Jig

The Jones Jig appliance has open coil nickel titanium springs delivering 70-75g of force over a compression range of 1-5mm. The anchorage unit consists of a modified Nance attached to the premolars.⁵⁴ In 2000, Brickman et al examined the results of 72 consecutively subjects treated with the Jones Jig. They found that 55% of the space created between molar and premolar was caused by distal movement of the molar crown. In addition, it produced tipping and rotation of maxillary molars, because the Jones Jig's line of force application lies occlusally and buccally to the center of resistance of the teeth.¹⁰

Pendulum appliance

The original Pendulum appliance was first described by Hilgers in 1992 for the same purpose and was later subject to numerous modifications.^{50,103} An intramaxillary anchorage unit is needed to counteract the forces and moments of molar distalization. A number of teeth are linked with bands or occlusally bonded wires to a palatal button according to Nance to create an anchorage unit. The Pendulum springs consist of 0.032" beta-titanium wire. They can achieve molar distalization without causing any friction. Considerable research has been

conducted on the Pendulum appliance supporting its effectiveness in maxillary molar distalization.

But, Ghosch and Nanda evaluated 41 subjects treated with the Pendulum appliance and found that 57% of the maxillary space was created by molar distalization. The remaining 43% resulted of anchorage loss measured at the maxillary first premolars and anterior teeth. They also reported an average of 8.4° of first molar distal tipping.³⁹ Friction-free palatal acting appliances appeared to produce faster molar distalizing effects, but with significant tipping of the molars. In addition, vertical movements are also present, and extrusion of incisors and premolars is observed.

Distal Jet

In previous distalization systems, orthodontic forces are applied to the crowns of the maxillary first molars, and the molar movement shows tipping and rotation of the crowns. In 1996, Carano developed the Distal Jet appliance with force passing by close to molar's center of resistance in order to achieve bodily distalization without tipping. Carano reported that the Nance button should be as large as possible for stability and should be attached to the second deciduous molars or the second premolars, if present.¹⁸ In 2002, Bolla et al reported that the distal jet appliance effectively moves the maxillary molars distally with minimal distal tipping, however, a loss of anchorage has to be expected during this process.⁷

Although, as described above, various appliances have been developed in order to distalize maxillary molars since the use of headgear, some undesirable side effects have been confirmed. Most of the conventional intraoral appliances for non-compliance molar distalization result in some anchorage loss, by means of mesial movement of premolars or protrusion of the anterior teeth. Haydar et al reported in 2000 that short treatment time is the main advantage of intraoral distalization when compared with headgear, and that mesial movement and protrusion of the anchorage unit has to be considered during intramaxillary distalization.⁴⁹ In 2008, Antonarakis et al described in a systematic review that non-compliance intramaxillary molar distalization appliances all acted by distalizing molars with a concomitant and unavoidable loss of anchorage, as revealed by incisor and premolar mesial movement.¹

Conventional anchorage designs of intraoral appliances for non-compliance maxillary molar distalization combine an acrylic button placed on the palatal mucosa and the periodontal tissue of the anchor teeth. The major drawbacks associated with this anchorage is the fact that the anchoring effect of a palatal Nance button on the anterior palate's resilient mucosa is insufficient for the distalization of maxillary molars.²⁷ In addition, other drawbacks include

hygiene restriction, contraindications during certain developmental stages of the dentition and local findings such as a flate palate.⁶⁶

3.2. Skeletal anchorage

In orthodontic tooth movement, a stable anchorage is very important.³⁶ The significance of anchorage was first recognized by Archimedes (287-212 BC), who said "give me a place to stand on, and I will move the earth". Furthermore, Newton's third law of motion, "actio = reactio," according to which "all forces occur in pairs, and these two forces are equal in magnitude and opposite in direction," is important and should be considered seriously when dealing with anchorage issues in orthodontic treatment. In order to minimize or eliminate anchorage loss, skeletal anchorage devices have been developed.

3.2.1. Dental implants

The idea of using screws fixed to bone to obtain absolute anchorage goes back to 1945, when Gainsforth and Higley placed vitallium screws in the mandibular ramus of 6 dogs to retract their canines.³⁷ A lot of clinical case reports and experimental studies indicate that endosseous prosthetic implants inserted into the alveolar ridge resist orthodontic forces and can thus be used to provide stable orthodontic anchorage.^{24,46,75,89,100,108,111,112} Toward the end of the 1980s, a number of clinicians focused on the use of dental implants as temporary anchorage for orthodontic tooth movement and as permanent abutments for tooth replacement. The major advantage of these implants is that they make it possible to move multiple teeth without loss of anchorage.

However, the majority of orthodontic patients is subject to different requirements than prosthodontic patients, because a full dentition is present or extraction spaces need to be closed. The introduction of interoral anchorage system not inserted in the alveolar process has been welcomed. If alveolar bone is not available for insertion purposes, alternative sites are required. Roberts used in 1990 endosseous prosthetic implants as orthodontic anchorage in the retromolar area.⁹⁹ Disadvantages of dental implants are the need for an invasive surgical procedure during insertion and explantation, the limitations on placement sites, the time required for osseointegration prior to force application, and high costs.

3.2.2. Onplant, mini-plates and palatal implants

Since the middle of the 1990s, onplants, mini-plates, and palatal implants have been developed for the use in orthodontics. In 1995, Block and Hoffman reported the successful use of an onplant, a subperiosteally applied titanium alloy discoid fixture coated with hydroxylapatite, as an orthodontic anchorage device.⁵ The advantage of this fixture is that no intraosseous cavities have to be prepared

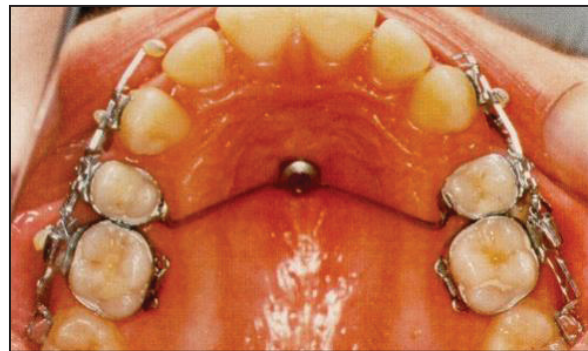


Fig.3: Palatal anchored implant system: palatal implant.

during insertion and explantation. In 1992, Triaca et al first reported of a palatal implant system for orthodontic anchorage using a short endosseous implants in the palate (Fig 3).¹⁰⁶ Further in 1996, an endosseous orthodontic implant anchor system, Orthosystem, for palatal anchorage was developed.¹¹³ This device made of a titanium alloy consists of a screw-type endosseous section, a cylindrical transmucosal neck, and an abutment. On the other hand, Umemori et al used titanium mini-plates which were fixed at the buccal cortical bone as a skeletal anchorage for open-bite correction.¹⁰⁹ But they have similar disadvantages as dental implants such as invasive surgical procedure. Moreover, a three month healing period is recommended after placement of an onplant and a palatal implant before force loading.

3.2.3. Mini-implants

Because the device mentioned above still have many limitations, most orthodontists have turned to mini-implants. Creekmore found in 1983 that small screws, like those used for rigid fixation in maxillofacial surgery, work for orthodontic anchorage.²⁴ In 1997, Kanomi first mentioned a temporary mini-implant which should be small enough to be placed in any area of the alveolar bone.⁵⁶ The following year, Costa et al reported of a mini-implant with a special bracket-like head.²³ Mini-implants for orthodontic anchorage have diminished surgical invasiveness and they can be loaded immediately and be removed easily after use as orthodontic anchorage device. Histological studies in animals have shown that the osseointegration of titanium mini-implant is less than half of conventional dental implants.^{23,85} But incomplete osseointegration represents a distinct advantage in orthodontic applications, allowing for effective anchorage with easy insertion and removal. There was no significant difference in the bone surrounding the mini-implant sites whether the mini-implants were

loaded or unloaded with force.^{26,90}

3.3 Maxillary molar distalization using skeletal anchorage

The esthetic and social concerns of use of headgear wear for maxillary molar distalization and anchorage loss that occurs with the application of intraoral molar distalization mechanics stimulated many investigators to use implants for anchorage. In recent years, various maxillary molar distalization techniques using of the skeletal anchorage, especially with mini-implant, have been developed.

3.3.1. Palatal mini-implant placement

For mini-implants, buccal insertion is commonly used in orthodontic applications because of the ease of access. But, they present the following problems:

- Risk of damaging the roots or periodontal tissues of teeth.
- Possibility of mini-implants root contact resulting in early screw failure.¹⁹
- Risk of screw fracture during placement, due to the smaller mini-implant diameter needed for interradiaculal positioning.
- A loss rate as high as 10-30%.^{2,33,83,114}

These risk of damaging the roots or the periodontium can be avoided by using the hard palate, the maxillary tuberosity, or the portions of the zygomatic buttress in the maxilla. However, the tuberosity cannot be regarded as entirely safe, because unerupted third molars or thick mucosa may prevent successful insertion.⁹⁶ Insertion into the wrong portion of the zygomatic buttress increases the risk of perforating the maxillary sinus.⁴⁵ In 2011, Wilmes et al reported, the risk of mini-implant fracture should be kept in mind at the time of insertion, especially if mini-implants with a small diameter are employed.¹¹⁵ Furthermore, failure of mini-implants for orthodontic anchorage has been reported to result from peri-implant inflammation and thin cortical bone.⁸³ Mini-implants placed within movable mucosa cause tissue irritation and inflammation resulting in implant failure, while implants placed within the attached gingiva show greater than 90% success rates.⁷⁶ Therefore, in the maxilla, the hard palate has been regarded as a safe alternative to other mini-implant insertion sites.

In a histomorphometric study, Yildizhan investigated a total of 22 specimens of the human hard palate to compare vertical height in the sagittal and transverse dimension. While the mean height of the bony plate was found to be 8.08 mm median, a clear reduction to 3.34 mm

was observed in paramedian measurements 3 mm right and left. Mean height clearly decreased from anterior to posterior according to median and 3mm paramedian measurements. This indicates that the ideal location for insertion of mini-implants is the anterior median region with closed suture.^{66,119} Recently, Ludwig et al. described in three-dimensional computed-tomography (CT) studies, the anterior palate appears to be one of the best sites for mini-implants or palatal implants.⁷⁷ Cortical bone is typically thicker in the palatal than at buccal interradicular insertion sites, and favorable attached mucosa is available, ensuring high success rates. The anterior palate may also offer higher patient comfort and greater acceptance compared to other locations.⁴⁸

3.3.2. Maxillary molar distalization using palatal mini-implants

In 2003, for molar distalization, Keles et al. used the modified Keles Slider and a palatal implant for anchorage.⁵⁹ They reported that the molars were distalized bodily without anchorage loss. But the system had the disadvantage of a more invasive surgical intervention for insertion and removal of the palatal implant or anchorage plate. In 2006, Kinzinger G et al. developed a skeletonized Distal Jet appliance anchored to two paramedian palatal mini-implants.⁶² Elimination of the acrylic palatal button improves the patient's access for oral hygiene. Under local anesthesia, two mini-implants (8mm long, 2mm in diameter) were inserted at paramedian locations in the anterior palate. The mini-implants for orthodontic anchorage have diminished surgical invasiveness and allowed easy removal after use as orthodontic anchorage device.

3.3.3. Beneslider

Orthodontic mini-implants have become increasingly popular because of their versatility, minimal invasiveness, and low cost. However, the effectiveness of conventional mini-implant system for maxillary molar distalization is limited by the lack of a stable connection to the orthodontic appliance.

As an alternative, recently, the Beneslider, a distal-movement appliance connected one or two coupled mini-implants with an interchangeable abutments in the anterior palate, was developed. This effectively combines elements of the Distal Jet and the Keles Slider with the Benefit mini-implant. To further enhance stability, two Benefit mini-implants placed about 5-10mm apart along the line of the force can be coupled with a Beneplate.^{116,118} Therefore, Beneslider was described as next generation non-compliance maxillary molar distalization

device using direct skeletal anchorage with stable abutments.

4. Subjects and Methods

4.1 Inclusion and exclusion

The criteria for this study included a mild to severe Class II malocclusion or anterior crowding in the maxillary arch caused by mesial movement of the molars. All patients had bilateral Class II molar relationship (quarter to 1.5 cusp). Patients having the parodontitis or a systemic diseases affecting bone metabolism or wound healing, whose cephalometric radiographs were of poor quality or whose appliance was damaged and could not function, as determined from their corresponding treatment records, were excluded from the study sample. In addition, poor oral hygiene and severe carious lesions were also excluded from this study.

4.2 Study sample

A sample of 51 consecutively treated patients (30 females, 21 males, mean age of 17.8 ± 9.6 years) of the orthodontic clinic of the university of Duesseldorf was treated with the Beneslider appliance for maxillary molar distalization and evaluated retrospectively. All patients fulfilled the criteria mentioned above. According to age and presence of the second upper molar, patients were divided into three groups (Table 1). The first group consisted of 14 children (9 females, 5 males, mean age of 11.5 ± 1.5 years) with unerupted upper second molars. 23 adolescents (11 females, 12 males, mean age of 13.7 ± 1.8 years) with erupted upper second molar included group 2. Group 3 comprised 14 adults (10 females, 4 males, mean age of 30.9 ± 9.5 years) with erupted upper second molars. During the maxillary molar distalization using the Beneslider, all patients were not subjected to any treatment in the mandible.

	<i>n</i>	<i>age</i>		<i>sex</i>	
		<i>mean</i>	<i>SD</i>	<i>female</i>	<i>male</i>
<i>group 1</i>	14	11.5	1.5	9	5
<i>group 2</i>	23	13.7	1.8	11	12
<i>group 3</i>	14	30.9	9.5	10	4
<i>overall</i>	51	17.8	9.6	30	21

Table1: Patient groups and number of patients.

All studies on humans described in the present manuscript were carried out with the approval of the responsible ethics committee in Düsseldorf university. The study number is 4022.

4.3 Treatment protocol

The first step was the insertion of two mini-implants in the anterior median region of the palate. After local anaesthesia, the thickness of soft tissue was measured using a dental probe to ensure a thin mucosa ($\leq 2\text{mm}$) at the insertion. It is important to avoid a large lever arm and thus to achieve sufficient primary stability.^{11,117} Pre-drilling was performed with a diameter of 1.3 mm to a depth of approximately 3 mm. Benefit mini-implants (PSM medical solutions; Tuttlingen, Germany) (Fig.4,A) of a size of 2x11 mm in anterior position and 2x9 mm in the posterior position were inserted approximately parallel to each other.¹¹⁶ Orthodontic bands with palatal sheaths were attached to the maxillary first molars. The Beneslider was fabricated indirectly using transfer caps (Fig.4,C) and laboratory analogues (Fig.4,B) to take a impression. After taking impression, the laboratory analogues were placed on the transfer caps. After the bands were positioned in the impression, a plaster cast was made. The Beneslider consists of a long hole plate (Beneplate) with a rigid .045" stainless steel wire in place on the palatal side (Fig.4, H).¹¹⁸ This wire was bent to provide guidance at the level of the centre of resistance of the molars to minimize tipping moments. The Beneplate was mounted on the implant's head using micro-screws inserted into the inner thread of the respective implant (Fig.4, I). Various abutments with integrated miniature fixing screw can be fixed into the inner thread of mini-implant. (Fig.4, D, E, F and Fig.5).

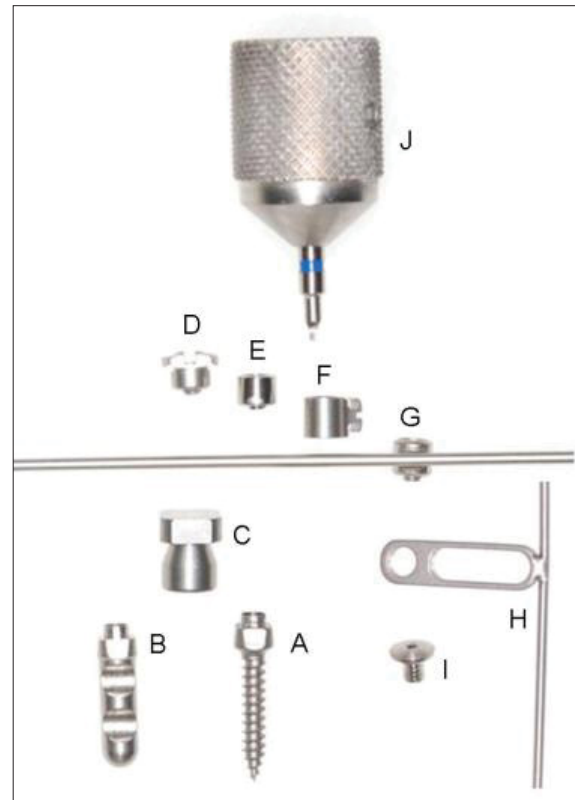


Fig. 4: Benefit system. A: Mini-implant, B: Laboratory analog, C: Impression cap, D: Slot abutment, E: Standard abutment, F: Bracket abutment, G: Abutment with .045" stainless steel wire, H: Beneplate with .45" stainless steel wire, I: Fixation screw for Beneoplate, J: Screwdriver for abutment fixation



Fig. 5: Mini-implant and abutment with integrated miniature fixing screw.

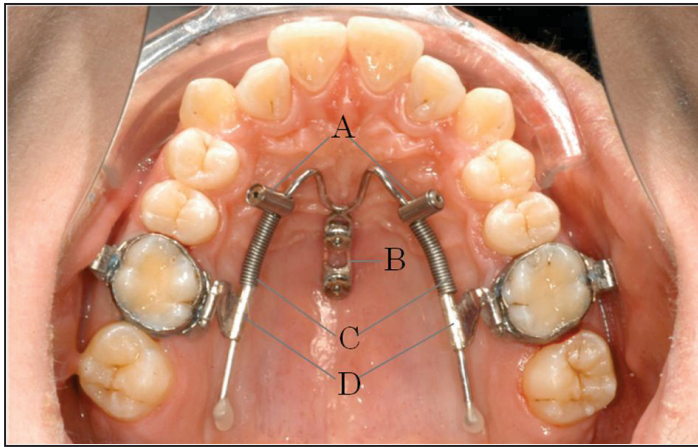


Fig.6: Beneslider distalization appliance. A: activation lock; B: long hole plate with a rigid wire in place; C: NiTi springs (500 g) activated by inbus locks; D: sliding hooks inserted into the palatal sheaths.

Special kind of hooks, Benetubes, were inserted in the palatal sheaths of the molar bands allowing sliding along the guiding stainless steel wires (Fig.6,D). For activation, inbus locks were used to compress a NiTi-spring towards the Benetubes (Fig.6,A,C). In group 1, 2.4 N NiTi-springs were used, in group 2 and 3, 5.0 N NiTi-springs were applied. For the first two months, the springs were compressed only by half to avoid

overloading the mini-implants during the healing phase. Distalization was continued by activating the NiTi-springs with the inbus locks, until Class I molar relationship was achieved and sufficient space was created (Fig. 7,A,B,C,D).



Fig.7,A: 14.5-year-old female patient (group2) with dentoalveolar Class II malocclusion and anterior crowding at the start of treatment; situation immediately after insertion of Beneslider appliance; 500 g springs were compressed by only half to prevent overloading of the mni-implants during the healing phase.

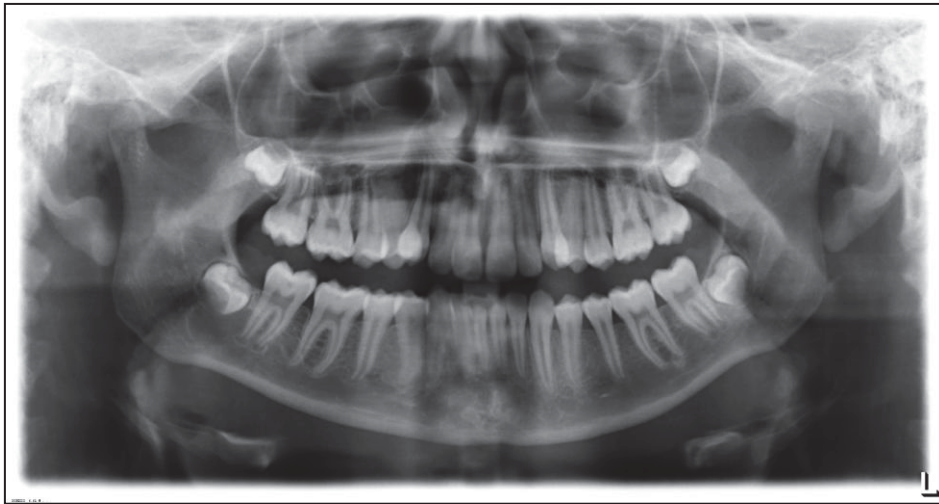


Fig.7,B: Situation at the start of treatment; Orthopantomogram were taken before distalization.



Fig.7,C: Situation after 5 months; Class I molar relationship achieved with bodily distalization of the first molars; premolars have also moved distally due to pulling on the gingival fibers.

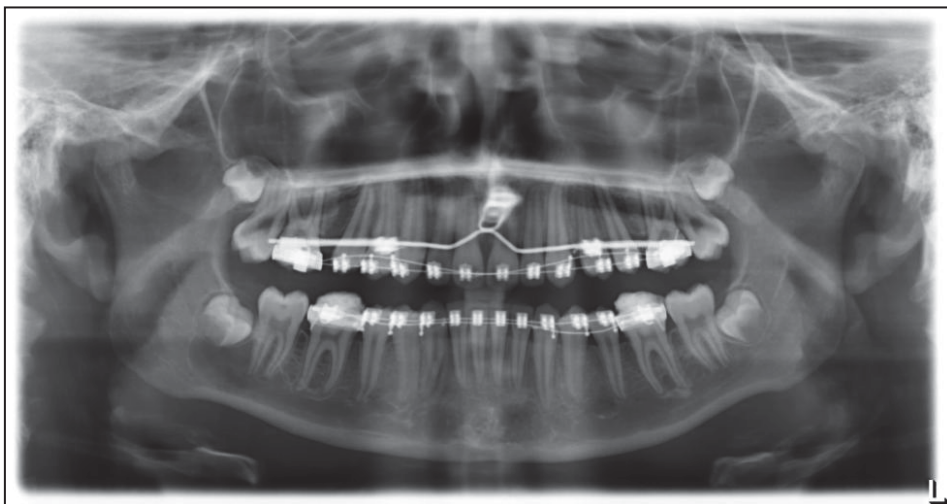


Fig.7,D: Situation after 5 months; Orthopantomogram taken on the day of bracket bonding.

4.4 Evaluation of treatment outcomes

Lateral cephalograms of each patient were taken before insertion and immediately after distalization of maxillary molars. All cephalograms were taken using digital X-ray equipment (Orthophos XGplus, Sirona; Bensheim, Germany) and under the same conditions. All lateral cephalometric radiographs were traced, degitzed, superimposed and analyzed by the same operator and verified by a second operator. For determination of the method error, 20 randomly selected cephalograms were measured twice by the same operator within one week. Random error according to Dahlberg and coefficient of reliability were calculated.^{25,51}

In total, 16 variables (21 cephalometric points) were used for evaluation of dento-alveolar and skeletal changes. 9 angular and 7 linear variables were assessed.

<i>Dento-alveolar variables</i>	<i>Skeletal variables</i>
Overjet	<i>Sagittal</i>
Overbite	SNA
Centroid M1-PtV	SNB
Centroid M2-PtV	ANB
Trifurcation M1-PtV	WITS
Trifurcation M2-PtV	<i>Vertical</i>
M1-NL	NSL-ML
M2-NL	NSL-NL
U1-NL	NL-ML

Table 2: Variables for evaluation of dento-alveolar and skeletal changes.

In order to investigate the tooth movement accurately on the cephalometric radiographs, the centroid, described by Ghosh and Nanda, was used to represent to position of the crown.³⁹ This point is defined as the midpoint between the greatest mesial and distal convexity of the crown as seen on the cephalogram (Fig. 8,A).

To assess bodily tooth movement of the molars, the trifurcation point which is known to coincide with the center of resistance of a molar was identified. A displacement of this point caused by distalization thus represents translatory movement. For accurate measurement of the molar inclination, molar axis is represented by a connection of the centroid and the trifurcation point (Fig. 8,B). The axis of the upper incisors was determined as connection of apex and cuspid point.

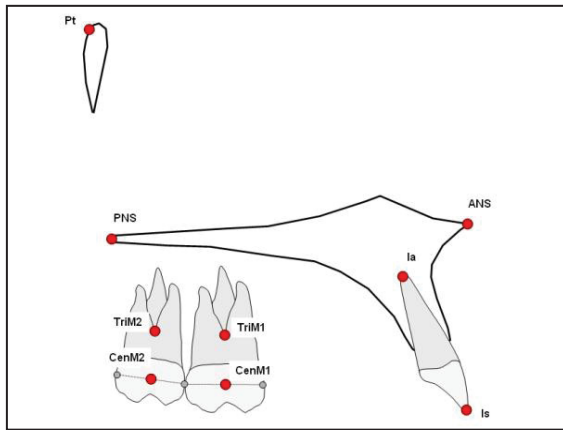


Fig.8,A: Cephalometric points. *Is* incisor superior: incisal tip of most prominent maxillary central incisor; *Ia* incisor apex: apex of the most prominent maxillary central incisor; *CenM1* centroid point on the first molar: midpoint between the greatest mesial and distal convexity and the first molar's crown convexity; *CenM2* centroid point on the second molar: midpoint between the greatest mesial and distal convexity of the second molar's crown; *TriM1* first molar's trifurcation: furcation of the buccal roots of the first molar as visible in the cephalograms; *TriM2* second molar's trifurcation: furcation of the second molar's buccal roots as visible in the cephalograms; *Pt* pterygoid point: posterior superior margin of the pterygomaxillary fissure; *ANS* anterior nasal spine: tip of the anterior nasal spine; *PNS* posterior nasal spine: tip of the posterior nasal spine.

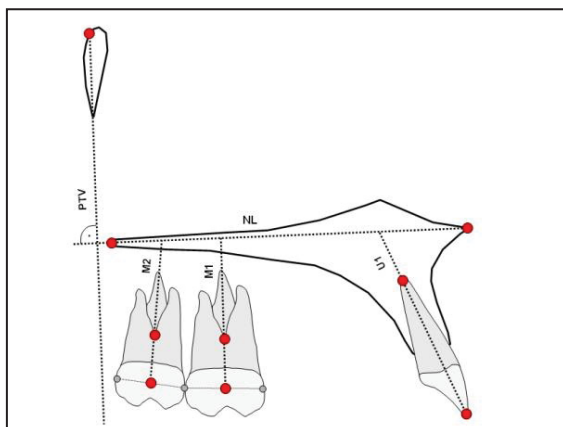


Fig.8,B: Cephalometric lines and axes: *NL* nasal plane: ANS-PNS; *PtV* pterygoid vertical: vertical to nasal plane through Pt; *M1* first-molar axis CenM1-TriM1; *M2* second-molar axis: CenM2-TriM2; *U1* axis of the most prominent maxillary incisor Is-Ia.

To assess molar movement, changes of the distances between the molar points and the pterygoid vertical (PtV) were measured (Fig. 8,C). For angular changes, tooth axes in relation to the palatal plane (ANS-PNS) were measured (Fig. 8,D). Side effects, such as changes of overbite, overjet, the skeletal sagittal relation (SNA, SNB, ANB, WITS) and skeletal vertical relation (NSL-ML, NSL-NL, NL-ML) were recorded. In cases of double projection of the molars, a medial contour was traced and used for measurements.

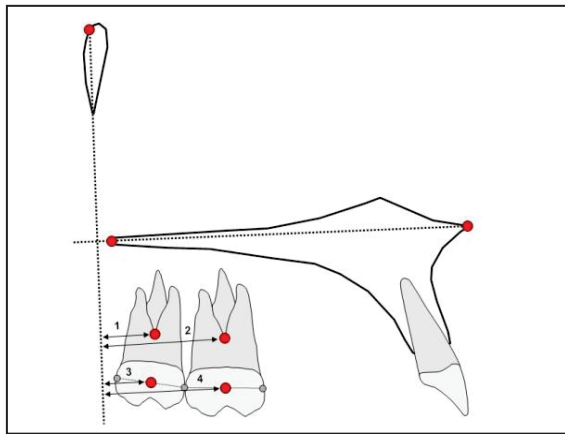


Fig.8,C: Cephalometric linear measurements: distances from dental points to pterygoid vertical; 1: TrifurcationM2-PtV; 2: TrifurcationM1-PtV; 3: CentroidM2-PtV; 4: CentroidM1-PtV.

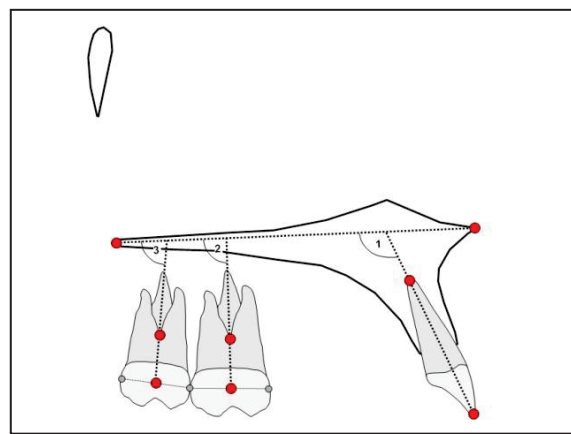


Fig.8,D: Cephalometric angular measurements: angles between dental axes and nasal plane: 1: U1-NL; 2: M1-NL; 3: M2-NL; (not illustrated: mandibular plane to nasal plane, ML-NL) .

Superimposition of the pre- (T1) and post-treatment (T2) cephalograms was established by identification of the stable reference structures of the anterior cranial base according to Björk and Skieller.³ (Fig.9) Duration of distalization was investigated and distalization speed was calculated by the quotient of distalization distance defined as displacement of the trifurcation point and duration.

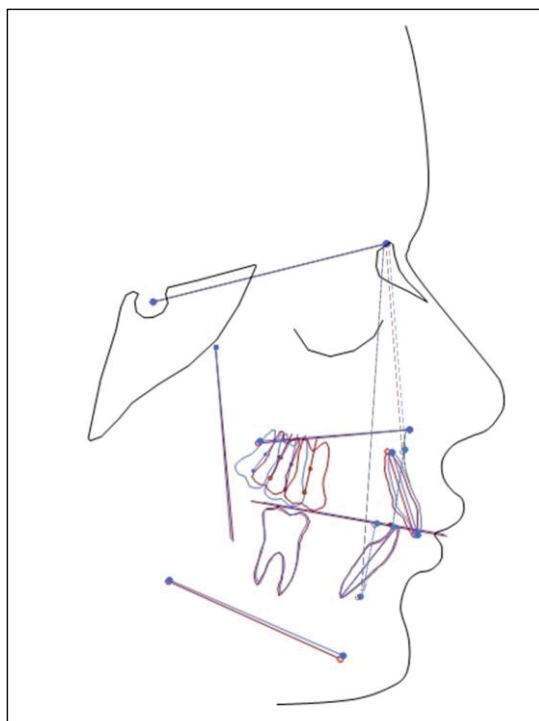


Fig.9: Digital drawings of superimposition of pre- (red) and post-treatment (blue) cephalograms on the stable reference structures of the anterior cranial base.

4.5 Statistical analysis

For statistical evaluation Shapiro-Wilk-test was initially performed to assess the data distribution of each variable. Cephalometric data between the three groups at pre-treatment (T1) were tested to determine the significant differences. The paired t-test was used to determine the significant differences between the mean values of the cephalometric measurements for pre- (T1) and post-treatment (T2). In case of data sets which did not show normal distribution, the Wilcoxon-test was applied. Differences in cephalometric measurements, treatment duration and distalization speed between the three groups were tested using ANOVA. The unpaired t-test was used to analyze only data concerning the eruption status of the second upper molar. The Kruskal-Wallis-test was used in case of data sets which did not show normal distribution. All statistics were performed using SPSS version 19 (IBM, Armonk, New York, USA).

5. Results

After maxillary molar distalization, Class I molar relationship was achieved in all patients. All mini-implants showed a high primary stability and remained stable during treatment. Only two mini-implants showed slight mobility after appliance removal.

Random error ranged from 0.13 mm to 0.40 mm for linear measurements and from 0.20° to 0.58° for angular measurements. Coefficient of reliability ranged from 0.91 to 0.97 for linear measurements and from 0.94 to 0.99 for angular measurements.

5.1 Inter-group comparison of the measurements at T1

5.1.1 Dentoalveolar measurements

In mean values of Centroid M1-PtV at T1, there was inter-group difference between group 1 and group 3 (Table 3). Mean values of Trifurcation M1-PtV between group 1 and group 3 showed significant inter-group differences (Table 3). Mean angle values of M1-NL between group 1 and group 2, group 1 and group 3 were significant inter-group differences (Table 3). Mean angle values of M2-NL between group 2 and group 3 showed significance differences (Table 3).

	group 1		group 2		group 3		total		<i>p</i>	
	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>		
<i>Overjet</i>	3.0	1.1	4.2	2.7	3.1	3.1	3.6	2.5	.111	³
<i>Overbite</i>	1.8	1.4	2.3	2.0	2.9	2.4	2.3	2.0	.359	¹
<i>Centroid M1-PtV</i>	-19.1	4.9	-22.5	4.6	-24.0	2.5	-22.0	4.5	.011***	¹ 1vs3(<i>P</i> =.011***)
<i>Centroid M2-PtV</i>	-	-	-13.5	4.5	-14.7	2.3	-14.0	3.8	.383	²
<i>Trifurcation M1-PtV</i>	-20.6	4.4	-23.4	4.3	-25.0	2.2	-23.1	4.1	.010*	³ 1vs3(<i>P</i> =.001**)
<i>Trifurcation M2-PtV</i>	-	-	-15.9	3.6	-15.9	2.3	-15.9	3.1	.932	²
<i>M1-NL</i>	106.0	6.8	100.2	6.6	97.8	6.4	101.1	7.1	.005***	¹ 1vs2(<i>p</i> =.029***), 1vs3(<i>p</i> =.005***)
<i>M2-NL</i>	-	-	111.3	9.5	102.2	8.6	107.9	10.1	.020*	⁴
<i>U1-NL</i>	107.7	7.7	108.9	10.3	105.6	13.6	107.6	10.6	.670	¹

p*<.05, *p*<.01, ****p*<.001

¹ = ANOVA

² = unpaired t-test

³ = Kruskal-Wallis-test

⁴ = Mann-Whitney-test

Table 3: Inter-group differences at pre-treatment (T1) in dentoalveolar measurements.

5.1.2 Skeletal measurements

Overall mean values of sagittal and vertical skeletal measurements at T1 showed non-significant inter-group differences (Table 4-5).

	group 1		group 2		group 3		total		<i>p</i>	
	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>		
<i>SNA</i>	79.7	6.0	81.0	3.0	80.5	4.1	80.5	4.1	.652	¹
<i>SNB</i>	76.7	5.9	77.7	4.1	77.9	4.6	77.5	4.7	.829	¹
<i>ANB</i>	2.9	2.0	3.3	3.0	2.6	4.8	3.0	3.3	.801	¹
<i>WITS</i>	-0.2	3.2	2.0	3.5	0.7	8.5	1.1	5.3	.450	¹

p* < .05, *p* < .01, ****p* < .001

¹ = ANOVA

² = unpaired t-test

³ = Kruskal-Wallis-test

Table 4: Inter-group differences at pre-treatment (T1) in skeletal sagittal measurements.

	group 1		group 2		group 3		total		<i>p</i>	
	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>	<i>T1</i>	<i>SD</i>		
<i>NSL-ML</i>	35.0	8.5	31.0	5.2	31.5	6.9	32.2	6.8	.395	³
<i>NSL-NL</i>	6.9	3.0	6.2	3.5	6.9	4.3	6.8	3.6	.788	³
<i>NL-ML</i>	28.1	6.1	24.8	6.1	24.5	6.3	25.6	6.2	.347	³

p* < .05, *p* < .01, ****p* < .001

¹ = ANOVA

² = unpaired t-test

³ = Kruskal-Wallis-test

⁴ = Mann-Whitney-test

Table 5: Inter-group differences at pre-treatment (T1) in skeletal vertical measurements.

5.2 Comparison of the measurements between pre- and post-treatment

5.2.1 Dentoalveolar measurements

Distalization of the maxillary first molar (Trifurcation-PtV; Centroid-PtV) resulted in a highly significant (*p* < 0.001) treatment effect (Table 6-9). The amounts of overall mean distal displacement of the trifurcation point of maxillary first molar (Trifurcation M1), i.e. bodily distalization, was 3.6 ± 1.9 mm (Table 6). Mean distal movement values of Trifurcation in each group showed 3.6 ± 1.3 mm in group 1, 3.7 ± 2.3 mm in group 2 and 3.3 ± 1.6 mm in group 3, respectively (Table 7-9). Significant inter-group difference between the all groups were not observed (Table 10).

Mean distal movement value of maxillary first molar at the point of centroid (Centroid M1) for all groups was 3.8 ± 1.9 mm (Table 6). Mean distal movement values of Centroid M1 showed 4.3 ± 1.6 mm in group 1, 4.1 ± 2.0 mm in group 2 and 2.9 ± 1.8 mm. (Tables 6-9) Mean distal movement values of Centroid M1 in each group showed non-significant inter-group differences (Table 10).

Depending on treatment need, the distalization ranged from 1.7 to 6.0 mm in group 1, 0.8 to 8.5 mm in group 2 and 1.2 to 5.9 mm in group 3 (Table 11). This resulted in a non-significant distal tipping of the first molars by $1.5 \pm 6.7^\circ$ (Table 10). In group 3, Trifurcation (3.3 ± 1.6

mm) moved even more distally than Centroid point (2.9 ± 1.8 mm) representing a non-significant mesial tipping or distal root movement by $-1.2 \pm 5.4^\circ$ (M1-NL) (Table 9). Being pushed distally without any guidance the second molars significantly tipped by $5.9^\circ \pm 7.9^\circ$ over all groups (Table 6). Only in group 3 tipping of the second molars did not reach a level of significance of $p < 0.05$ (Table 9). Mean treatment duration was 7.5 ± 2.9 month with no statistical difference between the groups (Table 11). Distalization speed ranged from 0.5 to 0.6 mm per month without significant inter-group differences. Mean overall distalization speed was 0.6 ± 0.4 mm per month (Table 11).

The overall mean value of change of overjet decreased slightly by 0.6 ± 2.0 mm ($p = 0.046$) (Table 6). In each group, however, mean values of overjet showed 0.2 ± 1.2 mm in group 1, -0.9 ± 1.7 mm in group 2, -0.9 ± 2.9 mm in group 3 (Table 7-9). There was no significant difference of measurement of overjet within the groups (Table 9).

Analysis of measurements of U1-NL-angle, overall mean value was $-1.0 \pm 7.5^\circ$ (Table 6). Mean values of each groups was $-1.2 \pm 4.3^\circ$ in group 1, $-1.5 \pm 8.0^\circ$ in group 2, $0.1 \pm 9.4^\circ$ in group 3, respectively (Table 7-9). Mean treatment change of U1-NL-angle had no statistical significance (Table 6-9). Inter-group differences of treatment effects also showed no significance (Table 10).

In the analysis of measurements of overbite, overall mean value showed 0.0 ± 1.2 mm. Mean values of each group were -0.4 ± 0.9 in group 1, 0.4 ± 1.3 mm in group 2, -0.1 ± 1.2 mm in group 3 (Table 7-9). There was no significant change of overbite in overall and groups (Table 6-9). Inter-group differences of treatment effects were not significant (Table 10). Overbite decreased slightly but without significant tipping of upper incisors.

total

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
Overjet	3.6	2.5	3.0	3.4	-0.6	2.0	.046*	²
Overbite	2.3	2.0	2.4	1.8	0.0	1.2	.799	¹
Centroid M1-PtV	-20.3	4.2	-16.5	4.6	3.8	1.9	.000***	¹
Centroid M2-PtV	-12.8	3.3	-9.4	4.1	3.4	2.2	.000***	¹
Trifurcation M1-PtV	-21.6	3.9	-18.0	4.1	3.6	1.9	.000***	¹
Trifurcation M2-PtV	-14.6	3.1	-12.2	3.7	2.4	2.1	.000***	¹
M1-NL	101.1	7.1	102.7	9.1	1.5	6.7	.130	¹
M2-NL	107.8	10.1	113.8	12.2	5.9	7.9	.000***	¹
U1-NL	107.7	10.6	106.7	7.6	-1.0	7.5	.366	¹

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

Table 6: All patients: cephalometric dentoalveolar measurements and treatment effects.

group 1

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>Overjet</i>	3.0	1.1	3.2	1.7	0.2	1.2	.623	¹
<i>Overbite</i>	1.8	1.4	1.4	1.4	-0.4	0.9	.105	¹
<i>Centroid M1-PtV</i>	-17.4	3.4	-13.2	3.4	4.3	1.6	.000***	¹
<i>Centroid M2-PtV</i>	-	-	-	-	-	-	-	¹
<i>Trifurcation M1-PtV</i>	-19.0	3.2	-15.5	3.2	3.6	1.3	.000***	¹
<i>Trifurcation M2-PtV</i>	-	-	-	-	-	-	-	¹
<i>M1-NL</i>	106.0	6.4	108.4	6.6	2.4	6.5	.190	¹
<i>M2-NL</i>	-	-	-	-	-	-	-	¹
<i>U1-NL</i>	107.7	7.7	106.6	7	-1.2	4.3	.338	¹

* $p < .05$, ** $p < .01$, *** $p < .001$ ¹ = paired t-test² = Wilcoxon

Table 7: Group 1: cephalometric dentoalveolar measurements and treatment effects.

group 2

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>Overjet</i>	4.2	2.7	3.3	2.7	-0.9	1.7	.052	²
<i>Overbite</i>	2.3	2.0	2.7	1.6	0.4	1.3	.153	¹
<i>Centroid M1-PtV</i>	-20.4	4.1	-16.4	4.4	4.1	2.0	.000***	¹
<i>Centroid M2-PtV</i>	-12.2	3.5	-8.1	4.2	4.1	2.1	.000***	¹
<i>Trifurcation M1-PtV</i>	-21.7	3.8	-17.9	3.9	3.7	2.3	.000***	¹
<i>Trifurcation M2-PtV</i>	-14.3	3.4	-11.6	4.0	2.7	2.0	.000***	¹
<i>M1-NL</i>	100.2	6.6	102.8	9.9	2.6	7.4	.132	¹
<i>M2-NL</i>	111.3	9.5	118.8	11.1	7.5	8.3	.002**	¹
<i>U1-NL</i>	108.9	10.3	107.3	7.2	-1.5	8.0	.274	²

* $p < .05$, ** $p < .01$, *** $p < .001$ ¹ = paired t-test² = Wilcoxon

Table 8: Group 2: cephalometric dentoalveolar measurements and treatment effects.

group 3

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>Overjet</i>	3.1	3.1	2.2	5.3	-0.9	2.9	.253	¹
<i>Overbite</i>	2.9	2.4	2.9	2.1	-0.1	1.2	.875	¹
<i>Centroid M1-PtV</i>	-22.9	3.2	-20.0	3.5	2.9	1.8	.000***	¹
<i>Centroid M2-PtV</i>	-13.7	2.8	-11.5	3.1	2.2	1.8	.001	¹
<i>Trifurcation M1-PtV</i>	-24.0	3.1	-20.7	3.5	3.3	1.6	.000***	¹
<i>Trifurcation M2-PtV</i>	-15.1	2.6	-13.2	3.0	2.0	2.2	.005**	¹
<i>M1-NL</i>	97.8	6.4	96.7	5.8	-1.2	5.4	.430	¹
<i>M2-NL</i>	102.2	8.6	105.7	9.5	3.5	6.8	.177	²
<i>U1-NL</i>	105.6	13.6	105.7	9.0	0.1	9.4	.955	¹

* $p < .05$, ** $p < .01$, *** $p < .001$ ¹ = paired t-test² = Wilcoxon

Table 9: Group 3: cephalometric dentoalveolar measurements and treatment effects.

	group 1		group 2		group 3		total		<i>p</i>	
	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>		
<i>Overjet</i>	0.2	1.2	-0.9	1.7	-0.9	2.9	-0.6	2.0	.242	¹
<i>Overbite</i>	-0.4	0.9	0.4	1.3	-0.1	1.2	0.0	1.2	.112	¹
<i>Centroid M1-PtV</i>	4.3	1.6	4.1	2.0	2.9	1.8	3.8	1.9	.107	¹
<i>Centroid M2-PtV</i>	-	-	4.1	2.1	2.2	1.8	3.4	2.2	.614	²
<i>Trifurcation M1-PtV</i>	3.6	1.3	3.7	2.3	3.3	1.6	3.5	1.9	.791	¹
<i>Trifurcation M2-PtV</i>	-	-	2.7	2.0	2.0	2.2	2.4	2.1	.698	²
<i>M1-NL</i>	2.4	6.5	2.6	7.4	-1.2	5.4	1.5	6.7	.217	¹
<i>M2-NL</i>	-	-	7.5	8.3	5.5	6.8	5.9	7.9	.831	²
<i>U1-NL</i>	-1.2	4.3	-1.5	8.0	0.1	9.4	-1.0	7.5	.803	¹

p* < .05, *p* < .01, ****p* < .001

¹ = ANOVA

² = unpaired t-test

Table 10: Cephalometric dentalveolar inter-group differences of treatment effects.

	distalization		bodily movement (mm)			duration (month)			speed (mm/month)		
	<i>min</i>	<i>max</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>mean</i>	<i>SD</i>	<i>p</i>	<i>mean</i>	<i>SD</i>	<i>p</i>
<i>group 1</i>	1.7	6.0	3.6	1.4	.107 ¹	7.0	2.5	.780 ¹	0.6	0.3	.564 ²
<i>group 2</i>	0.8	8.5	3.7	2.3		7.7	3.3		0.6	0.5	
<i>group 3</i>	1.2	5.9	3.3	1.6		7.5	2.7		0.5	0.3	
<i>overall</i>	0.8	8.5	3.6	1.9		7.5	2.9		0.6	0.4	

p* < .05, *p* < .01, ****p* < .001

¹ = ANOVA

² = Kruskal-Wallis-test

Table 11: Effectiveness of bodily distalization.

Fig.10-18 show box-plots which mean the differences between before and after distalization of each group by dentoalveolar measurements.

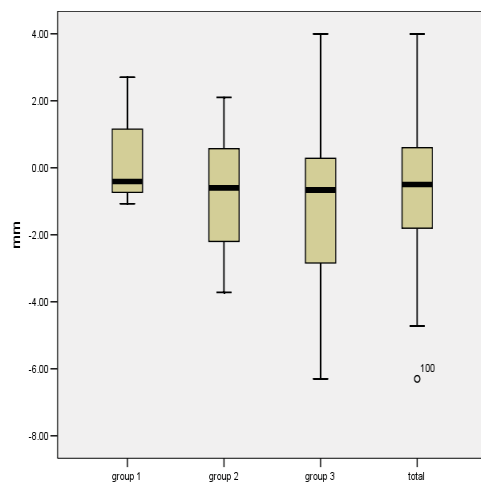


Fig.10: Overjet: differences between before and after distalization of each group.

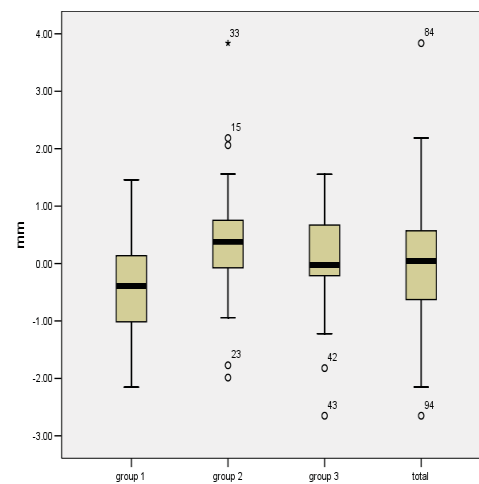


Fig.11: Overbite: differences between before and after distalization of each group.

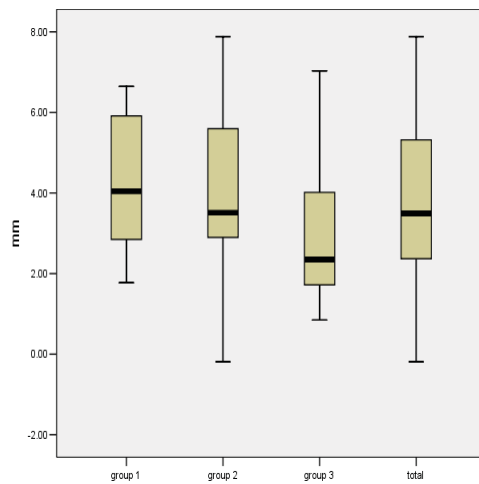


Fig.12: Centroid M1-PtV: differences between before and after distalization of each group.

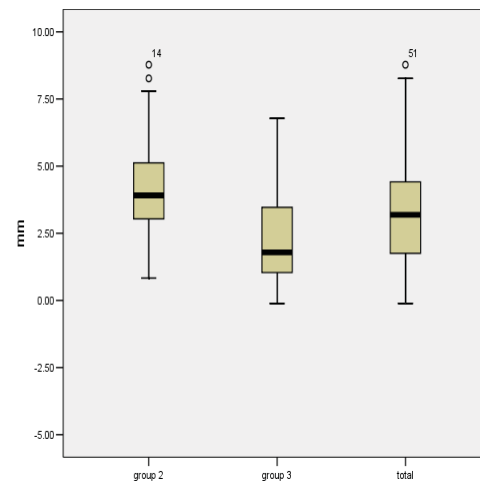


Fig.13: Centroid M2-PtV: differences between before and after distalization of each group.

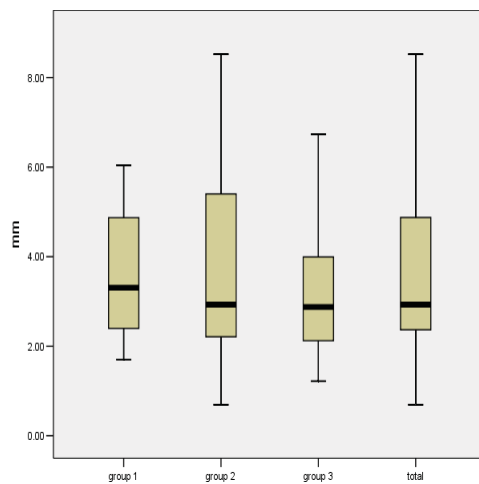


Fig.14: Trifurcation M1-PtV: differences between before and after distalization of each group.

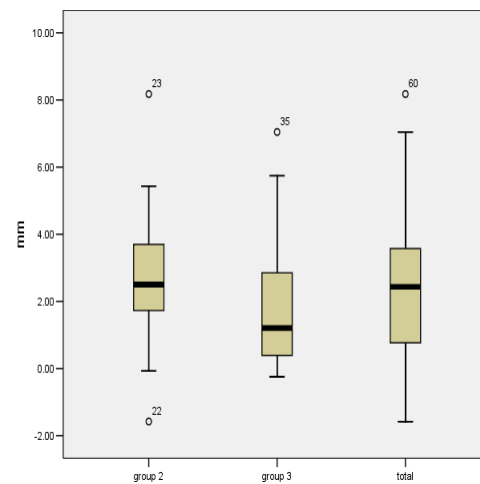


Fig.15: Centroid M2-PtV: differences between before and after distalization of each group.

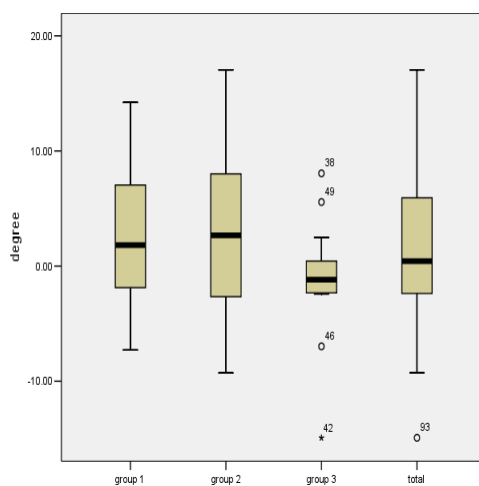


Fig.16: M1-NL: differences between before and after distalization of each group.

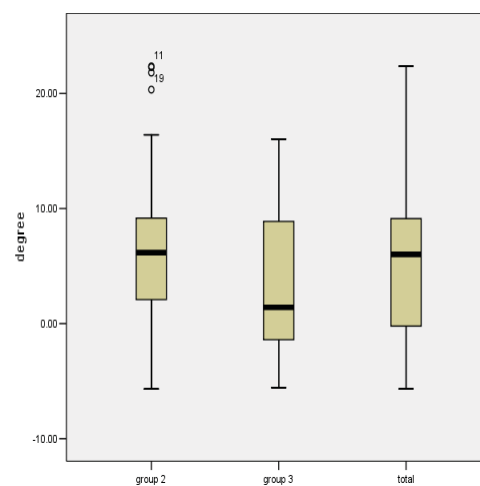


Fig.17: M2-NL: differences between before and after distalization of each group.

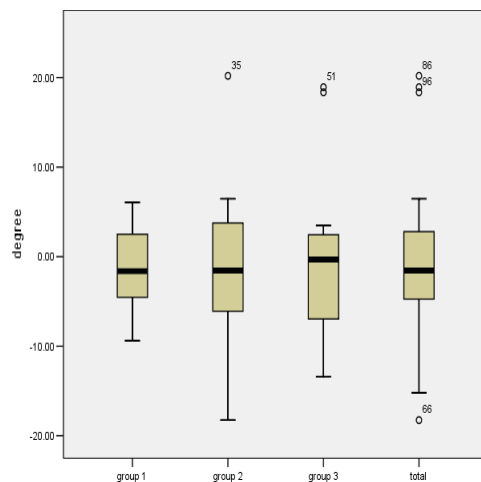


Fig.18: U1-NL: differences between before and after distalization of each group.

5.2.2 Skeletal measurements

5.2.2.1 Sagittal measurements

In the analysis of angular measurements of SNA, overall mean value of change of SNA was $-0.3 \pm 1.6^\circ$ (Table 12). In each group, mean value of SNA $-0.6 \pm 2.1^\circ$ in group 1, $-0.2 \pm 1.2^\circ$ in group 2 and $-0.4 \pm 1.7^\circ$ in group 3 (Table 13-15). There was no significant change of SNA overall and within each group (Table 12-15). Mean values between the groups showed no significant inter-group differences (Table 16).

Overall mean value of change of SNB was $-0.3 \pm 1.3^\circ$ (Table 12). Mean values showed $-1.0 \pm 1.4^\circ$ in Group 1, $0.0 \pm 1.0^\circ$ in group 2 and $-0.2 \pm 1.5^\circ$ in group 3, respectively (Table 13-15). Mean values SNB in overall ($p=.036$) and group 1 ($p=.016$) showed a significant change. Mean values between the groups showed no significant inter-group differences (Table 16).

Mean value of change of ANB for all groups was $0.1 \pm 1.6^\circ$ (Table 12). In each group, mean values showed $0.4 \pm 1.9^\circ$ in group 1, $0.0 \pm 1.4^\circ$ in group 2 and $-0.1 \pm 1.5^\circ$ in group 3 (Table 13-15). There was no significant change of ANB overall and within each group (Table 12-15). Mean values between the groups showed no significant inter-group differences (Table 16).

In the analysis of measurements of WITS, overall mean value showed 0.1 ± 2.8 mm (Table 12). Mean values of each group were 1.1 ± 2.8 mm in group 1, 0.0 ± 2.2 mm in group 2, -1.1 ± 3.5 mm in group 3 (Table 13-15). There was no significant change of WITS in overall and groups (Table 12-15). Inter-group differences of treatment effects showed no significance (Table 16).

In the analysis of skeletal sagittal measurements, only mean values of change of SNB for all groups ($-0.3 \pm 1.3^\circ$, $p=.036$) and group 1 ($-1.0 \pm 1.4^\circ$, $p=.016$) decreased.

Fig.19-22 show box-plots with mean differences between before and after distalization of each group by skeletal sagittal measurements.

total

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>SNA</i>	80.5	4.1	80.3	4.3	-0.3	1.6	.179	²
<i>SNB</i>	77.5	4.7	77.2	4.7	-0.3	1.3	.036*	²
<i>ANB</i>	3.0	3.3	3.1	3.4	0.1	1.6	.599	²
<i>WITS</i>	1.1	5.3	1.1	5.5	0.1	2.8	.746	²

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

Table 12: All patients: cephalometric skeletal sagittal measurements and treatment effects.

group 1

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>SNA</i>	79.7	6.0	79.2	5.7	-0.6	2.1	.344	¹
<i>SNB</i>	76.9	5.9	75.8	5.7	-1.0	1.4	.016*	²
<i>ANB</i>	2.9	2.0	3.3	2.6	0.4	1.9	.414	¹
<i>WITS</i>	-0.2	3.2	0.9	4.8	1.1	2.8	.165	¹

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

Table 13: Group 1: cephalometric skeletal sagittal measurements and treatment effects.

group 2

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>SNA</i>	81.0	3.0	81.0	3.1	-0.2	1.2	.933	¹
<i>SNB</i>	77.7	4.1	77.7	3.8	0.0	1.0	.984	¹
<i>ANB</i>	3.3	3.0	3.3	3.2	0.0	1.4	.907	¹
<i>WITS</i>	2.0	0.5	2.1	4.5	0.0	2.2	.970	¹

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

Table 14: Group 2: cephalometric skeletal sagittal measurements and treatment effects.

group 3

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>SNA</i>	80.5	3.5	80.1	4.5	-0.4	1.7	.449	¹
<i>SNB</i>	77.9	4.6	77.7	5.2	-0.2	1.5	.591	¹
<i>ANB</i>	2.6	4.8	2.4	4.5	-0.1	1.5	.729	¹
<i>WITS</i>	0.7	8.4	-0.4	7.3	-1.1	3.5	.263	²

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

Table 15: Group 3: cephalometric skeletal sagittal measurements and treatment effects.

	group 1		group 2		group 3		total		<i>p</i>	
	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>		
<i>SNA</i>	-0.6	2.1	0.0	1.2	-0.4	1.7	-0.3	1.6	.874	²
<i>SNB</i>	-1.0	1.4	0.0	1.0	-0.2	1.5	-0.3	1.3	.125	¹
<i>ANB</i>	0.4	1.9	0.0	1.4	-0.1	1.5	0.1	1.6	.782	¹
<i>WITS</i>	1.1	2.8	0.0	2.2	-1.1	3.5	0.0	2.8	.241	¹

* *p* < .05, ** *p* < .01, *** *p* < .001

¹ = ANOVA

² = Kruskal-Wallis-test

Table 16: Cephalometric skeletal sagittal inter-group differences of treatment effects.

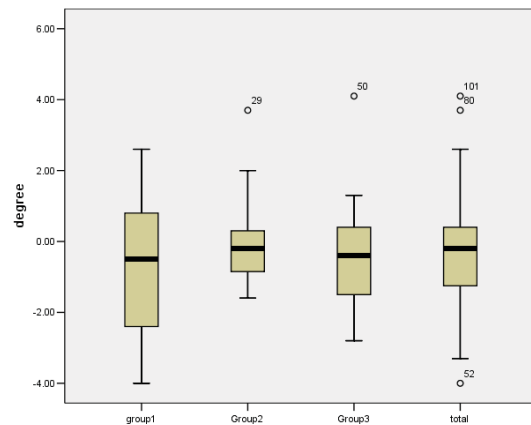


Fig.19: SNA: differences between before and after distalization of each group.

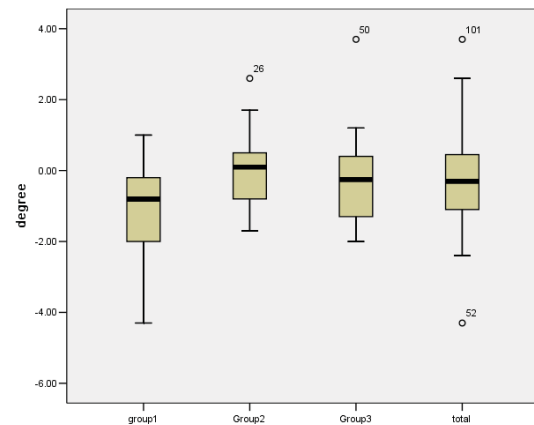


Fig.20: SNB: differences between before and after distalization of each group.

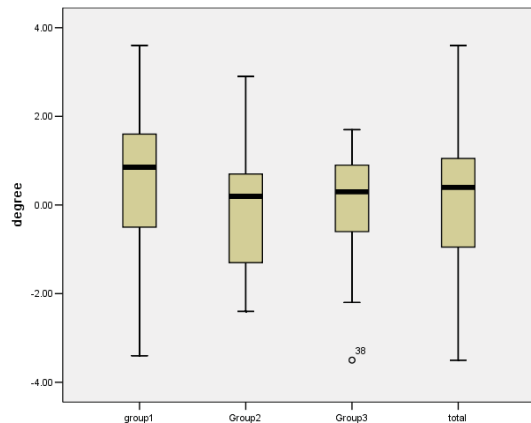


Fig.21: ANB: differences between before and after distalization of each group.

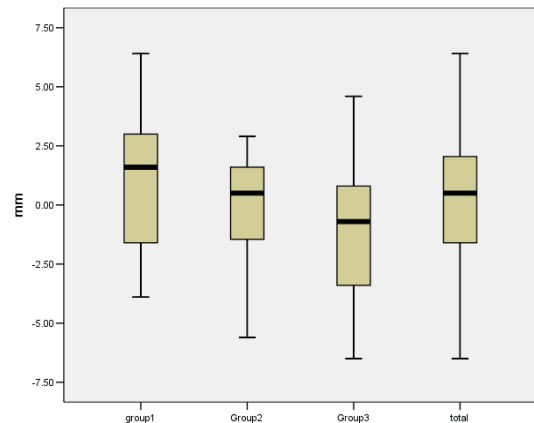


Fig.22: WITS: differences between before and after distalization of each group.

5.2.2.2 Vertical measurements

In the analysis of angular measurements of NSL-ML, overall mean value of change of NSL-ML was $-0.2 \pm 1.4^\circ$ (Table 17). In each group, mean values of NSL-ML showed $-0.5 \pm 1.5^\circ$ in group 1, $-0.2 \pm 1.3^\circ$ in group 2 and $0.1 \pm 1.6^\circ$ in group 3 (Table 18-20). There was no significant change of NSL-ML overall and within each group (Table 17-20). Mean values of NSL-ML between all groups showed no significant inter-group differences (Table 21).

Mean value of NSL-NL for all groups was $-0.4 \pm 1.2^\circ$ (Table 17). In each group, mean values of NSL-NL showed $-0.4 \pm 1.4^\circ$ in Group 1, $0.6 \pm 0.9^\circ$ in group 2 and $-0.2 \pm 1.4^\circ$ in group 3 (Table 18-20). Mean values of NSL-NL in overall ($p=.013$) and group 2 ($p=.002$) showed a significant change. Mean values of NSL-NL between all groups showed no significant inter-group differences (Table 21).

Overall mean value of change of NL-ML was $0.3 \pm 1.5^\circ$ (Table 17). Mean values of NL-ML showed $0.0 \pm 1.2^\circ$ in group 1, $0.4 \pm 1.6^\circ$ in group 2 and $0.3 \pm 1.7^\circ$ in group 3, respectively (Table 18-20). There was no significant change of NL-ML overall and within each group (Table 17-20). Mean values of NL-ML between all groups showed no significant inter-group differences (Table 21).

In the analysis of skeletal vertical measurements, only mean values of NSL-NL for all groups ($-0.4 \pm 1.2^\circ$, $p=.013$) and group 2 ($-0.6 \pm 0.9^\circ$, $p=.002$) decreased.

Fig.23-25 show box-plots with mean differences between before and after distalization of each groups by skeletal vertical measurements.

total

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>NSL-ML</i>	32.2	6.8	32.0	6.6	-0.2	1.4	.651	²
<i>NSL-NL</i>	6.6	3.6	6.1	3.4	-0.4	1.2	.013*	²
<i>NL-ML</i>	25.6	6.2	25.9	5.9	0.3	1.5	.200	¹

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

Table 17: All patients: cephalometric skeletal vertical measurements and treatment effects.

group 1

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>NSL-ML</i>	35.0	8.5	34.5	7.9	-0.5	1.5	.262	²
<i>NSL-NL</i>	6.9	3.0	6.5	2.7	-0.4	1.4	.510	²
<i>NL-ML</i>	28.1	6.1	28.1	5.9	0.0	1.2	.975	²

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

Table 18: Group 1: cephalometric skeletal vertical measurements and treatment effects.

group 2

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
<i>NSL-ML</i>	31.0	5.2	30.8	5.0	-0.2	1.3	.497	¹
<i>NSL-NL</i>	6.2	3.5	5.5	3.2	-0.6	0.9	.002**	¹
<i>NL-ML</i>	24.8	6.1	25.3	5.6	0.4	1.6	.195	¹

* $p < .05$, ** $p < .01$, *** $p < .001$

¹ = paired t-test

² = Wilcoxon

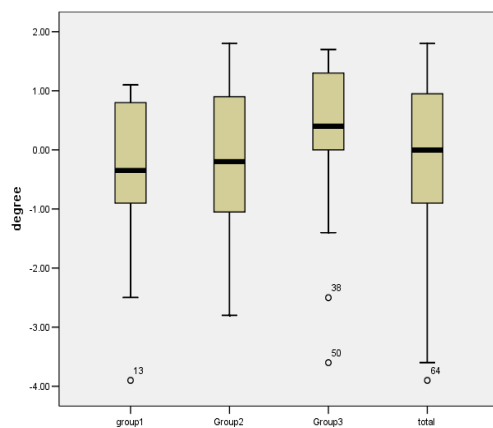
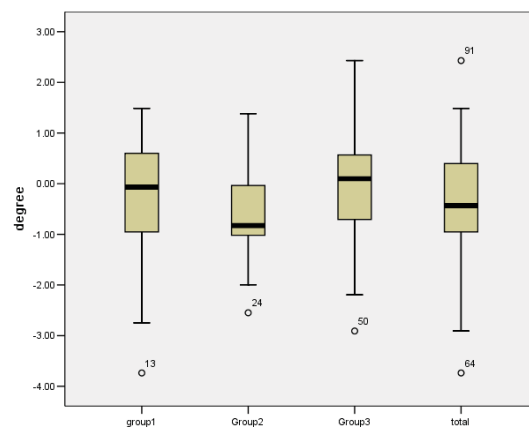
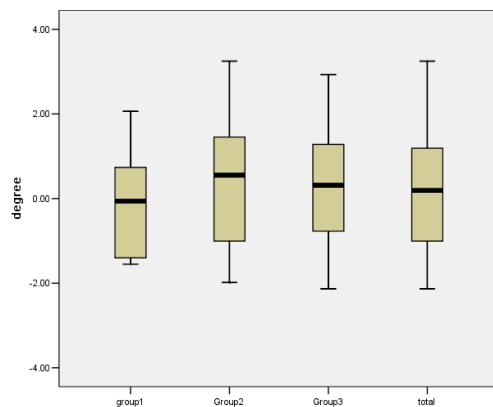
Table 19: Group 2: cephalometric skeletal vertical measurements and treatment effects.

group 3

	<i>T1</i>	<i>SD</i>	<i>T2</i>	<i>SD</i>	<i>Diff</i>	<i>SD</i>	<i>p</i>	
NSL-ML	31.5	6.9	31.6	7.2	0.1	1.6	.767	¹
NSL-NL	6.9	4.3	6.8	4.4	-0.2	1.4	.975	²
NL-ML	24.5	6.3	24.8	6.2	0.3	1.7	.531	¹

p* < .05, *p* < .01, ****p* < .001¹ = paired t-test² = Wilcoxon**Table 20: Group 3: cephalometric skeletal vertical measurements and treatment effects.**

	group 1		group 2		group 3		total		<i>p</i>	
	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>	<i>T2-T1</i>	<i>SD</i>		
NSL-ML	-0.5	1.4	-0.2	1.3	0.1	1.6	-0.2	1.4	.459	²
NSL-NL	-0.4	1.4	-0.6	0.9	-0.2	1.4	-0.4	1.2	.709	¹
NL-ML	0.0	1.2	0.4	1.6	0.3	1.7	0.3	1.5	.847	¹

p* < .05, *p* < .01, ****p* < .001¹ = ANOVA² = Kruskal-Wallis-test**Table 21: Cephalometric skeletal vertical inter-group differences of treatment effects.****Fig.23: NSL-ML: differences between before and after distalization of each group.****Fig.24: NSL-NL: differences between before and after distalization of each group.****Fig.25: NL-ML: differences between before and after distalization of each group.**

6. Discussions

One of the major challenges in treating patients with a Class II molar relationship is the need for distalization of maxillary molars into a Class I relationship.

For years, headgear was used routinely for distal movement of maxillary molars.⁷² However, many patients reject headgear because of social and esthetic concerns, and the success of this treatment depends on patient cooperation.³⁰ In many cases, a lack of cooperation results in unsatisfactory treatment. In addition, it is difficult to adjust the outer bow so that the direction of force coincides with a vector orientated correctly to the centre of resistance of the molar.⁷³ Another disadvantage in the use of headgear wear is the possibility of creating serious facial and eye injuries.⁹⁸

Many intramaxillary non-compliance appliances and methods for molar distalization have been introduced to overcome the problem of compliance and to correct Class II malocclusion efficiently.^{4,18,40,47,50,54,84,95} However, some other problems were usually present:

- (1) Anchorage loss of the anterior dental unit expressed as forward movement and proclination of the anterior teeth,^{1,86}
- (2) Distal tipping of the molars during active maxillary molar distalization,^{13,39,95}
- (3) Anchorage loss of the posterior dental unit in the forward direction that takes place after distalization during the subsequent stage of anterior tooth retraction and final alignment of the dental arch.⁴⁹

In order to solve these problems, implants have been used as stable anchorage for maxillary molar distalization.^{15,59} They necessitate an invasive placement and surgical removal procedures must be performed. In addition, placement locations are limited, they are more expensive than other anchorage modalities, and a waiting period for osseointegration before loading the implants with orthodontic forces is necessary.

Recently, mini-implants have been used as stable temporary anchorage devices for maxillary molar distalization, because they are not associated with the problems mentioned above. The alveolar ridge has been used as the most common insertion site for orthodontic mini-implants.^{101,102} This location seems to be not very appropriate for molar distalization followed by retraction of the anterior teeth, because mini-implants happen to be in the path of moving teeth. When dental root gets into contact with mini-implants during dental moving, root resorption may occur.⁷⁸ Although mini-plates in the infrazygomatic buttress were suggested by many studies, this site cannot be regarded as entirely safe.^{22,104}

One or two mini-implants inserted in the anterior palate provide sufficient anchorage stability for molar distalization.^{29,38,64,69,88} From an anatomical point of view, in this insertion site, root contact or traumatic interference is rather unlikely.^{55,70}

The anterior palate also provides a very good bone quality.⁵⁵ Cortical bone is typically thicker in the palate than at buccal interradicular insertion sites. The abundant available space enables insertion of mini-implants with larger diameters that also contribute to improved mini-implant stability.^{83,114} In addition, this location has a favourable thinner attached mucosa.⁷⁷ These aspects might explain why the mini-implants used in this study showed a high primary stability and remained stable during treatment. Furthermore, stable coupling of the screws with the appliance avoids tipping of the mini-implants. This may also lead to an increased biomechanical load capacity.

There is a need for well designed studies evaluating the clinical performance of non-compliance maxillary molar distalization with mini-implants. It may not be reliable to use clinical results based on small samples, because there is a large variability of appliances and the response of patients. In the current study, a comparatively large sample of 51 patients could be investigated. Recent studies on this topic typically relied on sample sizes between 10 and 25 individuals.³⁴

In order to improve the informative value of the results, inclusion and exclusion criteria were appropriately defined. For the reduction of technical errors, measurements of digital x-ray and superimpositions were performed by one examiner and verified by a second operator. Using the stable anatomical structures of the anterior cranial base helped to minimize superimposition errors.³ Assessment of the method error according to Dahlberg and coefficient of reliability showed a high reproducibility of the measurements.^{25,51}

To document dentoalveolar intramaxillary changes caused by the non-compliance distalization appliances, ANS-PNS-plane was chosen as reference for angular measurements and for construction of PTV. In addition to molar axis changes and movement of Centroid point, the displacement of Trifurcation representing the centre of resistance was investigated to evaluate the quantity of the bodily distalization.

For statistical evaluation, Shapiro-Wilk-test was performed to assess the normal distribution of each variable. Depending on the results of this evaluation, further statistical analysis of the data was performed with the paired t-test or Wilcoxon-test to determine any significant changes after treatment with this appliance.

The correction of the Class II molar relationship by means of the presented appliance was achieved with a mean maxillary first molar distal bodily movement of 3.6mm. Regarding the use of maxillary molar distalization devices with temporary skeletal anchorage, literature

reports values ranging from 3.3 to 6.4 mm.³⁴ But only mechanics based on stable guiding wires like Distal Jet or vestibular sliding mechanics enabled bodily distalization with molar tipping ranging from 0.8 to 3.0 °.^{22,38,64} In these studies, the amount of distalization was 3.3 to 3.9 mm referring to coronal measuring points and thus comparable to current results. However, the evaluating the displacement of coronal reference points have a possibility to overestimate actual distalization effects. In order to make a reliable assessment of the bodily molar distalization effects, the trifurcation point of maxillary molar was identified as reference point. The trifurcation point seems to be more appropriate than the coronal reference point like the centroid, because the trifurcation point is near the central resistance of the tooth. The amount of maxillary molar displacement in the current study could be more accurately evaluated compared to previous studies.

In studies dealing with frictionless appliances such as the Pendulum, the amount of distalization related to crown movement reported in a range from 4.0 to 6.4 mm.^{29,69,91,97} However, the tipping of molars occurring simultaneously with its displacement was in a range from 9.1 to 12.2 °.

The speed of first molar bodily distalization in current study was 0.6 mm per month. Other studies also dealing with mechanics enforcing bodily distalization revealed comparable speeds of 0.5 to 0.7 mm.^{22,38,64} Crown movement using Pendulum appliances with skeletal anchorage showed a higher speed of 0.6 to 0.9 mm due to tipping of the molars.^{29,69,91,97}

In order to avoid overload of the mini-implants, the activation of NiTi-springs were initially carried out 50 % less than the normal activation after the healing phase. Consequently, no major distalization effect was expected during the first months which may result in a lower overall speed. In children with not erupted second molars, 2.4 N NiTi-springs were applied at each side. On the other hand, 5 N springs were applied in adolescents and adults with fully erupted second molars. Comparing force magnitudes reported in the literature these values range in the upper third.³⁴ Because sliding mechanics always causes friction, the effective force applied to the molars is considered to be much lower. Due to variation of force level, speed of distalization did not decrease significantly after eruption of second molars and in older patients. In contrast, other studies report a deceleration of distalization after eruption of the second molars.^{57,63} In the current study, the amount of distalization depends on patient's needs and ranged to up to 8.5 mm with second molar in place demonstrating anchorage's stability and mechanics' effectiveness.

Currently, the types of appliances used most frequently for non-compliance molar distalization, pendulum appliances and palatally-located compression-coil spring systems included Beneslider, are based on two different biomechanical concepts. In a biomechanical

point of view, Pendulum appliances seems to have more complex factors. The molars are supposed to be distalized bodily along the arc of a circle as defined by the Pendulum springs' geometry. To make this happen, it is necessary to modify and to pre-activate the Pendulum springs.⁶⁵ In most cases, the distal horizontal arm of the Pendulum spring is needed to be activated for the upprighting of the molars. Clinically, applied pendulum appliances requires a rather complex operation. On the other hand, a combined application with palatal compression-coil spring appliance is a different biomechanics. The line of force in the sagittal plane determined by the active components runs almost through the first molar's center of resistance. Therefore, these appliances can reduce the tipping moment of force and hence friction without need of a complex clinical procedure.

Molar distalization often leads to bite opening caused by protrusion of the incisors or clockwise rotation of the mandible.^{35,43} In this study, no significant changes of overbite and incisor inclination were found. In the analysis of skeletal vertical measurements, only significant changes of NSL-NL for all groups and in group 2 could be observed. But there were no significant changes in measurements of NSL-ML and NL-ML which remained unchanged due to the stable anchorage system with mini-implants and guidance by rigid stainless steel wires. This results suggest the possibility that this current appliance could be applied in various cases, including the open bite.

7. Conclusions

The results of this study by means of analysis of lateral cephalograms indicate that the Beneslider is an effective non-compliance appliance and enables bodily distalization of maxillary molar in adequate treatment time. Due to stable direct skeletal anchorage, two coupled mini-implants, side-effects such as anchorage loss or vertical changes like bite opening or posterior mandible rotation can be avoided. Since high forces of up to 5 N on each side can be applied, the higher resistance caused by erupted second molars can be compensated without significant reduction of distalization speed.

The Beneslider has the potential to expand the possibilities of orthodontic treatment. Because the use of heavy wire guidance, which runs near the center of resistance, the Beneslider can be applied in patients with open bite. The direct skeletal anchorage system can be also used in patients where the canines are not yet erupted. In addition, a sufficient aesthetic effect can be expected in adult patients as well as in children. The implementation of an efficient and reliable maxillary molar distalization may also result in a significant reduction of extractions in orthodontics.

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Eidesstattliche Versicherung

Ich versichere an Eides statt, dass die Dissertation selbstständig und ohne unzulässige fremd Hilfe erstellt worden ist und die hier vorgelegte Dissertation nicht von einer anderen Medizinischen Fakultät abgelehnt worden ist.

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