The application of skeletal anchorage in the management of maxillary deficiency in growing children

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1. Declaration

Candidate Certification

This is to certify that the candidate carried out the work in this thesis, in the Orthodontic Department, University of Sydney, and it has not been submitted to any other University or Institution for a higher degree

Nour Eldin Yehia Tarraf

2. Dedication

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4. Abbreviations

2D	Two-dimensional
3D	Three dimensional
A	A point: most concave point of the curve of maxilla between ANS and dental alveolus
A-TV	Perpendicular line from A point to the True Vertical
AB-TV	The difference between A-TV and B-TV
Alt-RAMEC	Alternating Rapid Maxillary Expansion and Contraction
ANB	ANB angle: relates the anteroposterior position of the maxilla to the mandible
ANB	The angle between the NA and NB lines relates the anteroposterior position of the maxilla to the mandible
ANS	Anterior Nasal Spine
AO	Perpendicular line from A point to the Occlusal Plane
AO	Perpendicular line from A point to the Occlusal Plane
Ar	Articulare: a point at the intersection of the image of the posterior margin of the ramus and the outer margin of the cranial base
Ar-Go-Me	Gonial Angle: Articulare to Gonion to Menton
B	B point: most concave point of curve along anterior border of symphysis
B-TV	Perpendicular line from B point to the True Vertical
BAMP	Bone Anchored Maxillary Protraction
BO	Perpendicular line from B point to the Occlusal Plane
BO	Perpendicular line from B point to the Occlusal Plane
BSSO	Bilateral Sagittal Split Osteotomy
CAD	Computer-aided design
CAD/CAM	Computer-aided design and computer-aided manufacturing
CAlt-SRAMEC	Continuous Alternating Semi Rapid Maxillary Expansion and Contraction
CAM	Computer-aided manufacturing
CBCT	Cone Beam Computed Tomography
Cl	Class
cm	Centimeter
cN	Centi Newton
CO	Centric Occlusion
CR	Centric Relation
CRe	Centre of Resistance
CS	Cervical Stage
CVM	Cervical Vertebral Maturation
CVMS	Cervical Vertebral Maturation Stage

CW	Clockwise
DO	Distraction Osteogenesis
FEA	Finite Element Analysis
FEM	Finite Element Model
FH	Frankfurt Plane: linear measurement from Porion to Orbitale, equivalent to the True Horizontal when patient is standing upright
FM	Facemask
Forsus FRD	Forsus Fatigue Resistant Device
FR-3	Fränkel Functional Appliance 3
g	Gram
GA	General Anaesthetic
Gn	Gnathion: the lowest, most anterior midline point of the chin midway between menton and pogonion
Go	Gonion: The point on the curvature of the angle of the mandible located by bisecting the angle formed by the lines tangent to the posterior ramus and the inferior border of the mandible
GTRV	Growth Treatment Response Vector
HE	Hybrid Expander
HE-FM	Hybrid Expander Facemask therapy
HE-MP	Hybrid Expander miniplate combination
HG	Headgear
HH	Hybrid Hyrax
HH-FM	Hybrid Hyrax Facemask therapy
HTH	Hank Telescoping Herbst
i-CAT	Cone Beam Computed Tomography Scanner
IGF-1	Insulin like Growth Factor 1
L1	Lower incisor
L1-MP	The angle between the lower incisor and mandibular plane
L6	Lower first molar
L6-MP	The angle between the lower first molar and mandibular plane
LA	Local Analgesic
LLA	lower lingual arch
LOP	Lower Occlusal Plane
LOP-MP	The angle between the lower occlusal plane and mandibular plane
Me	Menton: the most inferior point on the mandibular symphysis in the midline
MES	Minimum effective strain
mm	Millimetre
MP	Miniplate

MP	Mandibular Plane
N	Nasion: The most anterior part of the frontonasal suture
N	Newton
NewTom	Cone Beam Computed Tomography Scanner
NiTi	Nickel Titanium
OB	Overbite
OJ	Overjet
OP	Occlusal Plane: A line joining the mesiobuccal cusp of the upper first molar to a point midway between the overlap of the upper and lower incisors
Or	Orbitale: the most inferior point of the infraorbital rim
oz	Ounce
PNS	Posterior nasal spine
Po	Porion: upper most superior point of the external auditory meatus
PP	Palatal Plane
PP-MP	The angle between the palatal plane and mandibular plane
RCT	Randomised Controlled Trial
RME	Rapid Maxillary Expander
RME-FM	Rapid Maxillary Expansion combined with facemask therapy
S	Sella: The centre of the sella turcica
SD	Standard deviation
SN	The line between Sella and Nasion representing the anterior cranial base.
SN-MP	Mandibular plane angel: The angle between the anterior cranial base (Sella to Nasion) mandibular plane
SNA	The angle between the anterior cranial base (Sella to Nasion) and the NA (nasion to point A) line
SNB	The angle between the anterior cranial base (Sella to Nasion) and NB (nasion to point B) line
SPSS	Statistical Package for Social Sciences
SS	Stainless steel
T1	Pre-treatment point
T2	Posttreatment point
TAD	temporary anchorage device
TFBC	Twin Force Bite Corrector
TH	True Horizontal Line
TMD	Temporomandibular Joint Disorders
TMJ	Temporomandibular Joint
TV	True Vertica Line
U1	Upper incisor
U1-PP	Angle between the upper incisor and the palatal plane

U1-SN	Angle between the upper incisor and the anterior cranial base line
U6	Upper first molar
U6-PP	Angle between the upper first molar and the palatal plane
UOP	Upper Occlusal Plane
UOP-PP	The angle between the upper occlusal plane and palatal plane
UOP-SN	The angle between the upper occlusal plane and the anterior cranial base line
Wits	The distance between AO and BO, the projection of points A and B perpendicularly to the occlusal plane
Y-axis	The angle between the line from Sella to Gnathion SN-Gn and the Frankfurt horizontal plane and indicates the downwards, rearwards or forwards position of the chin in relation to the upper face.

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7. Literature review

7.1.Introduction

Skeletal Class III malocclusion is among the more challenging malocclusions to treat in growing children. It is defined as a skeletal facial deformity characterised by a forward position of the mandible in relation to the cranial base and/or the maxilla.[1] Conventional management relies on the use of growth modification methods to stimulate maxillary growth, restrain mandibular growth or achieve a combination of the two.[2] The protraction facemask combined with maxillary expansion was considered the gold standard in managing maxillary deficiency.[3-6] This method results in downwards and forwards maxillary growth and restraining of mandibular growth, with backward rotation of the mandible and an improvement in overjet.[3-6] However, there are several limitations to facemask therapy. Firstly, the facemask is a cumbersome extraoral appliance. Secondly, patients are required to wear the appliance 13-16 hours a day which can be challenging and produce unsatisfactory results if patient compliance is poor. Thirdly, the appliance is tooth-borne and presents several unwanted dental side effects, such as mesial movement of the maxillary dentition, molar extrusion and retroclination of the mandibular incisors.[3-6] Fourthly, the results for facemask therapy seem to be poor in older children.[7-9]

The introduction of skeletal anchorage has changed many aspects of Class III treatment. Skeletal anchorage has been used in conjunction with facemasks[10,11] but also with completely intraoral applications, such as miniplates and Class III elastics.[12] It has been found to increase the skeletal effect in Class III growth modification and to reduce dental side effects.[13-15] However, the methods used have been completely dependent on patient compliance with either the use of a protraction facemask or intraoral Class III elastics. Patient compliance can be unpredictable, and most research shows that it is usually lower than orthodontists require.[16,17]

This project explores the use of three different types of skeletal anchorage supported appliances for Class III correction in growing children and compares them with conventional tooth-borne facemask therapy.

The first study in this project examines the skeletal and dental effects of a CAD/CAM Hyrbrid (tooth-bone-borne) Expander and facemask combination with only bedtime wear compared with conventional tooth-borne maxillary expansion and facemask treatment with 14-16 hours of facemask wear. Most studies on facemask therapy request patients to wear a protraction facemask 12-16 hours a day for a treatment duration of approximately 9-12 months.[3,18,19] This regime could be quite demanding for most young children, especially if they have after-school activities and hobbies. Furthermore, this requirement alone could lead to poor acceptance of treatment as well as poor compliance. Studies on patients' adherence to medical regimes have shown that treatments which require greater changes to patient lifestyle can lead to poor compliance and thus poor outcomes.[20] Wearing a facemask for the greater part of the after-school hours (as well as bedtime) would be a demanding task for most children to adhere to, especially for a whole year, and could significantly disrupt their quality of life. On the other hand, limiting facemask wear to bedtime only seems easier to adhere to and can more easily fit into the child's normal routine without too much disruption. This factor alone may result in better treatment acceptance among patients and their families, and potentially result in better compliance and more regular facemask wear. Research shows that young children under the age of 11 sleep between 10 and 12 hours every night.[21] So with the use of skeletal anchorage increasing the efficacy of the facemask, fewer hours' of wear may be able to deliver similar skeletal outcomes. This would not, however, be an effective strategy in older children and adolescents, who sleep for fewer hours.[22]

Older children and adolescents are also less likely to be accepting of the facemask as they are more appearance-conscious. Additionally, the facemask hooks which connect the intraoral appliance to the elastics are likely to be visible, which may also provide an aesthetic reason for objecting to the appliance. In older children, it would be more desirable to avoid extraoral forces and to rely on purely intraoral approaches, such as the bone anchored maxillary protraction (BAMP)[23] and the Hybrid Hyrax Mentoplate[24] approaches. Such approaches place continuous intraoral elastic forces on the maxilla and mandible while the whole treatment remains invisible.

The second part of this project aims to compare the effect of the Hybrid Expander and Miniplate combination using intraoral Class III elastics with conventional maxillary expansion and facemask therapy.

Despite the use of miniscrews with the facemask improving skeletal outcomes and the incorporation of miniplates completely eliminating the need for extraoral forces, both these treatment regimens are reliant on patient compliance. Similar limitations have been faced in the management of Class II malocclusion with headgear as well as functional appliance wear.[25,26] Studies show that treatment regimens which do not rely on patient compliance are more efficient and also preferred by patients.[25,26]

The third and final part of this project was to develop and trial a compliance-free bone-borne Class III corrector that can benefit from the advantages of skeletal anchorage while reducing the need for patient compliance.

The importance of early management of Class III malocclusion cannot be understated. Early management and normalisation of the facial appearance may have a positive impact on the psychosocial development of children.[4] It may also prevent asymmetric jaw development and reduce irreversible damage to the enamel of the teeth, which may be caused by abnormal wear patterns and traumatic occlusion. Furthermore, treatment is more effective at a young age.[7,8] Early treatment of Class III malocclusion has been shown to reduce the need for orthognathic surgery in adulthood.[6] This means that, if well implemented, such treatment could dramatically reduce demands on the healthcare system and health insurance costs in the future. Early intervention costs a fraction of orthognathic surgery with significantly less risk and morbidity.

7.2.Class III malocclusion

7.2.1.Definition and characteristics

The definition of Class III malocclusion has evolved over the years from a dental classification focused purely on the occlusal relationship to a differentiation between a skeletal and a dental pattern with many possible variations. In his early attempt to define normal occlusion as the basis of orthodontics, Edward H. Angle described malocclusion based on the relationship between the mesiobuccal cusp of the upper first molar in relation to the buccal groove of the lower first molar.[27] He defined a Class III malocclusion as the distal position of the mesiobuccal cusp of the upper first molar in relation to the mesiobuccal groove of the lower first molar.[27] This was a classification purely based on dental relationships, and he later extended his classifications to describe skeletal jaw relationships.[28] With the introduction of cephalometrics, the skeletal pattern associated with various malocclusions was taken into account.[29] In 1966,[30] Charles Tweed categorised Class III malocclusion into two types: category A, which he designated as pseudo Class III with a conventionally shaped mandible, and category B, which he defined as a skeletal Class III with an underdeveloped maxilla and a large mandible.

In a more modern sense, and more closely related to this research, a Class III skeletal malocclusion has been defined as "a skeletal facial dysplasia characterised forward mandibular position with respect to the cranial base and/or the maxilla" which can be a result of maxillary retrognathia, mandibular prognathia or a combination of both.[31] Historically, individuals with a Class III malocclusion where diagnosed as prognathic and the aetiology of the malocclusion was assumed to be mandibular excess.[29] However, several studies that looked at the skeletal characteristics of Class III individuals found that this is not the case, and that there are a very large variety of skeletal patterns in which maxillary deficiency plays a significant role.[31-34]

7.2.2. Prevalence

The prevalence of Class III malocclusion in the literature is highly variable and differs between various ethnic groups. Additionally, variability in the definition of Class III malocclusion across epidemiological studies will impact the differences found. For example, in a systematic review of the literature, Hardy et al. found the incidence of Angle Class III malocclusion to vary from 0-26%. The prevalence of Class III seems to be highest in some Asian populations, particularly those of Chinese and Malaysian descent, at 15.69% and 16.59% respectively. These values are significantly higher than those reported in other populations, for example, in middle eastern populations such as Egypt, Turkey and Iran, where prevalence fell around 9-11%.[35-37] The incidence seems to be lower in European white populations, ranging from two to five percent,[38-40] with the lowest incidence being reported among Indian populations.[41]

7.2.3.Differential diagnosis

The differential diagnosis of Class III malocclusion should differentiate a true skeletal Class III malocclusion from what can be termed a ‘pseudo-Class III’ or simply a ‘dental Class III’.

Anterior crossbite

Anterior crossbite is often defined as a feature of a Class III malocclusion. It is defined as an anterior occlusion in which the upper incisors are in linguoversion to the lower incisors[42]. This, however, is not necessarily always an indicator of a Class III skeletal pattern. In fact, in many cases, an anterior crossbite is caused by an over retained deciduous incisor[43] which leads to palatal eruption of the permanent incisor, which is subsequently caught in a crossbite with the lower incisors. Furthermore, a skeletal Class III malocclusion can be present with a positive overjet[44]. In such cases, there is usually evidence of dento-alveolar compensation[45], such as retroclination of the lower incisors and/or proclination of the upper incisors[44]. However, in the presence of an anterior crossbite, it is critical for the clinician to differentiate a pseudo-Class III malocclusion from a true skeletal Class III malocclusion.

7.2.4.Pseudo Class III malocclusion

The importance of differentiating a true skeletal Class III malocclusion from a pseudo-Class III malocclusion in the presence of anterior crossbite and a functional shift has been emphasised by Ngan.[42] Where patients with an anterior crossbite are able to posture the mandible back into an edge-to-edge bite. this indicates the presence of a discrepancy between centric occlusion (CO) and the centric relation (CR), also known as the CR-CO discrepancy. This shift can exaggerate the prognathic appearance in a Class III patient. Furthermore, it can mean that the malocclusion is actually dental, but that the patient shifts forward, giving it a pseudo-skeletal nature. Thus, in the diagnosis of Class III malocclusion, a functional assessment is important to determine the relationship of the mandible to the maxilla and assess whether a CR-CO discrepancy exists. Anterior positioning of the mandible may be just a result from abnormal tooth contacts that force the mandible into a forward position. Patients who present with a forward shift of the mandible on closure may have a Class I skeletal pattern with a normal facial profile and a Class I molar relation in CR, but present with a Class III skeletal and dental pattern when in CO. Such a situation is referred to as a pseudo-Class III malocclusion. By eliminating the CR-CO shift, the clinician can reveal whether it is a simple Class I malocclusion or a compensated Class III malocclusion. On the other hand, a patient with no shift on closure most likely has a true skeletal Class III malocclusion.[44]

Rabie and Gu[46] set some criteria for what would be considered a pseudo-Class III malocclusion in a group of southern Chinese children:

- Molars and canines in Class I in CO and in a slight Class II in CR or when incisors are in an edge-to-edge relationship.
- Retrusive upper lip
- Forward position of the mandible with normal effective mandibular length
- Retroclined upper incisors and normal lower incisor inclination
- No family history of Class III malocclusion in 75%.

In a subsequent study, they also found that such cases responded well to non-skeletal treatment with simple fixed partial appliances.[47]

The presence of a functional shift, however, does not mean that the Class III relationship is not skeletal in nature, but it can indicate the prognosis of treating the malocclusion. Those Class III malocclusions with a CR-CO discrepancy may be less severe than the occlusal pattern suggests and would likely have good prognosis in treatment. On the other hand, the presence of an anterior crossbite with the absence of any forward shifting of the mandible may indicate a more severe Class III pattern[4,42].

The following flow chart (Figure 1) adapted from Dr Peter Ngan's[4,42] work is useful in determining the nature of a Class III malocclusion:

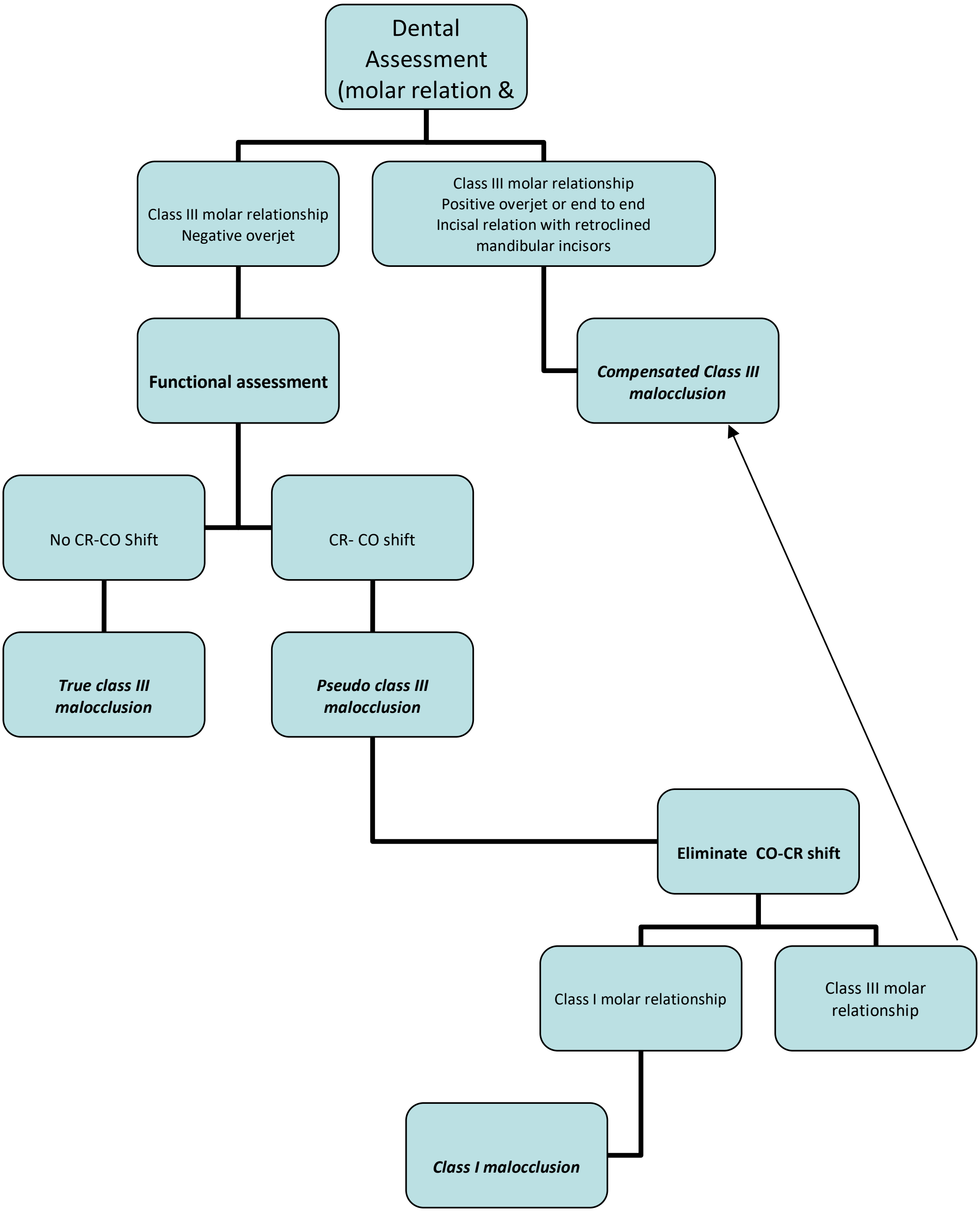


Figure 1 Flow chart adapted from Dr Peter Ngan's work[4,42] showing the steps in the differential diagnosis of a Class III malocclusion.

7.2.5.Skeletal Class III malocclusion

As mentioned previously, a true skeletal Class III malocclusion pattern has historically been considered to be caused by mandibular excess, and the term ‘mandibular prognathism’ was used interchangeably with ‘Class III malocclusion’ up until the 1960s. Cephalometric studies, however, revealed that maxillary deficiency played a significant role in Class III malocclusion. One of the early cephalometric studies on European children by Dietrich,[34] for example, concluded that at least 40% of children were actually maxillary deficient. The complexity of the Class III phenotype was further investigated by several authors. In a study on 302 adult Class III patients, Ellis et al.[32,33] investigated the components of adult Class III malocclusion with at least an end-to-end Class III molar and canine relationship. They took into account the height of the face and considered the following five principal factors: the position of the maxilla, the position of the mandible, the maxillary alveolus, the mandibular alveolus and vertical development. Furthermore, 243 possible combinations were calculated, of which only 69 varieties were observed in their sample. They detected maxillary retrusion in more than half of their sample, with one third of the patients exhibiting a combination of maxillary retrusion and mandibular excess. Pure maxillary skeletal retrusion and a neutral mandible were found in 19.5% of the sample, while pure mandibular protrusion was only found in 19.1%. Their findings also showed that Class III individuals presented significant differences in the vertical dimension, with 30% of the entire adult sample exhibiting an open-bite component to their Class III malocclusion.

Skeletal features of Class III seem to be already apparent from early childhood, as Guyer et al.[31] found when they analysed Class III individuals from early childhood to early and late adolescence compared to Class I subjects from the Bolton-Brush Growth Study. They found that the patterns identified in Class III adults were already present in early childhood, becoming progressively more expressed with age. This was especially true for the increase in vertical skeletal disharmony, which became more apparent in older age groups. Moreover, similar results were reported with respect to maxillary retrusion being the more prevalent skeletal feature, as opposed to mandibular prognathism. Only 18.7% of the children in their group showed pure mandibular excess, while a combination of maxillary retrusion and mandibular protrusion was found in 34% and pure maxillary deficiency was found in 23% of the sample. In addition, 41% of the study group (59 out of 144) were found to have an increased lower face height. Guyer et al. also found significant differences in the morphology of the mandibles of

Class III individuals, as well as differences in the flexure of the cranial base, which are important considerations. Aside from shorted and more retrusive maxillae, there were signs that the mandible was longer and more forward-positioned in the Class III individuals than in those from Class I, and the gonial angle was also more obtuse and more forward-positioned, with a greater mandibular plane angle. Dentally, they also found that the maxillary incisors tended to be significantly more protrusive and the mandibular teeth more retroclined, except in the youngest age group (those aged five to seven years old).[31] These dental adaptations were later explained as dentoalveolar compensations for the skeletal discrepancy, as described by Sollow.[45]

Although their study[31] was cross-sectional, Guyer et al. found that certain measurements (especially those related to the mandible) became progressively more pronounced in the older age groups. However, the signs of Class III were evident in the youngest age group; the authors reported that "the maxilla was found to be retrusive, and the mandible protrusive, from age 5 to age 15."[31]

The data in the above-mentioned studies was mostly obtained using lateral cephalometric analysis to assess the anteroposterior and vertical components of Class III patients. Little attention was paid to the transverse dimension. In the first study of its kind, Franchi and Baccetti[48] examined the transverse dimensions of Class II and Class III individuals using postero-anterior cephalograms. They found that both groups exhibited a deficiency when compared to normal values at the skeletal level, the dentoalveolar level and the nasal base. Their analysis showed that the maxillary skeletal base for their Class III participants was on average 4 mm smaller in the transverse plane than in Class I controls.[48]

Most of the above evidence[31-34,48] suggests that maxillary deficiency is the most common feature in Class III individuals, with true mandibular prognathism found in a smaller proportion. Such deficiency was found both in the anteroposterior and the transverse dimensions. This has implications in terms of planning treatment strategies and the consideration for maxillary expansion and protraction. The evidence also suggests that individuals with Class III malocclusion display distinctive skeletal and dental deviations and that these can be observed early in childhood.[31] This underscores the importance of early assessment and screening for children. Additionally, there seems to be a very large variation in the skeletal and dental patterns of Class III individuals, with a variety of possible anteroposterior, transverse and vertical patterns which need to be considered when this type of malocclusion is being clinically assessed.

7.3. Aetiology of Class III malocclusion

The aetiology of malocclusion is considered multifactorial[43] and Class III malocclusion is no different.[2] It is believed that only 5% of malocclusions will have a well-defined cause, while most malocclusions including (Class III malocclusions) will be variations of normal growth and an interaction of various genetic and environmental factors.[43]

7.3.1. Genetics

Heredity is believed to play an important role in facial appearance, and a Class III skeletal pattern is considered to have strong hereditary tendencies.[43] Several studies of human inheritance and its role in Class III malocclusion support the claim that growth and the size of the mandible are affected by heredity.[43] The most well-known example of the heritability of facial traits is that of the Hapsburg family. The former Austro-Hungarian royal family were renowned for certain distinct facial characteristics, including a prognathic lower jaw. In a study of the Hapsburg family, 33 out of 40 family members for whom records were available showed prognathic mandibles.[29] Litton et al.[49] also studied the families of 51 individuals with severe Class III anomalies and found that one third of the group had one parent with a Class III malocclusion and one sixth had a sibling who was also affected. They concluded that the occurrence of dental Class III characteristics was linked to genetic inheritance in offspring and siblings.[49]

In another study on a Japanese sample of Class III patients[50] who were about to or had already undergone orthognathic surgery, the high occurrence of mandibular prognathism suggested a high genetic influence. Twin studies can be very useful in determining the heritability of any trait and also in differentiating epigenetic and environmental influences. Twin studies have also indicated that vertical cephalometric parameters are more hereditary than horizontal ones.[51] Additionally, anterior vertical facial dimensions appear to be more genetically determined than posterior vertical parameters, while the mandibular shape is more genetically determined than its size.[51] Twin studies specifically looking at mandibular prognathism also demonstrate an obvious genetic link. However, expressivity of this variable may actually vary, as demonstrated by a case of monozygotic twins where one showed a more severe expression of the phenotype than the other.[52]

The exact inheritance pattern involved in Class III malocclusion remains unclear. Examinations of large groups point towards a multifocal and polygenic background with a threshold for expression (or, possibly, a single autosomal dominant trait with incomplete penetrance and variable expressivity) as the most likely mode of inheritance.[53]

As the genetic contributions to Class III malocclusion became established, the need to identify the candidate genes arose. Linkage analysis is a statistical examination of the segregation of traits in affected families, and it is considered the best way to find loci of phenotype-related genes.[53] Several chromosome locations that have shown statistical significance have been identified using this method, such as 1p22.1, 1p22.3, 1p32.2, 1p36, 3q26.2, 4p16.1, 6q25, 11q22, 12pter-p12.3, 12q13.13, 12q23, 12q24.11, 14q24.3 to 31.2, and 19p13.2. Moreover, within these loci, the following appear among candidate genes: MATN1, EPB41, growth hormone receptor, COL2A1, COL1A1, MYO1H, DUSP6, ARHGAP21, ADAMTS1, FGF23, FGFR2, TBX5, ALPL, HSPG2, EVC, EVC2, the HoxC gene cluster, insulin-like growth factor 1, PLXNA2, SSX2IP, TGFB3, LTBP2, MMP13/CLG3, KRT7, and FBN3.[53-55]

Perhaps one of the limiting factors in interpreting the results of genetic studies is the heterogeneity in the definition of what constitutes the phenotype under question. While some authors have referred to ‘mandibular prognathism’, others use the description ‘Class III malocclusion’ or the ‘Angle Class III’ classification. Since Class III malocclusion is a fairly complex skeletal pattern with various contributing factors in terms of maxillary deficiency, mandibular excess and various combinations of the two, it can be difficult to extract information from many of the studies. Furthermore, genetic studies have also revealed the epigenetic involvement of several genes which may be involved to various degrees in the regulation of mandibular growth, indicating that other external and environmental factors may play a role in influencing the final phenotype.[53]

7.3.2. Environmental influences

Environmental influences have long been thought to play a role in mandibular growth.[52,56,57] Rakosi and Schilli[57] described some environmental influences, such as habits and mouth-breathing, as contributing to the aetiology of Class III malocclusion. They suggested that excessive mandibular growth could arise because of mandibular posture, as constant distraction of the mandibular condyle from the fossa may generate a growth stimulus. On the other hand, Delaire[56] described how normal maxillary development results not only from displacement of its constituent skeletal units and superficial bone apposition and resorption, but also from the specific growth of the antero-lateral regions. He also postulated that the development of the anterolateral part of the face depended mainly on orofacial functions, especially mastication and tongue pressure. Furthermore, he believed that insufficient development of the anterior face was as important as a set back of the maxilla in a Class III malocclusion, and that the state of the whole craniofacial skeleton and its different parts was a reflection of head posture and function. In his textbook, Proffit[43] notes that functional shifts of the mandible due to respiratory needs, size of the tongue or pharyngeal dimensions, may also affect the jaw size. However, it is not entirely clear why maxillary deficiency occurs, and a simple environmental cause appears to be unlikely. The degree to which inheritance and environment interplay may vary.[43] For example, cleft lip and palate patients are renowned for developing Class III maxillary deficient malocclusion, and it is believed that this deficiency results from the scarring caused by lip and palatal repair surgery, which could have an effect of restricting maxillary anteroposterior and transverse development[43]. Other conditions that cause Class III malocclusions are a number of syndromes such as Apert syndrome and Crouzon syndrome, which are characterised by a premature synostosis of the cranial sutures, restricting maxillary growth. Achondroplasia is also characterised by midface deficiency.[43] Several other syndromes exist that are characterised by Class III malocclusions, such as osteogenesis imperfecta and cleidocranial dysostosis, among others.[43] Hormonal disturbances such as excessive growth hormone secretion can result in acromegaly and excessive mandibular growth[58]. However, these are also rare and specific instances and do not explain the aetiology of the Class III growth patterns seen in the wider population.

As mentioned previously, with the more recent developments in the field of genetics, several genes have been identified that may play a role in epigenetic control of facial growth. It may soon be possible to determine which aspects of growth are genetically predetermined and where epigenetic influences may play a role. Tests are now becoming more accessible to allow faster and more accurate gene mapping. However, the complexity of the various genetic and epigenetic interactions is becoming clearer, and caution will be needed in interpreting the ensuing results.[53]

7.4.Class III growth

For non-syndromic Class III patients, the malocclusion is considered to be a variation of normal growth[43], resulting in Class III malocclusion. Several studies[31,32,34,59-63] have looked at the growth pattern involved and how growth may vary in individuals who develop a Class III malocclusion when compared to those who develop a Class I pattern.

The Class III pattern is believed to emerge early in life, with several studies[31,60,62] asserting that the features can be identified as early as the primary dentition phase. In their cross-sectional study of 144 Class III individuals aged 5-15 years, Guyer et al.[31] concluded that the distinct skeletal and dental characteristics of the Class III pattern were established early in life. The only dental characteristics that established themselves later (after the age of seven) were protrusive upper incisors and retroclined lower incisors. However, the skeletal features were already discernible in children as young as five years old, progressively becoming more established with age. Their control group was made up of 32 Class I cases from the Bolton Brush growth study.[31]

In a much larger cross-sectional study of 1376 untreated Japanese Class III females aged between 2.7 and 47 years of age, Miyajima et al.[60] also found the skeletal and dental features to be established early and to worsen gradually with age. They found that the maxilla is retrusive in relation to the cranial base and remains so over time, while the mandible is protrusive and worsens progressively. Both those features result in an antero-posterior skeletal discrepancy that gets worse over time. Additionally, dental compensations such as retroclination of the lower incisors and protrusion of the upper incisors also worsen with age.

In a longitudinal study of 22 untreated Class III cases, Baccetti et al.[62] also concluded that Class III malocclusion is not self-correcting, and that it worsens with age. The skeletal differential between the maxilla and mandible, the mandibular projection, the dental parameters of negative overjet, and the molar relationship all became worse with age.[62] Growth also varied in Class III individuals over the different growth stages. Furthermore, Baccetti et al. examined the variation in growth across different growth stages as, estimated by the cervical vertebral maturational index.[64] They examined the lateral cephalograms of 1091 individuals of European-American ancestry and found that mandibular growth increments were greater in Class III individuals. In addition, the duration of the peak growth interval which is considered to occur between CS3 and CS4 lasted approximately 6 months longer in Class III patients, which may account for the larger mandibular dimensions in Class III individuals. In the post pubertal period of growth from stages CS4 to CS5, individuals with a Class III malocclusion exhibited greater mandibular growth, as well as an increase in chin projection compared to Class I individuals. Moreover, the transition phase between the two stages also lasted longer. Baccetti et al. concluded that the mandible grows more and for a longer period of time after puberty in Class III individuals, with no catch-up growth of the maxilla. This accounts for the continual worsening of malocclusion following puberty.[64]

As in the case of general growth, there are also gender differences in Class III growth. Baccetti et al.[61] examined a large number of lateral cephalograms of Class III individuals of European-American ancestry cross-sectionally. Their data shows that there was no significant sexual dimorphism before puberty, but that significant differences were found between genders in the circum-pubertal period. Peak pubertal growth occurred earlier in females between 11-12 years, as opposed to 12-14 years in males. They identified that the anterior cranial base and the midface were shorter for Class III females. Furthermore, the mandibular lengths were shorter in female Class III participants in the pubertal and post-pubertal period and the females also had shorter upper and lower anterior facial heights when compared with male participants. From a soft tissue perspective, a larger amount of retrusion of the upper lip and milder amount of protrusion of the lower lip appeared to be characteristic of Class III female participants during the circumpubertal ages when compared to their male counterparts. Overall, the growth was greater in all parameters in the male Class III individials.[61]

From the above it can be concluded that the Class III growth pattern is established early in life and continues throughout the growth period. The evidence also suggests that Class III malocclusion does not self-correct. On the contrary, it progressively worsens with time, particularly during puberty, and individuals with Class III malocclusion tend to experience a greater amount of post-pubertal mandibular growth, for a longer period of time. All these findings have significant implications for treatment and retention requirements for such cases.

7.5. Treatment of Class III malocclusion in growing children

7.5.1. Rationale for early treatment of Class III malocclusion

In 2005, Ngan stated "The objective of early orthodontic treatment is to create an environment in which a more favourable dentofacial development can occur."[42] The goals of early Class III treatment may include the following[42,65]:

1. To prevent progressive irreversible soft tissue, bony or dental changes. Class III malocclusion is often accompanied with an anterior crossbite, which, if left uncorrected, may lead to abnormal wear of the upper and lower incisors.[42] Additionally, dento-alveolar compensations[45] of mandibular incisors may lead to thinning of the labial alveolar plate and/or gingival recession. This can also lead to more difficulty with gingival recession[43] when decompensation is required for surgical correction in early adulthood.
2. To improve skeletal discrepancies and provide a more favourable environment for future growth.[3] Excessive mandibular growth is often accompanied by dental compensation of the mandibular incisors. Early orthopaedic treatment using facemask or chin cup therapy improves the skeletal relationships, which in turn minimises excessive dental compensation such as overclosure of the mandible and retroclination of the mandibular incisors[65].
3. To improve occlusal function. Class III malocclusion with an anterior crossbite is often accompanied by a functional shift.[42] Early orthopaedic correction may aid in eliminating centric occlusion-centric relation (CO-CR) discrepancies[66] and avoid adverse growth potential.[67,68]
4. To simplify phase II comprehensive treatment.[4] In mild and moderate Class III patients, early orthodontic or orthopaedic treatment may eliminate the necessity for orthognathic surgery treatment.[6] Even if surgery is eventually needed, early correction of the transverse dimension and maximisation of the growth potential of the maxilla may minimise the extent of the surgical procedures.[42]

5. To provide more pleasing facial aesthetics, thus improving the psychosocial development of a child. Studies have shown that treatment with a facemask and/or chin cap improves lip posture and facial appearance, which may be particularly relevant for more severe cases.[42]
6. Early orthopaedic treatment will maximise the benefit from normal growth[4,69,70] and even if surgical correction is still needed in the future, the extent of the surgery may be reduced.[42]

7.5.2.Class III functional appliances from removable to fixed

7.5.2.1.Removable Class III functional appliances

Several studies have looked at the effects of intraoral tooth-borne and tooth-tissue-borne appliances in the correction of Class III malocclusion.[71-79] Some of the designs were simply a reverse of an appliance originally developed for Class II treatment, while others were specifically designed for Class III treatment. Perhaps the functional regulator, introduced by Frankel,[75] is one of the earliest and more widely studied designs of a tooth-tissue-borne appliance. Early on, Frankel believed that mandibular prognathism (as it was described at the time) was not solely a result of genetically a predetermined skeletal pattern, but that environmental influences also played a role in its development.[75] He designed an appliance aiming to counteract the muscular forces acting on the maxillary complex. The appliance was designed with maxillary vestibular shields high up in the sulcus, away from the alveolar buccal plates (Figure 2). This allowed forward development of the maxilla, while the shields in the lower arch were fitted closely to the alveolar process of the mandible to hold or redirect growth posteriorly. He postulated that the shields in the maxilla stimulate forward growth through the muscle-blocking effects and stretching of the periosteum.[75]

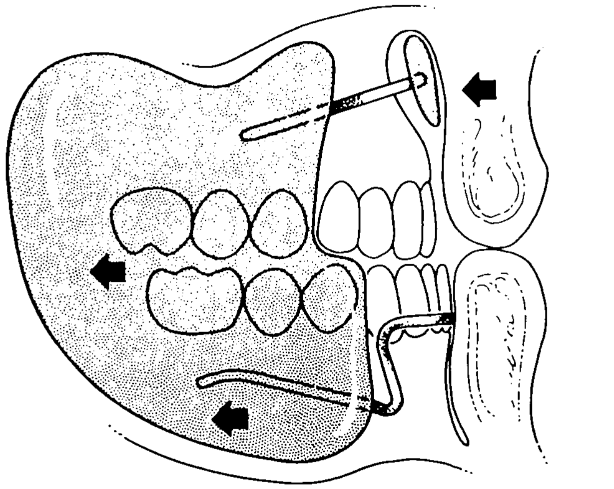


Figure 2 **Illustration of functional regulator III, with arrows highlighting the lip pads and cheek pads.**[75]

Most of the studies on the Frankel FR-III appliance, however, have shown predominantly dento-alveolar effects on the maxilla and backward rotation of the mandible.[72,77,80] McNamara presented three case reports on patients who were treated with the functional regulator, with two findings common among the three participants. Mandibular growth was redirected in a vertical direction and the maxillary dentition moved forward.[77] The responses on the maxilla were more variable.[77] With a larger group, Baik et al. [72] evaluated the skeletal and dental effects of the FR-III appliance on a sample of 30 consecutively treated Korean children with Class III malocclusions. The treatment effects were also mainly due to backward and downward rotation of the mandible and lingual tipping of the mandibular incisors.[72] Some of the effects of the FR-III include:[80]

- A significant increase in the maxillary intermolar, interpremolar, and intercanine width of the maxilla with an increase in palatal height.
- An increase in mandibular intermolar and intercanine width and a decrease in the lower arch depth.

An important point about the FR-III appliance is its manufacture. It requires significant skill from the clinician in the impression and bite registration, as well as highly trained and experienced technicians to make it,[81] potentially rendering it less accessible for some orthodontists.

Several other removable appliance designs have been reported in the literature. These include the reverse Bionator,[76] the mandibular retractor,[71] the reverse twin block,[82] and a magnetic Class III functional appliance. The Balters' Bionator (a type of reverse Bionator) (Figure 3) was used in the treatment of pseudo-Class III malocclusion.[76] The design differs in several ways from the traditional Bionator used in Class II correction. For example, the lingual wire is in a different position in order to control the position of the tongue, and the labial arch is placed in the middle of the lower teeth. The acrylic framework is as thin as possible in order to occupy minimal space. It is also concave in shape to accommodate the tongue, so it does not move between the posterior segments. Its vertical height is designed to be sufficient to correct the anterior crossbite, but it is not more than 3-4 mm high. The appliance also has vestibular shields to allow transverse maxillary development. The treatment changes are mostly dento-alveolar in nature.[76]

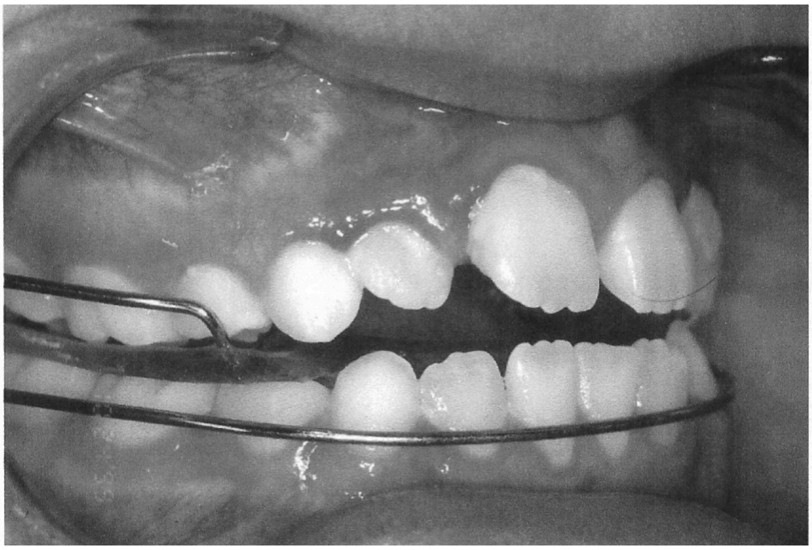


Figure 3 The Balters' Bionator, used in the treatment of pseudo-Class III malocclusion.[76]

Another well-studied appliance is the mandibular retractor.[71,83,84] It is an upper removable acrylic resin plate retained by Adams' clasps and incorporating a labial bow that extends to the cervical margin of the mandibular incisors (Figure 4). The labial bow is activated so that it falls 2 mm in front of the lower incisors when the mandible is in the most retruded position. The labial bow is thus intended to act as a stop for forward sagittal movement of the mandible. Expansion screws as well as springs for the proclination of upper incisors can be added. Several studies were conducted in which children in the deciduous mixed dentition phase were compared to untreated Class III controls.[71,83,84] The studies showed that the skeletal effects were greater when the treatment was performed early in the primary dentition, rather than during mixed dentition. The use of the appliance resulted in a reduction in mandibular protrusion, which stemmed from a morphogenetic rotation of the mandible due to an upward and forward direction of condylar growth, combined with a more vertical orientation of the mandibular ramus and reduction in the gonial angle. These studies also found forward displacement of the maxilla, as well as maxillary dento-alveolar protrusion and a reduction in mandibular dento-alveolar protrusion. The authors emphasised the importance of early Class III treatment.[71,83,84]

Figure 4 Removable mandibular retractor.[71]

Magnetic forces have been used for various applications in orthodontics, with magnetic functional appliances showing success in Class II correction.[85] Magnetic appliances have also been used for Class III correction. Darendeliler et al. introduced the concept in 1993[86] using a magnetic appliance to correct a Class III malocclusion. Tuncer et al.[87] examined the effects of a magnetic functional appliance in Class III correction during mixed dentition. The results indicated mostly dental changes, with protrusion of the upper incisors, retraction of the lower incisors and some skeletal correction. There was a reduction in the SNB angle mostly caused by backward rotation of the mandible, which improved the ANB angle.[87]

Another appliance design that was based on reversing a Class II functional appliance is the reverse twin block. The twin block introduced by Clark in 1980[88] has been well documented as a functional appliance used in the correction of Class II malocclusions.[26] Unlike the Bionator and the Frankel functional regulator, the twin block (as the name suggests) is made of two separate removable plates, one upper and one lower, with an inclined ramp on each side designed to force the mandible into a forward position aiming to correct the Class II pattern through a combination of skeletal and dento-alveolar effects.[26] The appliance can also be used in reverse, and where is it is used in this way it is termed the Class III twin block[82] or reverse twin block.[89] Kidner et al.[89] presented a series of 14 cases consecutively treated with the Class III twin block or reverse twin block. The results were similar to those obtained by other Class III functional appliances, with mostly dento-alveolar changes in the form of upper incisor proclination and lower incisor retroclination with backwards rotation of the mandible resulting in correction of the Class III malocclusion.[89]

Few studies have compared the use of Class III functional appliances with protraction facemask treatment. In a relatively small retrospective study by Seehra et al., a removable reverse twin block (Figure 5) showed less skeletal and more dental changes when compared with the protraction facemask.[79] There was significantly more maxillary skeletal protraction as measured at the level of the SNA angle in the facemask group (2.1 degrees, as opposed to 1.2 degrees with the reverse twin block). The overall skeletal change was greater as measured at the ANB angle, with a mean change of 3.8 degrees with the facemask and only 1 degree in the reverse twin block group. While both groups showed dental side effects, those effects were significantly more pronounced in the reverse twin block group in terms of upper incisor proclination and lingual tipping of the lower incisors.[79]

Figure 5 Removable Reverse Twin Block appliance from Seehra et al.[79]

7.5.2.2.Fixed compliance-free Class III functional appliances:

While Kidner et al.[89] found more skeletal effects from the facemask as opposed to the removable Class III twin block, different results were reported in a randomised clinical trial by Minase et al.[78] They compared treatment effects of a modified fixed reverse twin block combined with maxillary expansion using the RME facemask. The reverse twin block (Figure

6) was modified in two ways. Firstly, it was fixed. Secondly, Minase et al. incorporated maxillary vestibular shields akin to those used in the FR-III appliance to stimulate similar effects.

Figure 6 Fixed Reverse Twin Block with lip pads, from Minase et al.[78]

Minase et al. found that the modified reverse twin block showed more skeletal changes in terms of maxillary advancement and overall skeletal correction than the facemask group. And while both appliances had dental side effects in terms of upper incisor proclination, this was more pronounced in the facemask group. The authors postulated that the use of the vestibular shields may explain some of these differences.[78] However, it cannot be ruled out that variable compliance may have played a role in the difference in outcomes. The reverse twin block was fixed, and so the patient compliance variable was eliminated with guaranteed full-time wear; on the other hand, the results from the RME facemask group would have been strongly influenced by patients' adherence to wearing the facemask as prescribed. Most studies show that patients usually wear the appliances for 50-65% of the prescribed time.[16,17,90]

There are few reports on similar non-compliance Class III correction appliances. Liou[91] presented a compliance-free maxillary protraction spring (Figure 7), which he used after disarticulation of the maxillary sutures, using alternating rapid maxillary expansion and contraction (Alt-RAMEC) for 7-9 weeks. The expansion was performed using Liou's double-hinged maxillary expansion screw, and the protraction was carried out using an intraoral compliance-free beta titanium looped spring.[92] The protraction spring was composed of helical springs[92], constructed from 0.036" Beta NiTi. These were connected via ball pins to the maxillary and mandibular first molar headgear tubes. A lower lingual arch was used to prevent lower molar rotation. The arch also had built-in buccal root torque to prevent molar buccal flaring. The springs were activated on mandibular closure to produce a force of 400-500 g in an anterior and superior direction. The results with this protocol were compared to those of conventional RME facemask therapy.[91] The treatment protocol was to perform Alt-RAMEC for seven to nine weeks, then place the active protraction spring for one to two months of active protraction, followed by two to three months where the spring was left in place passively to maintain the correction. The total treatment duration was 6 months. At the completion of treatment with the protraction springs, the Alt-RAMEC group showed more advancement of the maxilla at A point (5.8 mm), which was approximately twice the amount recorded in the RME facemask group (at 2.6 mm). Additionally, the Alt-RAMEC group corrected in less time than the RME facemask group and the results were stable two years after treatment. The dental side effects of the appliance included an upwards canting of the maxillary occlusal plane with proclination of the upper incisors and mesial tipping of the maxillary molars. In the lower arch, the mandibular molars tipped distally and the incisors lingually. Liou also noted that these dental side effects tended to relapse, but the skeletal protraction of the maxilla remained stable two years after treatment.[91]

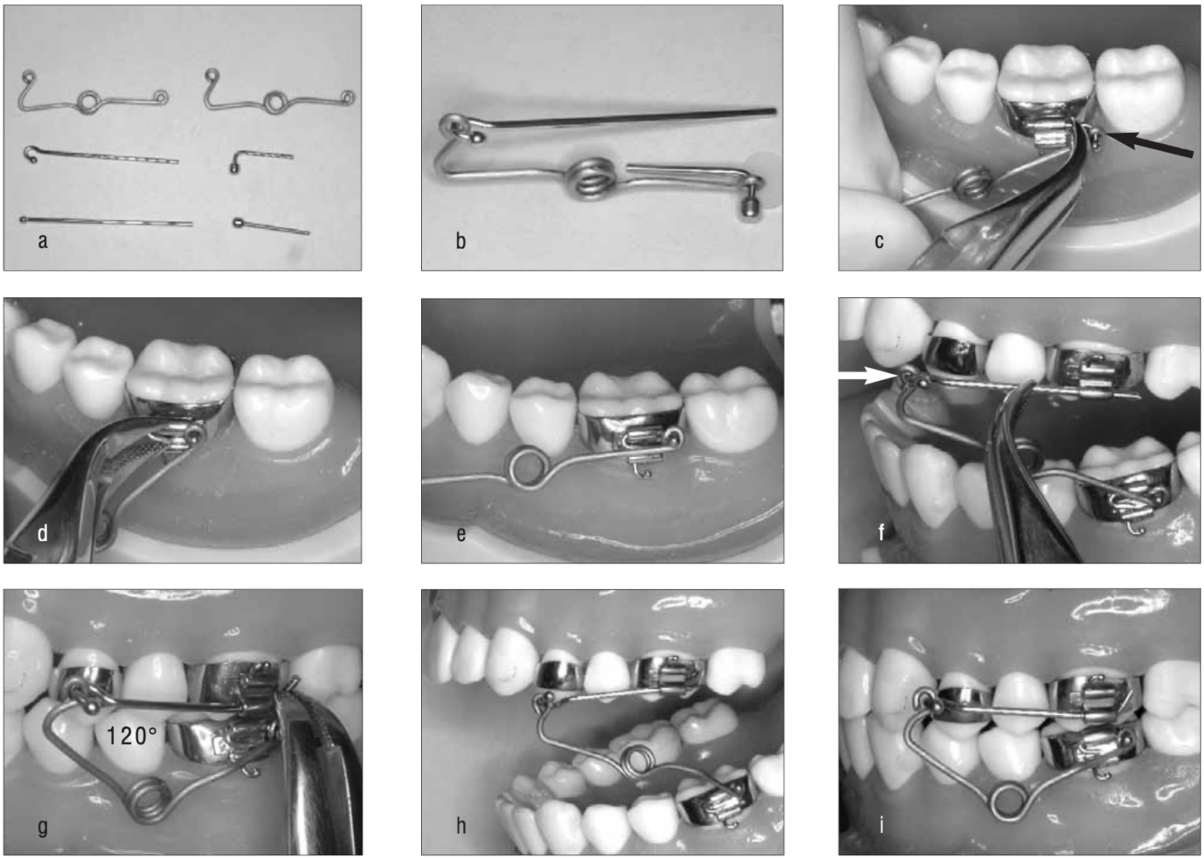


Figure 7 Components and installation of the maxillary protraction spring, by Dr Eric Liou.[91]

Although results for the protraction spring were promising, the author did not report on the breakage rate or survival of the protraction springs.[91] In a clinical trial at the University of Sydney by Buck et al.[93] using a similar spring design in conjunction with skeletal anchorage, the failure rate was also assessed. Patients were fitted with a bonded maxillary expansion appliance with a buccal headgear tube by the first molars and a rigid lower lingual arch with acrylic bite blocks and a headgear tube buccal to the lower molars (Figure 8). Four miniplates were then surgically placed: two maxillary zygomatic and two mandibular symphysial miniplates. The miniplates were then indirectly connected to the appliances via a bonded wire (Figure 9). After seven to nine weeks of Alt-RAMEC, the springs were inserted. Although the use of skeletal anchorage greatly reduced the dental side effects, the failure rate of the springs was exceedingly high with over 100 breakages reported during the trial. The failure rate ranged from 0-18 breakages per patient. The authors hypothesised that this was mostly due to metal fatigue from repeated flexing of the wires, which were already somewhat work-hardened by the wire bending process. In a clinical setting, this failure rate would be highly problematic, making the protraction spring difficult to use routinely.

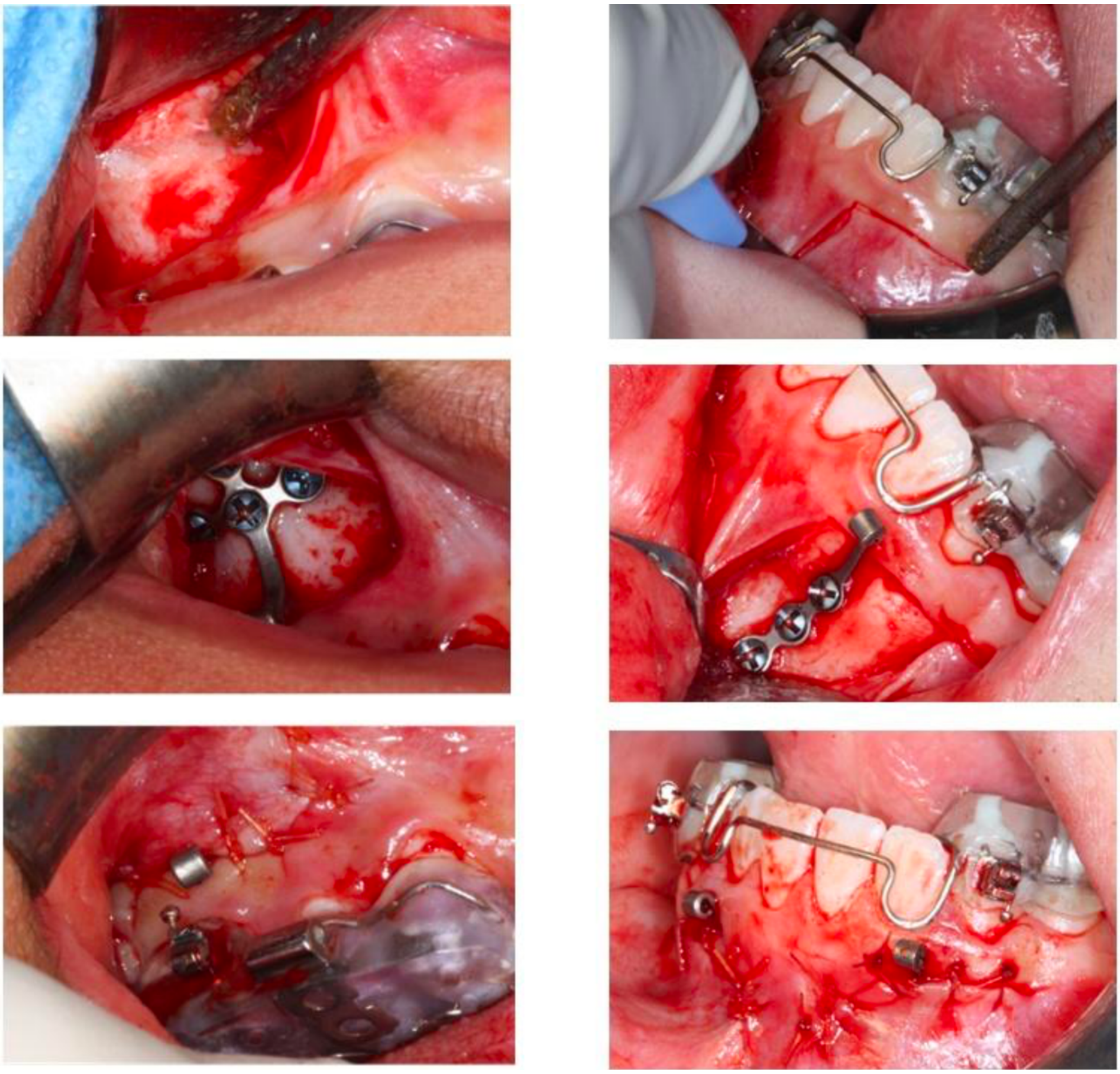


Figure 8 Step-by-step positioning of the miniplates, which are then connected to the RME and lower lingual arch.[93]

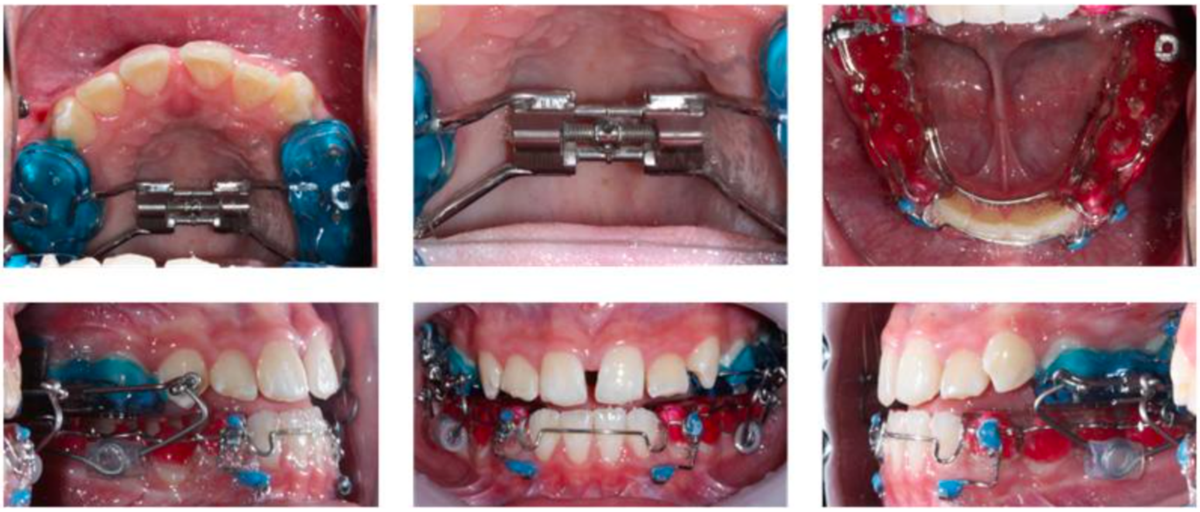
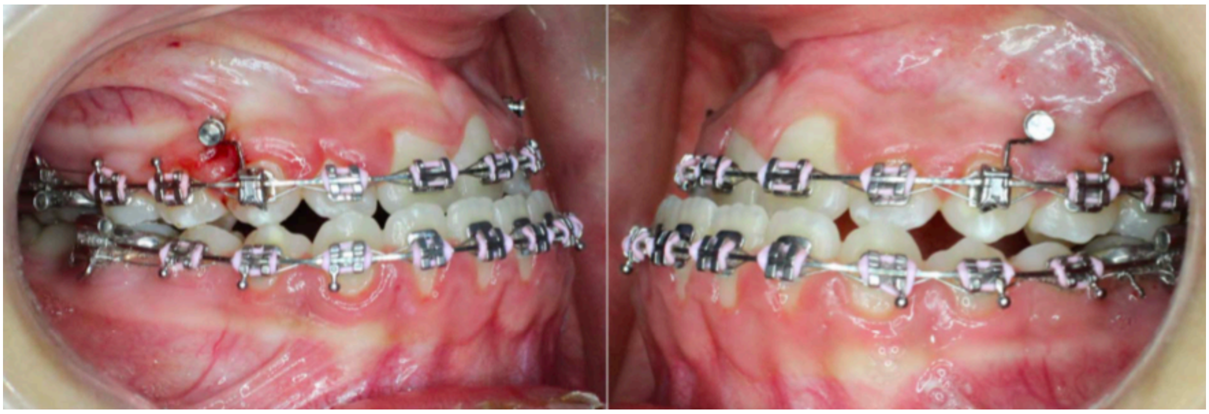


Figure 9 Appliance design, with bonded RME and lingual arch indirectly connected to the miniplate and the protraction springs in position.[93]

Recently, Vanlaecken et al.[94] reported on a fixed inter-arch spring-loaded module for Class III correction. The CS 2000® appliance (Dynaflex, St. Ann, MO, USA) (Figure 10) was used on 30 growing patients and compared to untreated Class III controls from the Bolton-Brush growth study. The authors found the appliance was successful in correcting Class III malocclusion through a combination of skeletal and dental changes. The changes were similar to those reported by other tooth-borne Class III functional appliances with forward movement of the maxilla, backwards and downwards movement of the mandible and proclination of the maxillary incisors. The molar relationship was corrected through mesial movement of the maxillary molars and distal movement of the mandibular molars, with a counterclockwise rotation of the occlusal plane. Although there was no direct comparison with the facemask in the study sample, the results reported were very similar to the skeletal effects of the facemask and delivered with a completely intraoral and compliance-free appliance.[94] It would be very interesting to see how this appliance could be combined with skeletal anchorage to reduce or eliminate unwanted dental side effects.

Figure 10 Fixed Class III correction appliance, the CS 2000® appliance (Dynaflex, St. Ann, MO, USA). A. CS2000 appliance; B. TB SAG appliance; C. MSX 2000 appliance.[94]

Eissa et al.[95] attempted to reduce the dental side effects of a reverse Forsus Fatigue Resistant Device (FRD; 3M Unitek Corp, Monrovia, CA, USA) by using two maxillary interradicular miniscrews. The Forsus FRD is a fixed functional appliance used in non-compliance Class II correction in conjunction with fixed appliances.[96] In their study, Eissa et al.[95] placed the Forsus FRD in reverse for Class III correction (Figure 11). All patients had full fixed appliances; levelling and alignment were completed using rigid rectangular stainless-steel wires. The authors then placed miniscrews between the maxillary canines and first premolars and indirectly anchored the miniscrews through a wire that was placed in the auxiliary vertical slot of the upper canine brackets. They found significant forward displacement of the maxilla with an increase in the SNA angle of 1.7 degrees, on average, and an overall improvement in the ANB angle of 1.8 degrees. The use of the miniscrews appeared to reduce the dental side effects on the maxillary teeth but did not eliminate them. There was a small, statistically significant, but probably clinically insignificant proclination of the maxillary incisors. The maxillary molars did, however, mesialise. The changes in mandibular dentition were significant, with retroclination of the mandibular incisors and distalisation of the molars. These dental changes led to a significant counterclockwise rotation of the occlusal plane with intrusion of the maxillary incisors.[95] Perhaps some of the changes can be explained by the mode of anchorage to the miniscrews. The method of connecting the miniscrews to the dentition using a small wire in the auxiliary slot would not be considered rigid enough to counteract the intrusive and mesialisation forces caused by the upwards and forwards vector of the Forsus FRD. Although there was no report of any miniscrew failures in Eissa et al.'s study, the interradicular placement of the miniscrews may be less than ideal, as the failure rate is higher in that area when compared to miniplates or palatal miniscrews and the failure rate can increase with movement of adjacent teeth.[97-99] However, the study showed that combining Class III functional appliances with skeletal anchorage in a compliance-free design may offer a predictable method for Class III correction while eliminating some of the dental side effects of the tooth-borne appliances.



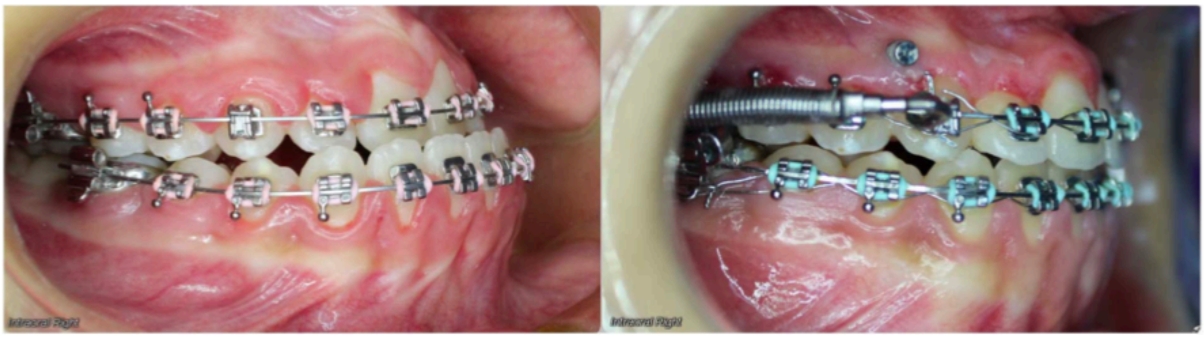


Figure 11 Forsus FRD (3M Unitek Corp, Monrovia, CA, USA) in reverse for Class III correction with one maxillary miniscrew on each side bonded to the canine through the auxiliary slot (from Eissa et al.[95]).

From the above, it can be concluded that functional appliances can be used effectively to correct Class III malocclusion, but the benefits are more dento-alveolar than skeletal. These appliances are a very viable option for mild Class III malocclusions with functional shifts as well as pseudo–Class IIIs, and very effective as retainers following the use of facemask therapy. Removable appliances may be considered less obtrusive than a protraction facemask by patients; however, they are still reliant on patient compliance to deliver the desired outcomes, which can be considered a significant drawback. Fixed Class III functional appliances may offer an advantage over removable ones, as well as over facemask therapy, due to the reduced need for compliance. Combining fixed Class III functional appliances with skeletal anchorage may be promising.

7.5.3.Chin cup therapy and mandibular restraining

As mentioned previously, Class III malocclusion was historically considered to be caused mainly by mandibular prognathism and the term 'prognathic' was, in fact, synonymous with Class III malocclusion.[2] Thus, growth modification treatment that focused on restraining mandibular growth by using a chin cup seemed to be the logical approach.

7.5.3.1.History

Chin cup therapy (Figure 12), also called 'chin cap' therapy in some studies, was reported as a method of reducing mandibular prognathism as early as the 1800s.[100] Janzen and Bluher reviewed the history of the chin cup and found that the earliest historical reference was recorded by Cellier in 1802.[100] Joseph Fox then used a chin cup in an attempt to correct mandibular prognathism one year later.[100] The chin cup started to lose favour at the beginning of the 19th century, after the introduction of intermaxillary elastics.[100] In 1907[28], Angle indicated that he no longer used it as frequently as he did previously, and the journals from the early years of 20th century contain little reference to it.[100]

In the 1960s and 70s, however, there was renewed interest in the use of the chin cup.[100-102] Janzen and Bluher[100] in 1965 assessed the cephalometric, anatomic and histologic changes in 4 growing *Macaca mulatta* monkeys, applying a constant force to retract the mandible. The head caps were permanently fixed to the body of the mandible using wires placed through the mandible below the deciduous canines, which is notably different from what a clinical application would be. Nevertheless, they found that the retracting mechanism had profound effects not only on the mandible but also on the growth pattern of the entire facial complex.[100] The changes that took place were not simply limited to the dento-alveolar process but also involved the maxillary and mandibular basal structures.[100] Clinically, however, similar results could not be achieved, and Graber and Graber[102] explained that the failures during early trials with the chin cup were due to the use of inappropriate force, little understanding of facial growth and use of the chin cup after the completion of skeletal growth.[102]

In his textbook[43], Proffit illustrates the difficulty involved in sufficiently controlling force direction and magnitude with a chin cup in humans and why this usually resulted in discouraging results. The shape of the condyle (which is rounded) makes force distribution over the whole condylar surface nearly impossible.[43] Additionally, the heavy forces (which showed success in animals), as well as the treatment duration, would be considered intolerable in humans.[43] Another aspect worth considering is that the animals used in the experiments have a significantly shorter growth period in comparison to humans, and in order to achieve similar results it would be necessary to continue treatment for five or more years, after which a successful result might still not be achieved.[43]

7.5.3.2.Force magnitude, direction and duration

Chin cups can be divided into two types: the occipital-pull chin cup that is used for patients with mandibular protrusion, and a vertical-pull chin cup (Figure 12) used in patients with excessive anterior facial height.[103] Most of the studies on the chin cup recommend an orthopaedic force of 300-500 g per side, and patients are required to wear the appliance for 7-

16 hours every day.[103-106] The force can be either directed through or below the condyle depending on the desired effect.

Figure 12 Vertical pull chin cup vs. horizontal pull chin cup.[103]

The treatment timing and duration associated with chin cups varies greatly in the literature. In one study, the treatment time varied from six months to four years and the authors explained the variation by patient compliance and severity of malocclusions.[107] Sugawara et al.,[108] however, found that cases treated before the age of seven years tended to maintain more of a downwards and backwards growth pattern of the mandible than those treated at nine and 11 years old, but that there was no statistically significant difference in the profiles of those treated at 9 and 11 years old.[108]

7.5.3.3.Effects of chin cup therapy

Chin cup therapy has been widely studied and shown to demonstrate several skeletal and dental effects.[107-112]

Effects on the mandible and mandibular growth[107-112]

- Redirection of mandibular growth in a more downward and backward direction
- Backward mandibular rotation
- Repositioning of the mandible backwards, with potential glenoid fossa and condyle remodelling

- Some short-term restraining of mandibular growth
- Reduction of the gonial angle.

Effects on the maxilla[107-112]

- Most studies show little or no effect on the maxilla. However, Sugawara et al.[108] suggested that very early correction of a crossbite may remove the restraining effect on the maxilla.

Dento-alveolar changes[107-112]

- Increase in overjet
- Retroclination of the lower incisors.

The study by Deguchi et al.[113] demonstrated these effects well. The authors compared 22 Japanese females with a Class III malocclusion (treated with a chin cup for 7-9 hours per day with a force of 400-500 g) with a group of 22 untreated Class III cases. They found that there was a significant increase of 1.2 degrees in the ANB angle in the treated group, due to a small reduction of -0.7 degrees in the SNB angle and a slight increase in the SNA angle of 0.9 degrees. They noted that in the treatment group, B point moved posteriorly by 0.2 mm per year, while in the control group, B point moved forward by 1.1 mm per year.[113] Vertically, Menton moved down by 3.1 mm in the treatment group while it moved up by 2.7 mm in the control group. Additionally, they found that the mandibular incisors retroclined by 3 degrees in the treatment group.[113]

The effects of the chin cup were recently summarised in a systematic review by Chatzoudi et al.,[110] who found no randomised clinical trials and only included five cohort studies in their review, totalling 120 treated cases. The authors' conclusions were guarded due to the heterogeneity of the studies; however, they reported that the chin cup was able to reduce the SNB angle by 1.97 degrees and improve the ANB angle by 2.48 degrees. The Wits appraisal also improved by 3.6 mm with no statistically significant effect on the SNA angle. In the vertical dimension, there was an increase in the mandibular plane angle of 1.17 degrees and a reduction in the gonial angle of 0.8 degrees. On the dento-alveolar level, they reported an increase in overjet of 2.62 mm.[110]

Effects of chin cup on the temporomandibular joint TMJ

Due to the way the chin cup loads the TMJ, there have been concerns regarding its potential negative effects and that it may predispose or contribute to the development of temporomandibular joint dysfunction (TMD). In a survey of chin cup patients, Deguchi et al.[107] found that the most commonly reported symptom was spontaneous TMJ pain followed by clicking, which occurred less frequently during and after treatment. Only 16% of patients experienced symptoms of TMD during treatment and only 6% experienced symptoms after treatment.[107] They attributed the symptoms to muscle dysfunction related to unstable posterior occlusion during the correction of anterior crossbite.[107] Mukaiyama et al.[114] also found similar results with the symptoms appearing in the first six months of active treatment, especially in those patients who reported wearing the chin cup for 16 hours a day or more. On the other hand, after a long term follow-up, Arat et al.[115] concluded that chin cup therapy is neither a risk factor for TMD nor a prevention. They performed a long-term follow-up (2-11 years) of patients treated with a chin cup with regards to signs and symptoms of TMD and compared them to two groups – untreated Class IIIs and dental students with acceptable normal occlusions.[115] In both the treatment group and the Class III malocclusion group, the distribution of symptomatic individuals was almost equal (at 25%), while it was significantly higher (at 41.5%) in the dental students.[115] Similarly, a recent systematic review of the literature on the effects of chin cup therapy on the TMJ found that, from the limited available evidence, the chin cup does not necessarily increase the risk of TMD.[116]

7.5.3.4.Long-term stability of chin cup treatment

The long-term stability of chin cup therapy remains uncertain. However, a resumption of the Class III growth pattern following treatment with rebound mandibular growth has been reported.[108]

The long-term effects of chin cup therapy where studied in 63 Japanese girls who had skeletal Class III malocclusions[108] and all underwent chin cap therapy. The study samples were divided into the following three groups according to participants' ages when they began therapy:

- a group that started **at 7 years of age** (n = 23),
- a group that started **at 9 years of age** (n = 20), and
- a group that started **at 11 years of age** (n = 20).

The patients were instructed to wear the chin cup for 14 hours a day with a 250-300 g force applied. Treatment time varied in the study, ranging from 1 year up to 9.5 years. The average treatment time was 4.5 years. There was a large range in treatment time across treatment groups, ranging from 1 year to 9.5 years, with an average of 4.5 years. Cephalograms were taken at ages 7, 9, 11, 14 and 17.[108] The authors found that the mandible displayed no forward growth during the initial stages of chin cup treatment, in all three groups. However, patients who had entered treatment at seven and nine years of age appeared to show a "catch-up manner" of mandibular displacement in a forward and downward direction before growth was completed. There was no statistical difference in the final skeletal profile between the group that had entered treatment at age 9 and the one that had entered at age 11. The maxilla grew downwards and forwards but showed minimal growth during ages 14-17, while the mandible was still undergoing growth changes. After age 14, growth in the subjects in this treatment group resembled that of the untreated Class III controls. By age 17, there was a reduced lower anterior facial height observed in the treatment group. However, in the anteroposterior plane, the skeletal profiles of the treatment groups were not significantly different to those of the control group at the end of the observation period.[108] Another long-term study also found that the skeletal changes were mostly lost with future growth, and that the treatment and control groups were very similar at long-term follow-up, with the exception of the dental relationship, which was corrected in the treatment group.[117] The Class I overjet was maintained long-term.[117]

7.5.4.Mandibular headgear

In 1973, Joho[118] assessed the effects of extraoral low pull mandibular headgear in monkeys. He used a cervical pull Kloehn-type face bow applied directly to the lower first permanent molars in a distal and downward direction in 4 *Macaca mulatta* monkeys. The applied force varied from 250 to 450 g, for 4.5-8 weeks. He reported that the change of the molar relationship from Class I to Class II was due to both a dental and a skeletal response.[118] Additionally, the gonial angle reduced and did not change significantly during relapse. There was also extensive remodelling in the TMJ, indicating that the joints appeared to have relocated in a forward direction during relapse after having been displaced posteriorly during active treatment.[118]

Later, studies evaluated the effect of mandibular headgear in humans (Figure 13). Orton et al.[119] used mandibular extraoral distal traction to either, a simple removable appliance, or to conventional edgewise fixed appliances in Class III cases. The cohort of 43 cases which they studied, represented a spectrum of Class III malocclusions, and Orton et al. showed that good results can be achieved in Class III treatment using extraoral traction applied to the mandibular dentition.[119] More recently, in a series of cephalometric studies, Rey et al.[120-122] and Baccetti et al.[123] evaluated the short- and long-term effects of mandibular cervical-pull headgear followed by fixed edgewise appliances. They compared a group of 21 prepubertal Class III patients with an average age of 10 years and 2 months treated with the MCH and edgewise appliances with a group of 20 untreated Class III controls.[120,122,123] The treatment started with the use of the MCH applied to molar bands on the mandibular first molars with a line force through the centre of resistance of the molar. Force magnitude was 300 g, and the patients were requested to wear the appliance for 14 hours every day. After 1.5 years of MCH, maxillary fixed appliances were placed, and the patients continued to wear the MCH. One year later, the mandibular fixed appliances were placed to finalise the occlusion. This was followed by retention with removable passive Hawley retainers. Outcomes were assessed at the completion of treatment, when patients were deemed to be in the post-pubertal stage based on the cervical vertebral maturational index.[124] The authors found favourable skeletal and dental changes in the treatment group compared to the controls.[122] There was a significant improvement in the sagittal skeletal relationship, with a 4 mm change in the Wits appraisal. There was a reduction in the mandibular growth, with the authors observing smaller increases in mandibular length and forward growth in the treatment group.[122] There was also a significant downward and backward rotation of the mandible of 2.8 degrees on average. The overjet improved in the treatment group by an average of 4.4 mm relative to the controls. Orton et al. concluded that MCH treatment followed by fixed appliances can be considered an effective treatment for the management of skeletal Class III malocclusion with the results being stable at post-pubertal observation.[122]

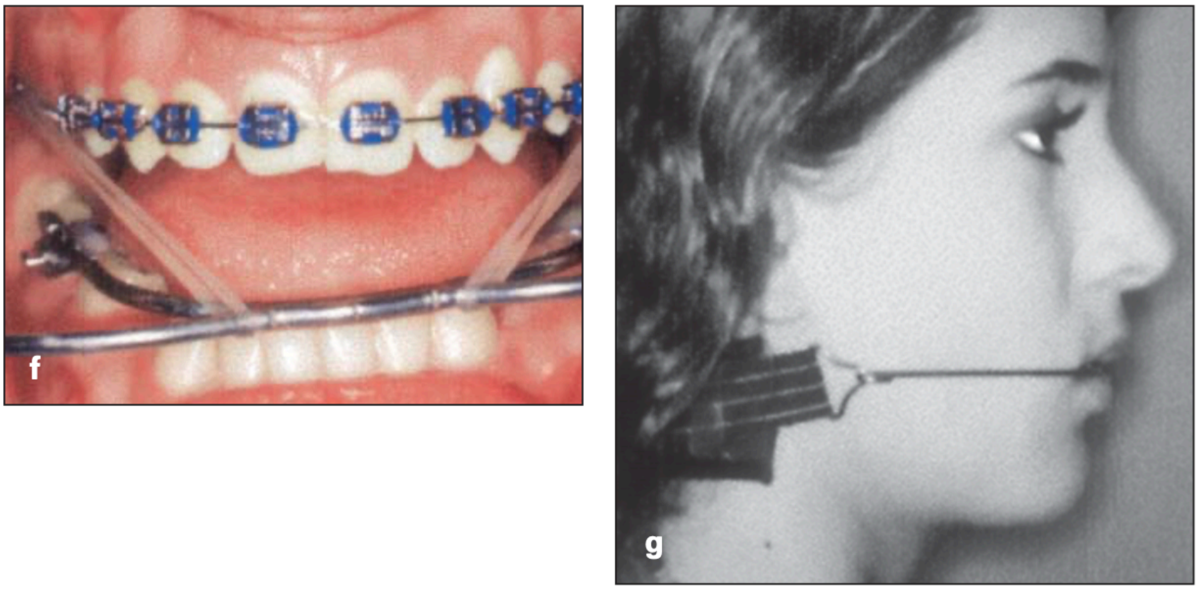


Figure 13 Mandibular cervical pull headgear, from Rey et al.[121]

Although Joho[118] observed significant remodelling in the TMJ with cervical headgear in monkeys, there did not seem to be any adverse changes in humans when the effects of the mandibular headgear on the TMJ were assessed.[120] Rey et al. did not find any significant difference in TMD when they compared Class III cases treated with the MCH and fixed appliances with Class I cases treated with fixed appliances only or untreated individuals.[120]

Long-term evaluation of the outcomes of the mandibular headgear showed reasonably stable results when subjects were assessed five years after completing treatment, where they were judged to be at stage CS 6 of growth.[123] Cephalograms of treated subjects were compared to cephalograms of untreated Class III controls at a similar growth stage obtained from the University of Michigan and the University of Florence. The authors found that the treatment effects remained stable at long-term follow-up.[123] Compared to untreated controls, the treatment group showed reduced mandibular length and protrusion. The treatment group did not display the same counterclockwise rotation of the mandible experienced with growth in the untreated subjects, which tends to increase to mandibular protrusion.[123] The authors emphasised that part of the reason for the success of the treatment was that it was maintained during the pubertal growth period where the mandible shows the greatest changes with growth.[123]

The effects of the mandibular headgear appeared to be quite similar to those of the protraction facemask.[125] One retrospective cephalometric study[125] examined the effects of mandibular headgear compared to those of a protraction facemask. The authors stated, "Surprisingly, despite the very different methods of applying the extra-oral force, the two treated groups showed strikingly similar therapeutic effects."[125] Most of the skeletal and dental changes were very similar in both groups. There was proclination of the upper incisors and retroclination of the lower incisors, with downwards and backwards rotation of the mandible and advancement of the maxillary complex. However, the soft-tissue profile, especially of the lower lip, improved more with the facemask.[125]

The mandibular headgear appears to have reasonably good effects when used in Class III treatment. However, from a clinical and practical perspective, the treatment duration and required wear regimes are quite demanding, with treatment times ranging from 1-3.5 years and 14 hours of wear required every day.

7.5.5.Facemask therapy

7.5.5.1.History

As mentioned above, up until the 1960s a Class III malocclusion was considered to be largely caused by excessive mandibular growth, and the term 'mandibular prognathism' was used synonymously with Class III.[2] With the introduction of cephalometrics, several studies showed that maxillary deficiency was the more common contributor to Class III patterns and that pure mandibular prognathism was less common than originally assumed.[31-34]

One of the early reports on maxillary protraction came from Oppenheim in 1944. Oppenheim reported on three cases treated with a chin cup that had spurs to connect elastics to a maxillary soldered lingual arch.[126] A similar approach was also reported by Kettle and Burnapp[126] in 1955. However the development of what we know today as the protraction facemask started with the work Delaire.[127] He modified the chin cup and added a forehead rest and metal framework with spurs for the connection of elastics to an intraoral component. The design was later on modified by Petit[69], who replaced the rectangular framework with a rigid midline wire(Figure 14). This was contemporaneous with Haas'[128] work on maxillary orthopaedic expansion. Haas postulated that expansion alone can allow the maxilla to move downwards and forwards, leading to backward rotation of the mandible and improvement in Class III malocclusion.[129]At the same time, an increased scientific understanding of the process of maxillary protraction was being developed from several studies on maxillary protraction in monkeys.[130-133] Early reports emerged with McNamara in 1987[134], who published three case reports on the use of a protraction facemask in combination with a bonded maxillary expansion appliance in the correction of Class III malocclusion, a design which was used in many subsequent studies. In the 1990s there was an explosion in the research into the effects of the protraction facemask and several of its modifications with regards to different age and ethnic groups.[3,7,19,70,135] The facemask was established as one of the main approaches for managing maxillary deficiency in growing children.

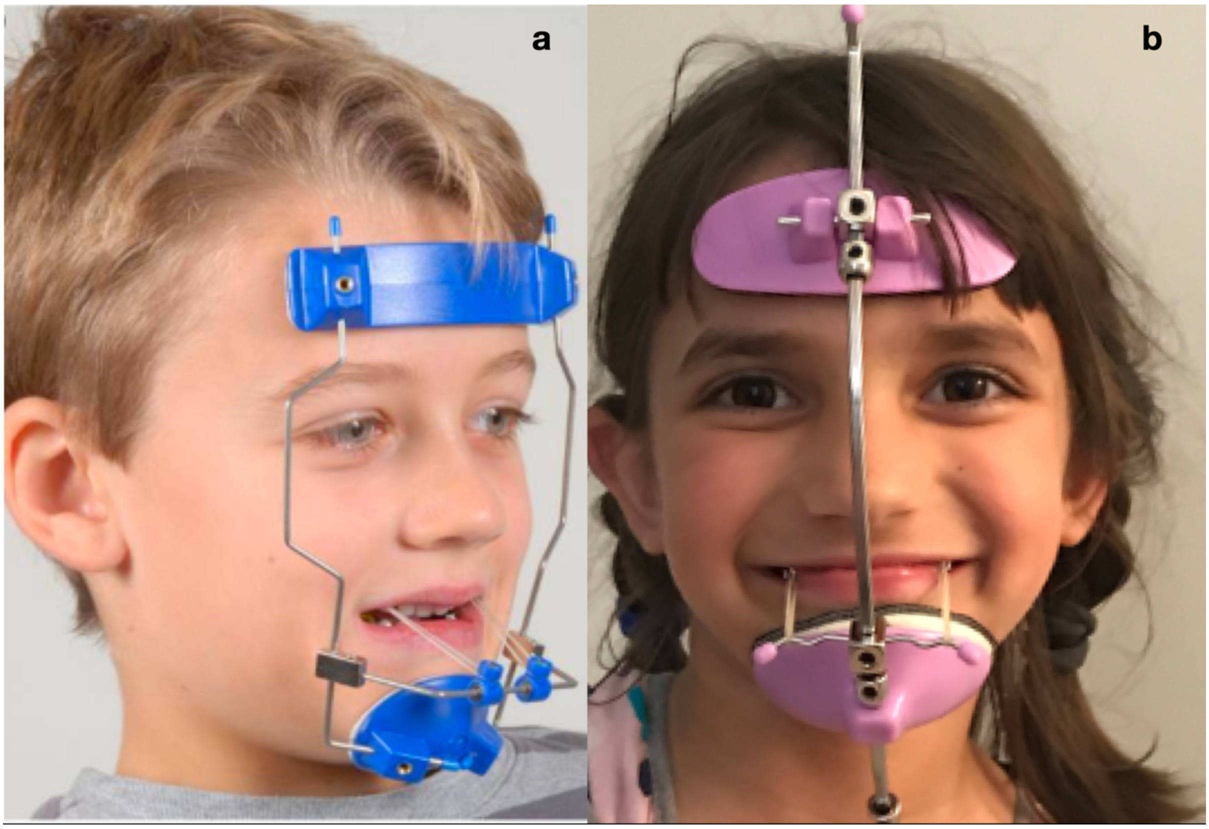


Figure 14 Two types of facemask. A. Delaire style Facemask from Nienkemper et al.[11]; B. Petit style facemask (photo of the author's daughter).

7.5.5.2.Components of the protraction facemask

Extraoral framework

The protraction facemask is composed of two extraoral pads that contact the soft tissue at the chin and the forehead region, using them as anchorage for the protraction forces. The pads are connected by a wire framework (Fig). This can be either a rectangular shaped frame (as in the original Delaire[127] design) or a rigid midline wire (as in the Petit[69] design). The wire framework carries hooks or spurs for the application of elastics. The position of the soft tissue pads and the hooks can be adjusted using a set of screws, which can be loosened. These screws move the components up and down the wire frame to allow customisation to the individual patients' face as well as to the desired force vector.

Intraoral anchorage unit

The intraoral component is what transmits the traction forces to the maxillary complex. It consists of a tooth-borne framework with hooks extending anteriorly to the canine region to allow the application of elastics, which connect to the hooks on the extraoral frame.

The literature is rich with various designs for the intraoral component. They can be divided into two major groups: those which include a maxillary transverse expansion and those which do not. The merits of expansion versus no expansion with maxillary protraction will be discussed later in this text.

The three major designs include

- Rigid labiolingual appliance with a transpalatal bar
- Banded palatal expansion appliance
- Bonded palatal expansion appliance with acrylic occlusal coverage.

7.5.5.3.Biomechanics of the protraction facemask:

The protraction facemask aims to place tension on the circummaxillary sutures in order to stimulate maxillary downwards and forward growth.[43] There are several sutures that are involved in this process, namely the frontomaxillary, nasomaxillary, zygomaticotemporal, pterygopalatine, intermaxillary, ethmomaxillary, and lacrimomaxillary sutures.[42]

The effects the protraction facemask therapy has on the maxillary complex depends on the line of the forces and the moments they create at the sutures. Thus, several studies have tried to identify the centre of resistance (CRe) of the maxillary complex to better understand how protraction forces work. However, the location of the centre of resistance reported across studies has varied according to their methodology (i.e., whether the study used patients, dried skulls or computer-generated models). The location of the CRe of the dento-maxillary complex was identified by Lee et al.[136] using laser holography (Figure 15). When viewed in the sagittal plane, it is positioned on a line perpendicular to the functional occlusal plane located at the distal contacts of the maxillary first molars, as seen on a lateral cephalogram.

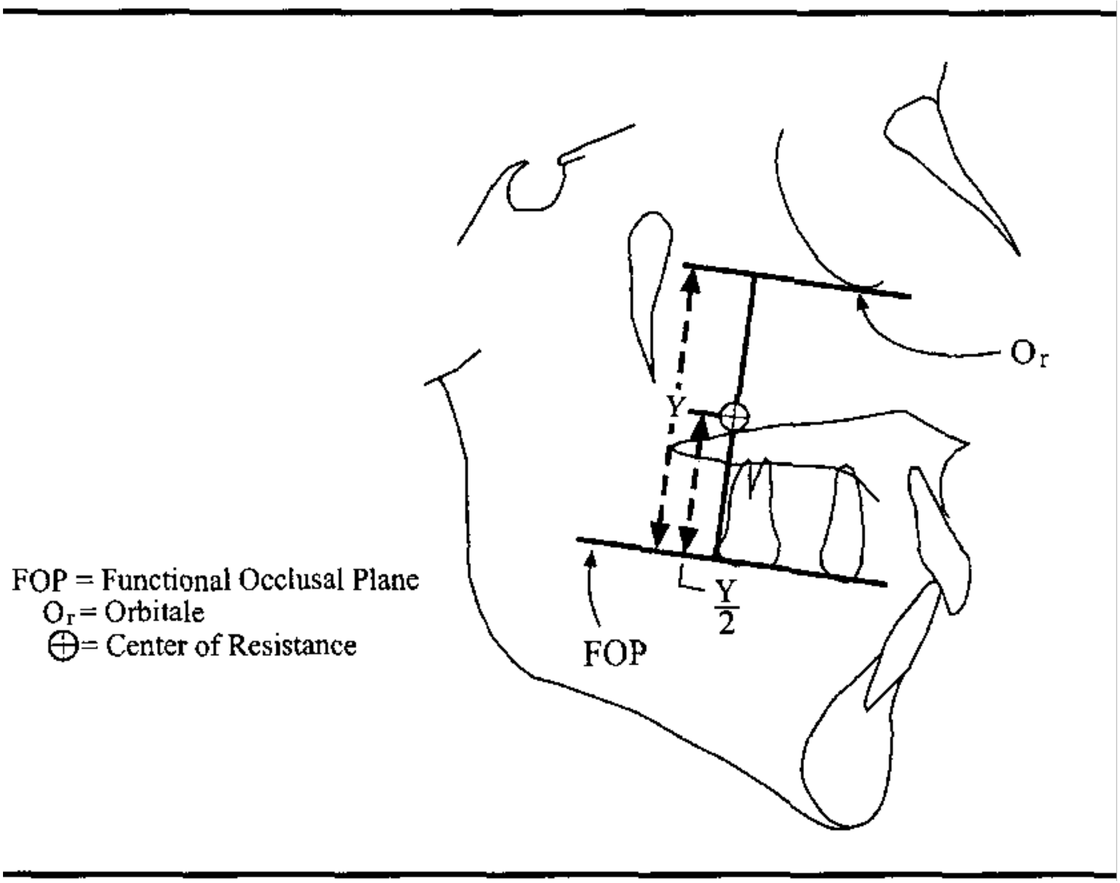


Figure 15 Illustration from Lee et al.[136] showing the centre of resistance of the maxilla from the sagittal view in relation to the occlusal plane.

The CRe of the maxilla is further identified to fall at half the distance from the functional occlusal plane to the inferior border of the orbit.[137] Furthermore, there are two centres of resistance for the maxillary complex when viewed from the frontal plane.[138] The maxillary complex essentially consists of two individual bones: a left and a right maxilla, with each containing half the dental arch.[138] The two maxillary bones articulate with each other at the median palatine suture and relatively symmetrically on each side with the frontomaxillary suture, the nasomaxillary suture, the zygomaticomaxillary suture and the transverse palatine suture. When forces are applied in a line below the centre of resistance, they will tend to produce a counterclockwise moment. If forces are applied above the centre of resistance, they will tend to have the opposite effect.[137-139] In the simulations, a 500 g force applied 15 mm above and directed 20 degrees below the occlusal plane produced a translation of the maxillary complex.[136] In most cases, upward rotation of the anterior portion of the maxilla changed to translation, or to downward rotation, as force direction was changed from parallel to the occlusal plane to 20 degrees downward from the occlusal plane.[136] This would have implications in a clinical setting when managing various vertical facial types. In the case of a neutral facial type, it may be desirable to aim for pure translation of the maxilla, while in a deep bite pattern it may be desirable to achieve some counterclockwise rotation of the maxilla. Lee et al. also postulated that maxillary expansion counteracted the constrictive effect of protraction forces.[136]

In another study using strain gauges and displacement transducers on a human skull, Hata et al.[139] evaluated the effects of protraction forces applied to the maxillary molars at three different levels. At the maxillary occlusal level, 5 mm above the palatal plane and 10 mm above the Frankfort horizontal plane, they found that at 5 mm above the palatal plane there was pure forward translation, and assumed it to be the centre of resistance. At the level of the occlusal plane, protraction forces resulted in counterclockwise rotation, and at 10 mm above the FH plane it resulted in clockwise rotation. The protraction forces were also found to be constrictive on the anterior palate, and thus maxillary expansion should be advocated with protraction.[139] Tanne et al.[138] asserted that determining the CRe within the craniofacial system can be very difficult due to the complex nature of the structures. They attempted to locate the CRe of the maxilla using a detailed finite element model, where they applied a force at 5 different levels in the relation to the functional occlusal plane. They found that the maxilla translated forward when a force was applied horizontally, passing through the super point of the pterygomaxillary fissure. Any forces away from that line resulted in rotation of the complex. They located the CRe of the maxillary complex at the superior ridge of the pterygomaxillary fissure. Using this data and similar modelling applied to previous studies, Miyasaka-Hiraga et al.[137] concluded that a maxillary protraction force acting at 30 degrees downwards from the maxillary canines gave the desired stress distribution in the sutural system.

These mechanics were tested clinically by Keles et al.[140] in a randomised clinical trial, where they assessed the effect of varying force direction on maxillary protraction. The trial was on 20 patients with Class III maxillary deficiency, who were randomly divided into two groups.

The intraoral anchorage was gained from a cap splint-type rapid palatal expander which was activated twice a day for 10 days.

- In group 1, the force was applied intraorally from the canine region with a forward and downward direction at a 30-degree angle to the occlusal plane.
- In group 2, the force was applied extraorally 20 mm above the maxillary occlusal plane()Figure 16.

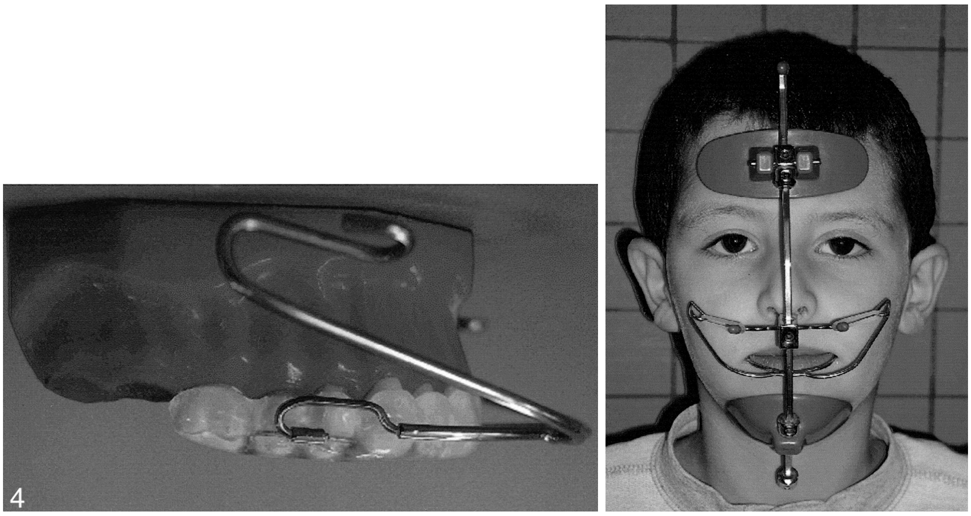


Figure 16 The modified facebow used by Keles et al.[140] to move the protraction forces closer to the centre of resistance of the maxilla.

Results	Group I	Group 2
Skeletal effects	Maxilla advanced forward with a counterclockwise rotation	Anterior translation of maxilla without rotation
Dental effects	Maxillary occlusal plane did not rotate	Clockwise rotation
Maxillary incisors	Maxillary incisors were proclined slightly	Retroclined and extruded

Table 1 Summary of results from Keles et al.[140]

Keles et al. concluded that force application near the CRe of the maxilla was effective in preventing unwanted side effects such as counterclockwise rotation of the maxilla. Results for group 2 (Table 1) suggested that this method can be used effectively on patients who present with a Class III malocclusion combined with an anterior open bite.[140] Although this concept made sense from a biomechanical point of view, it was not widely adopted. For the majority of clinical facemask studies, protraction forces are still applied at approximately 30 degrees down from the occlusal plane.[4]

7.5.5.4.Effects of the protraction facemask

7.5.5.4.1.Effects of protraction forces on sutures in animal models

Current understandings of the biologic mechanism underlying sutural growth modification and maxillary protraction come from animal studies on protraction in monkeys. Using cephalometric radiographs, Dellinger[130] showed maxillary forward growth in two adolescent monkeys after two weeks of protraction. In a larger study including eleven monkeys in mixed and permanent dentition, Kambara[131] used a 300 g extraoral protraction force (Figure 17) and analysed the effects using study casts, cephalometrics, tetracycline bone marking, microradiographs and histologic preparations. He found that two weeks of protraction caused significant changes in circummaxillary sutures and maxillary tuberosity. The maxillary complex showed a forward positional change, which Kambara[131] attributed to increased sutural activity. The response at the sutures was due to opening of the suture, stretching of the connective tissue fibres, new bone formation along the stretched fibres and a homeostasis that maintained the sutural width. There were some changes in the adult monkeys, but these were less pronounced than those in the younger monkeys. It is also worth mentioning that there an increased bone apposition was found at the maxillary tuberosity in a posterior and inferior direction, indicating an increase in the maxillary length even at the level near the dental arch.

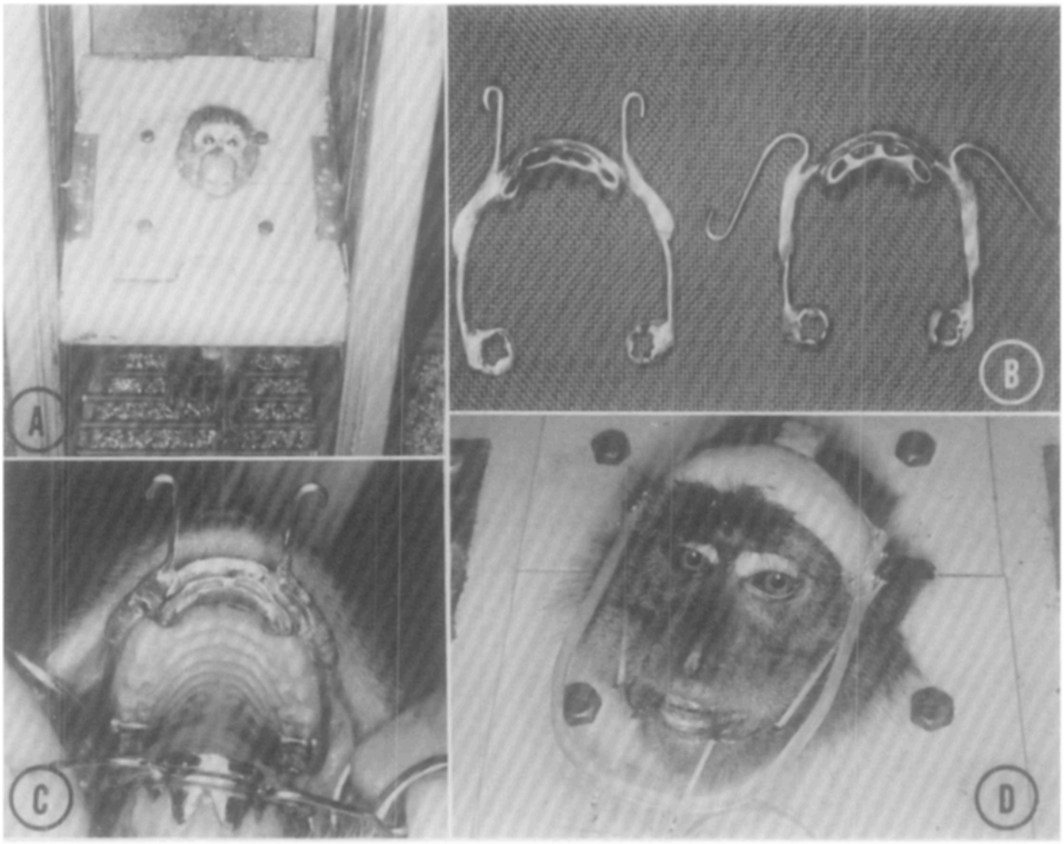


Figure 17 From Kambara[131]. A. Monkey cage with head restraint; B. Intraoral appliance with maxillary splint (left) and mandibular splint (right); C. Appliance cemented; D. Head cap fixed in the experimental monkey.

Jackson et al.[132] also performed maxillary protraction on monkeys, but followed their subjects for longer in order to assess the post-treatment response and relapse potential with and without stabilisation. Similarly, they found a forward displacement of the maxillary complex with protraction forces, with extensive remodelling at the circummaxillary sutures. An interesting observation was that the sutural response and remodelling was greater in the sutures that were closest to the line of force and in those sutures that lined up well with the line of action of the force, such as the zygomaticomaxillary, zygomaticopalatine, palatomaxillary and pterygopalatine sutures. They also demonstrated that the dental relapse exceeded the skeletal relapse by four folds. It was also clear that there was a tendency for sutural relapse in the absence of long-term retention, which was greatly reduced if fixed retention was used. Additionally, the protraction forces were found to influence distant structures such as the cranial base. Later on, Nanda et al.[133] found that the orientation of the force significantly influenced the sutural remodelling, especially at the zygomaticomaxillary suture, and that this would greatly influence the effect the protraction forces had on the maxillary complex. Additionally, they found that these sutural gains were stable after a six-month observation period.

These animal studies and others consolidated the understanding of the changes experienced with maxillary protraction in humans in terms of sutural adaptation and dental side effects, but also the role the direction of the applied force may play in the overall response.

7.5.5.4.2.Effects of facemask therapy on humans:

The effects of the conventional protraction facemask have been extensively studied in the orthodontic literature over the past three decades. With some variations, the changes can be summarised as follows: the maxilla and maxillary dentitions move forward and downward, and the mandible and mandibular dentitions move backward and downward.[3,6,18,19,135,141,142]

The effects can be broken down into skeletal and dental on the maxilla and mandible:

Effects on the maxilla:

- The maxilla moves downwards and forwards with forward movement of the A point, to a greater extent than is observed in untreated Cass III controls.
- There is some counterclockwise rotation of the maxilla.

Effects on the mandible:

- The mandible rotates downwards and backwards, resulting in backward movement of the B point, which is also associated with an increase in lower anterior face height.
- There is some restriction of mandibular growth.
- Overall facial convexity is increased.

Dental effects:

- Extrusion, forward movement and mesial tipping of maxillary molars
- Proclination of maxillary incisors
- Increased anterior crowding
- Retroclination of mandibular incisors.

In addition, a significant change in the soft tissue profile can be expected, with maxillary protraction and better lip competence and posture. However, one should anticipate individual variations in treatment response and subsequent growth changes.[4] The effects of the facemask have been studied in various ethnic groups and have been found to show similar results in Caucasians[3,7,143], Chinese[19] and Korean[144] populations.

The quantification of the changes resulting from facemask therapy have been mostly studied using lateral cephalometric radiographs. Several studies referred to the changes in the SNA angle to highlight maxillary growth changes, showing an increase of 1 to 2.7 degrees with facemask treatment. The changes observed usually exceeded those recorded in control Class III cases by 0.8-1.5 degrees. Mandal et al. showed a 1.1 degree increase in the SNA angle in their study while others showed changes of 0.7 [14], 1.8 degrees[8] and 2.7 degrees[18]. Linear measurements have also been used to record the forward displacement of the A point from a vertical reference line.[13,14] Studies showed a maxillary advancement of 1-1.5 mm with treatment; however, the actual reference line used varied between studies.[13,14] Changes in the mandible have also been recorded using the SNB angle, with typical reduction in the SNB angle ranging from -1 to -1.7 degrees.[3,6,18,19,135,141,142] In most studies, reduction in the SNB angle was considered to be partially due to backward rotation of the mandible, which in most reports was between 1 and 3 degrees. [3,6,18,19,135,141,142] Linear changes were also measured in reference to a vertical reference line, with an overall reduction in the forward projection of B point by -0.2 to -1.3 mm.[13,14] In most studies, overall skeletal changes were assessed by variations in the ANB angle, which typically showed a change of 2.4-2.6 degrees[6,8,14] and the Wits appraisal, which typically showed an improvement of 1.5-2.5 mm.[6,8,14] The dental changes resulting from facemask therapy included counterclockwise rotation of the maxillary occlusal plane in the range of 1-4 degrees, with mesial movement of the upper dentition and an increase in upper incisor inclination of 1.2-5 degrees.[3,6,14,145,146] Some of the differences in outcomes between studies could be attributed to differences in patient age, treatment duration, and (potentially) patient compliance.

7.5.5.5.Treatment timing and duration:

In one of the earlier studies, Ngan et al.[19] reported that orthopaedic changes were already evident after six months of facemask therapy, but in most studies patients were required to wear the facemask for 13-16 hours a day for a treatment duration of 9-12 months with elastic forces ranging from 300-600 g per side.[6,7,18,19,147,148] The effect of age on the response to the protraction forces has been well researched.[7-9,141,144,148,149] Many authors postulate that the response to protraction forces is better in younger patients.[7,9] As the maxillary sutures become more interlocked and interdigitated with age, it is thought that younger patients with less mature sutures will respond better to the forces, as has been demonstrated in animal models.[43] However, some earlier studies[144] did not find a significant difference between age groups. Kapust et al.[7] compared the effects of facemask therapy with maxillary expansion therapy among Class III children from three age groups using serial cephalograms. Pre-treatment and post-treatment cephalometric radiographs from 63 Class III patients aged 4 to 13 years were analysed. As controls, the serial cephalometric tracings of 32 Class I subjects made at 4, 6, 8, 10, 12 and 14 years were used. The effect of age on treatment response appeared minimal when comparing the differences in angular and linear measurements alone. However, when analysing the algebraic sum of treatment effects along the occlusal plane using the pitchfork analysis, significantly greater differences were observed in the 4-7 and 7-10 age groups when compared with the 10-14 age group.[7] Below is a summary of the results (Table 2):

Age range	4-7 yrs	7-10 yrs	10-14 yrs
Number of patients	15	32	16
Skeletal changes in mm Maxilla	+4	+3	+3
Skeletal changes in mm Maxilla	-0.8	-1	+1
Total skeletal changes in mm	5	4	2
Total molar and skeletal changes in mm	6	5.5	3

Table 2 Summary of the results from Kapust et al.[7]

It seemed that there was significantly better response in the two younger age groups. This was thought to be due to the increased sutural complexity which develops with age. However, it must also be considered that compliance with facemask use may have declined in the older age group, who likely slept fewer hours and may have used the facemask less during the day. In addition, between the age of 10 and 14, most children will be going through the late mixed dentition phase, losing the primary molars. This may have also reduced the amount of anchorage available for the application of the protraction forces.[7]

Cha et al.[149] used bone age rather than chronologic age to evaluate the effects of facemask therapy with expansion. They looked at 85 subjects with a Class III malocclusion and maxillary deficiency divided into three groups based on skeletal maturity (determined from hand-wrist radiographs): a prepubertal growth peak group (SMI 1-3), a pubertal growth peak group (SMI 4-7), and a postpubertal growth peak group (SMI 8-11). They found that there was no difference in the effects of maxillary advancement between the prepubertal growth peak and the pubertal growth peak group, but there was a decrease in response in the postpubertal growth peak group. The postpubertal group showed reduced skeletal and increased dento-alveolar changes. Perhaps their results emphasise the importance of the biologic skeletal age as opposed to dentition stage or chronologic age when attempting growth modification.

The importance of biologic age was also emphasised by Baccetti et al.[124], who advocated the use of the cervical vertebral maturation index over hand-wrist radiographs, as the index saves the patient from additional radiation exposure while still providing information regarding their growth status. They suggested that growth modification would be most successful in cervical vertebral maturation stages CS 1-2, which were prepubertal.[64] Similar findings were also presented more recently by Koh et al.[8] who examined the effects of tooth-borne and bone-borne maxillary protraction, taking into account age and vertical facial pattern. In their sample, it was also evident that protraction was more effective in the younger age group. Another recently published long-term study by Wendl et al.[9] emphasised that early treatment resulted in a greater number of skeletal changes and fewer dental side effects when compared to late treatment. The authors followed two groups of patients long term and collected data 25 years post-treatment. The early group were those who started treatment before the age of nine and a late treatment after the age of nine. On the contrary, a meta-analysis of Class III treatment with facemask concluded that there was no significant difference between early (before the age of 10) and late (11-14 years old) treatment. They did, however, explain that perhaps the changes observed in younger patients would be more skeletal in nature, while those in older groups would be of a more dento-alveolar nature. Looking at long-term stability of facemask therapy, Wells et al.[148] applied stepwise discriminant analysis to determine the indicators of success or failure. In their study a failure was defined as a relapse into a negative overjet at the 10-year follow-up.[148] They found that starting treatment after the age of 10 increased the chances of failure.

Although it may not be possible to derive a definite conclusion from the literature, facemask treatment before the age of 10 years or before puberty seems to result in more maxillary protraction and greater skeletal benefits. The patency of the sutures at a younger age is believed to a play a role in making them more responsive to protraction forces. Additionally, younger patients may be able to wear the facemask more as they sleep longer hours[21,22], which may play a role in the better response among this group.

7.5.5.6.Facemask with or without maxillary expansion

Maxillary expansion has been used in combination with facemask therapy for decades.[134] This may have started with the popularisation of orthopaedic maxillary expansion by Andrew Hass in the 1960 and 70s.[129] Finding that there was some spontaneous downwards and forwards movement of the maxillary complex with expansion alone, he stated, "Palatal expansion was just the beginning of dentofacial orthopaedics". It is postulated that maxillary expansion leads to distortion and disarticulation of the circummaxillary sutures, which leads to a better response to facemask protraction forces. This claim is supported by many authors who have worked extensively with the facemask, including Baccetti[3] and Ngan[4]. In a previously mentioned study, Baik et al.[144] compared maxillary protraction with expansion to protraction using a passive labiolingual appliance in a sample of Korean children. They found that both groups exhibited a very similar response; however, there was more maxillary forward displacement in the expansion group.

A meta-analysis by Kim et al.[135] in 1999 also concluded that the evidence suggested more maxillary protraction could be achieved with maxillary expansion. However, a randomised clinical trial by Vaughn et al.[18] (the first to examine the influence of maxillary expansion on facemask therapy) found no difference between the expansion and the non-expansion groups. Both groups experienced skeletal protraction of the maxilla, which was greater than what was observed with normal growth in the control group. This finding has been supported by a recent meta-analysis.[141]

However, the use of maxillary expansion with facemask therapy is still the preferred approach by most, perhaps for the following reasons. Firstly, most Class III patients with maxillary deficiency will also have a degree of transverse maxillary deficiency[48], meaning that (in most case) there is a need for expansion on this basis alone. Secondly, biomechanical analysis of facemask therapy[136,139] has found that protraction forces run outside the centre of resistance of the maxilla and thus have a constrictive effect. The rigidity of the expansion appliance can counteract this effect. Thirdly, one of the undesirable side effects of maxillary expansion is mesial movement of the maxillary dentition, which can lead to anterior crowding.[3] Expansion may help to overcome this crowding effect.

More recently a protocol of repeated maxillary expansion and contraction (Alt-RAMEC) has been proposed by Liou[91]. The aim of this protocol is to disarticulate and break up the circummaxillary sutures and thus almost resemble distraction osteogenesis. There is some evidence[5] so far to suggest that this protocol does improve the response to maxillary protraction, and this will be discussed in more detail later in this text.

7.5.5.7.Retention following facemask therapy:

Several authors have advocated the use of Class III functional appliances to maintain the correction achieved with the facemask for six months to one year after treatment.[134,150] The Frankel FR III appliance is one of the more widely accepted designs, and in one study[151] it was found to be an effective means of retaining Class III correction as opposed to no retention. Others[152] used the Bionator III for retention following maxillary protraction. These appliances are discussed in more detail in a previous chapter.

7.5.5.8.Long term effects and stability of facemask therapy:

With Class III treatment advocated to be more effective in prepuberty, the question of the correction's long-term stability is very pertinent. How much of the correction is maintained and how does future growth influence the outcome, especially with the substantial mandibular growth that follows during puberty?

Looking at the short-term post-treatment effects, McDonald et al. monitored the maxillary and mandibular growth of a group of Class III cases treated with maxillary protraction and compared them with a control group of untreated Class IIIs of similar age, as well as a group of Class I subjects.[70] They looked at the growth rate during the period of treatment (T1-T2) and one year post-treatment (T2-T3). Firstly, in their inter control comparison they found that the Class III controls had significantly less forward movement of the maxilla and greater forward movement of the mandible than the Class I controls. The treatment group, on the other hand, displayed significantly more maxillary growth in the treatment period between T1 and T2, almost five times that of the Class III controls and three times that of the Class I controls. They also showed less mandibular growth than both control groups. In the year that followed (T2-T3) they found that the treatment group resumed the Class III growth pattern and grew in a manner which was more or less similar to that of the Class III control group. Thus, they advocated the need for overcorrection of the Class III malocclusion to compensate for post-protraction growth deficiency of the maxilla.[70]

Looking at the two years following treatment, Ngan et al.[145] conducted a prospective clinical trial on 20 Southern Chinese children to assess cephalometric and occlusal changes following maxillary expansion and protraction facemask use, comparing results to those of a control group. Despite some relapse, they found a net improvement in the maxillomandibular relationship, and a positive overjet was maintained in 18 out of 20 patients at the end of the follow-up period.[145] However, the majority of patients had not reached their pubertal growth spurt, and the ultimate success of such treatment can only be judged once growth is completed, or at least after the pubertal growth spurt.

Wells et al.[148] conducted a long-term post-treatment assessment of the success rate of facemask therapy. Patients were assigned to success or failure groups according to positive or negative overjet at the longest available recall. The cephalometric radiographs of 41 Class III malocclusion children treated with facemask therapy were evaluated before and immediately after treatment; at five years post-treatment; and, for only 18 patients, at 10 years post-treatment. The results showed that 75% of the patients maintained positive overjet, whereas 25% outgrew the correction. The authors then applied a stepwise discriminant analysis to determine the indicators for success or failure. Major indicators for an unfavourable mandibular growth were a large mandible and the vertical positioning of the maxilla and mandible that projected mandibular growth in a more horizontal way. Additionally, patients who showed significant downwards and backwards rotation of the mandible during treatment were more likely to relapse. The age at which treatment began had no effect on long-term success and failure for patients younger than 10 years, but the percentage of successful treatment decreased after that age.[148] Other studies in Italy and Hong Kong have also found that between 60-80% of Class III cases treated with the facemask tended to maintain the positive overjet or did not require orthognathic surgery.[153-155] Perhaps a better way of judging success would be the reduction in need for orthognathic surgery after growth completion. In a multi-centre two-arm randomised controlled trial, Mandall et al.[6] tried to assess whether this was the case. Class III malocclusion patients aged seven to nine were randomly allocated to a no-treatment group and a group that received early facemask therapy with maxillary expansion. A panel of consultant orthodontists then judged patient records at long-term follow-up six years later. The results showed that in the group that received early treatment, only 36% of cases were judged to still require orthognathic surgery compared to 66% in the control group.[6] This outcome emphasises the value of early intervention in terms of overall outcomes. However, the authors also found that there was no statistically significant difference between the groups at the six-year follow-up in terms of cephalometric measurements. They hypothesised that the improvement came from an accumulation of small changes which may not have been statistically significant on their own, but which resulted in a clinically different outcome between groups when combined. Further, no difference was found in the psychological parameters in terms of patients' self-esteem. However, this may be because severity of malocclusion plays a role self-esteem and there was no distinction made between those with severe facial disharmony and those with moderate or mild disharmony.

One can conclude that there is long-lasting benefit for patients with Class III malocclusion who receive an early growth modification treatment with expansion and facemask therapy. However, 25-30% of those cases will relapse and require further intervention. This means that proper patient education and information is very important, as well as adequate long-term follow-up to manage those who do relapse.

7.5.5.9.Prognosis of Class III therapy and second phase treatment

As in most cases, the original Class III growth pattern will resume and in 25-30% of cases there is a chance for relapse. Several authors have tried to establish predictors for treatment success. This is particularly pertinent if there are plans to continue with fixed appliance treatment, as in many cases this would represent a substantial investment in time and money.

Ngan[42] proposed the use of a Growth Treatment Response Vector (GTRV) analysis to individualise and enhance the success of predicting excessive future mandibular growth in Class III patients. He proposed that through the use of serial cephalometric radiographs of patients taken a few years apart, patients' growth patterns could be predicted after facemask treatment. After performing the treatment in the early-to-middle mixed dentition stage (to eliminate the anterior crossbite) the patient is then followed for three to four years for growth observation before a phase 2 treatment is initiated. A GTRV analysis (Figure 18) can then be performed during early permanent dentition to allow clinicians to determine whether the malocclusion can be camouflaged by fixed appliance orthodontic treatment or whether a surgical intervention may be necessary when growth is completed.[42] GTRV analysis uses lateral cephalometric radiographs taken after facemask treatment and during the three- to four-year follow-up appointment. The horizontal growth changes of the maxilla and mandible are plotted on the occlusal plane. The distance between the A point of the two tracings along the occlusal plane represents the growth changes of the maxilla and the distance on the occlusal plane of the B point of the two tracings represents the growth changes of the mandible. The GTRV ratio is then calculated using the following formula:

GTRV = Horizontal growth of the maxilla/horizontal growth of the mandible

The GTRV ratio of an individual with normal growth pattern from age 8 to 16 is calculated to be 0.77 from data obtained from the Bolton Brush growth study. This means the mandible usually outgrows the maxilla horizontally by 23%, allowing the individual to maintain a good skeletal relationship. If mandibular growth exceeds this then it can be considered to be growing in a Class III pattern. Ngan then applied the ratio to successful and unsuccessful Class III cases. They found that the mean GTRV ratio for the successful group was 0.49 ± 0.14, with a range of 0.33-0.88. This means that the mandible outgrew the maxilla by 51% during this observation period, which is higher than the 23% recorded in Class I individuals. However, the mean GTRV ratio for the unsuccessful group was 0.22 ± 0.10, with a range of 0.06-0.38. So, in the unsuccessful group, the mandible exceeded the maxilla in growth by 78%. His results confirmed that Class III individuals resume the Class III growth pattern after treatment; however, those with maxillary deficiency and a GTRV ratio that falls between 0.33 and 0.88 can be successfully camouflaged with orthodontic treatment. Class III patients with excessive mandibular growth together with a GTRV ratio that falls below 0.38 should be warned of the future need for orthognathic surgery.[42]

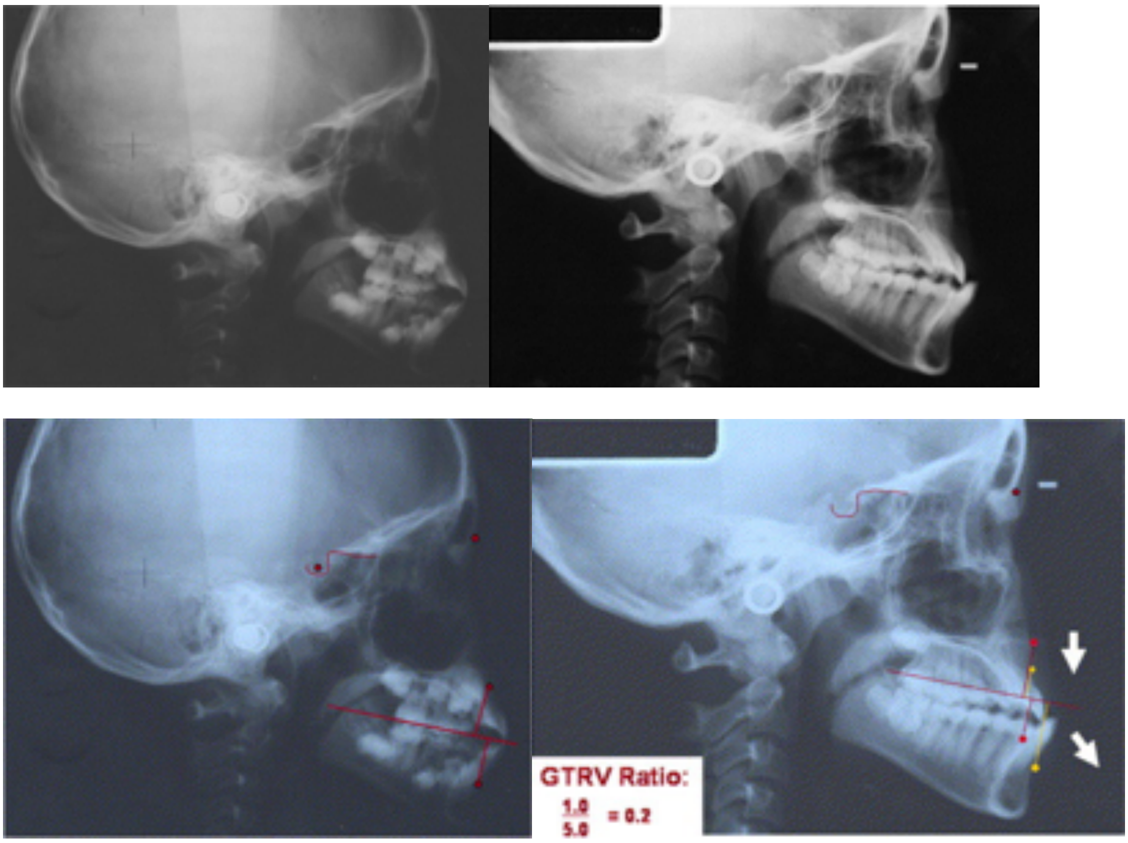


Figure 18 Growth treatment response vector analysis by Ngan.[42]

Other predictors for posttreatment relapse included low Wits appraisal, low ANB angle, reduced overbite, high SNB angle, long mandibular ramus reflected in increased posterior facial height, acute cranial base angle and steep mandibular plane angle.[153] Significantly greater decreases of the Wits appraisal and increases of ramus length during the follow-up were further associated with relapse. Long-term stability can be enhanced by a deeper overbite and the best possible skeletal correction, as well as a correction that occurs with no mandibular rotation or, even better, with forward rotation.[153]Additionally, Turley[150] emphasised that patient compliance is the key to successful orthopaedic correction of a Class III malocclusion.

Although early facemask therapy offers long-term benefits the treatment is also characterised by a number of shortcomings. Firstly, it seems that the window of opportunity for significant skeletal changes is small, and treatment should ideally be carried out before the age of 10.[7,9,148] This means there are limited options for children who have passed this stage, who seem to exhibit more of a dento-alveolar change with treatment. Secondly, the amount of skeletal correction may still be considered small, ranging from 3 to 5 mm of skeletal correction.[18,135] This may be insufficient to resolve some of the more severe cases. Thirdly, the appliances are tooth-borne, with undesirable dental side effects such as mesial movement of the upper molars and proclination and crowding of the upper incisors, as well retroclination of the lower incisors.[3,135,147] Lastly, to be successful, the appliances require good patient compliance, which can be unpredictable and highly variable.[16] The impact of patient compliance on Class III treatment regimens will be discussed in more detail later in this text.

Several innovations have aimed to overcome the above shortcomings.

7.5.6.Contemporary Class III treatment innovations

7.5.6.1.Alternating rapid maxillary expansion and contraction (Alt-RAMEC)

It has long been thought that maxillary orthopaedic expansion can improve the response to Class III treatment. Haas[129] showed that rapid maxillary expansion alone can lead to downwards and forwards displacement of the maxilla. He also postulated that maxillary expansion leads to distortion and disarticulation of the circummaxillary sutures, making them more responsive to protraction forces.[129] However, as mentioned previously, the literature is divided on the true influence of maxillary expansion on response to protraction.[5,18] In 2005, Liou[91] proposed a method to disarticulate the maxilla through repeated alternating rapid maxillary expansion and contraction, following the application of protraction forces. His Alt-RAMEC protocol entailed maxillary expansion of 1 mm a day for one week, followed by contraction of 1 mm a day for 1 week. This was repeated for seven to nine weeks until the maxilla showed visible mobility. Then protraction force was applied either through a facemask or an intraoral spring. Liou suggested that this would resemble a form of distraction osteogenesis.[91] He was able to demonstrate effective maxillary protraction in more mature teenagers for whom, it is thought, conventional protraction would be difficult due to increased sutural resistance.[156] In a prospective study, Liou and Tsai[156] compared the Alt-RAMEC protocol with conventional RME for maxillary protraction in 26 maxillary deficient cleft lip and palate patients aged between 9 and 12 years old. The expansion was performed using Liou's double-hinged maxillary expansion screw and the protraction was performed using an intraoral compliance-free beta titanium looped spring.[92] Even before the fitting of the protraction springs, Liou and Tsai[156] found significantly more anterior displacement of the maxilla in the Alt-RAMEC group. At the completion of treatment with the protraction springs, the Alt-RAMEC group showed more advancement of the maxilla at A point by 5.8 mm, which was approximately twice the advancement observed in the RME group (at 2.6 mm). Additionally, the Alt-RAMEC group corrected in less time than the RME group and the results were stable two years after treatment.

Although the results were promising, it was difficult to assert exactly what took place at the sutures with the Alt-RAMEC protocol, and so the protocol had to be assessed on an animal model. In a study on 12 cats, Wang et al.[157] examined the effects of Alt-RAMEC on 6 cats and compared these to the effects of one week of regular rapid maxillary expansion on the other 6 cats. They also used the two hinged expanders. The degree to which the circummaxillary sutures opened was assessed by probing along the suture using a periodontal probe. They categorised the sutures into four categories: those running sagittally and articulating directly with the maxilla, those running coronally and articulating directly to the maxilla, those running sagittally but articulating indirectly with the maxilla, and those running coronally and indirectly articulating with the maxilla. The suture opening was assessed by the ability to penetrate with the periodontal probe, and the percentage of suture opening for each suture was calculated based on the areas of effective suture opening within that suture. Not surprisingly, for sutures running coronally and articulating directly with the maxilla (such as the intermaxillary and the nasomaxillary suture), the opening was 100% for both Alt-RAMEC and RME groups. However, for all other circummaxillary sutures, there was significantly more suture opening with the Alt-RAMEC. This supported the hypothesis that Alt-RAMEC leads to more disarticulation of the circummaxillary sutures and could thus be used to make them more responsive to maxillary protraction forces. The authors also stressed that the Alt-RAMEC would need to be maintained for more than five weeks to result in effective disarticulation of the maxillary sutures.

Several clinical studies have since evaluated the effects of Alt-RAMEC on maxillary protraction. One study used a modified Alt-RAMEC protocol of only four weeks followed by facemask wear. It found that, compared to results of using a regular RME facemask, the protocol resulted in greater advancement of the maxilla at SNA by (1.2 degrees) and a greater improvement of 1.7 degrees at ANB and 1.6 mm on the Wits appraisal. They concluded that the Alt-RAMEC protocol increased the response to maxillary protraction. Several other studies and two meta-analyses have reached similar conclusions.[158-162]

One concern relating to this protocol would be the effect of this expansion and contraction with heavy forces on the roots of the anchorage teeth and whether this could also lead to dehiscence in the buccal bone, especially on the maxillary premolars. Franchi et al.[163] attempted to solve this problem by only cementing the maxillary expansion appliance to the deciduous teeth. However, this may be difficult to implement routinely, as patients present in many cases while approaching late mixed dentition, where the deciduous teeth serve as poor anchorage. Additionally, this technique aims to improve the responsiveness of more mature sutures, and so the appliance would likely need to be cemented on the first premolars and molars. This has prompted several authors to use palatal miniscrews to support the expansion appliance, thus reducing the load on anchorage teeth. Wilmes et al.[164] published a case report using the Hybrid Hyrax, which is anchored on two palatal miniscrews, and facemask following Alt-RAMEC. This approach showed rapid and effective maxillary protraction without dental side effects. In a prospective clinical trial on 14 patients with a mean age of 12.5 years, Almozany et al.[165] aimed to test the Alt-RAMEC protocol with a bonded Hybrid Hyrax appliance. Instead of a facemask, they used intraoral Class III elastics from upper appliance to a lower lingual arch, which was indirectly bonded to two mandibular miniscrews. They found rapid maxillary protraction, and the correction of the Class III malocclusion occurred in three months despite the relatively mature age of their sample. Similar rapid and effective correction was also found using the Alt-RAMEC protocol and facemask therapy.[166]

From the above, it can be concluded that Alt-RAMEC may be effective in disarticulating the circummaxillary sutures, making them more responsive to maxillary protraction in the short term. The effect seems to be faster response to the protraction forces, which may shorten the treatment time. The protraction effects, however, are only marginally better than with simple expansion only. It can also be said that, considering the heavy forces involved, it may be prudent to consider using this protocol with an expander that is bone-borne or tooth-bone-borne, in order to reduce the potentially negative impact on the anchorage teeth. Further research is required to determine any other negative effects which may arise from repeated expansion and contraction. For example, Liou and Tsai[156] reported that some patients experience severe pain in the nasal area during the Alt-RAMEC phase. It is also worth assessing whether this rapid disarticulation may have any negative effects on the future growth of the maxilla in such subjects.

7.5.6.2.Skeletal anchorage:

The case for skeletal anchorage in orthopaedic treatment:

From the review of most Class III treatment modalities, it can be seen that the goal of treatment is growth modification in an orthopaedic sense, with the aim of stimulating maxillary growth in all three dimensions – anteroposterior, vertical and transverse, while also restraining and/or redirecting mandibular growth. However, nearly all treatment methods rely on dental anchorage to transmit orthopaedic forces to the jaws. For decades this made sense, as the only way to transmit forces to the jaws was through the dentition. Nevertheless, such an approach is not ideal for several reasons. Firstly, teeth respond to any loading by moving in the direction of the applied force, which reduces the total orthopaedic correction and adds to the dento-alveolar compensation[45] that nature already provides. In Class III treatment this is quite undesirable, as the maxillary incisors are usually already proclined to compensate for the skeletal discrepancy. The side effects of maxillary protraction forces lead to further proclination and protrusion of the incisors, which can be aesthetically undesirable.[19,71] In addition, mesial movement of the maxillary molars would also result in less space in the anterior maxilla, as well as increased crowding.[3] Secondly, orthopaedic forces are usually significantly higher than those needed and recommended for orthodontic tooth movement[43], increasing the risk of unwanted root resorption,[167,168] dehiscence in the alveolar bone and gum recession.[169-171] Thirdly, Class III growth modification, especially protraction of the maxilla, is more effective the earlier it is started.[7-9] However, patients often present between the ages of 9 and 12 for treatment. During this time, the deciduous molars are shortening rapidly[43] and would provide poor anchorage for orthopaedic traction. Deciduous molars often shed during treatment, or even come out with the removal of appliances (Figure 19), which can cast a doubt on whether those forces were even being transmitted to the jaws during the treatment.

Figure 19 Bonded maxillary expansion appliance used for expansion and protraction, with two deciduous molars exfoliated inside the appliance at removal. This demonstrates how poor dental anchorage can be in the latter parts of the mixed dentition. Photo by the author.

Lastly, growth modification can take a long time. Class III growth will resume after the cessation of treatment[70], and in many cases it would be desirable to continue to apply the orthopaedic forces throughout and after puberty.[123] But this would be too risky, as prolonged heavy loading of teeth would increase all the above-mentioned side effects.

Despite all the drawbacks of the use of dental anchorage for orthopaedic treatment, it is the only way to access the jaws for force application, and orthodontists have always been aware of these problems. Appliance designs and treatment protocols have always aimed to minimise dental side effects. Earlier attempts at using skeletal anchorage were proposed by Kokich et al.[172] who used intentional ankylosis of the maxillary deciduous canines by intentional extraction and replantation to provide pure skeletal anchorage for maxillary protraction with a facemask. However, the replanted teeth provided anchorage only for a few months, after which replacement resorption of the roots took place and the teeth were lost. Others attempted a similar approach in a severe maxillary deficient case and showed significant maxillary protraction with no unwanted dental side effects.[173,174]

Nevertheless, the introduction of miniscrews and miniplates to orthodontics can be considered a major turning point in orthopaedic treatment in the last two decades. Initial reports in the late

1990s on the use of miniplates and miniscrews, now collectively described as temporary anchorage devices (TADs) in the literature, were mostly focussed on dental movement. TADs allowed orthodontists to perform large and difficult tooth movements without unwanted side effects such as loss of anchorage. They also made it possible to perform tooth movements (previously thought to be very difficult) with great predictability, such as molar intrusion[175-178] and the retraction or protraction of entire dental arches.[179-181]

It was not until 2003 that early applications for orthopaedic treatment were reported. Enacar et al.[182] reported on using one rigid implant in the maxilla in conjunction with a facemask for orthopaedic maxillary protraction, while He et al.[183] used an onplant with promising results. In 2006, Kircelli et al.[184] were the first to combine bone-borne expansion using four miniscrews with maxillary protraction, zygomatic miniplates and facemask in a case with hypodontia and severe maxillary hypoplasia. Then, in 2008, Wilmes et al.[185,186] simplified the use of palatal miniscrews to support maxillary expansion with the introduction of the Hybrid Hyrax appliance, which they also advocated with effective maxillary protraction.[11] Nevertheless, one of the major turning points in orthopaedic correction of Class III malocclusion would have to be the introduction of the BAMP protocol by Dr Hugo DeClerk in 2009[23]. DeClerk used pure bone anchorage through maxillary and mandibular miniplates for intraoral Class III traction with elastics.

The following section will discuss the various applications of skeletal anchorage in Class III growth modification, and can be broken down into two main groups: those using skeletal anchorage to support maxillary protraction with a facemask and those using intraoral means for anchorage, such as miniplates and Class III elastics.

7.5.6.2.1.Facemask with skeletal anchorage:

As mentioned above, the earliest attempts to provide skeletal anchorage for facemask therapy came through intentional ankylosis of the maxillary deciduous canines by extraction and replantation, followed by maxillary protraction.[172] The results showed that skeletal anchorage can reduce dental side effects and maximise the skeletal response. However, it wasn't until two decades later that early attempts to use TADs to reinforce anchorage for maxillary protraction were recorded. The early applications were usually in cases where there was an insufficient number of teeth to support protraction, such as Class III cases with hypodontia or oligodontia.

Enacar et al.[182] used one maxillary implant to bolster anchorage to manage a 10-year-old girl with oligodontia and maxillary hypoplasia with a protraction facemask. The effects were significant forward and downward development of the nasomaxillary complex, setting up the case with a positive overjet for future prosthetic management.[182]

Some authors[183] also used onplants for anchorage. Onplants are more technically demanding than miniscrews, and require a small flap surgery to be placed and a period of time for osteointegration. He et al.[183] used a palatal onplant to anchor a maxillary appliance for protraction with a facemask in a case report in 2005. They also concluded that the use of the skeletal anchorage eliminated the unwanted dental side effects of tooth-borne protraction and provided a greater skeletal response.[183]

Onplants did not gain popularity, as they required a small flap procedure to be placed, followed by a period for osseointegration, which made the procedure less practical when compared to miniscrews.

7.5.6.2.1.1.Facemask with miniplates:

A case report by Kircelly et al. in 2006 was an early sign of things to come.[184] The authors used 4 miniscrews placed in the palate to support maxillary expansion, as well as an infrazygomatic plate to support facemask protraction in a patient with severe maxillary hypoplasia, anterior crossbite and oligodontia.[184] They showed a significant amount of maxillary expansion and protraction without dental side effects. Perhaps with today's knowledge, the miniplates may not have been necessary and the palatal appliance could also have served adequately for the protraction. However, that early attempt was a good demonstration of what was possible in terms of maxillary growth modification with skeletal anchorage.

Following Kircelly et al.'s case report, several studies were conducted using miniplates in the maxilla combined with a protraction facemask.[8,10,146,187-193] Miniplates were either placed in the lateral nasal wall or the infrazygomatic crest. In a pilot study on six Class III patients with an average age of 11.8 years, Kircelly and Paktas[188] placed miniplates in the lateral nasal wall and used the facemask for protraction (Figure 20). The miniplates used were introduced by Erverdi[176] in 2002, and their adjustable ends allowed for various orthodontic applications. All patients were initially fitted with a bonded splint-type maxillary expansion appliance and after expansion, the appliance was left in place to allow disculsion until the crossbite was corrected. The patients were required to wear the facemask full-time until correction of the crossbite and then at night-time in the follow-up period, in order to maintain the correction. The results were remarkable, with 4.8 mm of maxillary advancement measured at A point achieved in a little over 10 months. The overall skeletal pattern improved by 6.1 degrees at ANB and 9 mm over the Wits appraisal.[188]

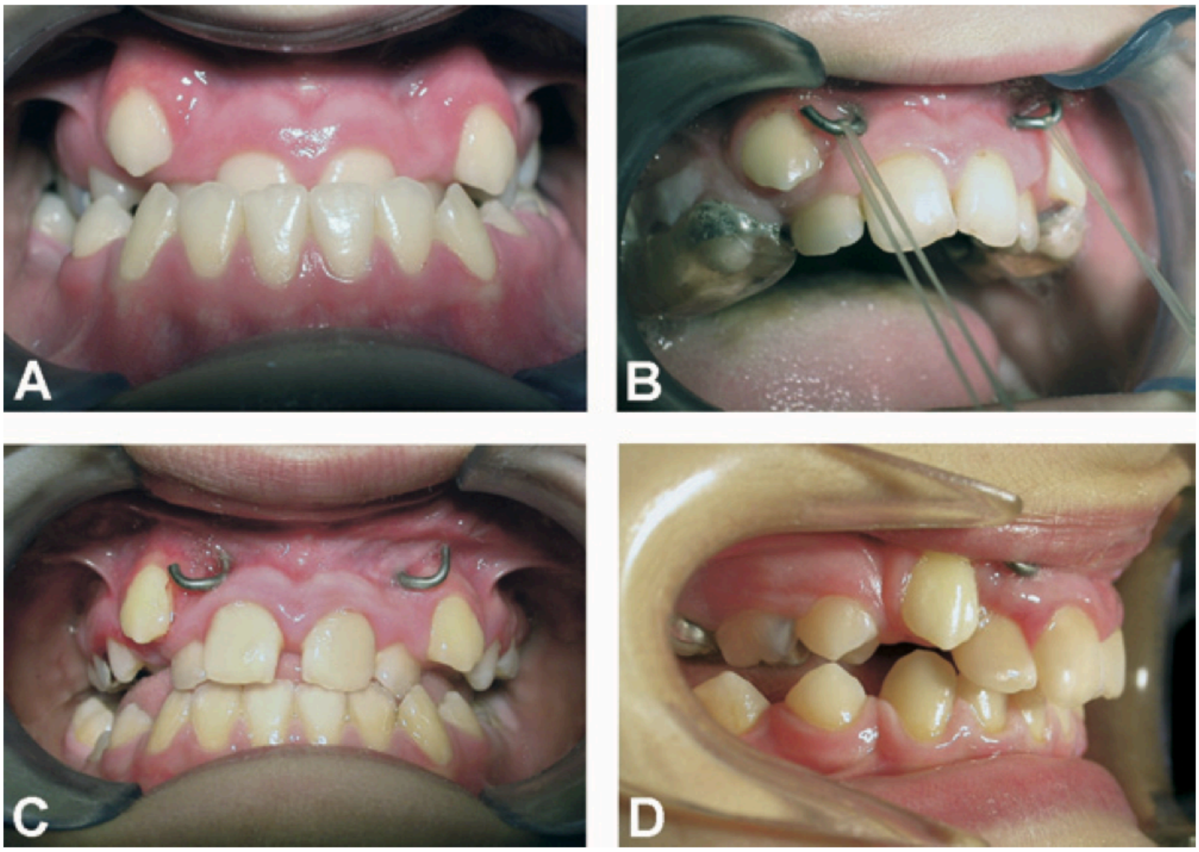


Figure 20 Maxillary miniplates by Kircelly and Paktas[188] placed in the lateral nasal wall for facemask protraction.

Sar et al.[189] compared the effect of maxillary protraction using miniplates in the lateral nasal wall with conventional RME facemask therapy, as well as including an untreated control group. Both treatment groups received a bonded maxillary expansion appliance. The maxillary protraction and correction of the malocclusion occurred in less time with the miniplates. The authors also found that there was more maxillary protraction in the miniplate group, with a 2.5 degree increase in the SNA compared to 1.8 degrees in the RME facemask group. The dental changes were more significant, with the RME facemask group showing significant protrusion of the upper incisors, while the miniplate group showed the opposite, with some retroclination of the upper incisors. In a similar study, Lee et al.[146] compared miniplates with the RME facemask. However, in their study, the miniplate group did not receive maxillary expansion prior to protraction. The authors placed the miniplates in the infrazygomatic crest as opposed to the lateral nasal wall. In their post-treatment analysis, there was more maxillary protraction with greater advancement of the A point. SNA increased by 2.7 degrees with miniplates as opposed to 1.2 degrees with the RME facemask. They also examined the difference in skeletal advancement at the level of the orbits (something few other authors have investigated) and found a greater advancement of the maxilla with miniplates at that level as well. As was the case in previous studies, they also found the protrusion of the upper incisors to be significantly higher with the tooth-borne appliance. Similar findings were also reported by Koh et al.[8] who, in addition, divided their subjects into groups, taking into account age and vertical skeletal pattern as well. They confirmed that maxillary protraction is more effective in younger patients and they added that the older or more skeletally mature the patients, the more value would be gained from the use of skeletal anchorage, as the difference was found to be greater between the miniplate group and the tooth-borne group in the older age bracket.

A major drawback of miniplates in the maxilla in children is the invasiveness of the procedure. The placement of miniplates requires flap surgery, which is usually done under a general anaesthetic. General anaesthetic is not risk-free and can be costly, which presents a significant obstacle to patients and their families in terms of cost and availability. Furthermore, the removal of the miniplates would require another surgery as well. An alternative, less invasive type of miniplate (namely, the palatal C-plate) was proposed by Kook et al.[191]. The appliance, which is more like a palatal arch, was fitted to the palate via 3 miniscrews, with hooks extending to the canine area for elastic traction (Figure 21).

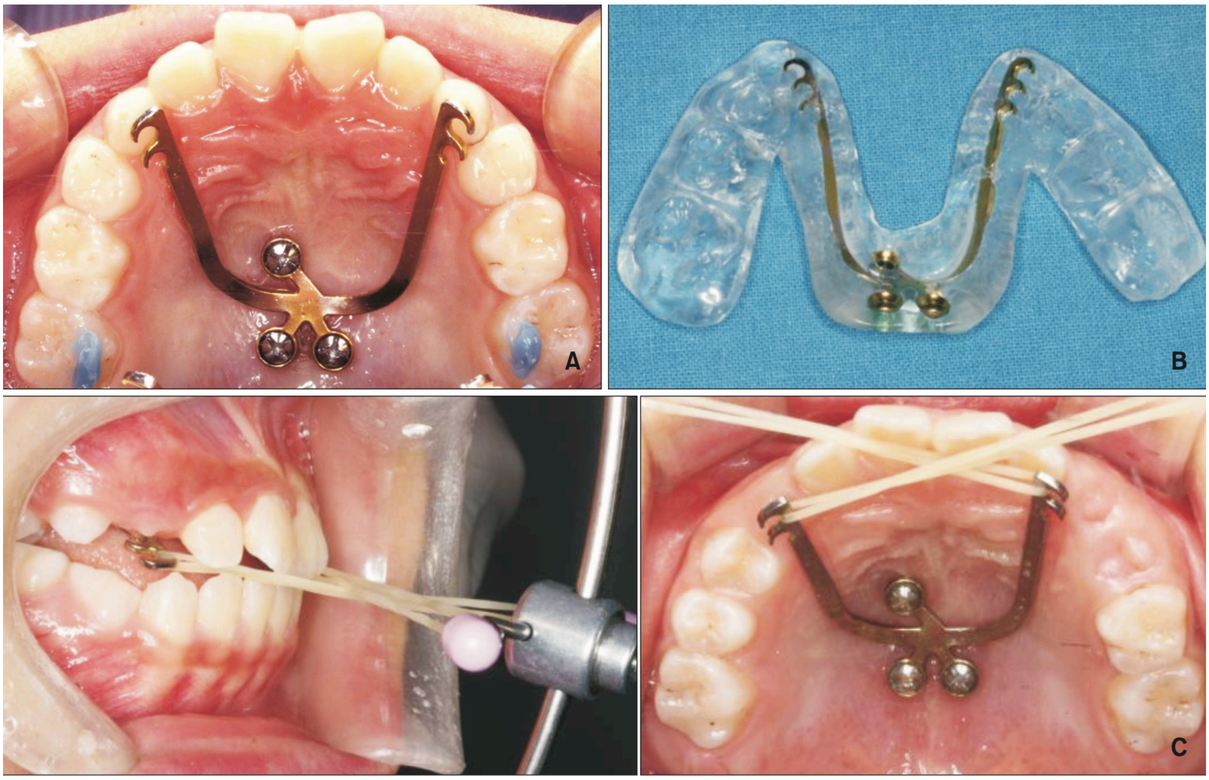


Figure 21. C-plate, as proposed by Kook et al.[191]

Kook et al. presented two case reports with successful maxillary protraction in Class III cases. A finite element analysis[190] also showed that the stress distribution using the C-plate design may be better at spreading the protraction more evenly over the maxilla compared to buccal miniplates. Clinically, possible limitations of this appliance include the difficulty in adapting it to differently shaped palates in different clinical scenarios, and the need to have a significant inventory of various sizes of plates to suit anatomic variations.

7.5.6.2.1.2.Facemask with miniscrews

In 2008, Wilmes et al. introduced the Hybrid Hyrax appliance (Figure 22).[185,194] The Hybrid Hyrax relies on two miniscrews in the anterior palate to share the load with two maxillary molars. The appliance has been used for expansion and also for expansion and protraction using a facemask.[11] The use of miniscrews in the anterior palate offers significant advantages. Firstly, the placement is simple and can be done in the orthodontic office. Secondly, the anterior palate is a fairly safe insertion site that provides adequate bone support[195-197]. Thirdly, maxillary expansion can be incorporated in the same procedure while also benefitting from skeletal anchorage to support the expansion. This becomes even more important when Alt-RAMEC is proposed, as the load for the expansion and contraction is then carried by the miniscrews. Only a small number of studies have since examined the effect of the Hybrid Hyrax with maxillary protraction using a facemask.[11,13,14]

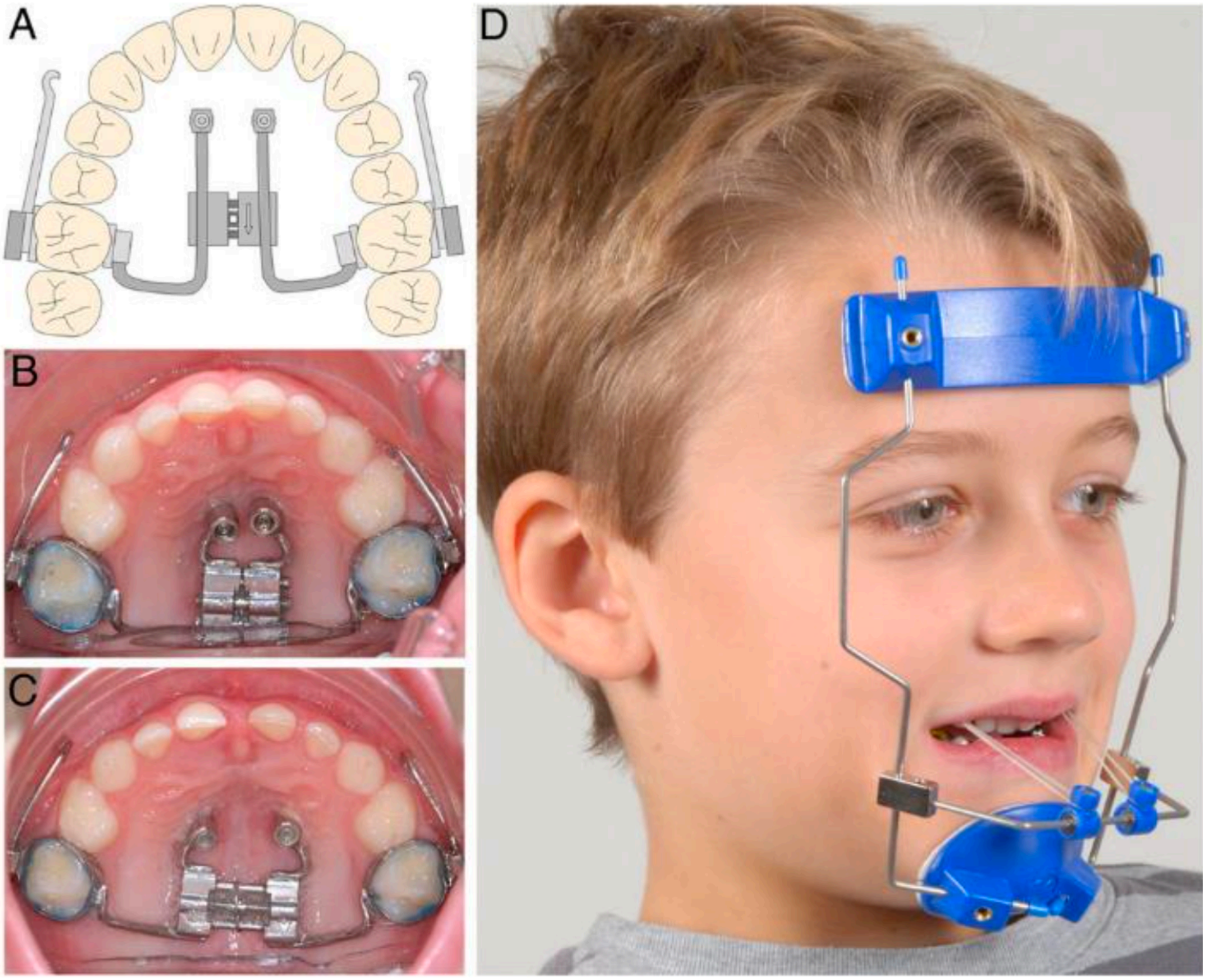


Figure 22 The Hybrid Hyrax Facemask combination from Nienkemper et al.[11]

Nienkemper et al.[11] reported on the skeletal and dental effects of the Hybrid Hyrax and facemask combination on 16 consecutively treated patients. The mean patient age was 9.5 years old. The authors reported significant skeletal changes, with SNA increasing by 2 degrees, a 1.2-degree reduction in SNB and a 3.2-degree improvement of the ANB, with no dental side effects such as incisor proclination or molar mesial movement. The effects of the Hybrid Hyrax in combination with facemask were then compared with conventional RME facemask treatment in another study,[14] where the maxillary advancement was shown to be a little over two-fold with the Hybrid Hyrax. The dental side effects were significantly higher in the RME facemask group while the vertical changes were reduced with the Hybrid Hyrax-facemask combination. The authors concluded that the incorporation of the miniscrews eliminated the dental side effects and improved the vertical control of the appliance. Seiryu et al.[198] compared the use of a facemask with a labio-lingual appliance anchored to only one palatal miniscrew without expansion to a tooth-borne labio-lingual appliance with a facemask (Figure 23). They found significantly greater maxillary advancement in the miniscrew group over the tooth-borne group, with an SNA increase of 2.2 degrees as opposed to 1.1 degrees. As was the case in other studies, there were very limited dental side effects in the miniscrew group, with significant incisor proclination and mesial movement of the molars in the tooth-borne group.[198]

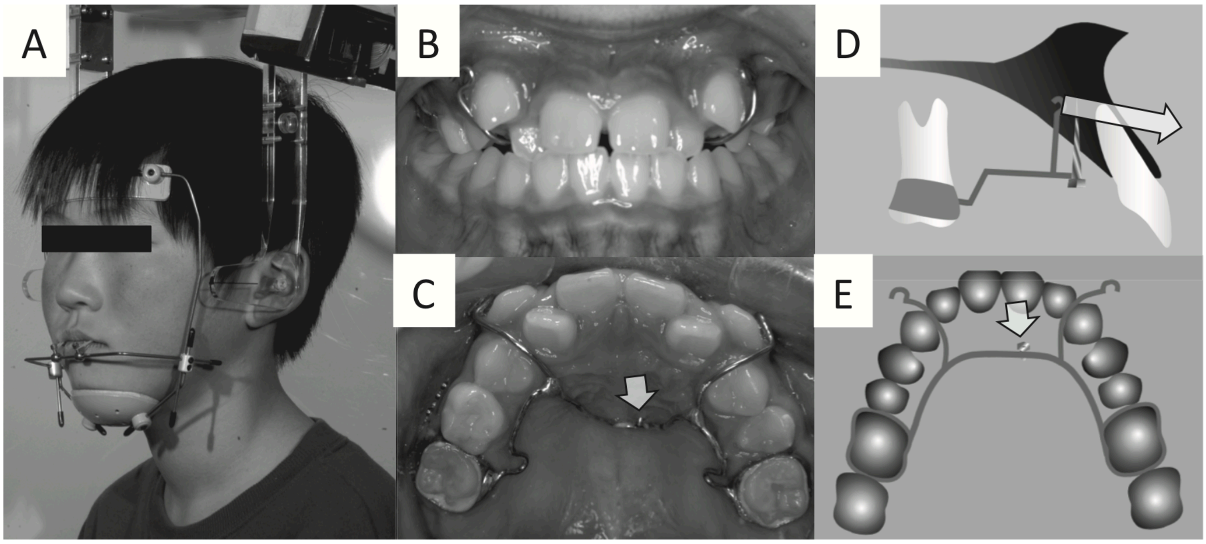


Figure 23 Facemask used with labiolingual appliance anchored to one palatal miniscrew by Seiryu et al.[198]

Although the facemask has been widely used for several decades, the extraoral nature of the appliance can be problematic in terms of patient acceptance, which can reduce compliance with treatment. The introduction of the BAMP protocol by De Clerck[23] in 2009 offered a good intraoral alternative.

7.5.6.2.2.Miniplates in Class III correction:

The introduction of the bone-anchored maxillary protraction (BAMP) protocol[23] by Dr Hugo De Clerck was a significant turning point in the orthopaedic management of Class III malocclusion. De Clerck used bilateral maxillary infrazygomatic and mandibular symphysial miniplates to apply Class III elastic traction directly to the maxilla and mandible without any dental loading (Figure 24). He only advocated the use of a tooth-borne bite plate to help unlock the bite and allow for Class III correction. The mandibular miniplates were placed between the mandibular canine and lateral incisor, meaning that the treatment was only possible after eruption of the mandibular canines, which happens (on average) around the age of 11. For the placement of the miniplate, a small flap was raised and a type of miniplates termed ‘bollard plates’ (Bollard; Tita-Link, Brussels, Belgium) were adapted and secured with 2-3 titanium screws (2.3 mm x 5 mm) each.[199] The placement was usually carried out under general anaesthesia. Three weeks post-surgery, intermaxillary Class III elastic wear was started for protraction. The loading started with elastic forces of 100 g per side and the patients were instructed to wear the elastics full time, replacing them at least once a day. The elastic force was then progressively increased up to 200 g per side and maintained for twelve months.

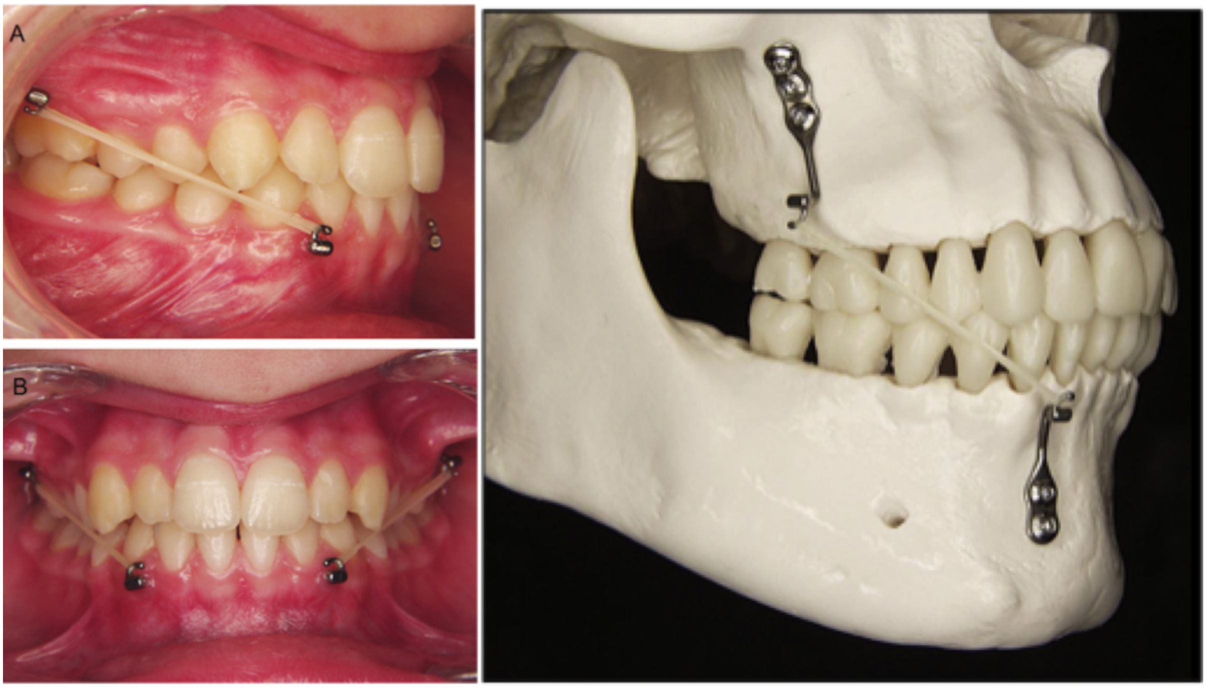


Figure 24 The bone-anchored maxillary protraction BAMP protocol using bollard plates (Bollard; Tita-Link, Brussels, Belgium) by Dr Hugo De Clerck.[23]

De Clerck studied 21 consecutively treated cases from his office and compared them with 18 untreated Class III controls from the University of Florence.[200] On average, De Clerck’s cases exhibited maxillary advancement of 4 mm more than the untreated controls. This was not limited to the dento-alveolar region but extended to the orbital ridge and pterygomaxillary fissure. A novel finding of the study was a tendency for the lower incisors to advance and procline with the treatment, which is contrary to the finding of most other Class III treatment studies.[200] Several other studies examined the effects of this protocol using cone beam computed tomography (CBCT).[12,15,201-203] Using 3D cranial base superimpositions (Figure 25), Heyman et al.[201] demonstrated the skeletal and soft tissue changes in six Class III patients treated with the BAMP method. They used colour histograms to demonstrate the changes which provided an excellent way to visualise the treatment effects. This method also demonstrated that the changes resulting from the orthopaedic treatment were highly variable between patients; while there was significant maxillary forward and downward displacement in some, the effect seemed to be more pronounced on the mandible in others. The authors also showed that there was significant remodelling taking place at the level of the glenoid fossa and mandibular condyle.[201]

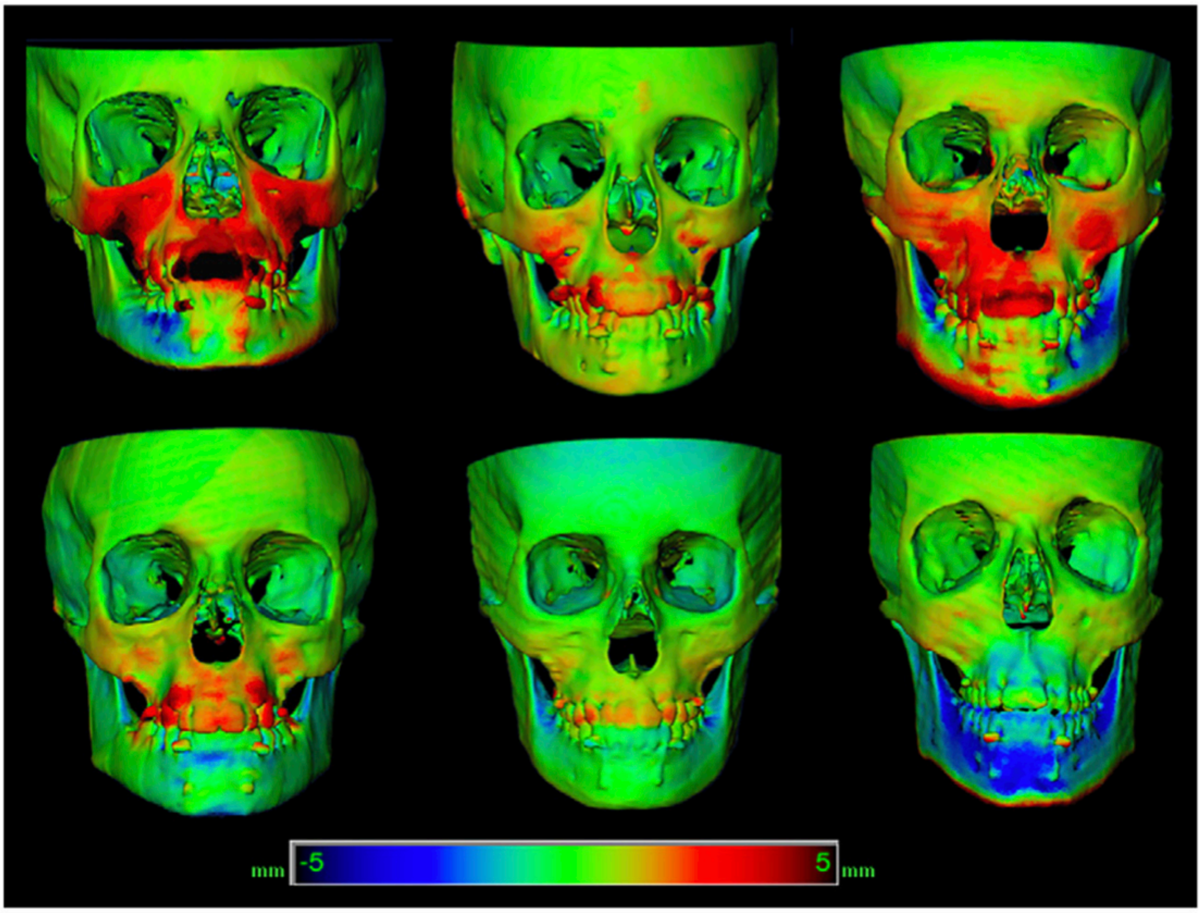


Figure 25 Colour histograms from 3D cranial base superimpositions by Heyman et al.[201] showing the variability in skeletal response, with the BAMP protocol, from significant maxillary advancement in red to mandibular backward displacement in blue.

Looking at 25 consecutively treated cases, Nguyen et al.[202] used similar CBCT superimposition methodology and reached very similar conclusions. There was significant forward and downward growth of the maxilla (up to 7 mm in some cases); however, there was a high variability between subjects, with some showing more of a change at the level of the mandible. The effects of the BAMP protocol on the mandible and the glenoid fossa have also been studied. De Clerck et al.[12] found that there was glenoid fossa remodelling and relocation posteriorly, with bone resorption on the posterior wall and apposition on the anterior wall. In addition, there was evidence that the shape of the mandible changed, with some closure in the gonial angle.[12]

There was some concern that the posterior relocation of the mandible may have had a negative impact on the pharyngeal airway. Nguyen et al.[204] examined the pharyngeal airway in 28 cases treated with BAMP. They used volumetric analysis of the airway, comparing the volume before and after treatment, and found that there was an increase in the airway volume over the period of treatment across all areas. They also compared the post-treatment airway volumes with those from a group of untreated Class III controls. There was no statistically significant difference between the two groups, and they concluded that this type of growth modification treatment did not hinder the development of the oropharyngeal airway.

The effects of BAMP were also studied on beagle dogs cephalometrcially and histologically.[205] Five young male beagle dogs were used as the experimental group, and five as a control. There was significant maxillary advancement and retroclination of the maxillary incisors with backward movement of the mandible and remodelling of the glenoid fossa and the condyle. The histology results showed significant bone appositional activity at the zygomaticomaxillary suture in the treatment group, which was not seen in the control group.[205]

When compared to conventional RME facemask treatment, the BAMP protocol resulted in significantly more maxillary protraction, without the dental side effects. Cevidanes et al.[206] compared 21 Class III cases treated with BAMP to 34 cases treated with the RME facemask. There was a notable difference in the age of the groups. The BAMP group were older, with a mean age of 11 years, while the RME facemask group had a mean age of 8. The BAMP treatment was, on average, two months longer, but the results were significantly greater in terms of maxillary advancement, being 2-3 mm higher than for those treated with the RME facemask. The dental side effects were also significantly greater for the RME facemask group, and the vertical control was better in the BAMP group, who showed less opening of the mandibular plane angle. Another study[15] compared the two protocols using CBCT and 3D cranial base superimpositions. The results were quite similar and confirmed that the BAMP protocol was effective in correcting Class III malocclusion without the dental side effects observed in patients treated with the tooth-borne RME facemask.[15]

Overall, results of the BAMP method were significantly better than those for the conventional tooth-borne RME facemask across several studies[15,200,206,207], and this was attributed to the absence of dental loading. Elnagar et al.[193] compared the BAMP protocol with purely bone-borne facemask protraction; their study also included a group of untreated Class III controls. They used infrazygomatic miniplates with a protraction facemask and compared results of this method with those for mandibular and maxillary miniplates and Class III elastics. Both groups were close in age, averaging 11.9 years and 12.1 years respectively. The authors found significant maxillary advancement in both groups, with no statistically significant difference between them. However, there was more backward rotation of the mandible in the facemask group, and the authors concluded that perhaps the BAMP protocol could be the treatment of choice for high angle cases.[193]

The use of miniplates, although an attractive option that avoids the extraoral facemask, does require the surgical placement of the miniplates. The process can be considered slightly invasive in comparison to the use of miniscrews. Each miniplate requires a flap procedure[199] to place it, this process has to be repeated to remove the plates at the conclusion of treatment. In most cases, this is done under a short general anaesthesia. As with any surgical procedure there can be complications, and there can be failures with any temporary anchorage device, which may require further surgical interventions to replace or remove the failed miniplates. In a study on patient and operator perceptions of miniplates for orthodontic tooth movement, Cornelis et al.[208] found the success rate was 92.7% in 200 miniplates. The clinicians found that the devices greatly simplified orthodontic treatment through the additional anchorage gained, and patients were mostly positive about the experience, with 82% reporting that the procedure was easier than expected and that the discomfort was lower than anticipated. The most common complication was postoperative discomfort, which lasted a few days after placement. It is worth mentioning that the miniplates in this study were mostly in adults, and for orthodontic and not orthopaedic loading.

Examining miniplates used for orthopaedic loading, De Clerck and Swennen[209] looked at 25 cases treated with the BAMP protocol – a total of 100 miniplates. Only three miniplates needed replacement. The authors reported that five miniplates exhibited mobility throughout treatment, as a result of which loading was interrupted and then restarted. Two miniplates subsequently stabilised and three did not. However, the success rate was significantly lower in a larger multicentre study between Belgium and the Netherlands.[210] The authors of this study looked at a total of 872 miniplates in 218 patients. In 10% of the patients, the treatment had to be terminated early due to failure of one or more of the miniplates. Several types of complication were observed. In 25.7% of the patients (56 in total), one miniplate failed and required replacement. In 37 cases the miniplates were mobile, in 11 they broke, in five patients they were infected, and three patients had mucosal excess. In addition, one lower canine was devitalised after drilling in the root. Most of the lost miniplates failed after at least eight months of loading. The failure rate was greater in the Netherlands than in Belgium, with 40% of patients in the Netherlands having complications compared to 15.7% in Belgium. This could indicate a difference in surgical technique and expertise between the centres. It is worth noting that the failure rate was six times higher in the maxilla, with 85% of the failures occurring in the maxilla and only 15% in the mandible. The overall success rate in the mandible for all plates was 98%. The authors explained this in terms of the lower cortical bone density in the maxilla. They also argued that a good alternative to maxillary miniplates could be the use of a Hybrid Hyrax,[194] which would rely on palatal miniscrews (which have a higher success rate for anchorage).[210]

7.5.6.2.3.Palatal miniscrews and miniplate combination:

The Hybrid Hyrax introduced above[194] relies on two palatal miniscrews in the anterior palate to share the load of maxillary expansion with two maxillary molars. Wilmes et al.[24] proposed the use of the Hybrid Hyrax in combination with a skeletal anchorage plate placed in the chin apical to the permanent mandibular incisors, which they called the Mentoplate (Figure 26).

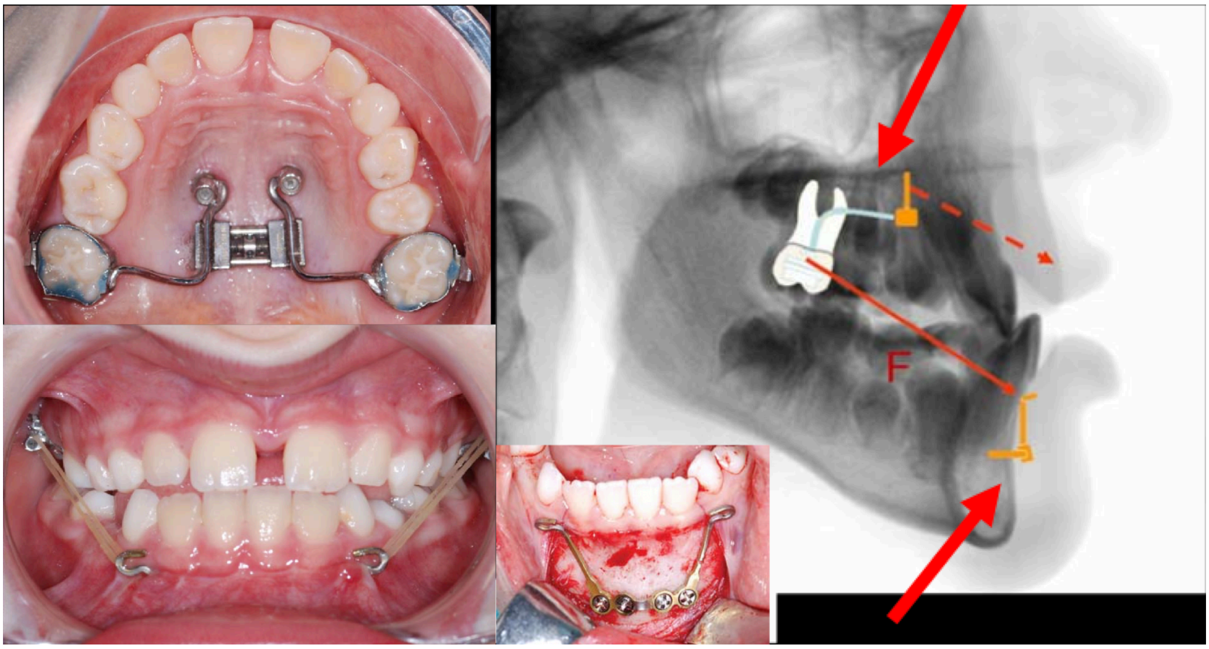


Figure 26 Left side top and bottom: Hybrid Hyrax Mentoplate setup. Right side: force vectors illustrated. Bottom right: large mucoperiosteal flap required to fit the Mentoplate. Slide courtesy of Prof Benedict Wilmes, through personal communication.

A mucoperiosteal flap is raised and one miniplate is placed and fixed with 3-4 screws apical to the mandibular incisors. The extensions of the Mentopate are adapted and bent into hooks for Class III elastics. Wilmes et al.[24] presented seven successfully treated cases with this protocol. This Hybrid Hyrax Mentoplate combination offers several advantages.[211] First, there is no need for extraoral traction, making it potentially easier for patients to accept. Second, compared with the BAMP protocol, the Hybrid Hyrax fulfils the role of the maxillary miniplates, which have a high failure rate, and reduces the number of flap surgeries. Third, the Hybrid Hyrax makes it possible to incorporate maxillary expansion into treatment. Finally, the Mentoplate can be placed before the eruption of the mandibular canines. With the BAMP protocol, the treatment cannot be commenced until after the eruption of the mandibular canines, as the miniplates are placed between the canines and the lateral incisors while the Mentoplate is placed apical to the incisors, avoiding the developing canines. This means that treatment with this protocol can be started earlier, where it is considered the maxillary sutures are more responsive.

Only two studies have examined this protocol so far.[24,212] Katyal[212] et al. analysed the records of 14 consecutively treated cases with a mean age of 10.4 years old. The results showed significant maxillary protraction, with a 2.1-degree improvement in the SNA angle. The overall skeletal pattern improved, with a 1.9-degree improvement in the ANB and a 3.1 mm increase in the Wits appraisal. The effect on the mandible seemed smaller than that reported in facemask studies. There were no significant dental side effects. Willmann et al.[13] then compared the Hybrid Hyrax Mentoplate protocol with the Hybrid Hyrax facemask. They looked at the pre- and post-treatment lateral cephalograms of 34 cases, with 17 in each group. The results showed that the effect on the maxilla was almost identical, with both groups showing a 2.23 degree increase in the SNA angle. Nevertheless, the facemask group showed a greater reduction in the SNB, which was attributed to the greater backward rotation of the mandible in the facemask group. The mandibular plane angle did not significantly change in the Mentoplate group, while it increased by 1.2 degrees in the facemask group. The authors concluded that the effects of the two protocols were very similar, but that the Mentoplate protocol may be a better choice in cases where greater vertical control is required.[13]

7.5.7.Fixed appliance therapy

The use of simple fixed orthodontic appliances to correct anterior crossbites and Class III malocclusion is well documented, although it may not necessarily fall under the category of growth modification treatment.

7.5.7.1.Partial fixed appliance therapy

Fixed appliances can be very reliable and can produce timely results for dental Class III treatment and pseudo-Class III treatment. Partial fixed appliances (described commonly as 2x4s or 2x2s) can be used with banded or bonded molar attachments, or even deciduous molar attachments.[43] Occlusal stops may be used in some cases with deep overbite to disclude the incisors and facilitate the crossbite correction. Usually, an expanded arch wire (or "stopped arch") with distal stops to the molars is used to tip or torque the maxillary incisors labially.[43] Gu et al.[213] compared the correction of anterior crossbite with 2x4 treatment with facemask therapy. They found that although both methods successfully corrected the anterior crossbite, the correction was purely dental in the partial fixed appliances group, while in the facemask group, the correction was 60% dental and 40% skeletal. They recommended that the 2x4 option be considered only in cases where the anterior crossbite is dental in nature.[213]

7.5.7.2.Comprehensive fixed appliance therapy

Skeletal discrepancies that cannot be resolved during mixed dentition by growth modification may require comprehensive fixed appliance therapy and/or even surgical treatment later.[43] Additionally, treatment of Class III malocclusion in adolescence is indicated in many instances to follow growth modification treatment, in order to establish a stable occlusion and control some of the relapse potential, especially during the rapid growth phase.[44] Furthermore, some cases that are managed during childhood will recur during the adolescent growth spurt and require retreatment.[44] Class III elastics and/or extractions sometimes permit mild Class III skeletal cases to be camouflaged by tooth movement and dento-alveolar compensation. As a guide, Ngan[42] proposed that a growth response treatment analysis be performed before a comprehensive fixed appliance treatment is commenced to avoid disappointing outcomes.

For patients with continued worsening of the Class III pattern due to disproportional sagittal and vertical growth, there may be little that can be done until growth has ceased.[4] Only then can a decision be made about treatment with either camouflage or orthognathic surgery.[4] In his textbook, Proffit describes camouflage treatment as the movement of teeth and dento-alveolar structures to improve the occlusal relationship in a malocclusion caused by a skeletal discrepancy without correcting the skeletal discrepancy itself.[43] In such cases, "the envelope of discrepancy" described by Proffit and Ackerman is a good guide to what dental treatment can achieve compared to what surgery may be able to achieve.[43] The challenge with Class III treatment using camouflage is that, in many cases, retraction of the lower incisors can result in accentuation of the chin prominence with a poor soft tissue profile.[43]

The characteristics of a good candidate for camouflage treatment are as follows:[2,43]

- too old for growth modification
- mild skeletal Class III
- good alignment of teeth
- good vertical facial proportions.

Treatment options include:

- Fixed appliances with Class III elastics[2,43]
- Lower premolar extraction[214]

- Lower incisor extraction[215]
- Lower second molar extraction[216]
- Using a skeletal anchorage device to distalise the entire lower arch.[217]

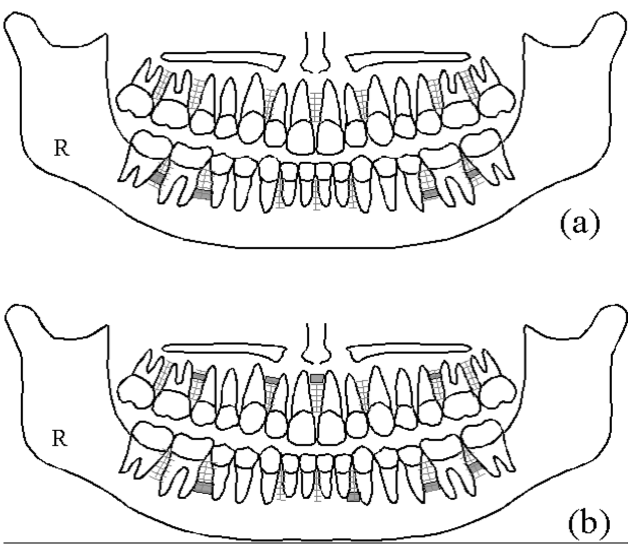
7.6.Anatomical considerations in miniscrew placement

The main advantage of miniscrews over other skeletal anchorage devices (such as osseointegrated palatal implants, onplants and miniplates) is that they can easily be placed in an orthodontic office with local analgesia, with no need for flap surgery or general anaesthetic.[211] When planning for miniscrew placement, several anatomic factors play a role in deciding where the screw should be placed. These factors include:

- Proximity to the roots and interradicular bone
- Proximity to vital structures such as major nerves and vessels
- Cortical bone thickness and bone quality
- Soft tissue thickness and attached or unattached gingiva
- Type of anchorage needed and biomechanical demands.

7.6.1.Interradicular miniscrew placement

The alveolar process close to the dentition and between the roots of the teeth is a very popular site, provided there is sufficient bone and space between the roots of the teeth. One of the earlier studies by Schnelle et al.[218] radiographically evaluated the availability of bone for the



placement of miniscrews using 60 panoramic radiographs of 30 subjects before and after orthodontic treatment. The study looked for areas where there was 3-4 mm of bone available

Figure 27 Interradicular safe miniscrew placement zones as assessed from panoramic radiographs by Schnelle et al.[218]

interradicularly and measured the vertical distances at which the bone was available. The authors identified the area mesial to the maxillary first molar between first and second premolar and mesial and distal to the mandibular first molar as the areas that consistently had enough bone and space between the roots to allow for the safe placement of miniscrews. Sufficient bone was usually found a little more than halfway down the length of the roots, which in most cases would be an area of unattached gingiva (Figure 27).[218] Although the study provides a useful insight into areas for miniscrew placement, there are certain limitations that need to be considered:

1. The study used panoramic radiographs, which suffer from magnification and distortion problems. Vertical magnification in panoramic radiographs has been reported to be approximately 18–21%, whereas horizontal magnification is more unreliable.[219]
2. Another problem inherent to panoramic films is the error in root angulation. In their study Mckee et al., [220] examined mesiodistal tooth angulations with four different panoramic machines. They found that the largest distortion of angulations in the maxillary dentition was an exaggerated root divergence between the canine and first premolar. The largest difference in the mandible was an exaggerated convergence between the canine and lateral incisor.

Nevertheless, several important conclusions can be drawn from this study:[218]

- Firstly, the study showed that bone availability increases with orthodontic treatment, which means that root alignment may improve the availability of bone for screw placement. This should be taken into consideration during treatment planning. For example, if miniscrew anchorage is part of the treatment plan, intentional root divergence at the site of placement may be planned, or at least care should be taken to avoid converging the roots at the site where screw placement is planned.
- Secondly, bone availability increases as the implant is placed further apically, but this also reduces the chances of placement in attached gingiva. In such cases, the angulation at which the screws are inserted can help overcome part of the problem. Placing the

screw in the attached gingiva and then angling it apically will place the screw towards the area where the roots begin to diverge.[218]

- Thirdly, it is not recommended that panoramic radiographs be used to assess bone availability for miniscrew placement, and ideally a CBCT (if available) should be used. However, a periapical radiograph with the paralleling technique could be sufficient.

CT and CBCT studies provide a more reliable source of information about safe zones for miniscrew placement. Poggio et al.[221] conducted a CBCT study using the NewTom Scan system to provide a guide for "safe zones" for miniscrew placement. They studied images of 25 maxillae and 25 mandibles and measured (for each interradicular space) the mesiodistal and the buccolingual distances at 2, 5, 8, and 11 mm from the alveolar crest.

In order of safety, the authors listed the "sites available in the interradicular spaces of the posterior maxilla" as follows:

- On the palatal side, the interradicular space between the maxillary first molar and second premolar, 2-8 mm from the alveolar crest.
- On the palatal side, the interradicular space between the maxillary second and first molars, 2-5 mm from the alveolar crest.
- Both on the buccal or palatal side between the second and first premolar, between 5 and 11 mm from the alveolar crest.
- Both on the buccal or palatal side between the first premolar and canine, between 5 and 11 mm from the alveolar crest.
- On the buccal side in the interradicular space between the first molar and second premolar, from five to eight mm from the alveolar crest.
- In the maxilla, the more anterior and the more apical, the safer the location becomes.

The following is the order of the safer sites available in the interradicular spaces of the posterior mandible:

- Interradicular spaces between the second and first molar.
- Interradicular spaces between the second and first premolar.
- Interradicular spaces between the first molar and second premolar at 11 mm from the alveolar crest.

- Interradicular spaces between the first premolar and canine at 11 mm from the alveolar crest.

Still, the authors stressed that their findings are statistical evaluations of data coming from a group of non-treated patients and that they only represent a guide for the clinicians, without eliminating the need for radiographic evaluation of available bone prior to miniscrew insertion.[221]

From the above studies, it does seem that the availability of bone for the placement of miniscrews in the alveolar process may be problematic for children in mixed dentition.[211] Most of the sites assessed to have adequate bone would be too close to the developing tooth buds of the permanent premolars and canines, or to the developing second molars. Thus, safe intra-alveolar placement may be considered very difficult for the sake of orthopaedic treatment.

7.6.2.Palatal Miniscrew placement:

The palate is often advocated as a favourable site for miniscrew placement due to the wider distance between the roots palatally and also due to the possibility of placing the implants midpalatally, which would be at a safe distance from the roots. The palate is also entirely covered by attached mucosa, which makes peri-implant inflammation less likely.[211] More importantly is the quality of the bone; the palate is thought be adequate.[195,197,222] Quality of bone has been found to play an important role in the primary stability of miniscrews and their success. Dalstra et al.[223] developed two 3D Finite Element models to evaluate the load transfer

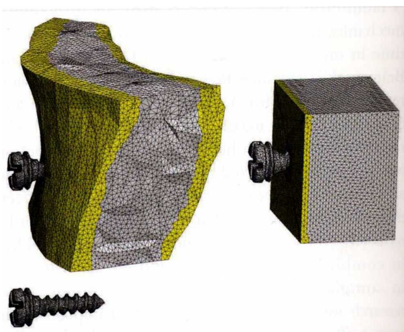


Figure 28 From Dalstra et al.[223] Left: geometrically accurate finite element model. Right: the parametric model. The yellow part represents the cortical bone and the grey the trabecular bone.

from miniscrews to the neighbouring bone (Figure 28). The first model was a geometrically accurate representative of a real bone-to-miniscrew interface, and was built on Micro CT images of a miniscrew implant placed in a human mandible obtained from autopsy material. In the second model, the bone from the first model was converted to a standard block of material rectangular in shape. The second model was used to systematically study the effect of varying cortical bone thickness and trabecular bone density on local strain distribution. The simulated cortical thickness was increased from 0 to 2 mm in 0.5 mm increments. The resulting number of models was 15. The force applied was 50 g, directed mesially to the head of the miniscrew.

Dalstra et al. found that the bulk of the load transfer occurred within the cortex for a single revolution of the screw thread. This was also confirmed by the images from the Micro CT, which showed that the screw is almost fully supported in the cortex and only loosely supported by the trabecular bone (Figure 29).

When the same was tested on the parametric model, it showed similar results to the geometrically accurate model, with load transfer predominantly taking place at the cortex. These results suggest that cortical bone thickness plays a significant role in the load transfer from miniscrews to the bone, while the density of the trabecular bone plays a minor role. The authors then attempted to relate the strains occurring in the bone with miniscrew loading to the mechanostat theory by Frost [224] in order to see which strains were within the MES (minimum effective strain). Strains within the MES would be able to evoke bone modelling, increasing the stability of the miniscrew, which would exceed the MES and thus lie within the pathologic overload window and evoke bone resorption with subsequent loosening of the implants. They found that Frost's pathologic window was reached only with a thin cortex (less than 0.5 mm) overlying low-density trabecular bone. Therefore, miniscrews should ideally not be placed in locations where the cortical bone is thin and supported by poor-quality trabecular bone.[223]

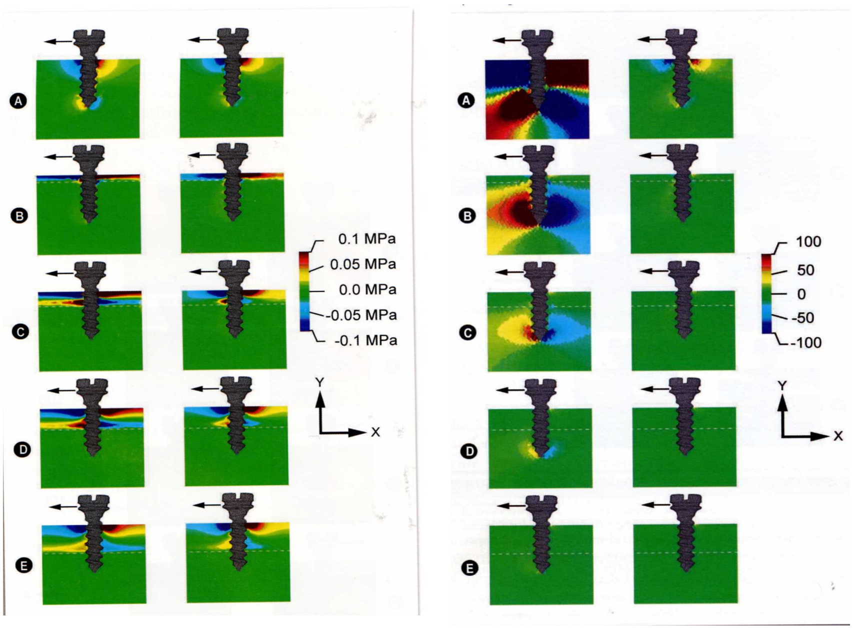


Figure 29 From the finite element study by Dalstra et al.[223] Left: distribution of transverse stress. Right: distribution of transverse strain. Within each figure, the left column represents low-density trabecular bone and the right column high-density. A. is 0.0 mm cortical bone thickness; B. 0.5 mm; C. 1 mm; D. 1.5 mm; E. 2 mm.

The anterior palate has been found to have areas of adequate cortical bone thickness,[195,197] and the area paramedian to the suture along the third Rugae line (designated the 'T-Zone'[196,222]) has become a recommended site for miniscrew placement in the palate. This recommendation was based on CT and CBCT studies.[195,197,225,226] A study by Kang et al.[227] investigated the bone thickness in the palate at midpalatal and paramedian areas in order to gauge the suitability of the different areas for miniscrew placement. The study was conducted on high-resolution CT scans of 18 adults, 9 males and 9 females aged between 18 and 35, with a mean age of 26.6 years. The cortical bone thickness was measured at 80 coordinates at regular intervals across the median and paramedian part of the palate. The authors created a map for available bone thickness in the palatal area for males and females and colour coded it based on the average thickness (Figure 30).

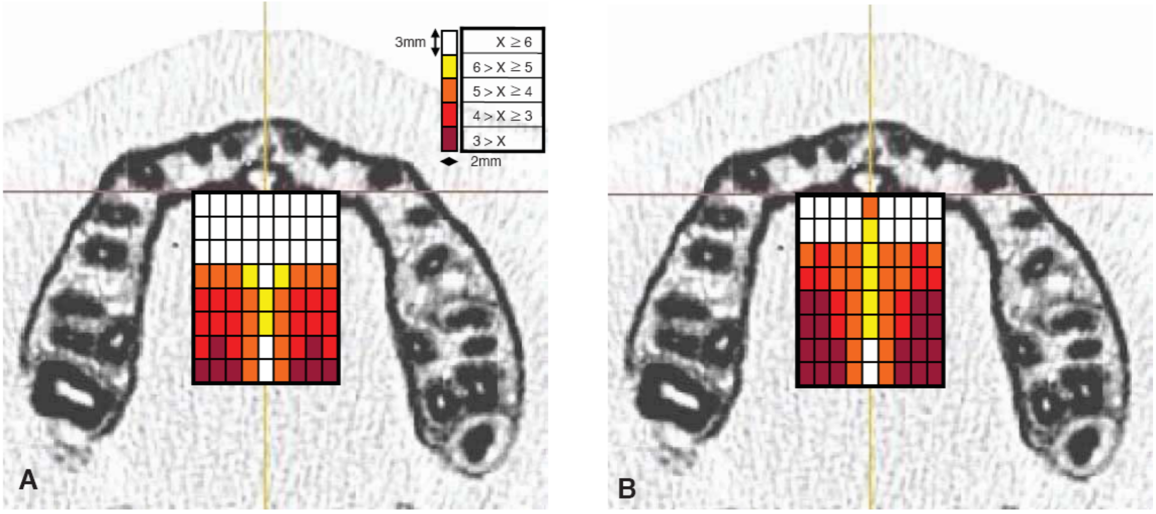


Figure 30 Colour maps for mean palatal bone thickness, A. for males and B. for females. The areas with light colours (white and yellow) represent areas of thick bone, which are safer for miniscrew placement. [227]

Kang et al. found that the best available bone was in the anterior palate in the Rugae area, as well as at midpalatal suture and in the 1 mm on either side of the suture going distally. They indicated that the paramedian part of the palate posterior to the first premolar area and in the molar area had very thin bone. However, this was a study on adults, and the authors highlighted that the placement of miniscrews in the midpalatal suture should be avoided in younger and growing individuals. On a larger sample using CBCT data and study models of 125 patients, Hourfar et al.[225,226] identified that the cortical bone thickness was highest in the anterior palate, becoming very thin posteriorly. They also managed to correlate their findings with the study models, and established that the line along the third Rugae line of the anterior palate corresponded well with an area that was safe and provided adequate bone support for miniscrew placement. Thus, they provided a clinical guide for safe and stable miniscrew placement.[225,226] In another study that included younger adolescent subjects, Becker et al.[197] observed 30 CBCTs to assess the ideal area for miniscrew placement, as well as assessing whether there was an ideal angle for the insertion of miniscrews in the palate. Their findings confirmed those of previous studies – i.e., that cortical bone thickness was best in the anterior palate and that the area along the line connecting the first premolars (which coincides with the third Rugae line) was the most ideal area for placement. They also mentioned that anterior to that line, the risk for perforating the nasopalatine canal and injuring the neovascular bundle increased, as did the risk of injuring the roots of the incisors. They found that the insertion angle did not make a significant difference in the areas with the greatest bone thickness. The insertion angle was significant only in the median positions anterior to the line (where a 20-

degree forward angulation was recommended) and posterior to the line (where a 30-degree inclination posteriorly was better). In the paramedian sites, it seemed to be more beneficial to tip the miniscrews 20-30 degrees posteriorly.[197]

7.6.3.Soft tissue thickness

Another factor critical to success is the soft tissue thickness at the site of placement, as it will influence decisions on the length of the neck of the screw. Thick soft tissue requires a longer neck or collar.[228] If the miniscrew does not have a long neck or collar, the screw threads will be in soft tissue, which may cause irritation and inflammation of the peri-implant soft tissue, which has been found by a number of studies to contribute significantly to miniscrew loosening and an increase in failure rate.[229-231] It also influences the total length of the screw and the total loading moment on the screw, as the longer the part outside the bone the greater the loading moment will be,[228] which in turn contributes to the success rate. A cadaver study by Kim et al.[232] investigated the soft tissue and cortical bone thickness in the maxilla for miniscrew placement. The authors examined the maxillae of 26 human cadavers, looking at the area between the teeth from the first premolars to the second molars on the buccal and palatal aspects, as well as the soft tissue thickness at the area near the midpalatal suture. They found that the palatal soft tissue thickness increased gradually apically from the cemento-enamel junction, then thinned out again over the midpalatal suture. The midpalatal mucosa was thickest at an area 4mm distal to the incisive papilla, remaining uniformly thick 1 mm posterior to this point. Additionally, the mucosal thickness on the palatal side was thickest 6 mm from the cemento-enamel junction between the first and second premolars and between the first and second molars. Between the second premolar and first molar, it was thinnest 2 mm apical to the cemento-enamel junction. They concluded that miniscrews should be placed in the area with the thinnest soft tissue and the thickest cortical bone in order to gain maximum stability.[232]

From the above, it seems that the paramedian area in the anterior palate along the third Rugae line seems to provide a good combination of good cortical bone thickness, safe distance from roots, nerves and blood vessels and thin keratinised mucosa, making it ideal for miniscrew placement.

7.7.Success and failure rate for miniscrews

Since their introduction two decades ago, the factors affecting the success or failure of miniscrews have been extensively studied.[97-99,229-231,233-240] In a recent meta-analysis, the overall success rate of miniscrews was found to be 84%.[241,242] Several variables have been studied in relation to their potential effect on the success rate of miniscrews, including:

- Screw length and diameter
- Insertion method (e.g., self-drilling vs. self-tapping screws)
- Pre-drilling vs. no pre-drilling
- Insertion torque
- Thread design and various coatings
- Area of placement:
    - attached vs. unattached gingiva
    - buccal vs. palatal/lingual
    - maxilla vs. mandible
- Mode of loading: immediate vs delayed loading
- Magnitude of force used for loading
- Periimplant inflammation
- Growth pattern
- Type of malocclusion
- Root proximity.

Many other factors have been studied beyond those listed above. It is difficult to draw a conclusion about the effect of the length and diameter of the implant on success rate, due to the fact that in studies that used implants of different lengths, the diameter of the implants was also different. Miyawaki et al.[229] recorded 83.9% success with implants of 1.5 mm in diameter and 11 mm in length, versus an 85% rate for implants 2.3 mm wide and 14 mm long. However, they recorded a 0.0% success rate for implants 1 mm wide and 6 mm long. Thus, it appears that above a certain diameter and length, there may be no difference in the success rate in relation to the miniscrew dimensions. One study[234] used implants of the same diameter but different lengths. Looking at 1.2 mm diameter miniscrews with 6 mm and 8 mm lengths, the authors recorded significantly higher success with the 8 mm miniscrews (84.7%) as opposed to 72.2% with the 6 mm miniscrews.[234]

Several other studies have concluded that length and diameter of the implants was not significant in terms of the screw's ability to resist orthodontic loading.[229-231,235,238] An important point related to the success of implants was the length of the part inside and outside the bone. Not screwing the implant all the way in, or in cases of thick mucosa as in the palatal shelves (where a large portion of the implant is outside the bone), reduces the implant surface bone contact area. Moreover, it increases the distance between the point of force application on the head of the implant and the centre of resistance of the implant in the area in contact with the bone surface, thus generating a larger moment on the implant.[228] Additionally, the finite element models by Dalsra et al.[223] demonstrated that the main load transfer was at the cortex, while the remainder of the miniscrew was deformed in a tipping mode. A shorter miniscrew would result in lower resistance of the trabecular bone against deformation, leading to higher bone strains. With this in mind, very short miniscrews should be avoided; 7 mm should be enough to avoid this risk.[223] The length of miniscrews may be an important factor if the longer miniscrew is able to engage a second cortical plate. Bicortical engagement seems to increase the success of the miniscrews, allow for more primary stability and reduce the tendency of miniscrews to tip or bend with loading.[243,244] This can be very pertinent when a miniscrew is being placed in the anterior palate, as a longer miniscrew may be able to engage the cortical bone at the floor of the nose in addition to the palatal bone.

Another consideration is the diameter of the miniscrews and their resistance to fracture during insertion and removal. Screws of a small diameter are more likely to fracture during insertion or removal. But a small diameter has the advantage of reducing the risk of injury to the roots of the teeth when the screw is placed in the interradicular space. According to Melsen and Costa[245], miniscrews should have a sufficiently large diameter to resist fracture but still be small enough to allow safe placement with minimal risk for root injury. In a sample of 59 miniscrews[234] of 1.2 mm diameter, two fractured during insertion, and in another study[235], eight implants fractured, seven of which were 1.2 mm in diameter. Most other studies (which used screws of 1.3 mm in diameter and above) recorded no fractures.[98,229-231,233] There does not seem to be a consensus on the minimal diameter, but several factors should be taken into consideration. Firstly, it is important to consider the differences between self-drilling and self-tapping screws. Self-drilling screws sustain more torque during insertion and so their diameters should be larger than self-tapping screws.[234] Additionally, the thickness of the cortical bone will also have an impact. Areas of denser cortical bone, such as the posterior mandible or the anterior palate, may require larger diameter miniscrews.[234] Carano et al.[233] examined the strength of three different miniscrew systems all with 1.5 mm diameter and concluded that all had sufficient strength to resist fracture during insertion. The screws were able to resist torsional forces of up to 40 N. They also showed that reducing the diameter of a screw by 0.2 mm dropped its strength by 50%. They concluded that a minimal diameter of 1.5 mm should be considered.[233] The diameter of the miniscrews plays a significant role in interradicular placement for the safety of the neighbouring teeth. In the anterior mid-palatal area, safety is, perhaps, less of a consideration and miniscrews can afford to be slightly bigger in diameter, as with the Benefit system (PSM Medical Solutions, Gunningen, Germany) 2 mm and 2.3 mm are used.

The site of placement can be considered one of the major factors influencing the success and failure of miniscrews. Studies have consistently shown that palatal placement is more successful than buccal interradicular placement,[98,99,236,237,246-248] with particularly high success rates in the anterior palate. A recent meta-analysis examined 61 studies and concluded that the success rates in the palate were higher for all placement sites compared to buccal interradicular placements.[99] In the palate, the success rate was 98.7% for midpalatal, 95.5% for paramedian and 94.5% for parapalatal insertion. Buccal insertion demonstrated a lower success rate than the palatal sites. Additionally, the success rate in the maxilla was higher (at 90.4%) than in the mandible (87.7%) for the interradicular sites.[99] There are many possible factors that can play a role in the increased failure rate for interradicular placement, but root proximity is probably one of the major factors. Kuroda et al.[97] found that proximity of the miniscrews to the roots of teeth was a major risk factor for failure. The study examined 216 titanium miniscrews placed in 110 patients. They categorised the implants according to the proximity to the roots in periapical radiographs into 3 categories (Figure 31). In category I, the screw was absolutely separate from the root; in category II, the apex of the screw appeared to touch the lamina dura; and in category III, the body of the screw was overlaid on the lamina dura.

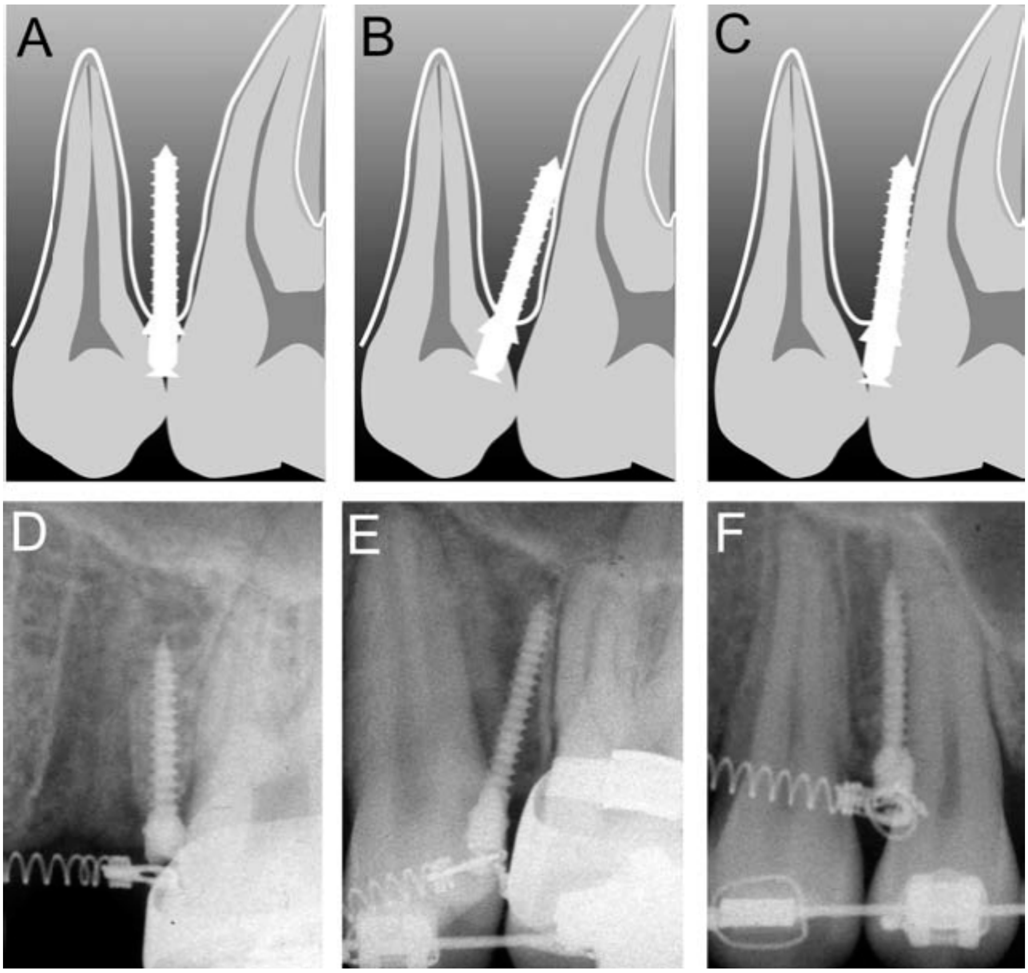


Figure 31 from Kuroda et al.[97] A, B and C are schematic illustrations of the classification. D, E and F represent the classification applied to radiographs. (A and D) the screw was absolutely separate from the root; (B and E) the apex of the screw appeared to be touching the lamina dura; (C and F) the body of the screw overlaid the lamina dura.

The results showed a significant correlation between success rate of the screws and their proximity to the roots. There were significant differences in success rates between categories I and II, I and III, and II and III. Although screws in all three categories in the maxilla and categories I and II in the mandible showed high success rates (above 75%), screws in category III in the mandible had a low success rate of 35%. The authors thus concluded that the proximity of a miniscrew to the root is a major risk factor for its failure. This tendency was more pronounced in the mandible. The authors also noted that even though category I with no proximity to the roots in the maxilla showed the highest success rate, 4% of those implants still failed, indicating that there are other factors which contribute to the success or failure of a screw. It should also be noted that 20% of category I still failed in the mandible.[97]

A study by Hourfar et al.[98] examined the paramedian insertion site in the anterior palate at the third Rugae line more closely, which is relevant to the use of palatal miniscrews for maxillary expansion. They compared this site to interradicular placement in a retrospective study, reporting a success rate for palatal insertion of 98.4% and 71% for interradicular placement.[98] They used a 1.8 mm diameter miniscrew, which may explain the slightly higher-than-average failure rate of the interradicular miniscrews, as this slightly larger diameter would increase the risk of root proximity compared to smaller miniscrews. They hypothesised that one of the reasons for the high success rate of miniscrews placed in the anterior palate was that they are usually used as two miniscrews in tandem, and that this increases the total surface area of the miniscrew, bringing it closer to the larger surface area of the Straumann osseointegrated palatal implant[246], which has a reported success rate of over 95%. However, in the sample reviewed by Hourfar et al.,[98] many of the cases were treated with a Hybrid Hyrax appliance for maxillary expansion, meaning that the miniscrews were not being used in tandem but rather against each other in a reciprocal anchorage model. Perhaps better explanations for the high success rate of the palatal miniscrews can be outlined as follows: firstly, the high-quality cortical bone usually found in the anterior palate, secondly, the fact that they are in keratinised mucosa, and thirdly, the thinness of the soft tissue.

Overall, the literature points to the placement of miniscrews in the anterior palate as a highly reliable site with a high success rate and reduced complications.

7.8. The Benefit miniscrew system

Although the anterior palate provides several advantages for miniscrew placement from a biological standpoint, it is challenging from a biomechanical standpoint. This is because the miniscrews are at a distance from the dentition, where forces are usually applied. The position of the miniscrews in the anterior palate makes it difficult to apply forces directly, and indirect anchorage is thus required. This may be difficult to achieve using traditional miniscrew designs where the head is designed to receive orthodontic forces directly via coil springs, elastics or wires. The Benefit system (PSM Medical Solutions, Gunningen, Germany) (Figure 32) introduced by Wilmes and Drescher[185] in 2008 offers a solution to this challenge. Wilmes and Drescher introduced a miniscrew system with interchangeable abutments, thus allowing the miniscrew to act in a manner similar to osseointergated implants, where the implant has an internal thread to which a variety of attachments can be fixed using small fixation screws and abutments. The appliance manufacturing would occur indirectly in the laboratory, but direct intraoral adjustment and placement of the appliance supra structures was also possible. The Benefit miniscrews (PSM Medical Solutions, Gunningen, Germany) were designed with two diameters (2 mm and 2.3 mm) and four lengths (7, 9, 11 and 13 mm).

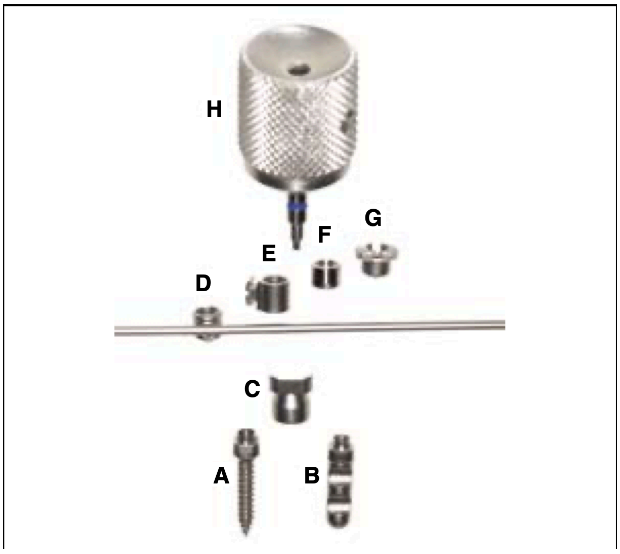


Figure 32 The Benefit miniscrews (PSM Medical Solutions, Gunningen, Germany). A. The Benefit miniscrews with two diameters (2 mm and 2.3 mm) and four lengths (7, 9, 11- and 13-mm); B. Laboratory analogue; C. Impression cap; D. Abutment with welded wire; E. Abutment with welded bracket; F. Plain abutment; G. Abutment with TPA slot; H. Screwdriver for abutments[185].

After miniscrew placement, an impression is obtained (Figure 33). Impression caps are designed to be used to transfer the position of the miniscrew through the impression to the laboratory. Once the impression is taken, laboratory analogues are placed, and the impression is casted for appliance manufacturing on a study model. The analogues then transfer the exact position of the miniscrews accurately to the lab. The superstructure can then be bent, adjusted and welded to the abutments, which are designed to fit the threads accurately in the miniscrew head.

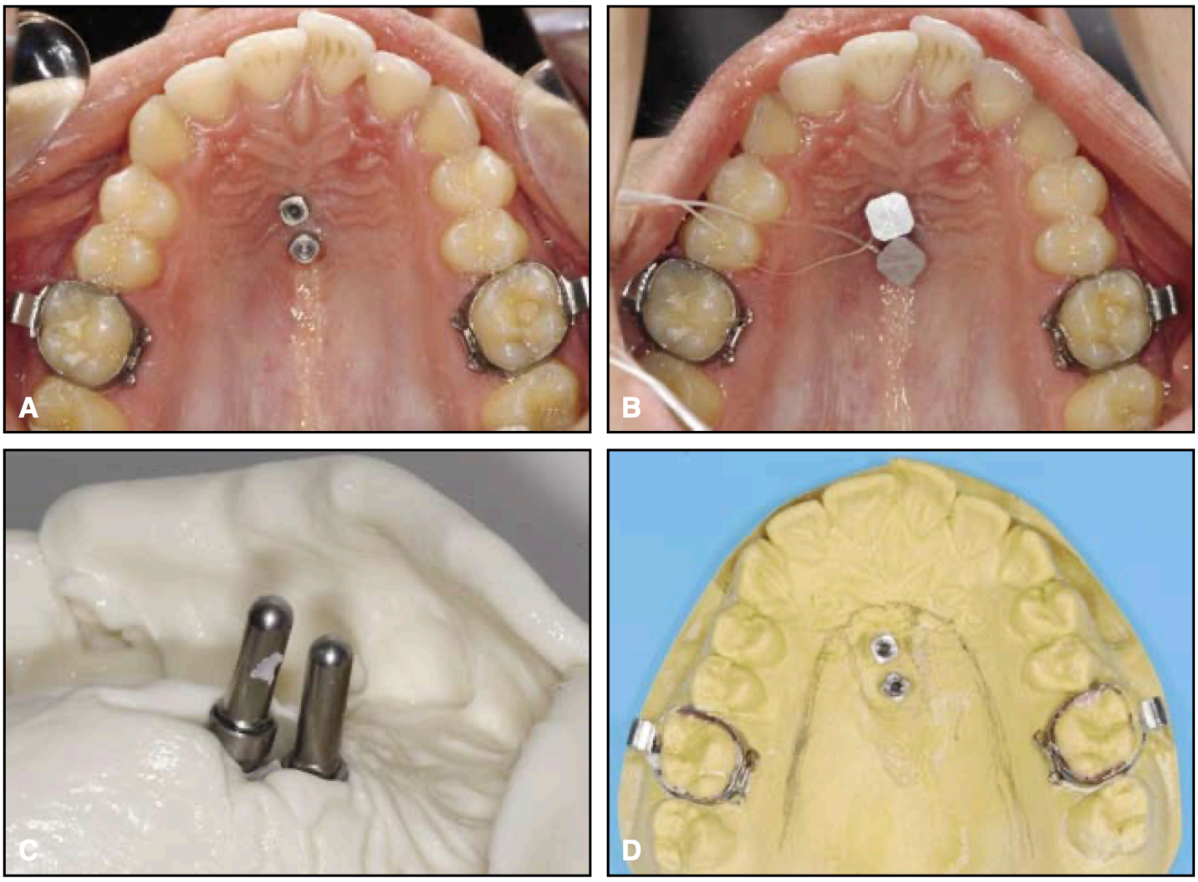


Figure 33 Transferring the miniscrew location to the cast. A. Miniscrews placed; B. Impression caps in position; C. Laboratory analogues placed into impression caps in the impression; D. Final cast with miniscrew analogues[185].

The authors introduced several applications in the article, the Hybrid Hyrax expander being one of them. The use of this system allows the miniscrews to be placed in the area of the best available bone and soft tissue while the mechanics can then be customised indirectly, thus expanding the possibilities for anchorage using the anterior palate.[185]

7.9. CAD/CAM orthodontic appliances

7.9.1.Intraoral scanning and digital models

For decades, study models have played an integral role in the diagnosis and treatment planning of orthodontic cases. In fact, 55% of decision making was found to be based on study models alone.[249] In addition, most orthodontic appliances were constructed on plaster models. As orthodontic records (such as radiographs and photographs) became digitised, the next step was the digitisation of the study casts. Plaster casts provided a three-dimensional diagnostic tool that was an accurate representation of the patients' dento-alveolar structures, while also being inexpensive and relatively easy to manufacture. However, such casts posed several problems in terms of transport and storage[250].

The digitisation of study models started with the scanning of impressions and/or the produced models and proved to be accurate and reliable for diagnosis and treatment planning. It also solved the storage and transport problems associated with casts.[250-252]

The introduction of intraoral scanning simplified the process of obtaining the digital models and eliminated the clinical step of impression taking.[253] Intraoral scanners have been found to be accurate and reliable in obtaining an accurate model of the dentition.[253-256] A systematic review by Rossini et al. found that intraoral scanners are as reliable and accurate as dental impressions.[257] Despite it taking longer to obtain an intraoral scan compared to an alginate impression, the process is considered more comfortable for the patient, especially with the reduced gag reflex.[256] Patients, especially small children, can have a break in the middle of the process without it interrupting the quality of the scan. From a practical point of view, intraoral scanning eliminates the need for an orthodontist to maintain a stock of impression trays and materials. Additionally, the scans can be available immediately for the orthodontist to analyse after scanning, and there is no need for casting or disinfection, wrapping, packaging and sending of impressions to the laboratory. The scan can be sent and become instantly available to the dental laboratory, saving time and money.

7.9.2.CAD/CAM appliance manufacturing

For decades, orthodontic appliances have been manufactured using study casts obtained from impressions. Maxillary expansion appliances in particular were either banded (using two or four bands which were then welded or soldered to the expansion mechanism) or bonded, which involved the creation of acrylic resin blocks covering the dentition with a metal framework embedded in the resin to support it. The construction of banded appliances required the placement of separators (metallic or elastomeric) followed by band sizing and fitting and then impression-taking to transfer the clinical situation to the laboratory for appliance manufacturing.[43] This process usually involved a minimum of three clinical appointments for patients, but often four, namely:

1) Placement of separators
2) Band sizing, fitting and impression
3) +/- placement of separators
4) Appliance cementation.

Although the digital models steadily made their way into the diagnosis and treatment planning side of orthodontics, orthodontic appliance manufacturing using digital technology was lagging behind. CAD/CAM technology has been available in dentistry since the 1980s, with the introduction of the CEREC system, which started with directly milled inlays, then onlays and single crowns, and now bridges.[258] In orthodontics, CAD/CAM technology was first used by Wiechmann et al.[259] to make customised lingual appliances, which later on became known as Incognito (Topservice, 3M Unitek Corp, Monrovia, CA, USA). The system allowed for the digital design of brackets for each tooth individually, then the designed brackets would be manufactured in wax using rapid prototyping. The wax prototypes would then be cast in gold (using the lost wax technique) in order to produce the final bracket. Although revolutionary at the time, it is a fairly labour-intensive and expensive process and could not be easily applied for conventional day-to-day orthodontic appliances such as expanders and other devices. CAD/CAM technology was also used in orthodontics to produce custom bent arch wires using a wire bending robot, which produced the wires based on the virtual prescription in the SuresmileÒ system (Orametrix Inc, Richardson, TX, USA).[260]

For the manufacture of removable and other cemented fixed appliances, however, digital models would have to be printed using rapid prototyping methods and then used for the manufacturing of appliances such as vacuum-formed retainers. This approach was carried out on a large scale by Invisalign (Align technology, San Jose, CA, USA) and now, with the availability of desktop printers, orthodontists can do this in their office.[261] For the manufacturing of other orthodontic appliances, however, such as metallic expanders and appliances that required an acrylic resin base, the scans would still need to be printed in resin and then duplicated into plaster for appliance manufacturing. This made the process more laborious and introduced several additional variables in the form of printing, duplication and casting, which can add to inaccuracy and also made the process less efficient. Al Mortadi et al.[262] manufactured a removable twin block appliance using rapid prototyping directly from virtual models. They used only virtual models and manufactured the appliance from a biocompatible resin. Pre-designed grooves were used to accommodate the metallic clasps and other metallic components, which still had to be added to the appliance afterwards.

Graf et al.[263] introduced the first direct printing of a metallic appliance using a completely digitised process and without the need for any study models in the process (Figure 34). They reported on the production of expansion appliances using metal 3D printing. The process of appliance design is completely digital, and at no stage of the process did they require a study model. A stereolithography (STL) file of the maxillary arch was created using an intraoral scanner (Trios Pod Version, 3Shape, Copenhagen, Denmark) and the STL file was sent to the technical laboratory. The framework was digitally designed using 3Shape Appliance Designer software (3Shape, Copenhagen, Denmark), where the goal was a framework which conformed well to the palatal contours, was as compact as possible, and provided sufficient rigidity. The final design was then exported to the Laser melting machine (Concept Laser, General Electric Company, CT, USA) and printed using the alloy Remanium (Dentaurum, Ispringen, Germany). The appliances were then cemented using light cured resin cement.

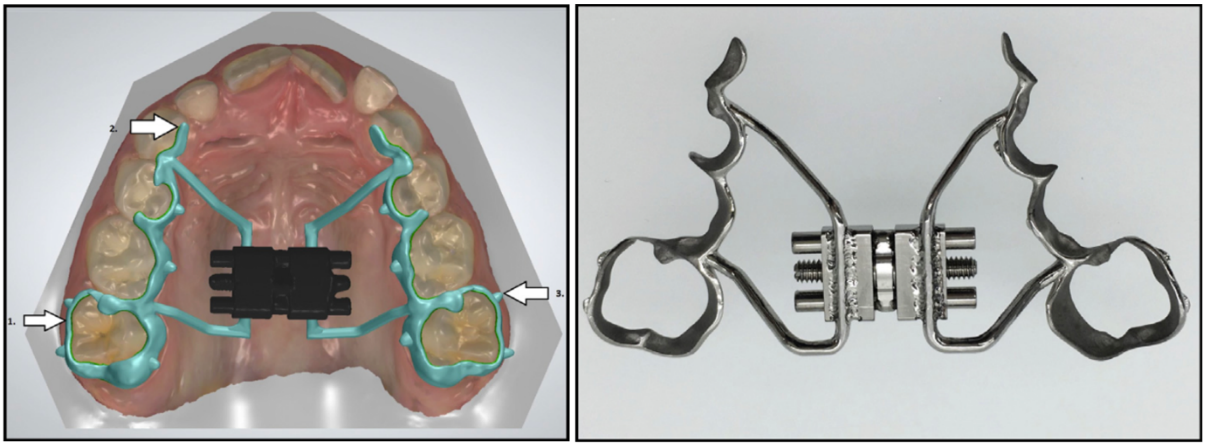


Figure 34 From Graf et al.[263] CAD/CAM Hyrax. Left: the digital design process. Right: The printed appliance.

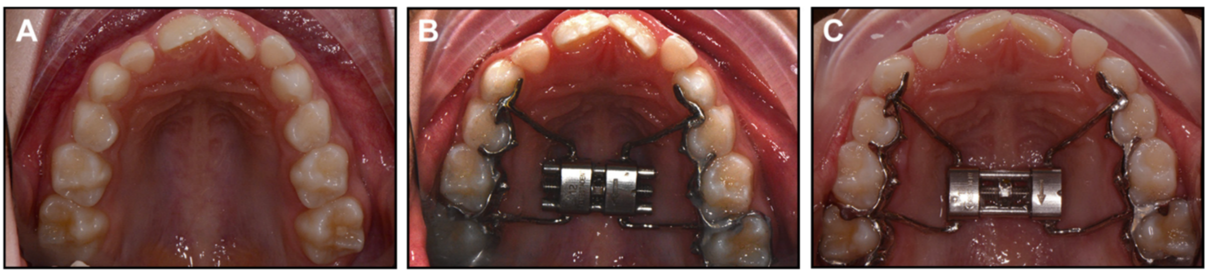


Figure 35 Clinical progression of a case from Graf et al.[263] treated with the CAD/CAM Hyrax appliance.

Graf et al. found the fit of the appliance to be excellent and the removal to be problem-free (Figure 35). The same approach was then used to manufacture a Hybrid Hyrax appliance with two palatal miniscrews.[264] In this case report by Graf et al.[264] the authors also digitally manufactured the rings to accommodate the palatal miniscrews (Figure 36). This paper was novel in that it showed how to accurately transfer the miniscrews to the digital model. The authors highlighted that some intraoral scanners may have difficulty in scanning the miniscrews. This is due to the reflectivity of the metal and the fact that some scanners have difficulty registering the hollow thread part in the miniscrew head. Software algorithms tended to delete the part automatically, registering it as an error.[264] One method to overcome such a problem was to use scan bodies, which could be placed over the miniscrews to facilitate the scanning. The scan bodies would then have a digital analogue with the exact shape of the miniscrews, which the laboratory could then use to replace them in the software.[264]

There are potential problems with the use of scan bodies. Firstly, they can be a hazard for small children, as they can be accidentally swallowed or aspirated. Secondly, they can be a source of error; if the scan body does not perfectly fit the miniscrew or if it moves during the scanning process, this could introduce an error in the miniscrew's position in the digital model, resulting in an ill-fitting appliance. One solution to this problem is to use an opaquer powder to reduce the reflectivity of the metal and allow a better scan.[264] The authors reported that an accurate representation of only three surfaces of the miniscrew head would be sufficient, as this would then allow a digital analogue to be superimposed on the scan, providing a very accurate miniscrew position.[264]

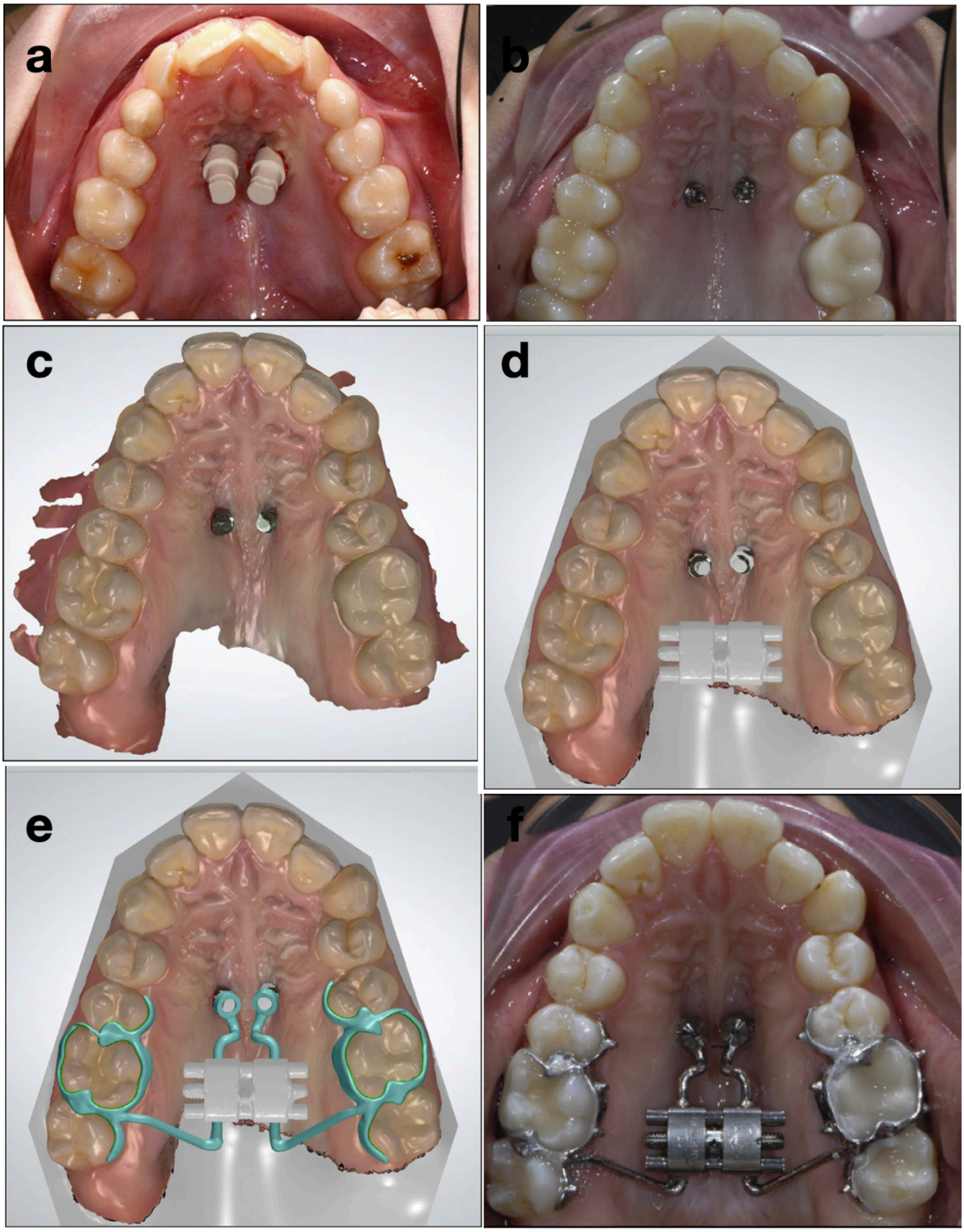


Figure 36 Adapted from Graf et al.[264] A. Scan bodies used with some intraoral scanner; B. After placement of miniscrews; C. Intraoral scan without scan bodies; D. Scan after superimposition of the digital analogues on the miniscrews and virtual placement of Hyrax screw; E. Digital design of framework; F. Finished appliance cemented and secured to the miniscrews.

7.9.3. Advantages of CAD/CAM appliances

Firstly, CAD/CAM appliances can be used to improve and simplify the orthodontic workflow by eliminating all the traditional impression drawbacks, such as patient discomfort and gag reflex. There is no need to stock an inventory of different jaw-specific impression trays and impression materials, and this eliminates some potential inaccuracies that may arise from material shrinkage or expansion during impression-taking and casting. There is also no need to package impressions and send them to the laboratory . Because the printed appliances do not extend into the interdental space, there is also no need for separators. This reduces the number of visits the patient needs to make to the office, as well as eliminating the discomfort associated with separators. In addition, the CAD/CAM method allows excellent communication between the orthodontist and the laboratory, with a great deal of freedom in design to fit the clinical needs of the case. Lastly, the appliances are accurate, as there are limited steps in the manufacturing process with direct printing from the digital design, which reduces human and material error.

Other than case reports, no study to date, however, has evaluated the use of CAD/CAM expanders on a sample of consecutively treated cases.

7.10. Compliance with Class III treatment regimens

Orthopaedic management of Class III in growing children has historically revolved around the use of extraoral devices, such as the chin cup and the protraction facemask. Both methods require good patient compliance for results to be achieved. In studies on the facemask[3,14,135] in particular, researchers have requested their patients to use the facemask for 13-16 hours every day, and the typical treatment durations have been in the vicinity of 9-12 months. Studies on the chin cup required even longer treatment duration of up to five years, with 9-16 hours of wear required.[107,108,112] However, no objective assessment has been made in those studies to evaluate the degree to which patients actually adhered to the regimen, nor how patient compliance correlated with study outcomes. In many orthodontic treatment approaches, compliance with treatment plays an important role in the success of treatment. This has been studied more extensively with regards to managing Class II malocclusion with functional appliances[16,265] and the cooperation of patients with removable orthodontic appliances such as retainers.[266] More recently, several studies have used sensors designed to objectively monitor compliance.[267,268] The TheraMon System[269] (Dentaurum Italia Spa, Bologna, Italy) is one such device, and it has been used in numerous studies to measure patient compliance with removable appliances as well as extraoral devices, even in applications outside of dentistry.[270] The device works by measuring the temperature of its environment at regular intervals. The recorded data can then be transmitted wirelessly to a dedicated workstation and the results can be displayed by a simple graph. It can give the practitioner an objective overview of a patient's compliance profile over a period of time. Studies employing this device have been able to shed some light on several aspects of compliance with orthodontic appliances.[16,17,269,271]

Overall, patients have tended to overestimate the amount of time for which they have worn appliances. Furthermore, both patients and their parents have tended to overestimate compliance with appliance wear protocols when actual wear time was measured objectively.[272] It seemed that patients wore the appliance, on average, between 50% and 65% of the prescribed times.[267] The use of a monitoring device did not improve compliance;[16,17] however, it made patients' estimates of their own appliance wear more accurate and less inflated.[17] Compliance with removable appliances was marginally better than with a protraction facemask.[16]

Several factors play a role in patient compliance, including gender, age, cultural background, severity of perceived deformity and relationship with the treating practitioner. For example, younger patients have tended to be more compliant than adolescents[16], while girls have tended to be more compliant than boys.[273] Surprisingly, knowing that their compliance was being monitored has not been reported to significantly improve patients' adherence to the treatment regime; it only made their self-assessment of wear time more accurate.[17] From the medical literature on patient compliance, research concludes that the more a treatment requires a significant lifestyle modification from the patient, the less likely the patient is to adhere to it.[20] It would be fair to say that wearing a protraction facemask for 13-16 hours a day requires significant adaptation from the child, especially if they pursue extracurricular activities and hobbies after school. Such a regime would require significant lifestyle modification, which many children would struggle to keep up for a whole year. The research also showed that compliance was highest at the beginning of treatment, gradually reducing after the fifth month of treatment.[16] There was also evidence that the perceived severity of the deformity may play a role in compliance.[274] Research has shown that those children who perceived their appearance to be more "ugly" because of their malocclusion were more likely to adhere to the treatment regimen[274]. Furthermore, the promise that the treatment or appliance wear would have an influence in improving their appearance also improved their willingness to use removable appliances.[275]

Perhaps an example of the potential effect of compliance is the discrepancy in Class III correction outcomes reported in the literature, in particular with the BAMP protocol. Initial results reported by De Clerck[15,23,200,202,206,209] were exceptional, yet a large multi-centre study[210] reported lesser effects. There may be numerous explanations for this discrepancy in outcomes; however, the effect of the treating practitioner is one factor that can be considered. The outcomes may have been influenced by Dr De Clerck having communicated well with his patients in his small private practice setting. Being the inventor of the method, he may have had more experience and more aids in asserting the need for compliance with his patients. When patient compliance is required for treatment success, it is important that the treating practitioner communicate well with the patient as to why and how their compliance is needed for the success of treatment. Indeed, studies from the medical literature indicate that one of the more important factors in how well patients adhere to treatment is their rapport with their practitioner.[20] This can be particularly challenging in an orthodontic setting when dealing with children and adolescents, as parental approval and support is often needed. Cultural and ethnic factors as well as the dynamics within the family can also affect this. Dr Marshall Rosenberg,[276] author of several books on effective communication, explains that it is important that a request made of somebody does not come across as a demand. He argues that a demand, even one which involves asking for something that may benefit the person, threatens that person's autonomy and immediately triggers a sense of rebellion or resistance. In daily practice, it may be very difficult for even the most committed of orthodontists to try and carefully formulate their requests for patient compliance in a way that would ensure sufficient understanding and thus adherence to the required treatment regime. As mentioned above, objective assessment of patient compliance shows clearly that adherence is falling short most of the time.[16,17]

In general, orthodontists have tried to reduce or eliminate the need for patient compliance in order to make results more predictable. This is well documented in the management of Class II malocclusion, for example. Studies on Class II correction have shown that results are more predictable with fixed compliance-free appliances as opposed to elastics or removable appliances. [25,26,277] Very few studies have attempted a non-compliance approach to Class III correction. Recently, Vanlaeken et al.[94] used an intraoral spring-loaded module CS 2000® appliance (Dynaflex, St. Ann, MO, USA), which connects the upper and lower arches to correct Class III malocclusion, much like fixed Class III elastics. The appliance, however, was purely tooth-borne and demonstrated mainly dental changes in terms of lower arch retraction, upper arch mesialisation and rotation of the occlusal plane. To date, there is only one study on a compliance-free Class III correction appliance that utilises bone anchorage.[95]

7.11.References

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8. Manuscript 1

The skeletal and dental effects of a CAD-CAM tooth-bone-borne hybrid expander with bedtime-only facemask wear compared with conventional RME and facemask wear in the treatment of Class III maxillary deficiency

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8.2. Abstract

This study examined the skeletal and dental effects of a CAD/CAM hybrid expander (HE-FM) in combination with bedtime facemask wear only, and compared the effects of this combination to conventional tooth-borne maxillary expansion and facemask (RME-FM) with 16 hours a day of facemask wear in Class III treatment.

Materials and Methods: This was a retrospective study. All patients were in prepubertal CS1-CS2 growth stages, with a Class III malocclusion. The HE-FM group consisted of 19 patients (5 girls and 14 boys; mean age = 8.3 ± 0.6 years). The RME-FM group consisted of 16 patients (4 girls and 12 boys; mean age = 9.9 ± 1.33 years). The HE-FM group were fitted with two palatal miniscrews which served as bony anchorage for the CAD/CAM appliance. The screws were cemented to the posterior teeth. The RME-FM group were fitted with a bonded Hyrax. After expansion, the patients with the HE-FM were required to wear a facemask to bed only, while the RME-FM group were required to wear one for 16 hours a day. Lateral cephalograms were taken before and immediately at the end of treatment.

Results: The treatment time was approximately 12 months. The Class III malocclusion was corrected in both groups, with forwards and downwards displacement of the maxilla, backward rotation of the mandible, and an increase in overjet. The difference was significant between the two groups. The maxilla advanced by an additional 3.6 degrees at SNA with the HE-FM appliance and an additional 2.4 mm at A-TV ($p < 0.001$). The effect on the mandible was similar in both groups and the overall skeletal change was significantly greater with HE-FM, for which there was an increase in the ANB angle of 3 degrees greater than that in the RME-FM group ($p < 0.001$), as well as a Wits appraisal of 2.6 mm greater than in the RME-FM group ($p < 0.001$). The dental changes were significantly higher for the RME-FM group, with an increase in incisor angulation (U1-SN) 6.2 degrees greater than that in the HE-FM group, and mesial tipping of the maxillary molar by 2.5 degrees ($p < 0.05$). These differences can be attributed to the use of skeletal anchorage. All CAD/CAM appliances fitted well, with no complications or breakages throughout the treatment period.

Conclusion: In prepubertal children, the use of skeletal anchorage for maxillary expansion and protraction significantly increases the skeletal effects and reduces unwanted dental side effects compared to tooth-borne maxillary expansion and protraction. Bedtime facemask wear combined with skeletal anchorage may be sufficient to produce skeletal correction of Class III

malocclusion in prepubertal children. The CAD/CAM appliances were effective and problem free.

8.3.Introduction

For many years the protraction facemask has been used for the management of Class III malocclusion with maxillary hypoplasia.[1] The appliance is usually tooth-borne, with or without maxillary expansion.[2,3] It is believed that maxillary expansion can aid in stimulating a better sutural response to protraction forces; however, the literature remains divided on this issue.[4-6] Maxillary protraction with a tooth-borne facemask produces maxillary downwards and forward growth with some backward rotation of the mandible.[2,3] However, this method is associated with several undesirable dental side effects, such as mesial movement of the maxillary dentition, extrusion and tipping of the maxillary molars and proclination of the incisors, with counterclockwise rotation of the occlusal plane.[2,3] Additionally, mesial movement of the maxillary buccal segments can result in increased anterior crowding.[7]

In recent years, miniplates in the maxilla have been used to provide pure skeletal anchorage and eliminate undesirable dental side effects associated with protraction facemasks.[8-12] Miniplates have been successfully used in the infrazygomatic crest[9,11] and the lateral nasal wall.[10,12] The placement and removal of the miniplates requires invasive flap surgery, which is usually performed under general anaesthesia. The introduction of the miniscrew-supported maxillary expansion and protraction with the Hybrid Hyrax[13] (as proposed by Wilmes et al.) provides a less invasive alternative to miniplates. Miniscrews can be placed in the T-Zone in the paramedian area of the anterior palate.[14,15] This area allows for safe placement of the miniscrews in the best cortical bone in the palate.[14,15] Additionally, this method allows for incorporation of maxillary expansion concomitant with the protraction.[13] This is often desirable as Class III cases often also present with a transverse maxillary deficiency.[16] When compared with tooth-borne expansion and facemask the Hybrid Hyrax with facemask showed significantly greater skeletal effects while reducing the undesirable dental side-effects.[17]

In most studies on facemasks, patients have been required to wear the facemask for 14-16 hours every day, for a treatment duration of approximately 12 months.[2-4,9,12,18] This wear regime would be quite demanding and laborious for most children at a young age, especially if they have after-school activities and hobbies. This requirement alone could lead to poor acceptance of treatment, as well as poor compliance. Studies patients' adherence to medical regimes have shown that treatments requiring greater changes in patient lifestyle can lead to poor compliance and thus poor outcomes.[19] Most studies on facemasks, however, have not measured compliance with prescribed wear times, which, when measured objectively using thermal sensors, has been recorded at only half to two-thirds of the prescribed duration.[20,21]

The manufacture of the Hybrid Hyrax has now been digitised through the use of CAD/CAM technology, which was introduced by Graf et al.[22] As well as facilitating the manufacture of a rigid and well-fitting appliance that ensures adequate force delivery with protraction and expansion, this technology helps to reduce the number of patient visits.[22,23] However, aside from a number of case reports, no studies have employed CAD/CAM appliances in a larger sample of consecutively treated patients. Therefore, the aim of this study is to compare the skeletal and dental effects of a CAD/CAM miniscrew-supported hybrid expander with bedtime-only wear of a protraction facemask (HE-FM) to the effects of conventional tooth-borne maxillary expansion and protraction worn 16 hours a day (RME-FM) in prepubertal children.

8.4. Materials and Methods

Ethics approval X20-0456 and 2020/ETH02668 was obtained from the human research Ethics Committee of the Sydney Local Health District.
This was a retrospective study of 35 Class III malocclusion patients treated with either the CAD-CAM hybrid expander and facemask (HE-FM) or tooth-borne RME with face mask therapy (RME-FM).

Inclusion criteria: patients with a Class III malocclusion and a Wits appraisal of -1 or less, an anterior crossbite or edge-to-edge relationship, a molar Class III relationship and no congenitally missing teeth, no craniofacial syndromes or history of previous orthodontic treatment. All patients were prepubertal in terms of skeletal maturity as assessed by the cervical vertebral maturation index[24] (CS1 and CS2). The HE-FM group were selected from a group of 35 consecutively treated cases treated in the first author's practice between 2016 and 2019. Nineteen cases fit the inclusion criteria, eight cases were excluded due to tooth agenesis and the rest where either skeletally more mature (CS3 or more) or had an overjet of 1 mm or more. The 19 cases in the HE-FM group consisted of 5 females and 14 males, with a mean age of 8.3 years (SD = 0.6; Table 1).

The RME-FM group were selected from a group of 34 consecutively treated Class III cases who had attended the Department of Orthodontics at the University of Ankara, Turkey treated between 2015 and 2018. Sixteen cases fit the inclusion criteria for this study; the rest were excluded due to skeletal maturity of CS3 or more. The sample consisted of 4 girls and 12 boys, with a mean age of 9.9 years (SD = 1.3; Table 1). Lateral cephalograms were obtained before treatment (T1) and at the end of treatment when a positive overjet was achieved (T2).

8.4.1. Treatment protocol for HE-FM group

The CAD-CAM hybrid expander design can be seen in Figure 1. Two palatal miniscrews (Benefit PSM Medical Solutions, Gunningen, Germany) were placed paramedian in the anterior palate in line with the third Rugae line or a line across the palate along the mesial half of the first deciduous molars in the T-Zone, where the best cortical bone can be found.[14,15] Cone beam computed tomography (CBCT) was used to plan the length of the miniscrews. The aim was to achieve bicortical engagement by engaging the thick cortical bone of the anterior palate and the cortical bone at the floor of the nose. A miniscrew long enough to engage both was selected to ensure miniscrew stability and reduce stresses on the screws' necks.[16] The miniscrews' lengths were either 9 mm or 11 mm, with a 2 mm diameter. Appliance fabrication was carried out using the method published by Graft et al.[22] Following miniscrew placement, a stereolithography (STL) file of the maxillary arch was created using an intraoral scanner (Trios Pod Version, 3Shape, Copenhagen, Denmark) and the STL file was sent to the technical laboratory. The framework was digitally designed using 3Shape Appliance Designer software (3Shape, Copenhagen, Denmark), with the aim of ensuring the framework conformed well to the palatal contours, was as compact as possible and provided sufficient rigidity (Figure 1b). The final design was then exported to the laser melting machine (Concept Laser, General Electric Company, CT, USA) and printed using the alloy Remanium (Dentaurum, Ispringen, Germany). Remanium is widely used in the printing of prosthodontic appliances and has recently been introduced to orthodontic appliance CAD-CAM manufacturing by Graf et al.[18] Following printing, the framework was polished and the PowerScrew expansion mechanism (Tiger Dental, Bregenz, Austria) was laser-welded to the bedding prepared in the framework, after which the appliance was polished.

The fitting surface of the appliance was then treated to improve bonding by sandblasting using CoJet Sand (3M Unitek Corp, Monrovia, CA, USA) for 10-15 seconds, followed by the application of a 3M ESPE SIL silane coupling agent (3M Unitek Corp, Monrovia, CA, USA). The finished appliance was then cemented to the teeth using a TheraCem dual-cured resin cement (Bisco, Inc, Schaumburg, IL, USA) following enamel preparation by sandblasting with 50 micron aluminium oxide powder, etching of the enamel with 27% orthophosphoric acid and the application of a dual-cured bonding agent, Excite F DSC (Ivoclar Vivadent AG, Schaan, Liechtenstein). The expander rings were secured to the miniscrews using two fixation screws (Benefit PSM Medical Solutions, Gunningen, Germany) to provide the skeletal anchorage component (Figure 2).

The patients were then asked to turn the expander once a day for one week, resulting in 1 mm of expansion in total. Subsequently, they were asked to turn it every second day for two weeks. At the end of three weeks of initial expansion, facemask wear was initiated, using a Petit style face mask by Ormco (Ormco Corporation, Glendora, CA, USA). Patients were instructed to continue to turn the expander once per week (1/6 mm) until the desired expansion was achieved. The elastic force was adjusted to 8 ounces or 200 g per side, which is equal to 400 g total protraction force. The elastic force vector was adjusted to run approximately 30 degrees down from the maxillary occlusal plane, as described by Ngan.[25] The patients were asked to wear the facemask every night at bedtime only. Updated records were obtained when a positive overjet of at least 3 mm was achieved, and the orthodontist assessed the malocclusion to be slightly overcorrected.

8.4.2. Retention

Following removal of the expander, the stability of the miniscrews was assessed. In order to maintain the transverse expansion, a rigid stainless steel miniplate was placed between the miniscrews and fixed with two fixation screws (Benefit PSM Medical Solutions, Gunningen, Germany).

8.4.3.Treatment protocol for RME-FM group

The RME-FM group were treated with a bonded splint-type expansion appliance with hooks near the canine area for the application of protraction elastics (Figure 4). The appliance was similar to that previously described by Baccetti et al.,[2] and used a Hyrax expansion screw (Dentaurum GmbH and Co. KG, Inspringen, Germany). Patients were instructed to turn the expansion mechanism once a day for three weeks, after which they were to begin wearing a facemask. They then continued turning the expansion screw at the same rate until the desired expansion was achieved. The facemask was adjusted so that elastic force vector was at 30 degrees down from occlusal plane, as described by Ngan et al..[25,26] The patients were instructed to wear the facemask for 16 hours every day with an elastic force of 400 g. Treatment continued until a positive overjet was achieved. A second set of records was then obtained (T2) following the removal of the RME.

8.4.4.Cephalometric analysis

All cephalograms were digitised and traced by the same examiner using OrthoTrac imaging V11.7.0.32 (Carestream Dental, Atlanta, GA, USA). Intra-observer reliability was tested by re-tracing radiographs of 11 randomly selected patients at intervals of one month apart. The intraclass correlation coefficients (ICC) showed excellent reliability, with values ranging between 0.981 and 0.993, except the L1-MP, for which inter-rater reliability was still high at 0.868 (Table 2). The cephalometric analysis used is highlighted in Table 3 and Figure 5.

8.4.5.Statistical analysis

IBM SPSS Statistics software (version 23.0. Armonk, NY: IBM Corp.) was used to analyse the data. Means and standard deviations are presented for all variables. A statistical significance level of $p < 0.05$ was chosen. Normality and homogeneity of variance of the data were assessed using Shapiro-Wilk's test and Levene's test for equality of variances, respectively. Differences between two timepoints within groups were tested for significance using a paired samples t-test. Differences between groups were tested for significance using an independent samples t-test.

8.5.Results

The mean treatment time for both groups was approximately 12 months (Table 1).

All CAD/CAM appliances fit well and there were no breakages or debonds recorded during the treatment time. In two patients, the right-side fixation screw fell out and had to be replaced, but the expander ring remained in position over the miniscrew head. Removal of the appliances was problem free. No miniscrew failures were recorded.

Analysis of the initial skeletal and dental characteristics of the two study groups before treatment (T1) showed that there were no statistically significant differences between the two groups (Table 1).

8.5.1.Comparison of the cephalometric changes in each group between T1 and T2 (Table 4; Figures 6,7 and 8):

From T1 to T2, there were significant changes across most parameters for both treatment groups. Skeletal measurements showed forward movement of the maxilla in both HE-FM and RME FM groups, with an increase in the SNA angle of 4.61 degrees (SD = 2.17) and 0.98 degrees (SD = 0.87), respectively, which was statistically significant ($p < 0.001$). This change was also reflected by the A-TV linear measurement, which increased by 4 mm (SD = 1.74) in the HE-FM group and 1.63 mm (SD = 1.02) in the RME-FM group ($p < 0.001$). The changes in the mandible showed a slight reduction of 0.5 degrees (SD = 1.49) with the HE-FM (which was not statistically significant), and a 1.13-degree (SD = 1.36) reduction with the RME-FM (which was statistically significant; $p < 0.01$). The B-TV linear measurement decreased slightly in both groups; 1.32 mm (SD = 2.1) with the HE-FM ($p < 0.01$) and 1.23 mm (SD = 2.28) with the RME-FM ($p < 0.05$). The overall skeletal change was significant in both groups, with a 5.11 degree (SD = 1.83) increase in ANB and a 6.1 mm (SD = 2.2) improvement in the Wits appraisal in the HE-FM group, as well as a 2.11 degree (SD = 1.17) increase in the ANB and a 3.55 mm (SD = 1.89) improvement in the Wits appraisal in the RME-FM group ($p < 0.001$). The vertical skeletal changes were small but showed statistical significance in the MP-PP angle, which increased by 1.42 degrees (SD = 2.18; $p < 0.01$) in the HE-FM group and 1.34 degrees (SD = 2.47; $p < 0.05$) in the RME-FM group. The mandibular plane angle (SN-MP) increased more in the RME-FM group (1.14 degrees; SD = 1.95) while the change in the mandibular plane angle in the HE-MP group was not statistically significant. The Y-axis angle also increased in both groups, indicating mandibular backward rotation of 0.63 degrees (SD = 1.28) in the HE-FM group and 1.35 degrees (SD = 1.33) in the RME-FM group, both of which were also statistically significant ($p < 0.01$). There was no significant change in either group with regards to the gonial angle. In both groups, there was a counterclockwise rotation of the upper occlusal plane in relation to SN (UOP-SN), which was not statistically significant for either group. The occlusal plane to the palatal plane angle (UOP-PP), however, showed a slight increase in the HE-FM group (1.23 degrees; SD = 3.69), and a decrease in the RME-FM group of 1.19 degrees (SD = 3.01), which was not statistically significant.

There were no statistically significant changes in the upper dental parameters, with the HE-FM group displaying few dental side effects, while there was a significant increase in upper incisor inclination in the RME-FM group, with a 4.9 degree (SD = 3.99) increase in U1-SN ($p < 0.001$) and a 4.63 degree (SD = 4.11) increase in U1-PP ($p < 0.001$), as well as mesial tipping of the maxillary molars (U6-PP) of 2.83 degrees (SD = 1.87; $p < 0.001$). The lower incisors retroclined with RME-FM by a mean of 4.83 degrees (SD = 4.08; $p < 0.001$) while there a lesser change in the HE-FM group of 1.85 degrees, with large variation (SD = 4.37), which did show statistical significance. The overjet increased in both groups: 4.86 mm (SD = 1.33) and 5.1 mm (SD = 1.86) for the HE-FM and RME-FM groups respectively ($p < 0.001$). The overbite showed a 2.93 mm (SD = 2.3) increase with HE-FM ($p < 0.001$) while there was no significant change with the RME-FM.

8.5.2.Comparison of cephalometric changes between the two groups:

Comparison between the two groups (Table 4; Figures 6, 7 and 8) showed significant differences on several parameters. The effect on the maxilla in the antero-posterior dimension as assessed by the SNA angle and A-TV showed a significantly greater advancement of the maxilla at A point in the HE-FM group, with an increase in the SNA that was 3.63 degrees ($p < 0.001$) greater than that observed in the RME-FM group (4.61 degrees; SD = 2.17 vs. 0.98 degrees; SD = 0.87). The SNA increase for the HE-FM group was thus 4.6 times that observed in the RME-FM group. The A-TV also displayed significantly more forward displacement for A point: 2.37 mm more with HE-FM than with RME-FM (4 mm; SD = 1.74 vs. 1.63 mm; SD = 1.02; $p < 0.001$), a difference which was slightly more than two-fold.

The mandibular skeletal measurement at the level of B point indicated a reduction in both groups, with no statistically significant difference between the two.

Assessment of overall skeletal change using the ANB angle and Wits appraisal showed significantly higher skeletal correction in the HE-FM group. The ANB angle increased by 3 degrees more in the HE-FM group than in the RME-FM group (5.11 degrees; SD = 1.83 vs. 2.11 degrees; SD = 1.17; $p < .0001$). Furthermore, the Wits appraisal increased by 2.5 mm more in the HE-FM group than in the RME-FM group (6.1 mm; SD = 2.2 vs. 3.6 mm; SD = 1.9) more ($p < 0.001$).

In the vertical dimension, there was slightly more increase in the mandibular plane angle with the RME-FM than with the HE-FM. However, the difference was not statistically significant. There was a slight difference in the change in the upper occlusal plane in relation to the palatal plane (UOP-PP), with a slight reduction of 1.23 degrees (SD = 3.69) in the HE-FM group and a slight increase of 1.19 degrees (SD = 3.01) in the RME-FM group, which was statistically significant ($p < 0.05$).

The dental changes in each group were also compared. There was a statistically significant change in the maxillary dentition in the RME-FM group, with no significant change in the HE-FM. The upper incisors proclined more with the RME-FM, with 4.9 degrees' (SD = 3.99) proclination (U1-SN; $p < 0.001$) and 4.63 degrees U1-PP ((SD = 4.11; $p < 0.01$) while there was a slight tendency for uprighting of the upper incisors with the HE-FM. There was also greater mesial tipping of the upper first molars (U6-PP) with the RME-FM: 2.5 degrees more than with the HE-FM ($p < 0.001$). The mandibular incisors showed more uprighting in relation to the mandibular plane (L1-MP) in the RME-FM group: 3 degrees more than for the HE-FM group ($p < 0.05$), with a large standard deviation in both groups of 4.08 degrees and 4.37 degrees respectively. The HE-FM group exhibited an increase in overbite that was 2.41 mm greater than that in the RME-FM group. This was statistically significant ($p < 0.001$). The changes in the overjet were very similar, at 4.86 mm (SD = 1.33) for the HE-FM group and 5.1 mm (SD = 1.86) for the RME-FM group.

8.6.Discussion

This study compared the skeletal and dental effects of two maxillary protraction protocols in the management of Class III malocclusion: the CAD/CAM hybrid expander (HE-FM) with only bedtime facemask wear and the conventional tooth-borne bonded RME-FM with 16 hours a day of facemask wear. The Class III malocclusion was corrected in both groups, with forwards and downwards displacement of the maxilla and backward rotation of the mandible and an increase in overjet. However, when both groups were compared, there were significant differences, with greater skeletal and lesser dental changes in the HE-FM group. These differences can be attributed to the use of skeletal anchorage.

The skeletal and dental changes associated with RME-FM in this study (Table 4) were consistent with results from other studies which adopted similar methodology. With a mean improvement in the SNA angle of 0.98 degrees, a 1.13 degree reduction in the SNB angle and an overall improvement of 2.11 degrees in the ANB angle, the results were similar to previous reports for tooth-borne expansion and protraction. Mandal et al.[27] reported a 1.1 degree increase in the SNA angle in their study, while others reported changes between 0.7[17] and 1.8 degrees[28]. They[17,27,28] also showed a reduction in the SNB angle from -1 to 1.7 degrees, with a similar overall change in the ANB angle (2-2.6 degrees)[17,27,28]. The dental changes associated with RME-FM were also similar to those in previous reports, including counterclockwise rotation of the maxillary occlusal plane with mesial movement of the upper dentition and an increase in upper incisor inclination.[2,11,17,27,29] This established the RME-FM group as a good control group for this study.

Age and skeletal maturity are thought to play a role in the success of facemask treatment. Younger patients with less interdigitated sutures may be more responsive to protraction forces.[28,30,31] However chronologic age may not be the best way to assess skeletal maturity. This study used the cervical vertebral maturation index[24] to select the subjects in both groups who were prepubertal in stages CS1 and CS2 (Table 1), where it is considered the maxilla is most responsive to protraction. [24,32,33] Baccetti et al.[24] found that the response to maxillary protraction is best when treatment is started early, in prepubertal stages CS1 and CS2. Although there was a difference in the mean age between the two groups in this study, this is unlikely to have played a role in the response to maxillary protraction, as both groups had similar cervical vertebral maturation staging.

When compared with tooth-borne RME-FM, the tooth-bone-borne CAD/CAM HE-FM demonstrated significantly more skeletal effect on the maxilla, with the increase in the SNA angle being 4.6 times greater, and a similar effect on the mandible (with approximately 1-degree reduction in the SNB angle) in both groups (Table 4; Figure 6). Overall, this led to a greater improvement in the skeletal pattern for the HE-FM group; HE-FM was associated with a 5.11 degree improvement in the ANB angle and a 6.1 mm improvement in the Wits appraisal, as opposed to a 2.11 degree improvement and a 3.55 mm improvement with RME-FM. This significant increase in skeletal effect can be attributed to the use of skeletal anchorage mostly improving the overall effects on the maxilla. The SNA angle increased by 4.61 degrees with HE-FM, which is similar to results from other studies using skeletal anchorage for maxillary protraction. For example, Elnagar et al.[9] found a 4.7 degree increase in the SNA angle using infrazygomatic miniplates with facemask protraction. On the other hand, Koh et al.[28] and Sar et al. reported a 2.5 degree increase in SNA with infrazygomatic plates and miniplates in the lateral nasal wall respectively. The slightly lesser result in those two studies is perhaps due to the older mean age of their subjects (11.2 years and 10.9 years, respectively) as opposed to a mean age of 8.3 years in the current study.

Although the use of miniplates in the infrazygomatic crest[9,11] or the lateral nasal wall[10,12] has resulted in excellent skeletal changes, the approach is more invasive and requires flap surgery. In the majority of reports the miniplates were also placed under a general anaesthetic which adds to the cost and risk of the procedure.[9,12,28] The HE-FM offers a less invasive approach to miniplates, with comparable skeletal changes.[34] Additionally, the same appliance can be used for simultaneous maxillary expansion. The literature is currently divided on the role of maxillary expansion in facilitating sutural response to maxillary protraction forces.[4,6] However, maxillary expansion is often still required, as many Class III cases present with a transverse maxillary deficiency as well.[35] Few studies have compared miniscrew-supported maxillary expansion and protraction with tooth-borne expansion and protraction. Ngan et al.[17] compared the Hybrid Hyrax with facemask with a tooth-borne RME and facemask. They found greater maxillary protraction (approximately two-fold) with the Hybrid Hyrax facemask combination as opposed to the tooth-borne one. The total change at SNA was lower than that reported in this study; however, this is again most likely due to the older age of the subjects. Recently, when maxillary protraction without expansion was studied using a labiolingual appliance with and without a palatal miniscrew, a greater skeletal response was evident with the use of one palatal miniscrew.[36]

The use of skeletal anchorage in this study resulted in a significant reduction in the dental side effects associated with the HE-FM. While there was a significant mesial movement of the maxillary dentition with the RME-FM (with an increase in upper incisor inclination and tipping of the maxillary molars) there were no significant dental changes in the HE-FM group (Table 4; Figure 8). The mesial movement of the upper dentition can lead to the undesirable effect of upper incisor protrusion as well as anterior crowding of the maxilla after Class III correction.[2] The elimination of these side effects can be considered a significant advantage of the use of skeletal anchorage. Similar findings have also been reported using the Hybrid Hyrax by Ngan et al.[17] and Willman et al.[34] and with the use of miniscrew-supported labiolingual appliances[36] as well.

The change in the overjet was similar in both groups, with a mean improvement of 5 mm; however, this seemed to be achieved by a combination of dental compensation and some skeletal change in the RME-FM group, while there was a significantly greater skeletal contribution in the HE-FM group (Table 4). This can be attributed to the use of skeletal anchorage reducing the dental compensation and maximising the skeletal response, as evident in the increased 2.37 mm linear advancement of A point and the lack of proclination of the upper incisors. The final overbite, however, was significantly deeper in the HE-FM group at the end of treatment. This may be explained by the lesser change in the upper occlusal plane and reduced proclination of the maxillary incisors in the HE-FM group (Table 2). Although in both groups there was a counterclockwise rotation of the maxillary occlusal plane, this was more pronounced in the tooth-borne group. The increased overbite can be considered a desirable change for the long-term maintenance of the overjet correction. Long term follow-up studies have shown that patients with more overbite at the conclusion of treatment tend to maintain more of the correction than those with shallower overbites.[7]

The use of CAD/CAM appliances was introduced by Graf et al.[22,23] Aside from the presented case reports, this is the first study to report the use of the appliances on a number of consecutively treated cases. The CAD/CAM appliances performed very well and were clinically problem-free and relatively easy to use. However, the cementation protocol adopted in this study (using a dual-cured resin cement) is technique-sensitive and requires very good isolation, something that may be difficult to achieve with some younger or less cooperative patients. It would be interesting to investigate whether a simpler and less technique-sensitive bonding protocol using glass ionomer cements may be as effective.

The use of the CAD/CAM hybrid expander offers some advantages in terms of clinical workflow. The digitisation of the appliance design and manufacture greatly simplifies the clinical steps. It eliminates the need for dental impressions following miniscrew placement, which can be challenging in younger patients, especially as impression caps[37] are needed to transfer the position of the miniscrews to the working models. This can be a hazard with young children, who may swallow or inhale them. Additionally, eliminating the impression and model casting steps reduces the number of inaccuracies that may be introduced due to material variables or human error, which may contribute to an ill-fitting appliance. The appliance is directly printed after the CAD process, without the need for any study models.[23] Another advantage is the elimination of separator placement, as the appliances fit as an occlusal overlay, reducing the number of appointments the patient needs to attend prior to appliance placement, as well as eliminating the associated discomfort. Lastly, the Remanium alloy (Dentaurum, Ispringen, Germany) used for the manufacturing process of these CAD/CAM appliances is very rigid[22,23]. This rigidity reduces the flex of the appliances[38], which has been considered a potential cause for some of the dental movements seen in previous studies in connection with the Hybrid Hyrax appliance. For example, Ngan et el[17] attributed some of the mesial tipping seen on the molars to wire bending. Almost no mesial tipping of the maxillary molars was seen with the CAD/CAM HE-FM in this study. Additionally, studies on the material properties of commercially available maxillary expansion appliances[38-40] reported a wide variability in the stiffness of these mechanisms, which can vary even more after soldering procedures. With the laser meting process using the rigid Remanium, it may be possible to eliminate such variability by providing a stiffer and more consistent appliance quality.

In this study, the patients using the HE-FM were requested to only wear the facemask at bedtime, which is a lesser amount of wear time than is commonly requested. Nevertheless, the skeletal and dental effects recorded here were on par with those of other studies.[9,12,17,28,34] Although actual wear time was not objectively measured in this study, it is unlikely that patients would have worn the facemask more than the prescribed bedtime hours. The RME-FM groups were requested to wear the facemask 16 hours a day, a similar amount of time to that reported in the majority of studies on facemask therapy, where patients were requested to wear the facemask for 13-16 hours every day for approximately 9-12 months.[2-4,9,12,18] This routine would be challenging for most children at a young age, especially if they are engaged in extracurricular activities or sports. In fact, this requirement alone could potentially lead to poor treatment acceptance and/or adherence. Studies on the adherence of patients to medical regimes have shown that treatments requiring greater changes in patient lifestyle can lead to poor compliance and thus poor outcomes.[19] When orthodontic appliance wear time was assessed objectively using a thermal recording sensor, it was found that patients wore appliances 50-65% of the prescribed time.[20,21,41] Patients using a facemask were found to wear the appliance on average 8.6 hours of the prescribed 13 hours in one study.[20] Stocker et al.[41] found that despite the patient being instructed to wear the facemask for 16 hours a day, they actually averaged 10.8 hours throughout the treatment. It can be hypothesised that by limiting facemask wear to bedtime only, the treatment may seem easier to adhere to and can more easily fit into the child's normal routine without too much disruption. This factor alone may result in better acceptance from patients and their families and potentially result in better overall compliance and more regular facemask wear. Research shows that young children under the age of 11 years old sleep between 10 and 12 hours every night.[42] So, with the use of skeletal anchorage increasing the efficacy of the facemask, fewer hours may be able to deliver sufficient skeletal outcomes. This would not, however, be an effective strategy in older children and adolescents, who sleep fewer hours.[43] Perhaps in young children (in whom sutures are very responsive to protraction) and with the efficacy offered by skeletal anchorage, bedtime facemask wear may be sufficient to stimulate sufficient maxillary protraction for Class III correction. Nevertheless, this would need to be assessed objectively and further study into the correlation between the duration of facemask wear and skeletal changes needs to be conducted to shed more light on this area. In addition, this study was retrospective in nature and the results should be investigated through a randomised clinical trial.

8.7.Conclusion

In prepubertal children, the use of skeletal anchorage for maxillary expansion and protraction with the CAD/CAM hybrid expander significantly increases the skeletal effects and reduces the dental side effects in comparison to the use of tooth-borne maxillary expansion and protraction. Bedtime facemask wear combined with tooth-bone-borne expansion may be sufficient to produce skeletal correction of Class III malocclusion in prepubertal children.

CAD/CAM appliances are effective, reliable and problem-free. They provide several advantages to the orthodontic workflow.

8.8.References

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8.9. List of figures

8.10. List of Tables

8.11.Figures

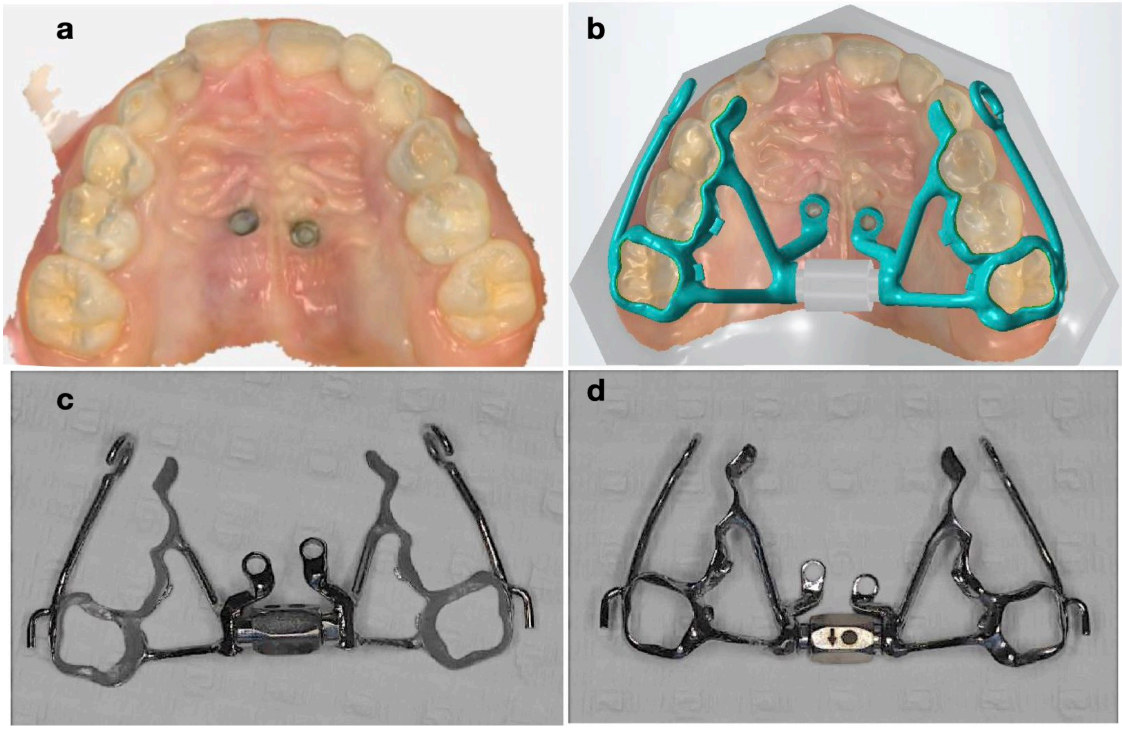

Figure 1. A. Intraoral scan obtained after placement of miniscrews; B. Digital design of the appliance framework with facemask hooks and bonding pads extended to the deciduous canines. Molars are covered by onlays without interproximal penetration. Rings are extended to the miniscrews and the virtual placement of the expansion mechanism; C. Roughened fitting surface of the appliance after treatment with sandblasting; D. Finished appliance from an occlusal view.

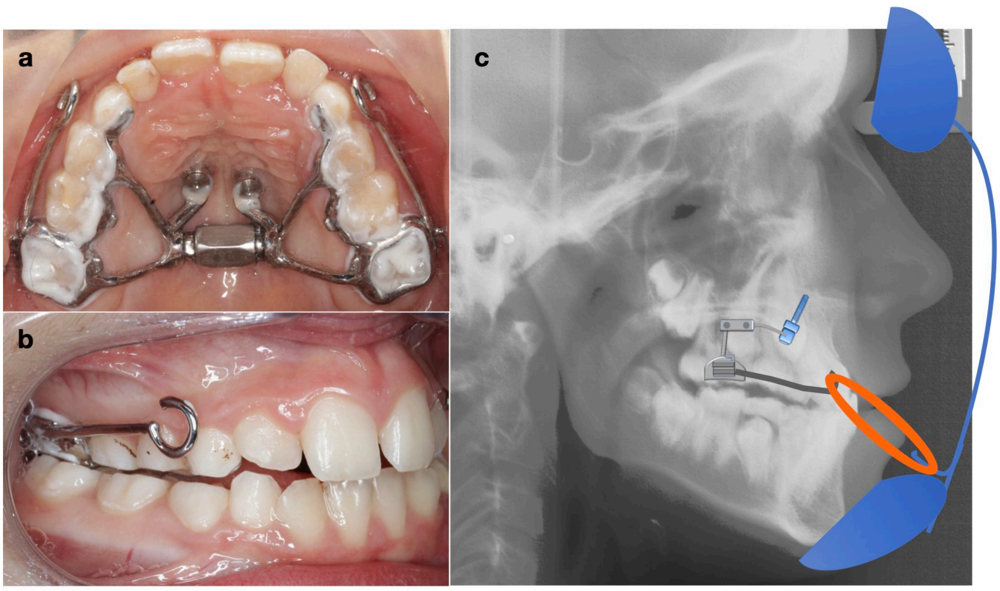

Figure 2. A. Appliance cemented and fixation screws in place. Flowable resin was used to add security to the fixation screws; B. Facemask hooks emerge from the molar band

positioned near the maxillary canines; C. Facemask protraction force vector approximately 30 degrees down from the occlusal plane.

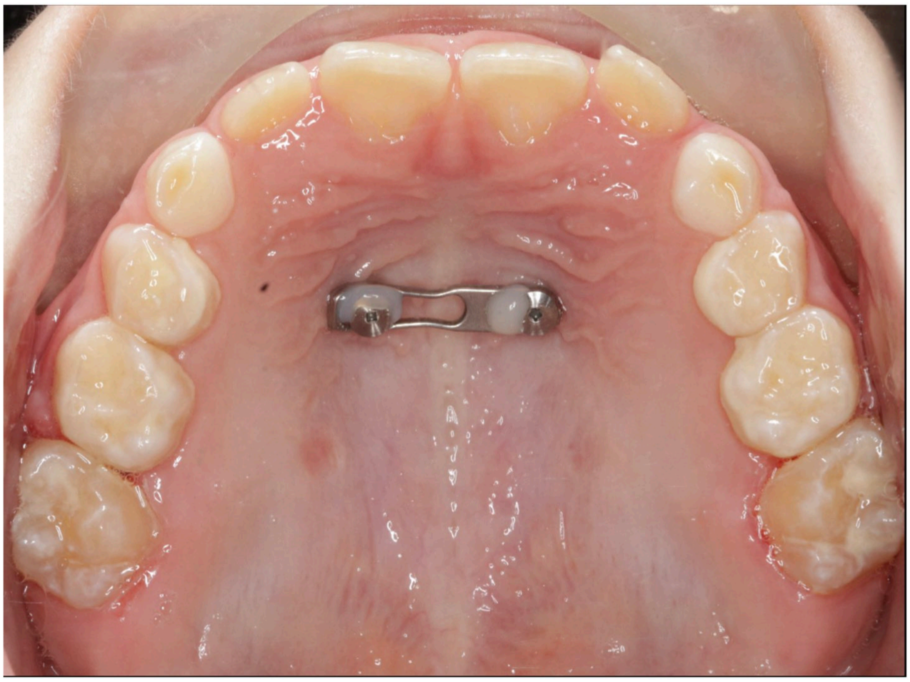

Figure 3. Retention of the transverse expansion using a stainless steel miniplate fixed with two fixation screws (Benefit PSM Medical Solutions, Gunningen, Germany) and flowable resin added to secure the fixation screws.

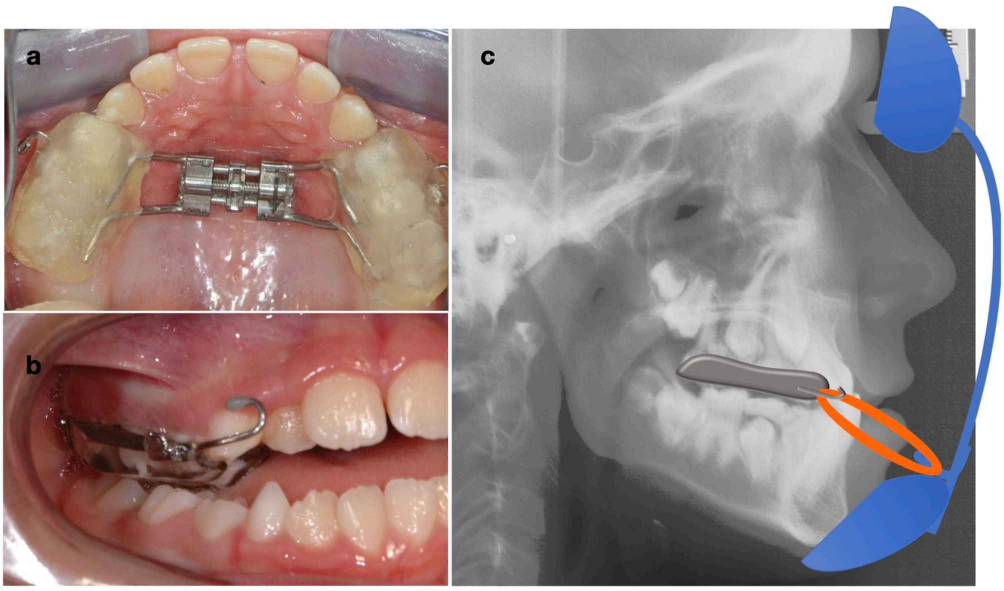

Figure 4 A. Bonded hyrax appliance with acrylic bite blocks; B. Facemask hooks emerge near maxillary canine for elastic application; C. Facemask elastic force vector at approximately 30 degrees from the occlusal plane.

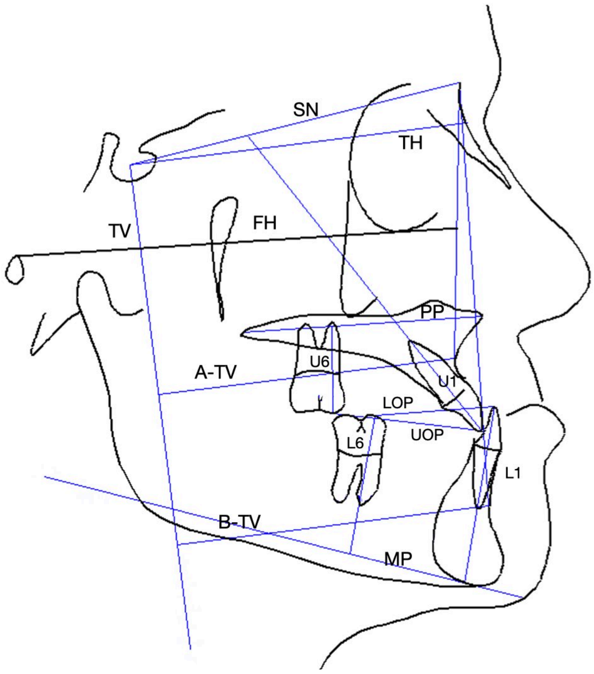

Figure 5. Cephalometric measurements and reference lines. SN (Sella-Nasion line). TH (true horizontal line, 7 degrees from SN). TV (true vertical line, 90 degrees from TH through Sella). A-TV (perpendicular distance from A point to TV). B-TV (perpendicular distance from B Point to TV). FH (Frankfurt horizontal line). PP (palatal plane through ANS-PNS). MP (Mandibular plane). UOP (upper occlusal plane: maxillary incisal tip to mesiobuccal cusp of first molar). LOP (Lower occlusal plane: mandibular incisor tip to mesiobuccal cusp of mandibular first molar). U1 (long axis of most labial upper incisor). L1 (long axis of most labial mandibular incisor). U6 (maxillary first molar long axis: mesiobuccal cusp to mesiobuccal root tip). L6 (mandibular first molar long axis: mesiobuccal cusp to mesial root tip).

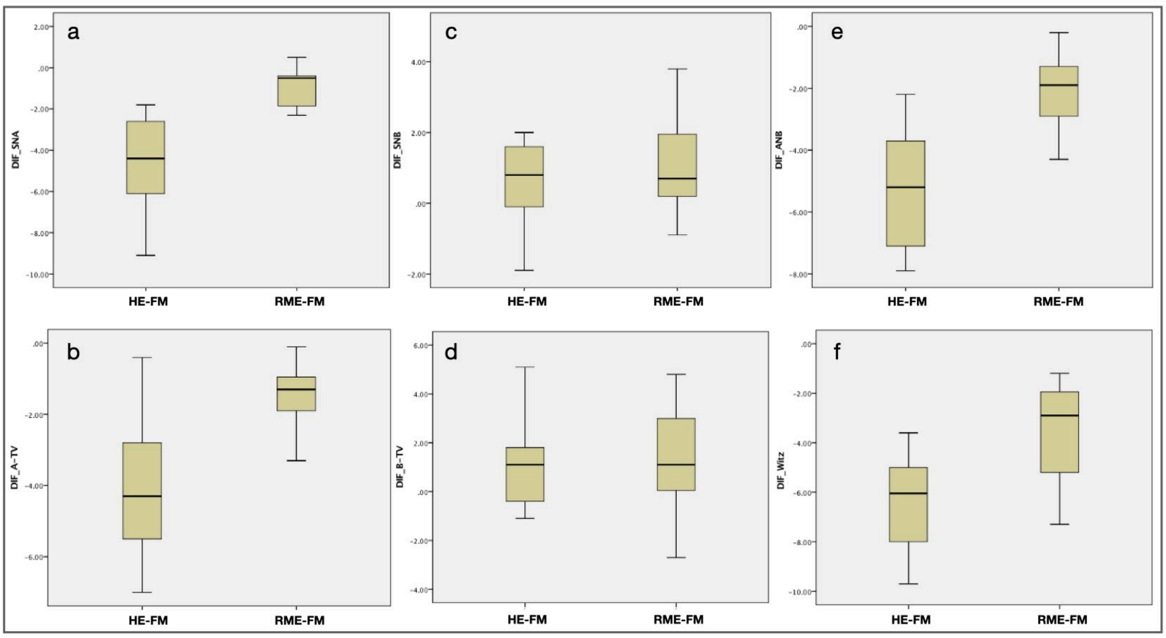

Figure 6. Box plots depicting anteroposterior skeletal changes between T1 and T2.

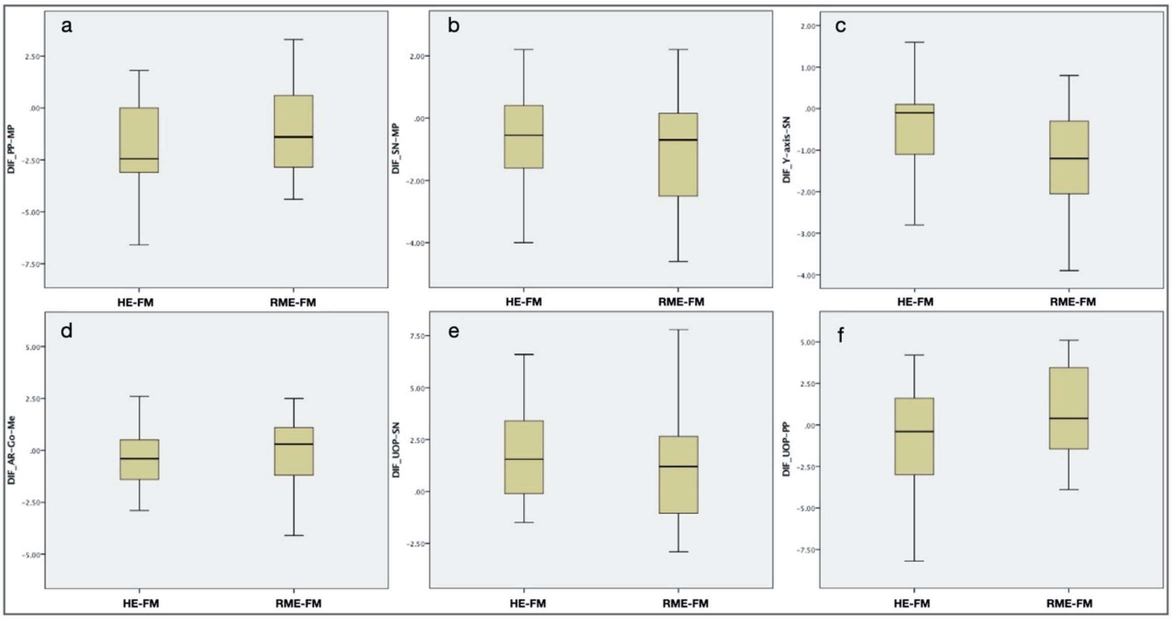

Figure 7. Box plots depicting vertical changes between T1 and T2.

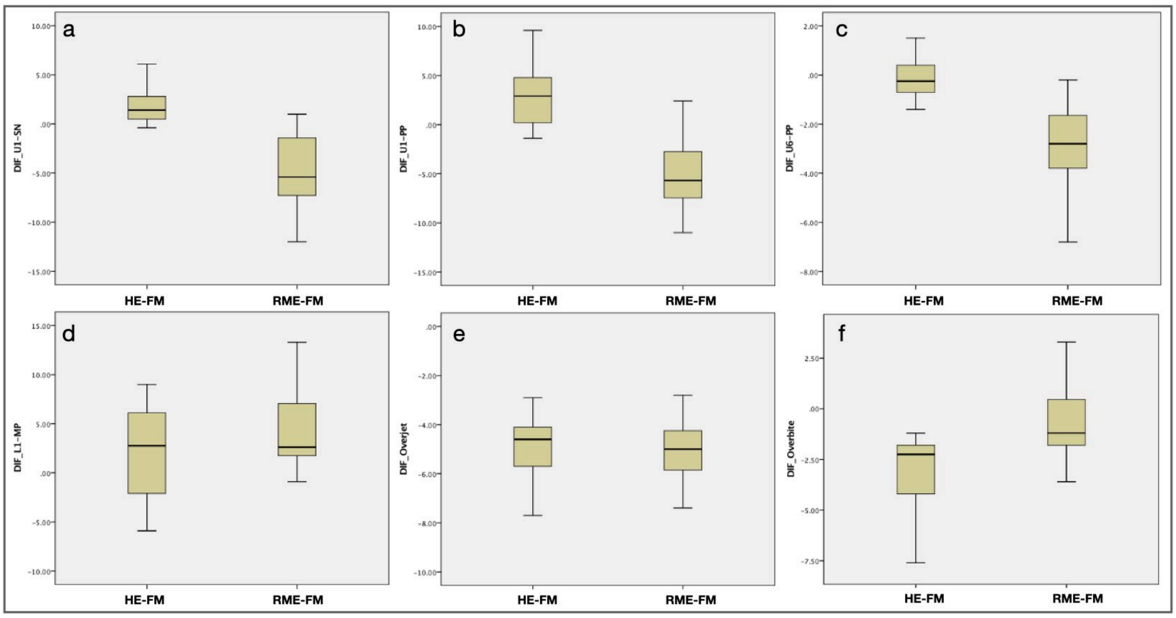

Figure 8. Box plots depicting dental changes between T1 and T2.

8.12.Tables

Table 1. Comparison between the two groups at T1 before treatment

	HE-FM (n=19)		RME-FM (n=16)				
Sex	**Female=5; Male=14**		**Female=4; Male=12**		**95% Confidence Interval of the Difference**		
CVMI stage	**CS1 = 9; CS 2= 10**		**CS1 =11; CS 2= 5**				
	Mean	**Std. Deviation**	**Mean**	**Std. Deviation**	**Lower**	**Upper**	***p***
Age at T1 years	8.34	0.60	9.93	1.33	-2.28	-0.90	0.00
Tx Duration months	12.21	2.54	12.46	3.65	-2.39	1.88	0.81
SNA°	78.15	4.29	79.07	3.51	-3.65	1.81	0.50
SNB°	78.41	3.50	80.36	3.14	-4.26	0.36	0.10
ANB°	-0.26	2.12	-1.29	1.59	-0.28	2.34	0.12
Wits mm	-3.92	1.94	-4.92	2.68	-0.59	2.60	0.21
A-TV mm	56.88	2.92	59.26	3.21	-4.49	-0.27	0.03
B-TV mm	54.34	4.76	58.88	5.00	-7.89	-1.17	0.01
PP-MP°	27.80	3.79	24.69	4.75	0.17	6.04	0.04
SN-MP°	34.90	4.71	33.31	3.92	-1.43	4.60	0.29
Y-axis-SN°	67.52	2.85	66.28	2.39	-0.61	3.09	0.18
AR-Go-Me°	139.18	5.78	136.42	5.43	-1.12	6.65	0.16
UOP-SN°	20.18	4.42	17.99	3.41	-0.59	4.97	0.12
UOP-PP°	12.84	4.19	11.27	4.32	-1.36	4.51	0.28

LOP-MP°	17.57	3.18	19.49	4.72	-4.65	0.82	0.16
U1-SN°	103.41	6.62	103.96	5.34	-4.74	3.64	0.79
U1-PP°	110.50	6.00	112.60	5.62	-6.12	1.92	0.30
U6-PP°	77.49	3.12	81.13	3.33	-5.86	-1.41	0.00
L1-MP°	86.89	4.45	86.94	6.21	-3.72	3.63	0.98
L6-MP°	81.89	4.34	77.31	5.78	1.10	8.07	0.01
Overjet mm	-0.98	0.95	-2.04	1.70	0.12	1.98	0.03
Overbite mm	-0.62	1.89	1.48	2.17	-3.49	-0.70	0.00

Table 2. Intra Class Correlation Coefficient for the intra-observer reliability

	Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound
SNA°	0.994	0.979	0.998
SNB°	0.993	0.974	0.998
ANB°	0.994	0.98	0.999
Wits mm	0.988	0.847	0.998
A-TV mm	0.984	0.937	0.996
B-TV mm	0.993	0.975	0.998
PP-MP°	0.991	0.967	0.998
SN-MP°	0.987	0.952	0.997
Y-axis-SN°	0.986	0.946	0.997
AR-Go-Me°	0.984	0.945	0.996
UOP-SN°	0.982	0.93	0.996
UOP-PP°	0.981	0.932	0.995
LOP-MP°	0.946	0.804	0.985
U1-SN°	0.994	0.98	0.999
U1-PP°	0.995	0.983	0.999

U6-PP°	0.981	0.934	0.995
L1-MP°	0.868	0.537	0.964
L6-MP°	0.99	0.963	0.997
Overjet mm	0.985	0.948	0.996
Overbite mm	0.989	0.961	0.997

Table 3. Variables used in the lateral cephalometric analysis

	Measurement	Definition
Anteroposterior skeletal relationship	SNA	The angle between the anterior cranial base (Sella to Nasion) and the NA (nasion to point A) line
	SNB	The angle between the anterior cranial base (Sella to Nasion) and NB (nasion to point B) line
	ANB	The angle between the NA and NB lines relates the anteroposterior position of the maxilla to the mandible
	Wits	The distance between AO and BO, the projection of points A and B perpendicularly to the occlusal plane
	A-TV	The distance between A-point and the true vertical line TV
	B-TV	The distance between B-point and the true vertical line
	AB-TV difference	The difference between A-TV and B-TV
Vertical skeletal relationship	PP-MP	The angle between the palatal plane and mandibular plane
	SN-MP	Mandibular plane angle: The angle between the anterior cranial base (Sella to Nasion) mandibular plane
	Y-axis	The angle between the line from Sella to Gnathion SN-Gn and the Frankfurt horizontal plane and indicates the downwards, rearwards or forwards position of the chin in relation to the upper face.

	Ar-Go-Me (gonial angle)	The angle between the Me-Go line and the Go-Ar line
Dental variables	UOP-SN	The angle between the upper occlusal plane and the anterior cranial base line
	UOP-PP	The angle between the upper occlusal plane and palatal plane
	LOP-MP	The angle between the lower occlusal plane and mandibular plane
	U1-SN	Angle between the upper incisor and the anterior cranial base line
	U1-PP	Angle between the upper incisor and the palatal plane
	U6-PP	Angle between the upper first molar and the palatal plane
	L1-MP	The angle between the lower incisor and mandibular plane
	L6-MP	The angle between the lower first molar and mandibular plane
	Overjet	The overjet
	Overbite	The overbite

Table 4. Comparison for each group between T1 and T2 and comparison of differences in changes between the two groups.

	HE-FM (n=19)							RME-FM (N=16)							HE-FM vs RME-FM						
	T1		T2		95% Confidence Interval of the Difference			T1		T2		95% Confidence Interval of the Difference			HE-FM		RME-FM		95% Confidence Interval of the Difference		
	mean	SD	mean	SD	Lower	Upper	p	mean	SD	mean	SD	Lower	Upper	p	Mean difference (T1-T2)	SD	Mean difference (T1-T2)	SD	Lower	Upper	p
SNA°	78.15	4.29	82.76	3.98	-5.66	-3.56	0.00	79.07	3.51	80.04	3.75	-1.44	-0.51	0.00	-4.61	2.17	-0.98	0.87	-4.81	-2.46	0.00
SNB°	78.41	3.50	77.91	3.34	-0.22	1.22	0.16	80.36	3.14	79.23	3.24	0.41	1.85	0.01	0.50	1.49	1.13	1.36	-1.62	0.36	0.20
ANB°	-0.26	2.12	4.85	2.26	-5.99	-4.23	0.00	-1.29	1.59	0.82	1.58	-2.73	-1.48	0.00	-5.11	1.83	-2.11	1.17	-4.08	-1.93	0.00
Wits mm	-3.92	1.94	2.18	2.83	-7.16	-5.04	0.00	-4.74	2.67	-1.19	2.04	-4.60	-2.51	0.00	-6.10	2.20	-3.55	1.89	-4.00	-1.09	0.00
A-TV mm	56.88	2.92	60.39	4.21	-4.82	-2.20	0.00	59.26	3.21	60.88	3.83	-2.17	-1.08	0.00	-4.00	1.74	-1.63	1.02	-3.39	-1.36	0.00
B-TV mm	54.34	4.76	53.03	5.38	0.31	2.33	0.01	58.88	5.00	57.65	5.77	0.01	2.44	0.05	1.32	2.10	1.23	2.28	-1.42	1.60	0.90
PP-MP°	27.80	3.79	29.22	3.67	-2.47	-0.37	0.01	24.69	4.75	26.03	4.79	-2.65	-0.02	0.05	-1.42	2.18	-1.34	2.47	-1.68	1.52	0.92
SN-MP°	34.90	4.71	35.15	4.97	-1.01	0.49	0.48	33.31	3.92	34.46	2.85	-2.18	-0.10	0.03	-0.26	1.56	-1.14	1.95	-0.32	2.09	0.15
Y-axis-SN°	67.52	2.85	68.15	2.91	-1.26	0.01	0.05	66.28	2.39	67.63	2.12	-2.06	-0.64	0.00	-0.63	1.28	-1.35	1.33	-0.19	1.63	0.12
AR-Go-Me°	139.18	5.78	138.75	5.13	-0.99	1.85	0.53	136.42	5.43	136.44	4.73	-1.61	1.57	0.98	0.43	2.95	-0.02	2.98	-1.59	2.49	0.66

UOP-SN°	20.18	4.42	18.97	4.52	0.07	2.35	0.04	17.99	3.41	16.68	3.76	-0.20	2.83	0.09	0.61	3.44	1.31	2.84	-2.90	1.49	0.52
UOP-PP°	12.84	4.19	14.07	3.58	-3.00	0.55	0.16	11.27	4.32	10.08	3.81	-0.41	2.80	0.13	-1.23	3.69	1.19	3.01	-4.76	-0.08	0.04
LOP-MP°	17.57	3.18	21.60	3.02	-5.17	-2.88	0.00	19.49	4.72	21.65	5.03	-4.06	-0.27	0.03	-4.02	2.38	-2.16	3.55	-3.91	0.19	0.07
U1-SN°	103.41	6.62	104.07	8.08	-3.18	1.85	0.59	103.96	5.34	108.86	4.96	-7.03	-2.77	0.00	1.34	1.90	-4.90	3.99	3.98	8.49	0.00
U1-PP°	110.50	6.00	110.13	7.81	-2.46	3.20	0.79	112.60	5.62	117.23	6.10	-6.82	-2.44	0.00	0.37	5.87	-4.63	4.11	1.45	8.56	0.01
U6-PP°	77.49	3.12	77.82	3.24	-0.83	0.18	0.19	81.13	3.33	83.96	3.78	-3.83	-1.84	0.00	-0.33	1.05	-2.83	1.87	1.49	3.52	0.00
L1-MP°	86.89	4.45	85.04	4.68	-0.26	3.95	0.08	86.94	6.21	82.11	7.10	2.65	7.00	0.00	1.85	4.37	4.83	4.08	-5.91	-0.05	0.05
L6-MP°	81.89	4.34	81.80	4.11	-2.06	2.25	0.93	77.31	5.78	77.09	6.19	-2.96	3.39	0.89	0.09	4.46	0.21	5.96	-3.70	3.47	0.95
Overjet mm	-0.98	0.95	3.88	1.49	-5.50	-4.22	0.00	-2.04	1.70	3.06	0.99	-6.09	-4.11	0.00	-4.86	1.33	-5.10	1.86	-0.86	1.34	0.67
Overbite mm	-0.62	1.89	2.31	1.19	-4.04	-1.82	0.00	1.48	2.17	1.99	1.28	-1.70	0.66	0.37	-2.93	2.30	-0.52	2.22	-3.97	-0.84	0.00

9. Manuscript 2

A comparison of two protocols for correction of skeletal Class III malocclusion in growing children: Hybrid expander with miniplates and rapid maxillary expansion with facemask

A condensed version of this manuscript is to be submitted for publication to the American Journal of Orthodontics & Dentofacial Orthopedics

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9.2. Abstract:

Conventional treatment of Class III malocclusion using a tooth-borne facemask is associated with unwanted dental side effects. The introduction of skeletal anchorage aims to eliminate dental side effects and increase skeletal effects.

This study examined the skeletal and dental effects of a hybrid maxillary expander with mandibular miniplates (HE-MP) and Class III elastics compared to conventional tooth-borne RME-FM with 16 hours a day of facemask wear in skeletal Class III treatment.

Subjects and Methods: This was a retrospective study. All patients were in growth stages CS1-CS3, with a Class III malocclusion. The HE-MP group consisted of 19 patients of mean age 10.1± 1.4 years, 8 girls and 11 boys. The RME-FM group consisted of 18 patients of mean age 10.6 ± 1.4 years with 7 girls and 11 boys. HE-MP involved a hybrid expander anchored on two palatal miniscrews and two maxillary molars with full-time wear of Class III elastics to two mandibular L-shaped miniplates. The RME-FM group were fitted with a bonded Hyrax and required to wear a facemask for 16 hours a day. Lateral cephalograms were taken before and after treatment.

Results: The treatment time was approximately 15.9 ± 2.8 months for the HE-MP group and 12 ± 3.4 months for the RME-FM group. Class III malocclusion was corrected in both groups and the difference in the correction was significant. The maxilla advanced more in the HE-MP group, with an increase in the SNA angle of 4.2 ± 2.1degrees and an increase in the A-TV linear measurement of 4.1 ± 3.1mm, compared to 1.1 ± 0.9 degrees and 1.7 ± 1.1 mm in the RME-FM group *(p* < 0.001). The effect on the mandible was similar in both groups, with a 1 ± 1.2 degree and 0.9 ± 1.2 degree reduction in the SNB, in the HE-MP and RME-FM respectively. The overall skeletal change was significantly greater with HE-MP, which was associated with an in the ANB of 5.2 ± 2 degrees and a Wits appraisal increase of 6.3 ± 2.9 mm, as opposed to 2 ± 1 degrees and 2.9 ± 1.8 mm with the RME-FM ($p < 0.001$). The dental changes were significantly higher with RME-FM, for which there was an increase in incisor inclination (U1-SN) of 5.5 ± 3.9 degrees and an increase in the U1-PP of 5 ± 3.9 degrees ($p < 0.001$). There were no statistically significant changes in the HE-MP group. The mandibular incisors retroclined by 5.3 ± 3.6 degrees at L1-MP with the RME-FM, while they advanced slightly with the HE-MP by 2.9 ± 5.2 degrees ($p < 0.001$).

Conclusion: The use of skeletal anchorage for maxillary expansion and protraction significantly increases skeletal effects and reduces dental side effects compared to tooth-borne maxillary expansion and protraction. These results need to be investigated in the long term.

9.3. Introduction

Class III malocclusion can result from maxillary deficiency, mandibular prognathism or a combination of both.[1] In growing children, treatment usually aims to stimulate maxillary growth in a downward and forward direction and restrain or redirect mandibular growth using a protraction facemask.[2-4] Rapid maxillary expansion (RME) is commonly combined with facemask therapy, as it is thought that the expansion may facilitate sutural response to the protraction forces; however, the literature is divided on this point.[2,5-8] Nevertheless, there are several limitations to facemask therapy. Firstly, the cumbersome nature of the extraoral appliance limits patient acceptance and compliance, and thus only part-time wear is possible.[2] Secondly, the appliance is tooth-borne, resulting in many dental side effects caused by mesial migration of the maxillary dentition, proclination of the upper incisors with increased anterior crowding, and lingual tipping of the mandibular incisors.[2,4,8-10] Additionally, the technique has the effect of rotating the mandible backwards, thus increasing the lower anterior face height, which may be aesthetically unfavourable (especially in high-angle cases).[2,4,8-10]

The introduction of skeletal anchorage using miniplates by De Clerck et al.[11] allowed the use of purely bone-anchored maxillary protraction (BAMP), thus eliminating dental side effects while also allowing the forces to be applied for 24 hours a day. This approach has proven effective in managing maxillary hypoplasia with significant skeletal changes, exceeding those produced using the conventional facemask, while avoiding dental side effects.[12] However, the use of miniplates in the maxilla does not incorporate maxillary expansion, which in many cases is required due to the transverse maxillary deficiency that usually occurs in Class III cases.[13] Additionally, incorporating maxillary expansion may have the effect of making the circummaxillary sutures more responsive to protraction forces,[14] with some authors even suggesting that RME alone may displace the maxilla downwards and forwards.[14,15] Wilmes et al. introduced the Hybrid Hyrax appliance,[16,17] which shares the load of maxillary expansion and protraction between the first molars and two palatal miniscrews. The majority of the load is carried by the miniscrews, thus reducing the dental side effects and maximising the skeletal effect.[18] The Hybrid Hyrax was combined with a mandibular anchorage plate[19] (coined the 'Mentoplate'), which is placed in the chin apical to the incisors to allow Class III elastic traction. This method was shown to be effective in maxillary protraction and the correction of Class III malocclusion[20] with similar results to those produced with the Hybrid Hyrax and facemask combination.[21]

While miniplate placement in the BAMP technique[22] requires lower canine eruption, meaning that treatment cannot typically start until around the age of 11 years, the Mentoplate is placed apical to the lower incisors and away from the developing canine, enabling treatment to start earlier.[19] However, compared to the BAMP method,[22] Mentoplate surgery is more invasive, with the single plate fixed with three to four bone screws apical to the permanent mandibular incisors after reflecting a single large mucoperiosteal flap.[19] To date only two studies[20,21] have assessed the effects of miniscrew-supported maxillary expansion combined with the wearing of Class III elastics to mandibular miniplates, and the effects were not compared with those of a conventional RME facemask.

This study aims to compare the effects of a miniscrew-supported hybrid expander combined with the wear of Class III elastics to miniplates in the anterior mandible with the effects of conventional tooth-borne RME facemask therapy.

9.4. Materials and Methods

Subjects:

Ethics approval (X20-0456 and 2020/ETH02668) was obtained from the human research Ethics Committee of the Sydney Local Health District.

The samples consisted of 37 Class III malocclusion patients treated with either the hybrid expander and mandibular miniplates protocol (HE-MP) or tooth-borne RME with facemask therapy (RME-FM).

Inclusion criteria: All patients in both groups presented with a Class III malocclusion with a Wits appraisal of -1 or less, an anterior crossbite or edge-to-edge relationship and a molar Class III relationship. All were prepubertal in terms of skeletal maturity as assessed by the cervical vertebral maturation index[23] (CS1-CS3). The HE-MP was a prospective group of 19 consecutively treated cases from the first author’s (NET’s) practice between 2013 and 2019.

The mean age was 10.1 years (SD = 1.4) with 8 girls and 11 boys (Table 1). Treatment continued until a positive overjet was achieved, after which new records were obtained.

The RME-FM group consisted of 18 consecutively treated Class III cases: 11 boys and 7 girls, treated at the University of Ankara's Department of Orthodontics between 2015 and 2018. Their mean age was 10.6 years (SD = 1.4) (Table 1). Lateral cephalograms were obtained before treatment (T1) and at the end of treatment, when a positive overjet was achieved (T2).

9.4.1. Hybrid expander – mandibular miniplate protocol (HE-MP):

A hybrid expander (Figure 1) modified from the Hybrid Hyrax designed by Wilmes et al.[17] was used. Two palatal miniscrews (2x9mm; PSM Medical Solutions, Gunningen, Germany) were placed paramedian on both sides of the midpalatal suture at the third palatine Rugae line, as described by Wilmes et al.[19] The PowerScrew (Tiger Dental, Bregenz, Austria) was laser-welded to the Benefit abutments (PSM Medical Solutions, Gunningen, Germany). At cementation, the appliance was secured to the miniscrews using two fixation screws (Benefit PSM Medical Solutions, Gunningen, Germany). Patients were instructed to turn the expander once a day for two weeks ahead of miniplate insertion. A full revolution of the hex nut equates to 1 mm of expansion. Expansion was then continued at a slower rate of 1-2 turns per week until the desired expansion was achieved. Miniplate insertion was performed by an oral surgeon using conventional trauma plates (Stryker Universal Orthognathic; Stryker, Kalamazoo, MI, USA). Two small mucoperiosteal flaps were raised and two L-shaped plates were placed, one on each side. This was particularly important in the younger patients, whose mandibular canines had not yet erupted. The L-plates were used so that the screws were placed apical to the mandibular central and lateral incisors on each side (Figure 2). The plate emerged in the attached gingiva or just at the junction of attached and unattached gingiva. After an initial eight-week period of healing, during which the maxillary expansion was being completed, the tops of the plates were converted to hooks using a high-speed carbide bur. Elastics were started with gradually increasing strength, similar to what was recommended by De Clerck et al.,[24] in order to gradually increase the bone density around the miniplates and increase their stability[25] (Figure 1c). For the first six weeks, 100 g per side elastics were used full time and changed a minimum of twice per day. The elastic force was increased to 170 g. At four months, 230 g elastics were used and continued until the end of the treatment.

Retention

Following removal of the expander, the stability of the miniscrews was assessed. In order to maintain transverse expansion, a rigid stainless steel miniplate was placed between the miniscrews and fixed with two fixation screws (Figure 3; Benefit PSM Medical Solutions, Gunningen, Germany).

9.4.2. RME-FM treatment protocol

The RME-FM group were treated with a bonded splint-type expansion appliance with hooks emerging near the canine area for the application of elastics (Figure 4). The appliance resembled that previously published by Baccetti et al.,[2] which used a Hyrax-type expansion screw (Dentaurum GmbH and Co. KG, Inspringen, Germany). Patients were instructed to turn the expansion mechanism once a day for three weeks before the facemask was started. They were then requested to continue expansion at the same rate until the desired expansion was reached. The facemask was adjusted so that the elastic force vector was angled at 30 degrees down from the occlusal plane as previously described.[26,27] Patients were then asked to wear the facemask for 16 hours every day with an elastic force of 400 g. Treatment continued until a positive overjet was achieved. A second set of records was then obtained (T2).

9.4.3. Cephalometric analysis:

All cephalograms were digitised and traced by the same examiner using OrthoTrac imaging V11.7.0.32 (Carestream Dental, Atlanta, GA, USA). The intraclass correlation coefficients (ICC) showed excellent reliability, with values ranging between 0.981 and 0.993, except the L1-MP for which inter-rater reliability was still high, at 0.868 (Table 2). The cephalometric variables used in the analysis are listed in Table 3 and illustrated in Figure 5.

9.4.4. Statistical analysis

IBM SPSS Statistics software (version 23.0. Armonk, NY: IBM Corp.) was used to analyse the data. Means and standard deviations are presented for all variables. A statistical significance level of $p < 0.05$ was chosen. Normality and homogeneity of variance of the data were assessed using Shapiro-Wilk's test and Levene's test for equality of variances, respectively. Differences between two timepoints within groups were tested for significance using a paired samples t-test. Differences between groups were tested for significance using an independent samples t-test.

9.5. Results

The initial analysis of the skeletal and dental characteristics of the two groups before treatment (T1) showed no statistically significant differences between the two groups at the outset (Table 1). The average treatment time was approximately 15.9 months (SD = 2.8) for the HE-MP group and 12 months (SD = 3.4) for the RME-FM group. One patient in the HE-MP group failed to reach a positive overjet due to poor compliance with elastic wear, as a result of which their treatment was stopped at 15 months.

Analysis of the changes experienced in both groups from T1 to T2 indicated significant differences between the two groups in terms of treatment response (Table 4).

9.5.1.Skeletal changes

The antero-posterior assessment of the effect on the maxilla as assessed by the SNA angle and A-TV indicated a significantly greater skeletal advancement of the maxilla in the HE-MP group. There was an increase in SNA of 4.2 degrees (SD = 2.1) and a 4.1 mm (SD = 3.1) increase in the A-TV measurement, as opposed to 1.1 degrees (SD = 0.9) and 1.7 mm (SD = 1.1) in the RME-FM group ($p < 0.001$; Figure 10).

The effect on the mandible was similar in both groups, with the HE-MP group showing a reduction of 1 degree (SD = 1.2) in the SNB angle and 1.2 mm (SD = 2.7) in the B-TV, while the RME-FM group displayed a reduction of 0.9 degrees (SD = 1.2) in the SNB angle and 0.9 mm (SD = 1.9) in the B-TV. The overall skeletal change was significantly greater in the HE-

MP group, with an increase in the ANB angle of 5.2 degrees (SD = 2) and an increase in the Wits appraisal of 6.3 mm (SD = 2.9). This was in comparison to increases of 2 degrees (SD = 1) in the ANB angle and 2.9 mm (SD = 1.8) in the Wits appraisal in the RME-FM group ($p < 0.001$; Figure 10). In the vertical dimension (Figure 11) there was slightly more increase in the vertical parameters for the RME-FM group, with a 1.1 degree (SD = 1.9) increase in the SN-MP angle and a 1.2 degree (SD = 1.3) increase in the Y-axis while the increases in the HE-MP group were 0.42 degrees (SD = 1.8) and 0.83 degrees (SD = 1.5) respectively ($p <0.001$). The change in these parameters from T1 to T2 was statistically significant in the RME-FM group and insignificant in the HE-MP plate group; there was no significant difference between the two groups.

9.5.2. Dental changes

The dental changes (Figure 12) were significantly higher for the RME-FM group, with an increase in incisor inclination (U1-SN) of 5.5 degrees (SD = 3.9) and an increase in the U1-PP angle of 5 degrees (SD = 3.9) ; ($p < 0.001$). However, there was no statistically significant difference in the incisor position for the HE-MP group. These differences can be attributed to the use of skeletal anchorage. The maxillary molars (U6-PP) tipped mesially by 3 degrees (SD = 1.8) in the RME-FM group and by 1.4 degrees (SD = 2.4) in the HE-MP group. There was some counterclockwise rotation of the maxillary occlusal plane in the RME-FM group (1.4 degrees; SD = 3) while there was no change in the HE-MP group. This, however, was not statistically significant. The mandibular incisor changes were significantly different between the two groups. The mandibular incisors (L1-MP) retroclined by 5.3 degrees (SD = 3.6) in the RME-FM group, while they advanced slightly in the HE-MP group by 2.9 degrees (SD = 5.2; $p < 0.001$).

9.5.3. Stability of the miniscrews and miniplates:

Only one palatal miniscrew (2.6%) failed in this study. The failure was not discovered until the completion of treatment, when the appliance was removed and the Beneplate retainer (PSM Medical Solutions, Gunningen, Germany) was to be placed. A new miniscrew was placed for retention. In five patients, the fixation screw (PSM Medical Solutions, Gunningen, Germany) fell out and had to be replaced; however, the Hyrax rings remained in place over the miniscrew.

Complications were experienced with 21% of miniplates, most of which were minor. Only two of the miniplates became loose during treatment, and only one had to be replaced. The second miniplate became firm again after reducing the elastic force to 60 g for eight weeks, which was similar to the protocol reported by De Clerck et al.[28] In one patient, gingival overgrowth around one miniplate had to be removed using a soft tissue laser and four patients experienced discomfort around the miniplates, mostly from gingival irritation. This, however, did not interfere with their ability to wear the elastics.

9.6. Discussion

The current study compared the skeletal and dental effects of two protocols in the correction of Class III malocclusion. The approaches differed significantly in the mode of force application used for maxillary protraction. The first approach (RME-FM) used a tooth-borne appliance with an extraoral facemask for part-time force application (14-16 hrs/day) while the HE-MP protocol relied on skeletal anchorage and the intraoral application of full-time elastic traction. The two groups were similar in age and dentofacial characteristics at the outset; however, the treatments resulted in different skeletal and dental responses, with the HE-MP showing significantly greater skeletal effects and minimal dental side effects, which can be attributed to the use of skeletal anchorage.

The skeletal changes shown in the RME-FM group in this study were similar to those reported by other studies using facemask therapy, with a 1.1 degree (SD = 0.9) increase in the SNA angle, a 0.9 degree (SD = 1.2) reduction in the SNB angle, an overall skeletal change of 2 degrees (SD = 1) in the ANB angle and a 2.9 mm change (SD = 1.8) in the Wits appraisal (Table 4; Figure 10). Using similar methodology in a randomised clinical trial, Mandal et al.[29] showed a 1.1 degree increase in the SNA angle. Other studies on the tooth-borne RME facemask have shown changes between 0.7[30] and 1.8 degrees[31]. Mandal et al.[29] and others[30,32,33] also reported a reduction in the SNB angle ranging from 1 to 1.7 degrees, with a similar overall ANB change of 2.4-2.6 degrees.[29-31] The dental changes with RME-FM were also similar to those reported in previous studies which have shown mesial movement of the upper dentition and an increase in upper incisor inclination.[2,29,30,32,33] These findings establish this study's RME-FM group as a fairly representative control group for conventional tooth-borne RME facemask therapy.

Differences in skeletal effects

When the HE-MP and RME-FM group were compared, the differences in the skeletal response between the two groups were significant (Table 4; Figure 10). The maxillary advancement was significantly higher in the HE-MP group, with more than threefold the increase in SNA angle than that observed in the RME-FM group. This was also reflected by the fact that the linear measurement in the HE-MP group displayed more than twice the advancement at A point that was observed in the RME-FM group. The effect on the mandible was similar in both groups, with a reduction in the SNB of approximately one degree. The overall skeletal change was significantly greater in the HE-MP group, with an increase in the ANB of 5.2 degrees and an increase in the Wits appraisal of 6.3 mm as opposed to 2 degrees and 2.9 mm in the RME-FM group . In addition, there was no significant change in the mandibular plane angle in the HE-MP group, while there was an increase in the mandibular plane angle of 1.1 degrees in the RME-FM group.

The greater skeletal changes seen in the HE-MP group can be attributed to the use of skeletal anchorage. A similar skeletal response was reported using the Hybrid Hyrax with a Mentoplate[20,21] as well as with a facemask.[21,30] Similar differences between skeletal anchorage and traditional tooth-borne expansion and facemask were also found by Cevidanes et al.[12] when comparing the BAMP protocol to the facemask with maxillary expansion. They reported a 5.9 mm improvement in the Wits measurement in the BAMP group as opposed to only 3.6 mm with RME-FM and, similar to the HE-MP in this study, the majority of the skeletal change was due to maxillary protraction with minimal vertical change (Table 4; Figure 11).

Differences in dental effects (Table 4) (Figure 12)

The differences in dental changes between the two study groups were significant. The dental changes were significantly higher in the RME-FM group, for which there was an increase in incisor inclination (U1-SN) of 5.5 degrees (SD = 3.9) and an increase in the U1-PP angle of 5 degrees (SD = 3.9; $p < 0.001$). The use of skeletal anchorage significantly reduced the dental side effects in the maxillary dentition, with no proclination of the upper incisors reported in the HE-MP group. These findings are consistent with those of other studies which have used hybrid expanders, where the use of palatal miniscrews to support expansion and protraction eliminated the maxillary dental side effects.[21,30] Nevertheless, there was a small amount of maxillary molar tipping observed with the HE-MP, which was similar to observations in other studies.[21,30] This maxillary mesial molar tipping can be attributed to some wire bending and flexure of the appliance.

As in previous studies[2,29,30,32,33], the mandibular incisors retroclined with the RME-FM by 5.3 degrees (SD = 3.6; $p < 0.001$). On the other hand, the mandibular incisors advanced slightly (on average) with the HE-MP by 2.9 degrees (SD = 5.2; $p < 0.001$). The standard deviation, however, shows that the response varied greatly between patients. This variability was also seen in other studies.[12,21] Willmann et al.[21] for example found that, on average, there was no change in the mandibular incisor inclination with Hybrid Hyrax Mentoplate treatment, while Cevidanes et al.[12] reported a slight advancement of the lower incisors, which was similar to results in this study. This seems to be a finding that is unique to the use of skeletal anchorage plates in the mandible, and may be attributed to two causes. Firstly, when Class III elastics are attached to the anchorage plates in the presence of an anterior crossbite, there is no direct force transmission to the lower incisors from the elastics. At the same time, the upper incisors are moving forwards as part of the downwards and forwards movement of the maxilla, and they may in turn indirectly push the lower incisors forward. Secondly, once the crossbite or edge-to-edge relationship is corrected and there is a positive overjet, there is a change in the tongue position, where it can now freely put pressure on the lingual surface of the lower incisors and move them to the newly established neutral zone between the lips and tongue.[12]

The overjet reduction with the HE-MP was slightly less (at 4.1 mm; SD = 1.5) than what was seen with the RME-FM (5.2 mm; SD = 1.9), despite the skeletal correction being greater in the HE-MP group. It was also noted that the treatment was, on average, 3 months longer with the HE-MP. This is likely due to the greater dental compensation associated with the RME-FM, which is achieved through upper incisor proclination and lower incisor retroclination, and which would lead to a faster development of a positive overjet. On the other hand, in the absence of dental compensation and even some mandibular dental decompensation, and with the correction almost exclusively stemming from skeletal changes, the overjet correction may take longer and show a smaller increase overall with the HE-MP. Similar results have also been shown with the BAMP protocol, where treatment has been recorded at an average of two months longer than with the facemask, with a smaller total correction in overjet.[12] It may be argued that for the long term stability of the treatment result, this is a positive finding, as Class

III patients tend to resume the original growth pattern when treatment is completed.[29] This lack of dental compensation may allow some room for future dental camouflage, should there be some relapse.

Although the HE-MP protocol shares similar skeletal and dental effects with the BAMP protocol,[12] there are several differences between the two. Firstly, there are four fewer surgical procedures involved with the HE-MP protocol, as the elimination of the zygomatic plates for maxillary anchorage using the hybrid expander halves the number of flap procedures. This also reduces the chances of miniplate failure, which has been reported to be six times higher in the maxilla than in the mandible.[34] The higher failure rate of the maxillary zygomatic miniplates may be due to the difficulty in placing them in younger patients, due to reduced bone density.[28,34] On the other hand, the use of palatal miniscrews in the anterior palate to support the hybrid expander for the maxillary anchorage insures the miniscrews are in an area of good bone quality[35,36] where success rate is high (more than 96%) and predictable, even in young patients.[37]Secondly, treatment with the HE-MP protocol can start earlier than with the BAMP protocol, which requires the mandibular canines to erupt prior to the placement of the miniplate. It is well documented that the maxilla is more responsive to protraction in younger patients, particularly those younger than 10 years old.[38-40] The use of L-plates allows the miniplates to be placed before the eruption of the mandibular canines, thus allowing treatment in younger patients, much like what was reported with the use of Mentoplates.[20] Lastly, the HE-MP allows the incorporation of bone-borne maxillary expansion, which allows the concomitant management of any transverse maxillary deficiency (often present in maxillary hypoplasia[13]) during Class III correction. In addition, maxillary expansion may also have the effect of making circummaxillary sutures more responsive to protraction forces.[14] By eliminating the more failure-prone maxillary miniplates and using the more reliable palatal anchorage, the HE-MP may offer a less invasive and more predictable alternative to the BAMP method, especially for younger Class III patients.

L-plates offer an advantage over the Mentoplate, as they make the right and left plates independent of each other, allowing the surgeon more freedom to vary the position of the plates and find the best cortical bone. Furthermore, the use of traditional trauma plates, as opposed to proprietary plates such as the Mentoplates (PSM Medical Solutions, Gunningen, Germany) or the Bollard plates (Bollard; Tita-Link, Brussels, Belgium), makes the protocol more accessible to patients and potentially reduces the cost, as most surgical theatres will be equipped with traditional orthognathic trauma plates.

The complications reported with the HE-MP were relatively minor, with only one miniscrew failure and only one miniplate needing replacement. This complication rate is consistent with that reported in other studies.[34,37]

An alternative approach that takes advantage of skeletal anchorage is to use miniscrew-supported maxillary expansion in conjunction with facemask wear.[41,42] The use of skeletal anchorage would enhance the skeletal response and reduce dental side effects.[41,42] Willman et al. found that when the Hybrid Hyrax-Mentoplate protocol was compared with the Hybrid Hyrax-facemask protocol, the results were very similar, except for more backward rotation of the mandible when the facemask was used. The facemask, however, has the significant limitation of reduced patient acceptance due to the obtrusive extraoral nature of the appliance.[21]

It is important to mention that the results of this study are limited to a short-term evaluation after treatment in two different centres. Long-term evaluation will be required to assess the stability of this treatment once the patients have completed postpubertal growth. It has been shown that facemask therapy is stable in 75-80 % of cases long-term.[10,43] It remains to be seen if the greater skeletal response in the active treatment phase with this skeletal anchorage protocol results in better long-term stability.

9.7. Conclusion

The results of this study indicate that, in the short term, the HE-MP approach produces a greater skeletal correction in Class III malocclusion in growing patients, with reduced dental side effects when compared to traditional tooth-borne RME-FM. Further study is required into the long-term stability of these skeletal corrections.

9.8. References

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9.11.Figures

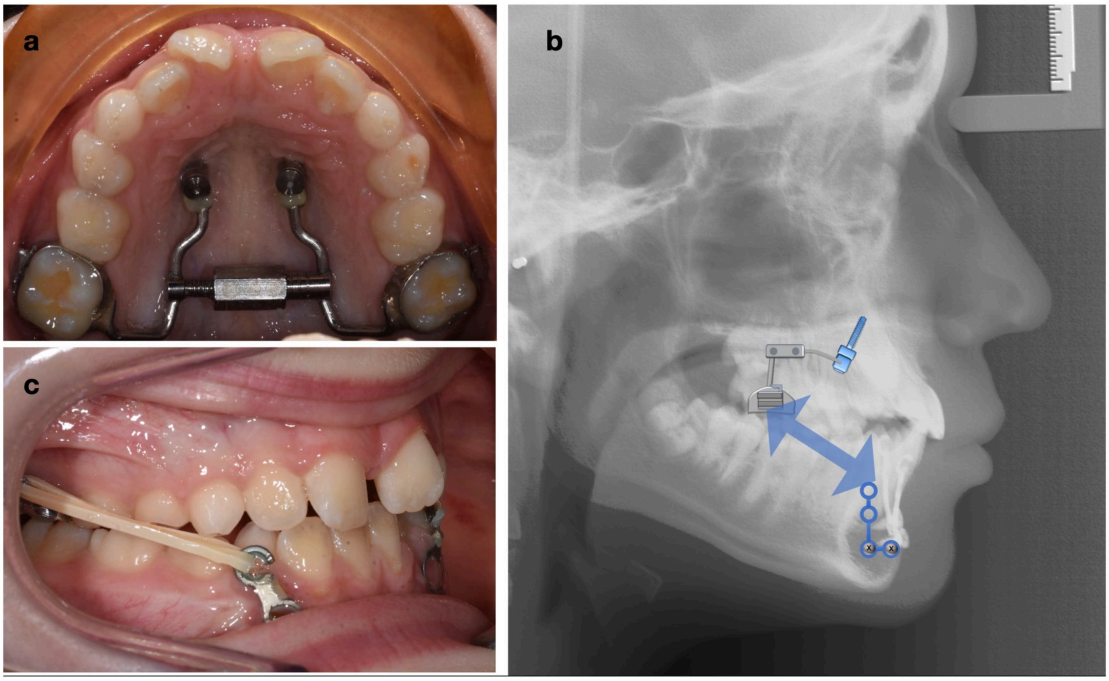

Figure 1. Hybrid expander miniplate (HE-MP) setup: A. Hybrid expander with two palatal miniscrews and molar bands with buccal hooks for elastic wear; B. Schematic representation of the biomechanics and force vector for elastic wear; C. Elastic band connecting the mandibular miniplate to the hook on the maxillary molar band. The miniplate has been converted into a hook by cutting an opening using a carbide bur.

Figure 2. The L-plate with two screws placed bilaterally apical to the lower incisors, to avoid the developing mandibular canine.

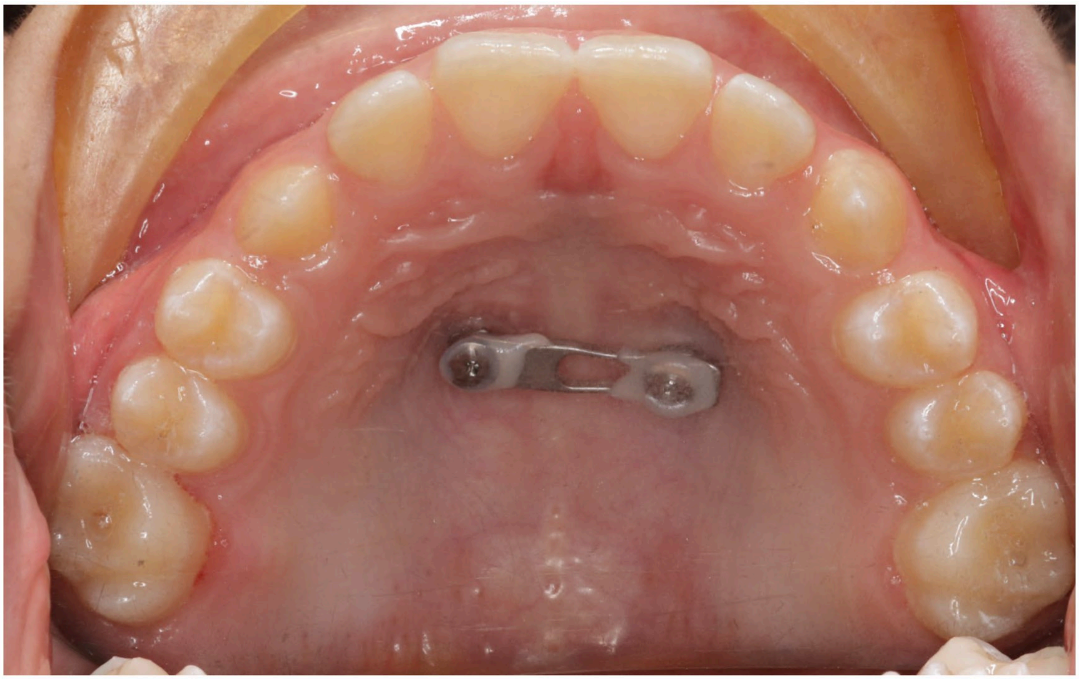

Figure 3. Retention of the transverse expansion using a stainless steel miniplate fixed with two fixation screws (Benefit PSM Medical Solutions, Gunningen, Germany) and flowable resin added to secure the fixation screws.

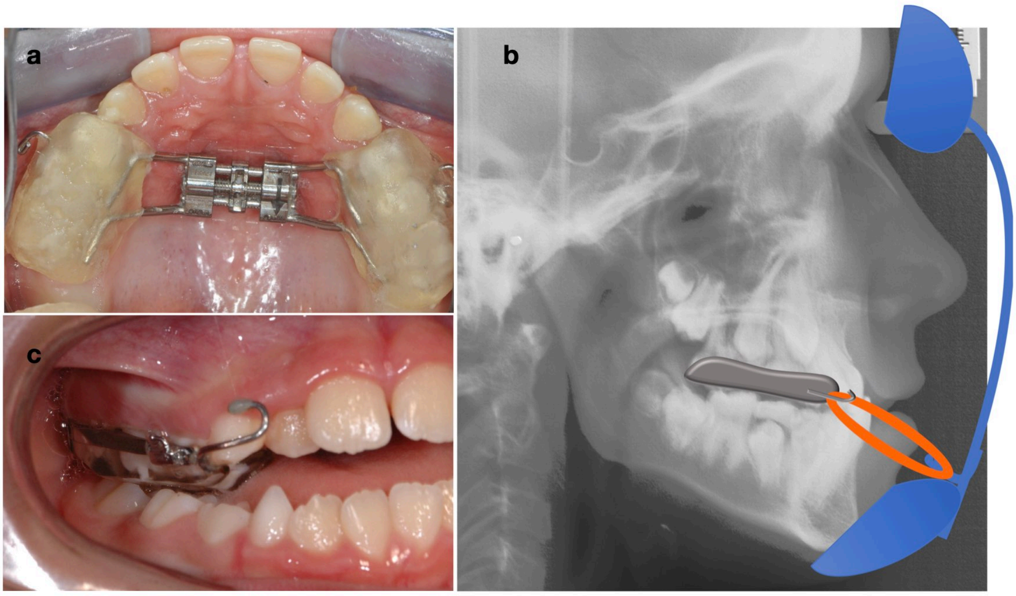

Figure 4. A. Bonded Hyrax appliance with acrylic bite blocks; B. Facemask hooks emerge near the maxillary canine for elastic application; C. Facemask elastic force vector at approximately 30 degrees down from the occlusal plane.

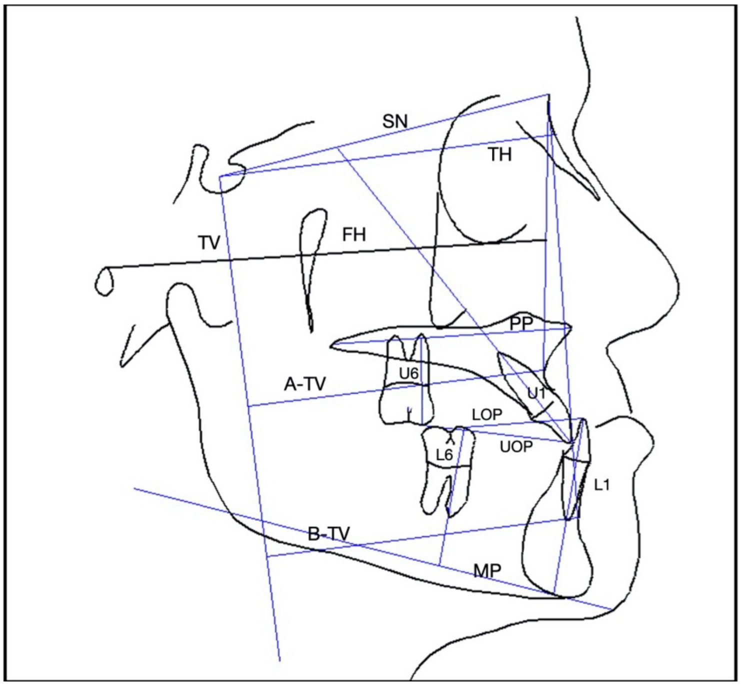

Figure 5. Cephalometric measurements and reference lines. SN (Sella-Nasion line). TH (true horizontal line 7 degrees from SN). TV (true vertical line 90 degrees from TH through Sella). A-TV (perpendicular distance from A point to TV). B-TV (perpendicular distance from B-Point to TV). FH (Frankfort horizontal line). PP (palatal plane through ANS-PNS). MP (mandibular plane). UOP (upper occlusal plane: maxillary incisal tip to mesiobuccal cusp of first molar). LOP (lower occlusal plane: mandibular incisor tip to mesiobuccal cusp of mandibular first molar). U1 (long axis of the most labial upper incisor). L1 (long axis of the most labial mandibular incisor). U6 (maxillary first molar long axis: mesiobuccal cusp to mesiobuccal root tip). L6 (mandibular first molar long axis: mesiobuccal cusp to mesial root tip).

Figure 6. One case from the HE-MP group. Class III malocclusion with anterior crossbite and bilateral posterior crossbite.

Figure 7. Progression of the case from the HE-MP group from start to finish. A. Start of elastic wear after conversion of the miniplates into a hooks; B. 7 months' progress with positive overjet developing; C. Treatment finished at 14 months with a positive overjet and slightly overcorrected molar relationship.

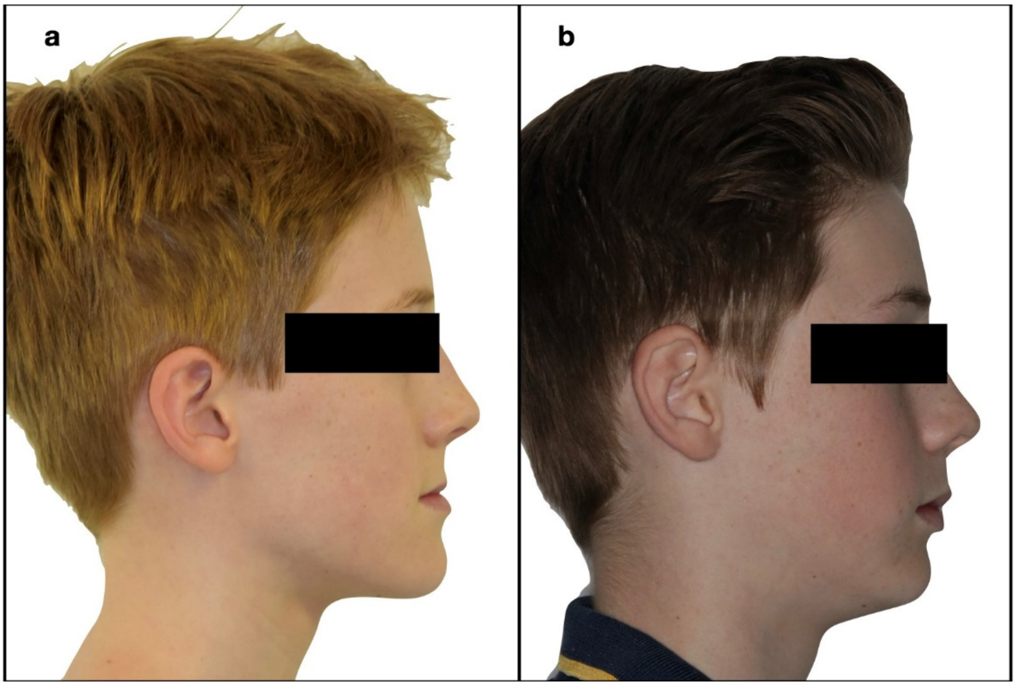

Figure 8. Before (a) and after (b) profile comparison. Significant increase in facial convexity and reduction in chin prominence.

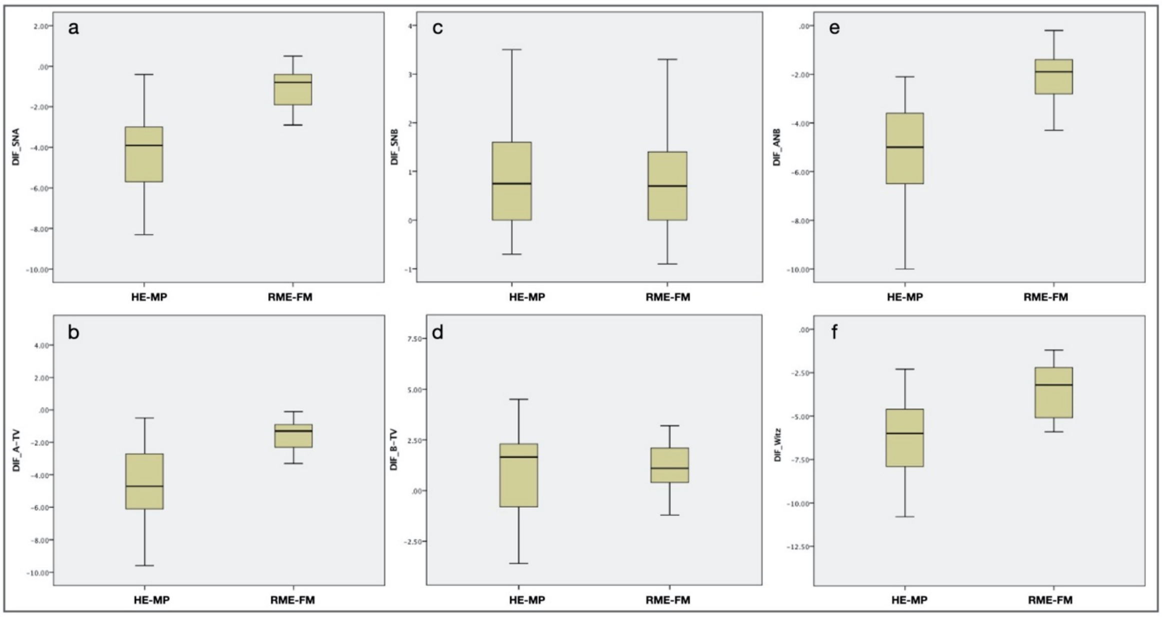

Figure 9. Box plots showing the difference in response between T2 and T1 in the anteroposterior skeletal parameters.

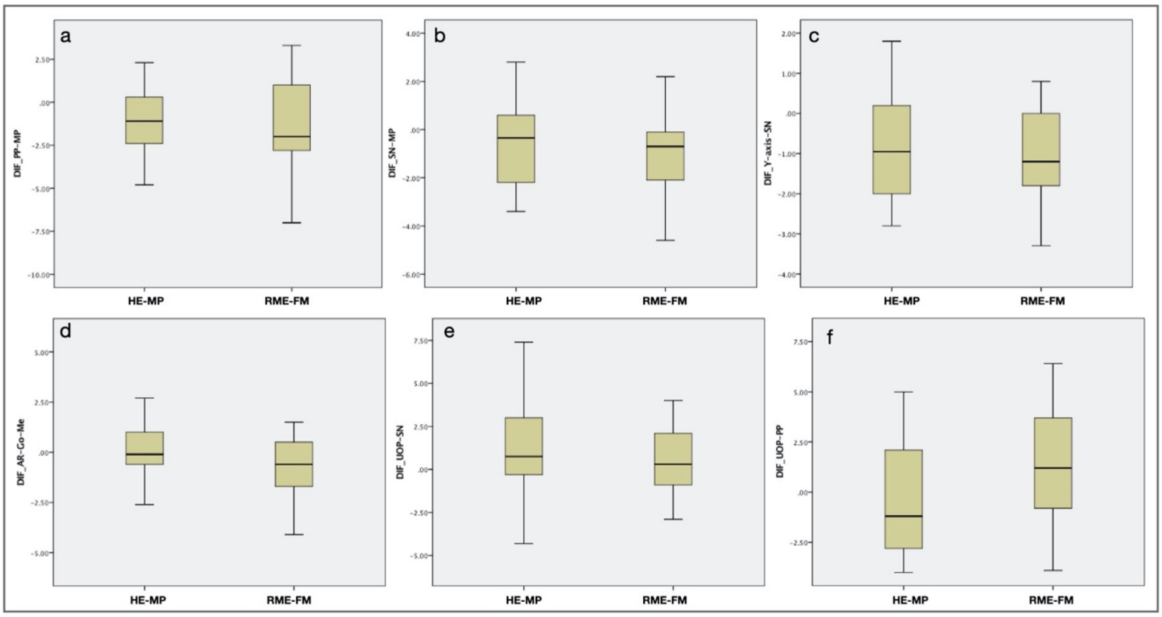

Figure 10. Box plots showing the difference in response between T1 and T2 in the vertical parameters.

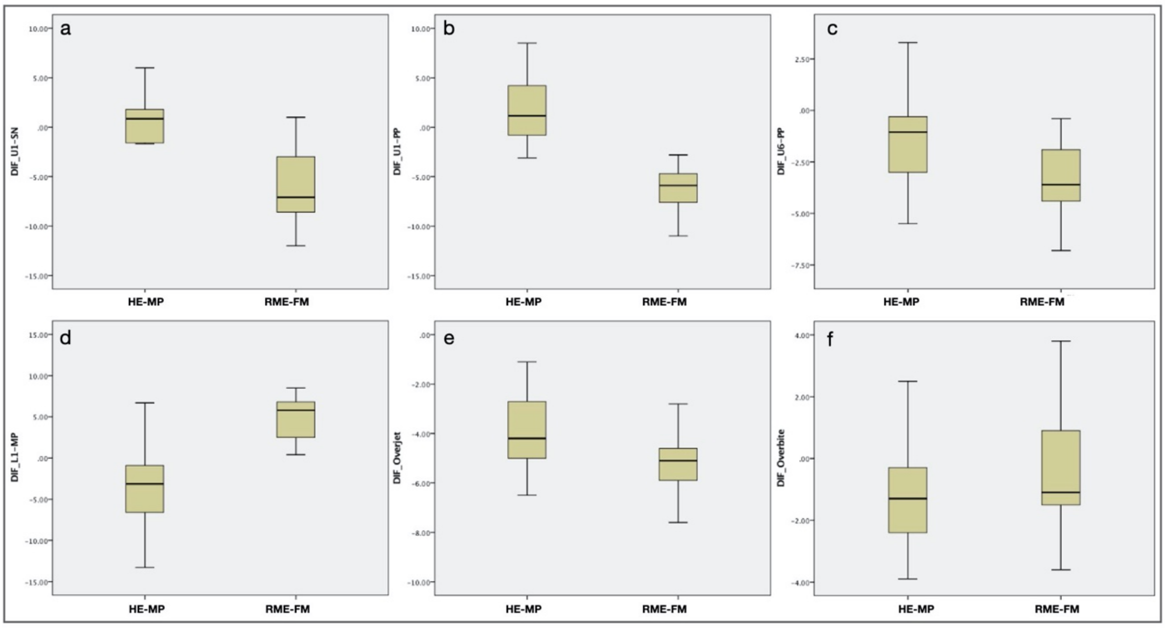

Figure 11. Box plots showing the difference in response between T1 and T2 in the dental parameters.

9.12. Tables

Table 1. Comparison of the two groups at T1 before treatment.

	HE-MP (n= 19)			RME-FM (n=18)					
Sex	**Female=8, Male =11**			**Female=7, Male =11**			**95% Confidence Interval of the Difference**		
CVMI	**CS1 = 7, CS2 = 10, CS3 =2**			**CS1 = 10, CS2 = 6, CS3 =2**					
	Mean	**SD**	**Std. Error Mean**	**Mean**	**SD**	**Std. Error Mean**	**Lower**	**Upper**	***p***
Gender	1.58	0.51	0.12	1.61	0.50	0.12	-0.37	0.31	0.85
Age at T1 years	10.12	1.37	0.31	10.56	1.41	0.33	-1.36	0.49	0.34
CVM	1.74	0.65	0.15	1.56	0.71	0.17	-0.27	0.64	0.42
Tx Duration years	15.9	2.8	0.64	12	3.45	0.81	1.8	6.02	0.00
SNA°	79.74	4.44	1.02	78.36	3.33	0.78	-1.25	4.01	0.30
SNB°	81.26	4.13	0.95	80.09	3.38	0.80	-1.36	3.70	0.35
ANB°	-1.53	2.33	0.53	-1.74	1.59	0.38	-1.12	1.55	0.75
Wits°	-5.35	1.69	0.39	-5.26	2.70	0.64	-1.58	1.41	0.91
A-TV mm	58.02	4.65	1.07	58.68	3.87	0.91	-3.53	2.20	0.64
B-TV mm	58.37	7.78	1.78	58.54	6.07	1.43	-4.84	4.50	0.94

PP-MP°	24.82	5.55	1.31	24.99	4.75	1.12	-3.67	3.34	0.92
SN-MP°	32.00	5.29	1.21	33.92	5.00	1.18	-5.36	1.52	0.26
Y-axis°	66.22	4.36	1.00	66.89	3.06	0.72	-3.20	1.86	0.59
AR-Go-Me°	132.63	6.69	1.54	136.50	4.78	1.13	-7.77	0.03	0.05
UOP-SN°	17.13	5.33	1.22	18.27	4.73	1.11	-4.51	2.23	0.50
UOP-PP°	10.62	4.08	0.94	11.53	4.84	1.14	-3.90	2.06	0.54
LOP-MP°	17.97	3.72	0.85	20.65	4.05	0.95	-5.27	-0.08	0.04
U1-SN°	107.72	9.28	2.13	103.77	5.41	1.28	-1.16	9.06	0.13
U1-PP°	115.13	7.97	1.83	112.71	5.87	1.38	-2.28	7.11	0.30
U6-PP°	79.29	4.47	1.02	81.19	3.52	0.83	-4.59	0.79	0.16
L1-MP°	88.84	6.74	1.55	85.96	6.52	1.54	-1.54	7.32	0.20
L6-MP°	78.53	7.01	1.61	77.22	5.73	1.35	-2.98	5.60	0.54
Overjet mm	-1.65	1.23	0.28	-2.23	1.65	0.39	-0.39	1.54	0.24
Overbite mm	0.65	1.75	0.40	1.67	2.53	0.60	-2.46	0.43	0.16

Table 2 Intra Class Correlation Coefficient for the intra-observer reliability

	Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound
SNA°	0.994	0.979	0.998
SNB°	0.993	0.974	0.998
ANB°	0.994	0.98	0.999
Wits°	0.988	0.847	0.998
A-TV mm	0.984	0.937	0.996
B-TV mm	0.993	0.975	0.998
PP-MP°	0.991	0.967	0.998
SN-MP°	0.987	0.952	0.997
Y-axis°	0.986	0.946	0.997
AR-Go-Me°	0.984	0.945	0.996
UOP-SN°	0.982	0.93	0.996
UOP-PP°	0.981	0.932	0.995
LOP-MP°	0.946	0.804	0.985
U1-SN°	0.994	0.98	0.999
U1-PP°	0.995	0.983	0.999

U6-PP°	0.981	0.934	0.995
L1-MP°	0.868	0.537	0.964
L6-MP°	0.99	0.963	0.997
Overjet mm	0.985	0.948	0.996
Overbite mm	0.989	0.961	0.997

Table 3.Variables used in the lateral cephalometric analysis

	Measurement	Definition
Anteroposterior skeletal relationship	SNA	The angle between the anterior cranial base (Sella to Nasion) and the NA (nasion to point A) line
	SNB	The angle between the anterior cranial base (Sella to Nasion) and NB (nasion to point B) line
	ANB	The angle between the NA and NB lines relates the anteroposterior position of the maxilla to the mandible
	Wits	The distance between AO and BO, the projection of points A and B perpendicularly to the occlusal plane
	A-TV	The distance between A-point and the true vertical line TV
	B-TV	The distance between B-point and the true vertical line
	AB-TV difference	The difference between A-TV and B-TV
Vertical skeletal relationship	PP-MP	The angle between the palatal plane and mandibular plane
	SN-MP	Mandibular plane angle: The angle between the anterior cranial base (Sella to Nasion) mandibular plane

	Y-axis	The angle between the line from Sella to Gnathion SN-Gn and the Frankfurt horizontal plane and indicates the downwards, rearwards or forwards position of the chin in relation to the upper face.
	Ar-Go-Me (gonial angle)	The angle between the Me-Go line and the Go-Ar line
Dental variables	UOP-SN	The angle between the upper occlusal plane and the anterior cranial base line
	UOP-PP	The angle between the upper occlusal plane and palatal plane
	LOP-MP	The angle between the lower occlusal plane and mandibular plane
	U1-SN	Angle between the upper incisor and the anterior cranial base line
	U1-PP	Angle between the upper incisor and the palatal plane
	U6-PP	Angle between the upper first molar and the palatal plane
	L1-MP	The angle between the lower incisor and mandibular plane
	L6-MP	The angle between the lower first molar and mandibular plane
	Overjet	The overjet
	Overbite	The overbite

Table 4. Comparison for each group between T1 and T2 and comparison of differences in changes between the two groups.

	HE-MP (n=19)							RME-FM (n=18)							HE-MP vs RME-FM						
	T1		T2		95% Confidence Interval of the Difference			T1		T2		95% Confidence Interval of the Difference			HE-MP		RME-FM		95% Confidence Interval of the Difference		
	mean	SD	mean	SD	Lower	Upper	p	mean	SD	mean	SD	Lower	Upper	p	Mean	SD	Mean	SD	Lower	Upper	p
SNA°	79.74	4.44	19	83.93	4.98	19	-5.21	-3.17	0.00	78.36	3.33	18	79.51	3.55	18	-1.61	-0.68	0.00	-4.19	2.11	19
SNB°	81.26	4.13	19	80.31	4.40	19	0.37	1.52	0.00	80.09	3.38	18	79.19	3.41	18	0.29	1.49	0.01	0.95	1.19	19
ANB°	-1.53	2.33	19	3.63	2.13	19	-6.13	-4.19	0.00	-1.74	1.59	18	0.30	1.54	18	-2.58	-1.51	0.00	-5.16	2.01	19
Wits°	-6.15	1.78	19	-0.33	2.17	19	-7.35	-4.30	0.00	-6.30	2.33	18	-3.36	1.99	18	-3.81	-2.07	0.00	-5.83	3.17	19
A-TV mm	-5.35	1.69	19	0.97	1.94	19	-7.72	-4.92	0.00	-5.12	2.72	17	-1.68	2.15	17	-4.27	-2.62	0.00	-6.32	2.91	19
B-TV mm	58.02	4.65	19	62.13	6.36	19	-5.59	-2.64	0.00	58.68	3.87	18	60.37	4.41	18	-2.22	-1.17	0.00	-4.12	3.07	19
PP-MP°	58.37	7.78	19	57.16	8.77	19	-0.09	2.50	0.07	58.54	6.07	18	57.62	6.58	18	-0.01	1.84	0.05	1.21	2.68	19
SN-MP°	24.82	5.55	18	26.28	4.79	18	-2.81	-0.11	0.04	24.99	4.75	18	26.51	4.87	18	-2.88	-0.16	0.03	-1.46	2.71	18
Y-axis°	32.00	5.29	19	32.42	5.56	19	-1.30	0.46	0.33	33.92	5.00	18	35.04	4.73	18	-2.07	-0.18	0.02	-0.42	1.83	19
AR-Go-Me°	66.22	4.36	19	67.05	4.37	19	-1.54	-0.13	0.02	66.89	3.06	18	68.07	3.03	18	-1.80	-0.55	0.00	-0.83	1.46	19
UOP-SN°	132.63	6.69	19	132.43	6.65	19	-0.44	0.86	0.52	136.50	4.78	18	136.98	4.52	18	-1.88	0.92	0.48	0.21	1.35	19
UOP-PP°	17.13	5.33	19	16.12	5.15	19	-0.32	2.34	0.13	18.27	4.73	18	17.15	4.98	18	-0.13	2.38	0.08	1.01	2.76	19
LOP-MP°	10.62	4.08	19	10.69	4.07	19	-1.55	1.40	0.92	11.53	4.84	18	10.09	4.68	18	-0.05	2.94	0.06	-0.07	3.07	19
U1-SN°	17.97	3.72	19	20.33	3.76	19	-3.83	-0.88	0.00	20.65	4.05	18	23.06	4.32	18	-4.21	-0.61	0.01	-2.36	3.06	19

U1-PP°	107.72	9.28	19	107.06	7.76	19	-1.13	2.44	0.45	103.77	5.41	18	109.24	5.34	18	-7.42	-3.54	0.00	0.66	3.70	19
U6-PP°	115.13	7.97	19	113.87	7.05	19	-0.68	3.20	0.19	112.71	5.87	18	117.73	6.38	18	-6.98	-3.07	0.00	1.26	4.02	19
L1-MP°	79.29	4.47	19	80.68	4.70	19	-2.56	-0.23	0.02	81.19	3.52	18	84.26	3.64	18	-3.95	-2.19	0.00	-1.39	2.41	19
L6-MP°	88.84	6.74	19	91.78	7.76	19	-5.46	-0.42	0.03	85.96	6.52	18	80.66	7.58	18	3.52	7.07	0.00	-2.94	5.23	19
Overjet mm	78.53	7.01	19	80.32	7.17	19	-3.82	0.24	0.08	77.22	5.73	18	76.59	6.21	18	-2.28	3.52	0.66	-1.79	4.22	19
Overbite mm	-1.65	1.23	19	2.43	1.35	19	-4.78	-3.38	0.00	-2.23	1.65	18	2.97	0.91	18	-6.12	-4.27	0.00	-4.08	1.45	19

10. Conceptualisation of the compliance-free Class III correction appliance NET3-Corrector

The conceptualisation of a compliance free tooth-bone-borne Class III bite corrector emerged from a clinical need. Despite the fact that the use of skeletal anchorage in Class III correction has improved clinical results and reduced dental side effects, the methods employed to date have been heavily reliant on patient compliance. In a clinical environment, this can make treatment outcomes unpredictable. If treatment is progressing poorly, it can be hard to gauge whether this is due to unfavourable growth, failure of the appliance, or poor patient adherence to the treatment regime. Furthermore, studies have shown that patients may overestimate the number of hours for which they wear orthodontic appliances, and even parents can tend to overinflate their child's compliance with prescribed wear times.[1-3] In our clinical experience, parental monitoring and encouragement is readily available when a child has been prescribed a protraction facemask. It is easy for parents to see if the child has gone to bed without the facemask. Conversely, when using methods that involve the use of intraoral elastics, such as bone-anchored maxillary protraction (BAMP), the Hybrid Hyrax Mentoplate or the hybrid expander mini plate (HE-MP), it can be hard for parents to keep track of the prescribed treatment.

During the initial consultation, "headgear free" methods are usually met with good acceptance and, in many cases, preferred over facemask therapy. Such methods are perceived as an alternative to an obtrusive extraoral device. However, once the miniplates have healed, the innocuous nature of such methods means that parents can often forget that the child is supposed to be wearing elastics full-time, and that they may require a reminder. Adherence to treatment then relies solely on the child. In the clinic, it was often the case that parents were somewhat surprised to hear that treatment was not progressing as planned, due to poor elastic wear. Clinically, this often leads to difficulties, and the need arose to design a compliance-free appliance that utilises skeletal anchorage. Additionally, the BAMP, Hybrid Hyrax Mentoplate and HE-MP protocols all require a flap procedure which, in most cases, is carried out under a general anaesthetic (GA). This can entail risk, cost, discomfort and inconvenience, with some parents viewing the procedure as overly invasive. Moreover, in the public health setting, the waiting lists for GA can be long. Such elective procedures may not always take priority, leading to treatment delays. Hence the need to design a compliance-free appliance using miniscrews only, with the objective of avoiding the need for a GA procedure.

10.1. Appliance design

Previous studies on maxillary protraction using a protraction spring that delivered an upward and forward force have reported several side effects, such as canting of the maxillary occlusal plane, protrusion of the upper incisors and mesial tipping of the maxillary molars.[4,5] In order to negate those side effects, several considerations were taken into the design process of NET3 appliance in this study:

10.1.1. The maxillary component

1. A hybrid expander[6] was selected with two palatal miniscrews in the anterior palate (Figure 1a). The aim was to allow bone-borne maxillary expansion, maximising its skeletal effect, while also providing indirect anchorage for the maxillary molars against the mesialising and tipping effect of the protraction forces when the cantilever is loaded in an anterior and superior direction.
2. Our preference was for a rigid cantilever arm that could come off the buccal surface of the first molar to avoid the the use of L-pins and/or ball pins in the molar headgear tube, as used in Liou's[4] design; this was a main source of breakage in a clinical trial by Buck et al.[7] conducted at the Sydney University Orthodontic Department. Additionally, the use of a cantilever engaging only the upper first molars makes it possible to eliminate any side effects on the rest of the maxillary teeth, including incisor intrusion and canting of the occlusal plane. Furthermore, it would allow the use of the appliance regardless of dentition stage. This could be particularly useful in the late mixed dentition stage, where anchorage can be difficult to gain from the deciduous molars.

   It was also thought that the presence of the miniscrews on the palatal side would stop the molars from tipping mesially when the cantilever was loaded in an anterior and superior direction; thus, the resultant effect would be restricted to skeletal protraction of the maxilla.

The 12 mm SuperScrew (The SuperScrew-SuperSpring Co. Los Angeles, CA, USA) was selected instead of the routinely used Hyrax screw. Its activation using a hex wrench from the front of the mouth and moving it from upper incisor to lower incisor (which equates to 1/12 of a millimetre of expansion per turn), was thought to be easier for parents and patients. Another practical advantage of the SuperScrew is that it allows reverse movement of the screw itself, which tolerates adjustments to compensate for any slight laboratory inaccuracies in the path of insertion of the Benefit miniscrew abutments. Currently, the SuperScrew is less available commercially; the PowerScrew (Tiger Dental, Bregenz, Austria) is a good alternative with very similar properties.

10.1.2. The mandibular component

The initial mandibular component was a rigid lingual arch based on the design used by Liou[4], with an additional buccal headgear tube attachment that accommodated the spring. The headgear tube was welded to the lower molar bands (Figure 1b). The lingual arch had rests on the lower premolars or, in some cases, the primary molars, but was not bonded to those teeth. This was planned to allow the lower first molars to freely tip distally and reduce the flow-on effect of the whole mandibular dental arch tipping and canting down posteriorly. Liou[4] reported that the mandibular molar distal tipping with his protraction spring tended to normalise or relapse after the appliance was removed, and we desired a similar effect in our design. Thus, the appliance was only cemented to the lower first molars. The rigid lingual arch was intended to prevent rotation and buccal rolling of the molars. Furthermore, by not requiring any additional dental anchorage, the appliance could also be used during the late mixed dentition stage when the lower deciduous molars are close to shedding.

10.1.3. Crowns vs. bands

There were clinical breakages with prototype 1, which involved the use of the Forsus FRD (3M Unitek Corp, Monrovia, CA, USA), as well as those reported in our clinic with other Class II correctors, which used headgear tubes on maxillary molars. It was evident that one potential problem area was fracture or even tearing and distortion of the molar bands themselves. This is of particular importance when a spring is used for Class III correction as opposed to Class II correction. In the case of Class II correction springs, the mandible readily moves and repositions forwards. However, with a Class III corrector, the forces would potentially be higher on the attachments due to the inability of the mandible to displace backwards. For this reason, we selected modified crowns, namely Rollo Bands (American Orthodontics, Sheboygen, WI, USA), for the upper and lower first molar component.

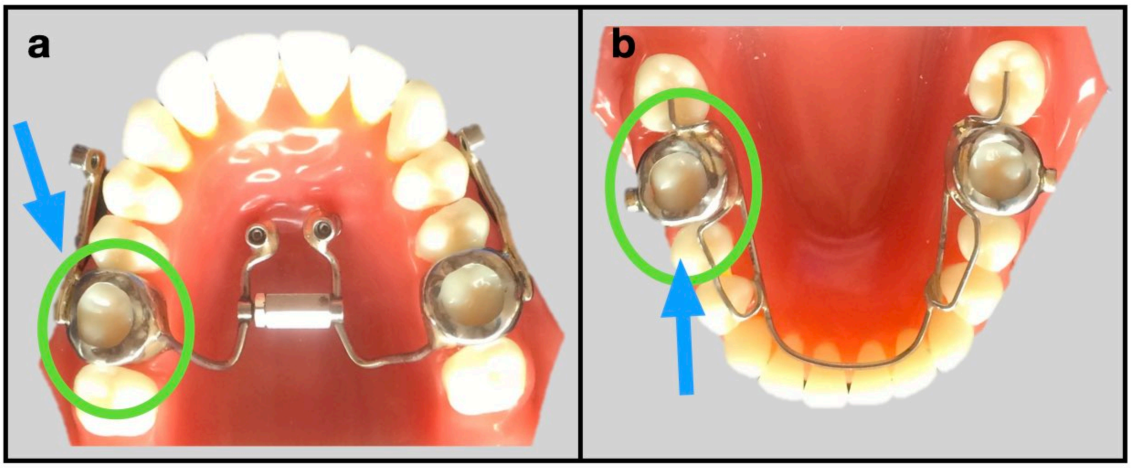

Figure 1. Maxillary and mandibular components. Blue arrows indicate the use of Rollo Bands (American Orthodontics, Sheboygen, WI, USA). A. Maxillary components with two palatal miniscrews and an expander with cantilever arms; B. Mandibular component with a lingual arch and rests on premolars and second molars.

10.1.4. The active component:

The initial idea was to try and use a reverse Herbst design. The author in his private practice was using a cantilever bite jumper, namely the Hanks telescoping Herbst appliance (HTH) (American Orthodontics, Sheboygen, WI, USA), for Class II correction with good results and limited breakages. The propensity for the cantilever bite jumper to have reduced breakages was confirmed by a 2014 comparative study[8] where the HTH demonstrated one sixth the breakage rate of a conventional Herbst. The cantilever allowed freedom in terms of minimising the number of teeth needed for anchorage. Moreover, the telescopic nature of the arms and the ball and socket joint at the attachments allowed a great deal of freedom of movement, especially lateral mandibular movement. This could, in turn, reduce the stresses on the cement and the appliance components, thus decreasing the breakage rate. However, reversing this appliance into a Class III correction device would not have been practical. The telescoping arms were rigid and worked by forcing the mandible into a forward position to correct the Class II malocclusion. In a reversed configuration, however, this would not have worked so readily, due to the inability of the maxilla to displace as the mandible can with forward forces, and the inability of the mandible to displace backwards. A modification was required to provide some form of spring loading for protraction. At that stage, American Orthodontics (Sheboygen, WI, USA) did not produce the Hanks telescoping arm with an internal spring, so a few alternative design possibilities were explored.

10.2. Prototype 1:

The first prototype followed the design reported in a clinical trial by Almozany et al., who described an innovative method for correcting Class III malocclusion using a bonded Hybrid Hyrax in combination with Class III elastics.[9] In the trial, two miniscrews were placed in the lower arch between the lateral and central incisor, and then indirectly bonded to a lower lingual arch. Two patients scheduled for treatment using this protocol presented with problems; one had insufficient space between the lower incisor roots to place the miniscrews, and the other had a failed miniscrew in the lower arch. For this reason, an alternative plan involved the use of a reverse Forsus Fatigue Resistant Device (FRD; 3M Unitek Corp, Monrovia, CA, USA). We felt that the EZ Module (3M Unitek Corp, Monrovia, CA, USA) of the Forsus FRD would be irritating to the cheeks. Consequently, it was substituted with the L-pin or ball pin attached to a headgear tube on the lower molar bands. The springs were installed after maxillary expansion was completed (Figure 2).

Figure 2. Case 1 using prototype 1 before the insertion of the Forsus FRD (3M Unitek Corp, Monrovia, CA, USA).

Figure 3. Case 1 – after a short stint with prototype 1, the patient had overexpanded and the appliance failed. The anterior crossbite was corrected, and the treatment progressed to fixed appliances.

Figures 2 and 3 show Case 1 before treatment and after expansion, respectively. Shortly after treatment started, the patient misunderstood the instructions and continued the expansion until the expander separated and the miniscrews failed (Figure 3). Hence, the appliance was removed prematurely. However, the crossbite had corrected, and the treatment was planned to continue with fixed appliances. In the second patient, the appliance corrected the Class III malocclusion; however, there were multiple breakages. The spring slipped off from the cantilever arm on several occasions and the L-pin in the lower arch broke three times. There were also significant problems with gingival irritation, as well as impingement by the spring and L-pin connection. It was evident that the design needed to be modified.

Figure 4. Prototype 1 in position with the Forsus FRD (3M Unitek Corp, Monrovia, CA, USA) activated. A. The gingival impingement and irritation, shown with the blue arrow. The miniscrew seen in the photos was from the failed attempt to treat the patient with the protocol proposed by Al-Mozany et al.[9]

10.3. Prototype 2:

The design of prototype 2 was based on the Twin Force Bite Corrector[10] (TFBC; Ortho Organizers, Inc., San Marcos, CA, USA) which is designed to fit with a clamp mechanism over full dimension stainless steel arch wires with full fixed appliances. This was then adapted to match the cantilever design attempted with the Forsus spring (3M Unitek Corp, Monrovia, CA, USA) described in prototype 1. Although this looked good on the model, it was not used clinically as it was thought that the wire welded to the cantilever would be able to survive the desired loading (Figure 5).

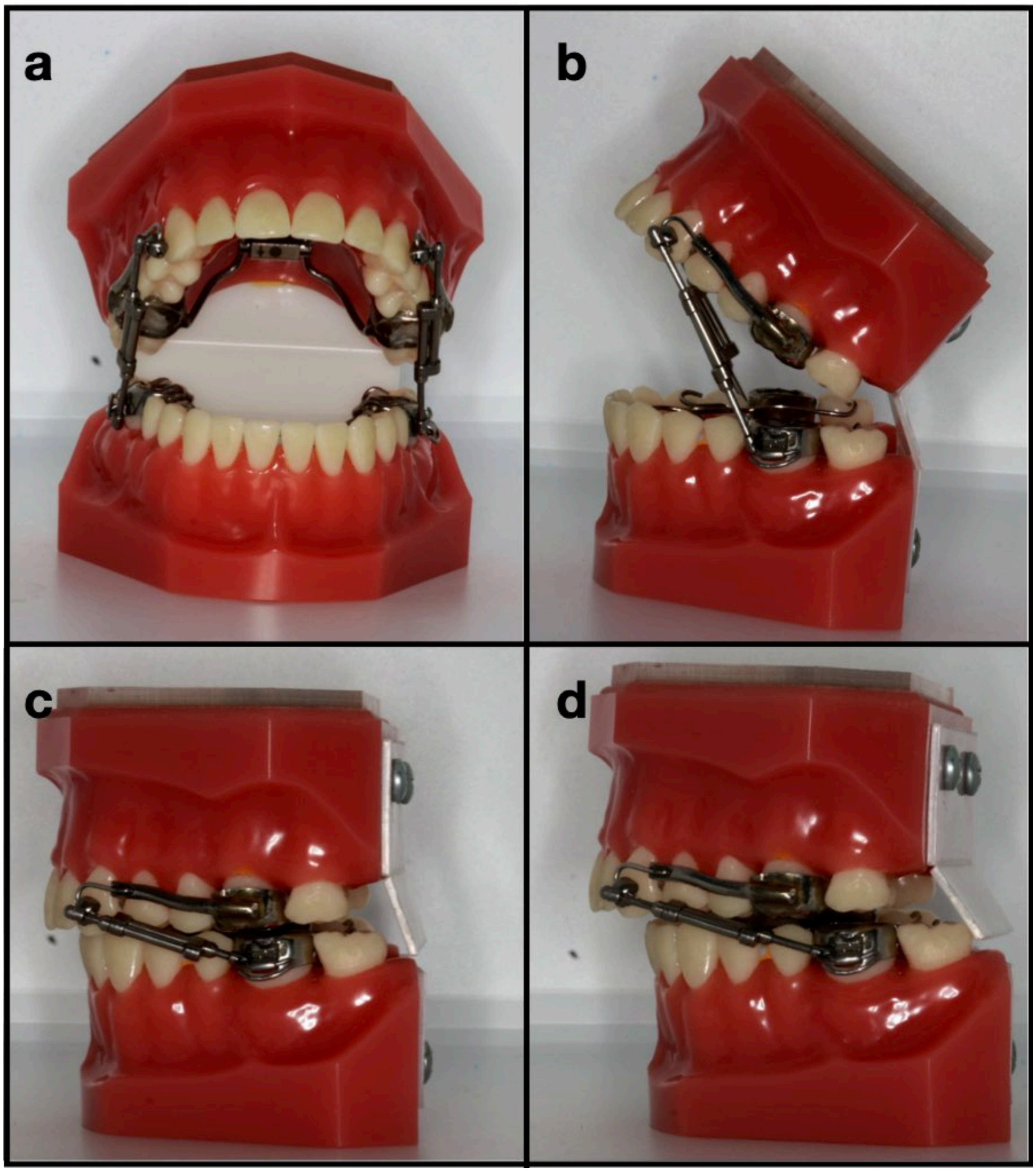

Figure 5. Prototype 2 using the Twin Force Bite Corrector[10] TFBC (Ortho Organizers, Inc., San Marcos, CA, USA). A. Springs in place allow a good range of mandibular movement; B. Side view showing how the TFBC attached to the appliance through the clamp mechanism on

a wire welded to the cantilever arm and through a wire designed to fit the headgear tube to the lower molar; C and D. The springs appear compressed when the patient bites, after which they gradually decompress, causing the maxilla to move forwards.

10.4. Prototype 3: NET3-Corrector

By the time we noticed the limitations of prototypes 1 and 2, American Orthodontics had released a new Class II corrector based on the Hanks telescoping Herbst design, which included an internal spring, namely the PowerScope appliance (American Orthodontics, Sheboygen, WI, USA). This new appliance had a telescoping arm and ball, and a socket joint similar to the Hanks telescoping Herbst. It also had an internal nickel titanium spring designed to deliver a force of 260 g for mandibular forward propulsion (Figure 6). Furthermore, it featured a special clamp mechanism which required an Allen key to thread the corrector onto an arch wire to lock it into place (Figure 7).

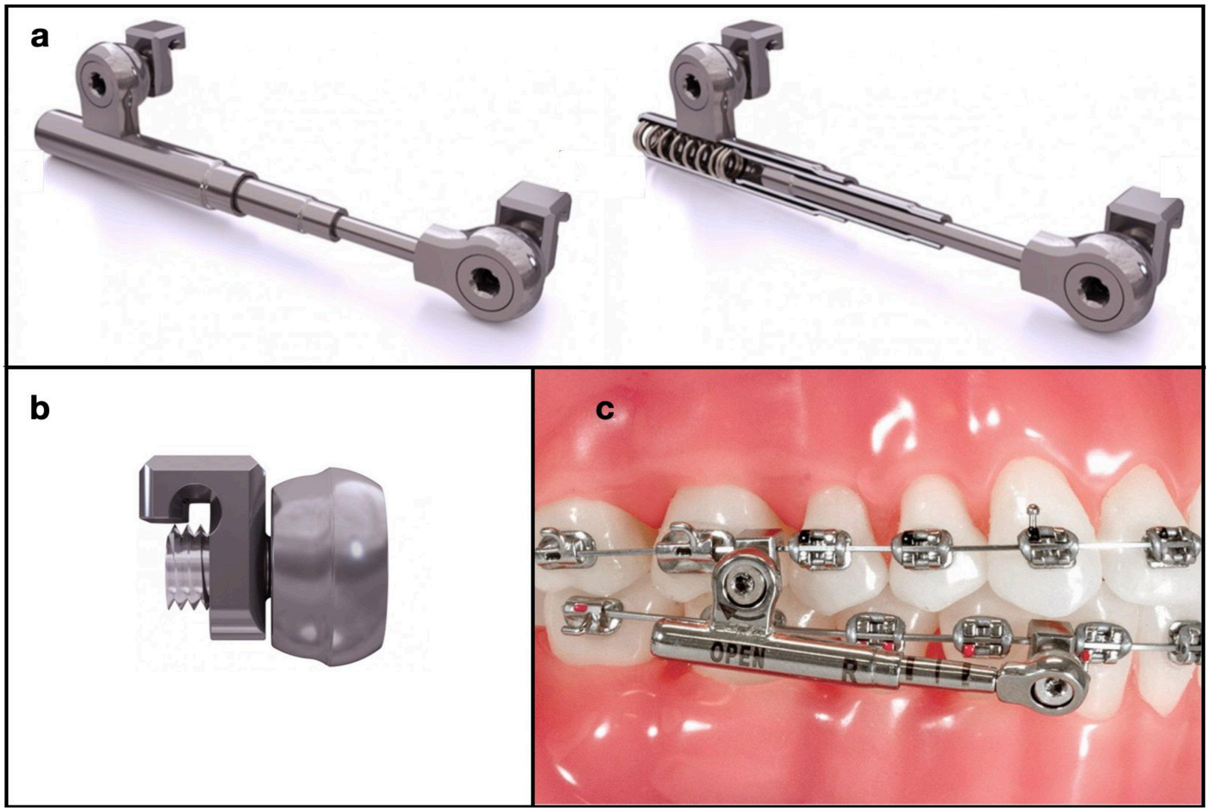

Figure 6. The PowerScope appliance (American Orthodontics, Sheboygen, WI, USA). A. Right: The PowerScope. Left: Schematic showing the internal 260g NiTi coil spring; B. The clamp mechanism that allows the PowerScope to engage the archwire; C. PowerScope in place, clamped to the archwires.

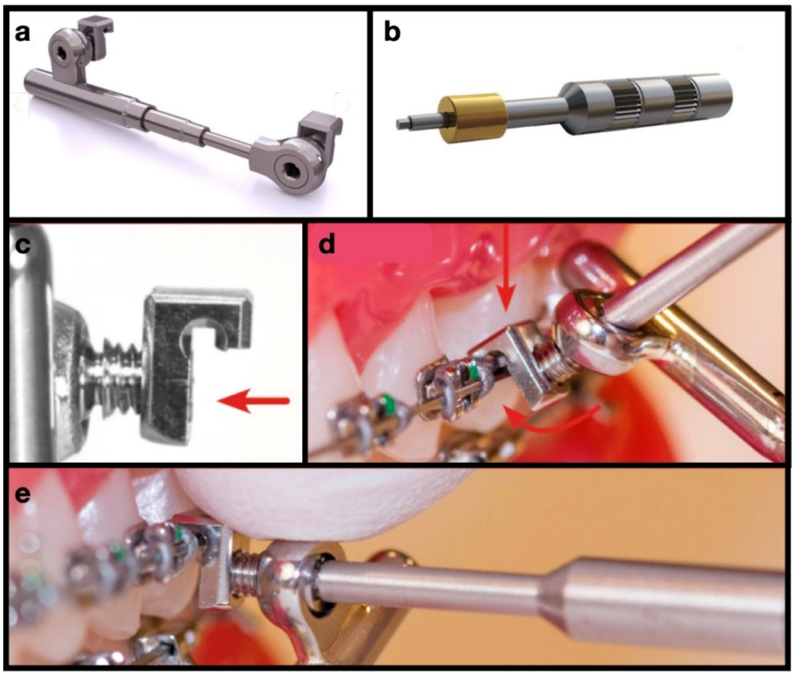

Figure 7. PowerScope attachment to the archwire. A. PowerScope spring; B. Allen key used to screw the spring into place; C and D. Clamp mechanism opened up and then screwed into place, respectively. Note: the right-hand spring is designed to turn in the reverse direction. E. The placement of the PowerScope using the driver.

For all intents and purposes, the PowerScope is very similar to the Hanks telescoping Herbst, with a few notable differences. Firstly, the PowerScope is intended to be a compliance-free Class II corrector, designed to fit on existing full-dimension archwires (Figure 7) simultaneous to full fixed appliance treatment, much like competitor springs such as the FFRD and the TFBC. This represents an advantage over the HTH, which is required to fit on special molar crowns and cantilever arms with welded nuts and threads to accept the telescoping arms. Secondly, the PowerScope was designed with the right-hand side springs having reversed threads to fit into the archwire attachments, while the HTH has conventional threads on both sides. The purpose of such a thread design in the PowerScope is to reduce the tendency observed in the Hanks appliance for the right-side bite jumper to become unscrewed during treatment. The company believed that the function of chewing and jaw movements somehow resulted in the right side gradually becoming undone, and that by reversing the thread, the new device could overcome this problem.

The incorporation of a NiTi spring made the PowerScope appliance a possible Class III bite corrector candidate. However, the Herbst nuts and cantilever arms which were available in the market only had conventional a thread on both sides, which was not compatible with the new PowerScope right-side reversed thread. The author approached American Orthodontics to ask if a special batch of cantilever arms and nuts could be manufactured with a reverse thread, in order to accommodate the use of a reverse thread on the PowerScope appliance for the left side of the Class III corrector. From a manufacturing perspective, it was simpler for the company to produce a special batch of PowerScope springs with conventional thread for the left side. The first batch of 25 modified PowerScope springs were donated to the department by American Orthodontics.

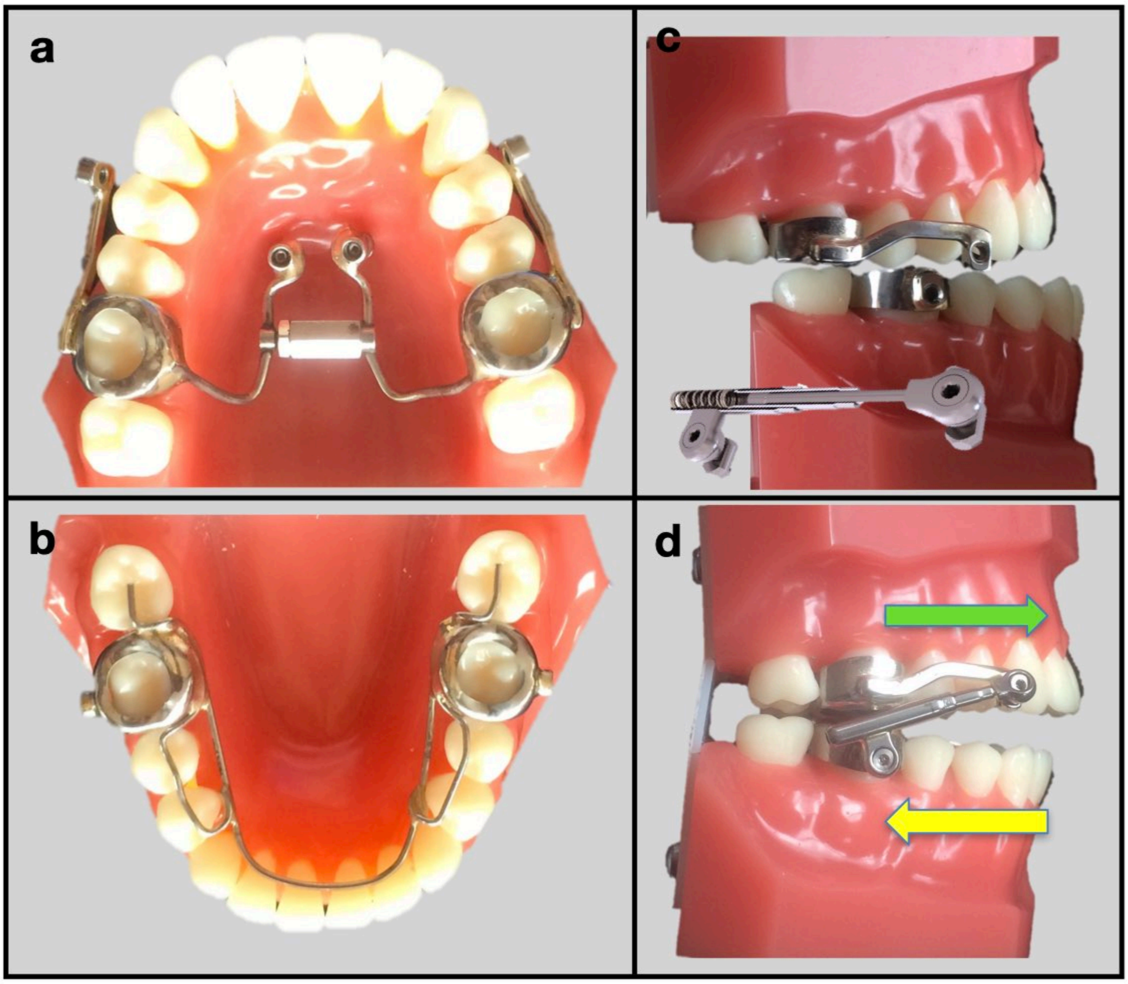

Figure 8 NET3 corrector design. A. Occlusal view of the maxillary arch showing the expansion appliance connected to the miniscrews and the molar bands with cantilever arms; B. Occlusal view of mandibular appliance with modified molar crowns, with the buccal Hanks Herbst nut (American Orthodontics, Sheboygen, WI, USA) with lower lingual arch and rests on the lower second molars (if erupted) and rests on the lower premolars (not bonded); C. Lateral view of the appliance before connecting the modified PowerScope spring

(American Orthodontics, Sheboygen, WI, USA) with diagram showing the internal structure of the PowerScope spring; D. Bite corrector activated by connecting the modified PowerScope spring, producing a forward force on the maxilla (green arrow) and backward force on the mandible (yellow arrow).

Ethics approval 2019/ETH06473 was obtained from the human research ethics committee of the Sydney Local Health District and the recruitment for the clinical trial started.

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11. Manuscript 3

The skeletal and dental effects of a newly developed compliance-free appliance – the NET3 corrector – compared with RME-facemask therapy in the correction of skeletal Class III malocclusion.

A condensed version of this manuscript is to be submitted for publication to the American Journal of Orthodontics & Dentofacial Orthopedics

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11.2. Abstract

The need for patient compliance in most Class III growth modification methods can make treatment unpredictable. This study examined the skeletal and dental effects of a compliance free tooth-bone-borne appliance for Class III correction (NET3 corrector) compared to conventional tooth-borne RME-facemask therapy (RME-FM) in skeletal Class III treatment.

Materials and methods: 20 skeletal Class III patients (9 girls, 11 boys; mean age 11.1±1.16 years) were prospectively recruited to the NET3 corrector group. Their results were compared to a group of 20 patients (7 girls, 13 boys; mean age 11.1±2.0 years) that were previously treated with RME-FM. The NET3 corrector consisted of a hybrid expander anchored on two palatal miniscrews and two maxillary first molars with a cantilever bite jumper design and a modified lingual arch. The intermaxillary force was provided through a modified PowerScope spring with 260 g of force. The RME-FM group were treated with a bonded tooth anchored RME and were required to wear a facemask for 16 hours a day. Lateral cephalograms were taken before and immediately after treatment.

Results: The treatment time was approximately 10.5±3.3 months with the NET3 corrector and 12±3.5months with the RME-FM. The NET3 corrector was well tolerated by patients and the Class III malocclusion was corrected in both groups, with forwards displacement of the maxilla and an increase in overjet. The differences between the two groups were significant. The maxilla advanced by an additional two degrees at the SNA angle with NET3 corrector ($p < 0.001$). In the RME-FM group, the reduction in the SNB angle was 1.1 degrees greater than that in the NET3-corrector group ($p < 0.001$). The overall skeletal change was higher with NET3, for which there was one degree of additional improvement in the ANB angle than with the RME-FM group ($p < 0.05$). The maxillary dental changes were significantly higher in the RME-FM group, while there was no significant change with the NET3 corrector. In both groups, there was a significant retroclination of the mandibular incisors ($p < 0.001$). Significant distal tipping of the lower molars was found with NET3 corrector ($p < 0.001$).

Conclusion: The compliance-free maxillary tooth-bone-borne, and mandibular tooth-borne appliance, the NET3 corrector, is effective in correcting Class III malocclusion and is well tolerated by patients. The use of skeletal anchorage for maxillary expansion and protraction significantly increases the skeletal effects and reduces the maxillary dental side effects in comparison to tooth-borne maxillary expansion and protraction. However, the appliance design requires some refinement to reduce the number of breakages.

11.3. Introduction

The treatment of skeletal Class III malocclusion in growing children can be one of the most challenging in the orthodontic office. Class III skeletal malocclusion is defined as a skeletal facial deformity characterised by a forward position of the mandible in relation to the cranial base and/or the maxilla.[1] This can be the result of a maxillary deficiency (which is the more common form), mandibular excess, or a combination of the two.[2]

Conventional therapy aims to stimulate the growth of the maxilla while restraining mandibular growth using a tooth-borne appliance, with or without expansion, in conjunction with a protraction facemask.[3] The facemask is typically worn in the evenings and during sleep for a total of 13-16 hours per day, for a period of 9-12 months.[3-5] In the clinical environment, this method has several limitations. First, the facemask is a fairly obtrusive extraoral appliance, which may lower patient acceptance. Second, the success of treatment is reliant on patient compliance, which can be unpredictable and will usually be lesser than the prescribed amount.[6,7] Third, the total amount of correction is limited and highly dependent on the timing of treatment, with the best skeletal response recorded when treatment starts before the age of 10[8] Finally, the appliances are tooth-borne, leading to undesirable dental side effects such as mesial movement of the maxillary teeth and proclination of the upper incisors.[4] In addition, the tooth-borne nature also means that in many cases, there is poor anchorage available to support the appliance during the latter part of the mixed dentition phase, when the deciduous molars gradually lose their roots.

The introduction of skeletal anchorage has overcome some of the limitations of conventional facemask therapy. DeClerck et al.[9] used titanium skeletal anchorage plates placed in the maxilla (in the zygomatic buttress) and in the anterior mandible (away from the dentition). This allowed them to apply the elastic traction directly between the maxilla and the mandible, without any kind of tooth-borne appliance. Wilmes et al. used palatal miniscrews to provide anchorage for maxillary expansion[10] as well as protraction with a facemask[11] or through a skeletal anchorage plate in the anterior symphysis (Mentoplate)[12] for Class III elastic traction.[13]

Both of the above-mentioned techniques have shown the ability to surpass the skeletal treatment effects produced by a traditional facemask while eliminating the dental side effects and improving patient acceptance by eliminating the extraoral facemask.[12-14] These techniques have also widened the age range for effective maxillary protraction, as both have been shown to be effective in early adolescence.[14] Despite the likely improvement in patient acceptance through elimination of the need for an extraoral appliance, both methods are still completely dependent on patient compliance with full-time elastic wear. As with facemask therapy, this can still make the treatment relatively unpredictable, as patient compliance can be difficult to control, especially in adolescents.[6,7,15,16] Additionally, the placement of the miniplates requires the use of flap surgery, usually conducted under general anaesthesia, which can be seen as somewhat invasive.[17]

Class III functional appliances have been used in Class III correction with some success; however, the effects are mostly dento-alveolar.[18-21] Nevertheless, fixed Class III correctors such as the reverse twin block have shown similar results to facemask therapy without the need for compliance.[22] Combining a fixed Class III functional appliance with maxillary miniscrews has been shown to reduce some of the dental side effects on the maxilla.[23]

Aim:

The aim of this study was to evaluate the skeletal and dental effects of a novel compliance-free Class III corrector (NET3 corrector), which gains anchorage through the use of palatal miniscrews, as compared to conventional tooth-borne maxillary expansion and protraction using a facemask.

11.4. Materials and Methods

The sample consisted of 40 Class III malocclusion patients treated with either a NET3 corrector or RME-facemask therapy. The study was a prospective clinical study of 20 patients treated using a compliance-free Class III appliance NET3 corrector compared with retrospective data from 20 patients treated using RME-FM. Ethical approval number 2019/ETH06473, X20-0456 and 2020/ETH02668 was obtained from the human research Ethics Committee of the Sydney Local Health District.

Selection criteria for subjects were as follows:

1. Cervical maturation stage up to CS 4, age 8-14, permanent incisors erupted or erupting by the start of treatment
2. Skeletal III malocclusion Wits appraisal ≤ -1
3. Anterior crossbite or edge-edge incisor relationship
4. No history of previous orthodontic treatment
5. No craniofacial anomalies or missing teeth
6. Patients in the NET3 corrector group had to be on the waiting list for orthodontic treatment at the Sydney Dental Hospital.

The NET3 corrector group consisted of 9 girls and 11 boys of mean age 11.1 years (SD = 1.16; Table 1). The patients were recruited and treated at the Department of Orthodontics, University of Sydney between 2016 and 2019.

CBCT scans (NewTom, Verona, Italy) were obtained before treatment (T1) and at completion of treatment (T2), which was when positive overjet of at least 2-3 mm was achieved, or after 12 months had elapsed from the beginning of treatment. Lateral cephalograms were rendered from the CBCTs using Anatomage software (Anatomage, San Jose, CA, USA) to allow cephalometric analysis.

A retrospective group treated with RME-facemask (RME-FM) of 20 consecutively treated patients matched to age obtained from the Department of Orthodontics, University of Ankara, Turkey treated between 2015 and 2018, was used as an active control group to compare the effects of the NET3 corrector with those of a conventional treatment approach. The group consisted of 7 girls and 13 boys of mean age 11.1 years (SD = 2.0; Table 1).

All radiographs were then imported into OrthoTrac imaging V11.7.0.32 (Carestream Dental, Atlanta, GA, USA) and calibrated.

11.4.1. Appliance design

Compliance-free NET3 corrector appliance design and treatment protocol:

The appliance is a modification of the Hanks telescoping Herbst appliance (American Orthodontics, Sheboygen, WI, USA), which is widely used for Class II correction. The design used the concept of the Herbst appliance in reverse, with some modifications. In order to reduce the rigidity of the telescoping arms and allow a gentler and more continuous force to be transmitted to the maxilla, the rigid Hanks telescoping arms were substituted with a modified PowerScope (American Orthodontics, Sheboygen, WI, USA), which is a telescopic bite jumper with an internal nickel titanium (NiTi) spring. This spring applies a 260 g force and is usually used for Class II correction in conjunction with fixed appliances.[24] This provides a consistent protraction force that can be easily tolerated by the patients. The commercially available PowerScope spring is designed to have a reversed thread on one side, and so did not fit the Hanks Herbst nut. A special version of the PowerScope was manufactured for this study to allow the spring to be connected to the Hanks Herbst cantilever arms and nuts. (Figure 1)

Two palatal Benefit mini-implants (2 x 9 mm; PSM Medical Solutions, Gunningen, Germany) were placed paramedian on both sides of the midpalatal suture at the third palatine Rugae, as described by Wilmes et al.[12](Figure 2). A hybrid expander (Figure 1) modified from the Hybrid Hyrax[12] designed by Wilmes et al. was used. The 12 mm SuperScrew (The SuperScrew-SuperSpring Co. Los Angeles, CA, USA) was selected instead of the Hyrax screw. Activated with a hex wrench from the front of the mouth, it is easier for parents and patients to use compared to conventional Hyrax turning mechanisms. The Hanks cantilever arms were welded to the upper first molar modified crowns (Rollo Bands; American Orthodontics, Sheboygen, WI, USA; Figure 1). A lower lingual arch was constructed using Rollo Bands and the Hanks Herbst nut was welded to the buccal surface of the lower first molars. After cementation of the appliances, patients were instructed to start maxillary expansion with two turns a day for three weeks. The modified PowerScope bite correcting spring (260 g) was then connected. Patients were requested to continue to expand the appliance once a day until the desired expansion was achieved. The appliances were reviewed every six to eight weeks to assess the activity of the springs. As the occlusion gradually corrected, reactivation was performed by adding split stops or shims (American Orthodontics, Sheboygen, WI, USA) to the telescoping arms to insure the NiTi coil was partially compressed when the patient was biting down.

11.4.2. Treatment protocol for the RME-FM group

The RME-FM group were treated with a bonded splint-type expansion appliance with hooks near the canine area for the application of protraction elastics. The appliance was similar to that previously described by Baccetti et al.,[4] who used a Hyrax expansion screw (Dentaurum GmbH and Co. KG, Inspringen, Germany). The patients were instructed to turn the expansion mechanism once a day for three weeks, after which the facemask was started. They then continued at the same rate until the desired expansion was achieved. The facemask was adjusted so that elastic force vector was at 30 degrees down and forwards from the occlusal plane, as has been previously described in the literature.[5,25] The patients were instructed to wear the facemask for 16 hours every day with an elastic force of 400 g. Treatment continued until a positive overjet was achieved. A second set of records was then obtained (T2) following the removal of the RME.

11.4.3. Cephalometric analysis

All cephalograms were digitised and traced by the same examiner using OrthoTrac imaging V11.7.0.32 (Carestream Dental, Atlanta, GA, USA). The intra-observer reliability was tested by re-tracing radiographs of 11 randomly selected patients one month apart. The intraclass correlation coefficients (ICC) showed excellent reliability, with values ranging between 0.981 and 0.993, except the L1-MP, for which inter-rater reliability was still high, at 0.868 (Table 2). The cephalometric variables used in the analysis are listed in Table 3 and illustrated in Figure 5.

11.4.4. Statistical analysis:

IBM SPSS Statistics software (version 23.0. Armonk, NY: IBM Corp.) was used to analyse the data. Means and standard deviations are presented for all variables. A statistical significance level of $p < 0.05$ was chosen. Normality and homogeneity of variance of the data were assessed using Shapiro-Wilk's test and Levene's test for equality of variances, respectively. Differences between two timepoints within groups were tested for significance using paired samples t-test. Differences between groups were tested for significance using an independent samples t-test.

11.5. Results

The NET3 corrector appliances were reasonably well tolerated by the patients, and the anterior crossbite was successfully corrected in all subjects. The mean treatment time with the NET3 corrector was 10.5 months (SD = 3.3) and 12 months (SD 3.5) with the RME-FM.

Analysis of the initial skeletal and dental characteristics of the two study groups before treatment (T1) showed no statistically significant differences between the two groups (Table 1).

11.5.1. Comparison of cephalometric changes in each group between T1 and T2

There were significant treatment changes from T1 to T2 for most parameters in both treatment groups (Table 4). Skeletal measurements (Figure 9) showed forward movement of the maxilla in both the NET3 and RME-FM groups, with an increase in the SNA angle of 3.1 degrees (SD = 1.9; $p < 0.001$) and 1.1 degrees (SD = 0.9; $p < 0.001$) respectively, which was statistically significant. This was also reflected by the linear measurement of A-TV, which increased by 3.6 mm (SD = 1.99) in the NET3 group and 1.6 mm (SD = 0.9) in the RME-FM group ($p < 0.001$). The changes in the mandible indicated a slight reduction in the SNB angle of 1 degree (SD = 1.1) with the RME-FM ($p < 0.001$), while there was no statistically significant change in the NET3 group. The linear measurement B-TV did not change significantly in the NET3 group, but displayed a slight reduction of 1 mm (SD = 1.8) in the RME-FM group ($p < 0.05$). The overall skeletal change was significant in both groups, with a 3.1 degree (SD = 1.4) increase in ANB and a 4.5 mm (SD = 2.2) improvement in the Wits appraisal in the NET3 group and a 2 degree (SD = 1) increase in the ANB and 3.4 mm (SD = 2.1) improvement in the Wits appraisal in the RME-FM group ($p < 0.001$). There were no statistically significant changes in the vertical skeletal parameters in the NET3 group, while the vertical skeletal parameters exhibited a statistically significant increase in the RME-FM group (Figure 10), where the MP-PP angle increased by 1.4 degrees (SD = 2.3), the SN-MP increased by 1 degree (SD = 1.2) and the Y-axis angle increased by 1.1 degrees (SD = 1.2) ($p < 0.01$), indicating some mandibular backward rotation. There was no significant change in either group with regards to the gonial angle. In both groups there was a counterclockwise rotation of the lower occlusal plane – 2.3 degrees (SD = 3.2; $p < 0.01$) with the NET3 and 2.5 degrees (SD = 3.4; $p < 0.01$) with the RME-FM.

There were no statistically significant changes in the upper incisor parameters with the NET3, indicating few dental side effects. However, there was a significant increase in the upper incisor inclination with the RME-FM, with a 5 degree (SD = 3.9) increase in U1-SN ($p < 0.001$) and a 3 degree increase in U1-PP ($p < 0.001$; Figure 11). There was a tendency for mesial tipping of the maxillary molars, with a change of 2.5 degrees (SD = 1.9; $p < 0.001$) in the NET3 group and 3 degrees (SD = 1.6; $p < 0.001$) in the RME-FM group. The lower incisors retroclined significantly in both groups, by a mean of 4.8 degrees (SD = 4.3) with the NET3 and 5 degrees (SD = 3.3) with the RME-FM ($p < 0.001$). The NET3 corrector caused significant distal tipping of the lower molars (7.7 degrees; SD = 5.2; $p < 0.001$), while the change was not statistically significant in the RME-FM group. The overjet increased significantly in both groups, by 4.3 mm (SD = 2.1) in the NET3 group and 4.9 mm (SD = 2; $p < 0.001$) in the RME-FM group, while the overbite did not exhibit a statistically significant change.

11.5.2. Comparison of the cephalometric changes between the two groups

Comparison between the two groups (Table 4) showed significant differences in several parameters. The effect on the maxilla in the antero-posterior dimension as assessed by the SNA angle showed a significantly greater advancement of the maxilla in the NET3 group – a further 2 degrees' ($p < 0.001$) increase in the SNA angle than was observed in the RME-FM group (Figure 9). The reduction in the SNB angle for the RME-FM group was 1.1 degrees greater than that observed in the NET3 group ($p < 0.05$). The overall skeletal change as assessed by the ANB angle and the Wits appraisal showed greater changes in the NET3 group, for which there was an ANB increase 1 degree greater than that observed in the RME-FM group ($p < 0.01$). The change in the Wits appraisal was also greater with the NET3; however, the difference was not statistically significant.

In the vertical dimension, there was slightly more increase in the mandibular plane angle in the RME-FM group. However, the difference between groups was not statistically significant (Figure 10).

Dental changes were also compared (Figure 11). The maxillary incisors proclined more in the RME-FM group, with an increase in the U1-SN that was 5.3 degrees greater than that in the NET3 group, and an increase in the U1-PP that was 5 degrees greater than that in the NET3 group, which was statistically significant ($p < 0.001$). There was no statistically significant difference between the groups in terms of lower incisor retroclination. The mandibular molars tipped significantly more distally with the NET3 – 7.3 degrees more than was observed with RME-FM ($p < 0.001$).

11.5.3. Appliance failure and complications

Only one miniscrew failure occurred in the bite corrector group. The failure occurred before appliance insertion, and so a new miniscrew was inserted and the appliance was remade. There was one case where the cantilever arm fractured from the maxillary molar band (Figure 6a), and two instances where the appliance debonded, once in the upper and once in the lower. The telescoping arm broke in three instances and a new modified PowerScope was placed (Figure 6c). The most recurring problem was the loosening of the modified PowerScope spring (Figure 6b). This occurred exclusively on the lower left-hand side, and the springs were simply reattached. This occurred at least once for every patient, but in two patients it occurred four times. The patients were able to reattach the spring using the supplied Allen key.

11.6. Discussion

All cases with the compliance-free appliance NET3 corrector were successfully treated in an average treatment time of 10.5 months (SD = 3.3). The correction was mainly due to maxillary skeletal protraction and mandibular dental compensation. There were limited changes in the SNB angle and few changes in the vertical dimension. The skeletal and dental changes exhibited by the active controls using RME-FM in this study were consistent with results from other studies using similar methodology[4,26-29], making this study's RME-FM group a good comparative group. There was a mean improvement in the SNA of 1.1 degrees (SD = 0.9), a 1 degree (SD = 1.2) reduction in the SNB angle and an overall improvement of 2 degrees (SD = 1) in the ANB angle (Table 4; Figure 9). These results were similar to previous reports with tooth-borne expansion and protraction. Mandal et al.[29] showed a 1.1 degree increase in the SNA angle in their study, while others showed changes between 0.7[28] and 1.8 degrees.[30] Similarly, Mandal et al. also showed a reduction in the SNB angle from -1 to 1.7 degrees with an overall similar ANB change of 2.4-2.6 degrees.[28-30] The dental changes with RME-FM were also similar to those reported in previous studies, with mesial movement of the upper dentition and an increase in upper incisor inclination.[4,26-29]

The results of this clinical trial suggest that the compliance-free NET3 corrector is effective in the treatment of Class III malocclusion in growing children. It produces skeletal changes that are similar to, but slightly higher than, the conventional tooth-borne RME and facemask combination. The main difference between the two techniques was in maxillary protraction (Table 4; Figure 9), with the SNA angle improving by 50% more in the NET3 corrector group than in the RME-FM group, with an increase of 3.1 degrees (SD = 1.9) as opposed to 1.1 degrees (SD = 0.9) for the facemask group ($p < 0.05$). On the other hand, the RME-FM had more of an effect on the SNB angle, reducing it by -1 degrees (SD = 1.1), while there was no significant change with the NET3 corrector ($p < 0.05$; Table 4) (Figure 9). However, this change in the SNB angle was mainly due to the backward rotation of the mandible, with an increase in the mandibular plane angle of SN-MP by 1 degree (SD = 1.7) and an increase in the Y-axis of 1.1 degrees (SD = 1.2; Table 4; Figure 10). On the other hand, the NET3 corrector did not introduce any significant vertical changes, which can be considered a favourable finding, as in many Class III cases it may be aesthetically undesirable to increase the lower facial height.

The use of skeletal anchorage in the maxilla with the NET3 eliminated the undesirable dental side effects usually seen with maxillary protraction. While the RME-FM group showed a significant increase in the upper incisor inclination (5 degrees (SD = 3.8) and 4.6 degrees (SD = 3.9) in U1-SN and U1-PP measurements respectively), there was no significant increase in the upper incisor inclination in the NET3 corrector group (Table 4; Figure 10). This can be attributed to the use of skeletal anchorage with the palatal miniscrews in the maxilla. Studies with maxillary protraction using the Hybrid Hyrax and facemask have also shown minimal dental side effects.[11,28] Nevertheless, there was some maxillary molar tipping in both groups. The NET3 corrector group showed 2.5 degrees of mesial molar tipping despite the use of skeletal anchorage. This was likely due to wire bending and flexion in the appliance, which was indirectly connected to the miniscrews. Similar molar changes were also reported by Ngan et al.[28] using the Hybrid Hyrax and facemask, and these changes were also attributed to wire bending.[28]

The effects on the mandibular incisors were similar for both treatment protocols in the study, with the NET3 corrector and the RME-FM showing lower incisor retroclination of 4.8 degrees (SD = 4.3) and 5 degrees (SD = 3.3) respectively (Table 4; Figure 10). Furthermore, the NET3 corrector had the additional effect of tipping the mandibular molars distally by 7.7 degrees on average (SD = 5.2). This dental side effect resulted in counterclockwise rotation of the mandibular occlusal plane only, and since the maxillary occlusal plane was unable to tip due to the skeletal anchorage, this resulted in a posterior open bite. This effect was expected and is similar to what would be seen in the maxillary molars with Class II correction using a fixed functional appliance, such as the Herbst appliance.[31] A similar effect on mandibular molars was also reported by Liou and Tsai with the maxillary protraction spring.[32] This molar tipping can be expected to rebound after treatment. Liou and Tsai reported that the mandibular molar tipping relapsed once the springs were removed.[32] For this reason, the mandibular component of the NET3 corrector (Figure 2) was designed not to engage any mandibular teeth other than the first molars, to avoid the side effects being carried to the remaining teeth.

With respect to the number of teeth included in the appliance, the NET3 corrector has an advantage over the conventional RME and facemask in that it does not include any teeth aside from the first molars, and so it can be effectively used in the transitional stage of the late mixed dentition, where it can be difficult to get sufficient anchorage for a tooth-borne appliance. This would make it an attractive treatment possibility for patients aged 9-12 years, who can be difficult to manage with a tooth-borne appliance.

Only one other study to date has used skeletal anchorage with a fixed Class III corrector. Eissa et al.[23] used a reversed Forsus FRD (3M Unitek Corp, Monrovia, CA, USA) supported by two interradicular maxillary buccal miniscrews. In their study, the dental arches had to be levelled and aligned with full fixed appliances and worked up to a rigid archwire before insertion of the miniscrews and the Forsus springs.[23] The miniscrews were then inserted in the alveolar process buccally between the maxillary canines and first premolars and secured to the canine bracket indirectly using a steel wire through the auxiliary slot.[23] This design is significantly different to that of the NET3 corrector used in this study, which may explain some of the differences in the findings. Firstly, the NET3 corrector does not require a full banding of the upper and lower teeth; anchorage is only gained from the permanent first molars and two palatal miniscrews, meaning that it can be used even when the premolars and canines have not yet erupted. Secondly, miniscrew placement in the palate is safer, with no chance of root injury and a higher documented success rate of 96-98% as opposed to 84-88% for maxillary interradicular miniscrews.[33,34] Additionally, paramedian placement in the palate allows for the miniscrews to be used for simultaneous maxillary expansion, which is often needed due to transverse deficiency (commonly seen in Class III cases[35]) as well as to stimulate more sutural response to maxillary protraction.[36] Although Eissa et al.[23] showed a reduction in upper incisor proclination, there was also some incisor intrusion with counterclockwise rotation of the maxillary occlusal plane.[23] This was not seen with the NET3 corrector in this study, most likely because the maxillary incisors were not directly loaded by the appliance. Although the forces from the NET3 corrector were directed upwards and forwards and would have the effect of tipping the maxillary molars mesially, this tipping was mostly negated by the molars being connected to the palatal miniscrews through the rigid framework of the expansion appliance. The slight maxillary molar tipping which was observed (2.5 degrees; SD = 1.8) was likely due to some wire bending, an issue which has also been reported by others.[28]

The main advantage of the NET3 corrector design is probably its elimination of the need for compliance. The facemask is a fairly obtrusive device and patient acceptance can be low. Additionally, the success of the treatment is completely dependent on the patient adhering to the prescribed hours of wear for the device. This can vary from patient to patient, and varies daily for the same patients. It can also be affected by multiple factors such as individual motivation and parental guidance. When compliance with orthodontic appliances has been measured objectively, it is almost always less than the prescribed amount.[15,16] Studies where compliance with appliance wear was monitored using thermal sensors showed that patients ended up wearing the appliances for 50-65% of the prescribed time.[15,37] Similarly, with facemask wear the wear time was approximately 60% of the prescribed time.[6,7] Furthermore, studies on Class II correction have shown that results are more predictable with fixed compliance-free appliances as opposed to elastics or removable appliances.[38-40] The compliance-free NET3 corrector was able to achieve comparable, if not slightly better, results than the facemask while eliminating the need for compliance, making it a more predictable alternative.

The BAMP[41] and Hybrid Hyrax-Mentoplate[12] protocols both eliminated the need for facemask wear, and are potentially more accepted by patients. However, both protocols are still reliant on patients wearing the prescribed elastics, which can make these treatments unpredictable. Additionally, both methods require flap surgery for the placement of the miniplates/Mentoplate.[9,12] This can add cost, discomfort and inconvenience. Furthermore, the increased invasiveness of the procedure can reduce the acceptance of those treatments by some families. The compliance-free NET3 corrector design does not require flap surgery and the whole treatment can be performed from start to finish in the orthodontic setting. Additionally, miniplates have a higher complication rate when compared to palatal miniscrews. In a study of 218 cases treated with the BAMP protocol between Belgium and the Netherlands[42], one miniplate failed and required replacement for 25.7% of patients (56 in total). On the other hand, palatal miniscrews in the anterior palate have a high success rate of over 97%[34] with very few complications. A failed miniscrew can also be replaced by the orthodontist, while a failure of a miniplate will likely require more flap surgery.

The overall skeletal correction reported with the NET3 corrector was comparable to and slightly better than that achieved with the tooth-borne RME-FM. The NET3 corrector resulted in 4.5 mm (SD = 2.2) of improvement in the Wits appraisal and a 3.1 degree (SD = 1.9) improvement in the ANB, with some dental side effects in the mandible. These skeletal effects are quite comparable to methods using hybrid tooth-bone-borne anchorage, such as the Hybrid Hyrax with Mentoplate[12] and the Hybrid Hyrax with facemask.[13,28,43] For example, Wilmann et al. showed improvements of 2.54 and 3.7 degrees in the ANB and increases of 4.1 and 4.8 mm in the Wits appraisal with the Hybrid Hyrax-Mentoplate and the Hybrid Hyrax-facemask, respectively.[13] However, when compared to the purely bone-borne method, the skeletal effects were slightly less. Using the BAMP method, Cevidanes et al.[44] reported a 5.9 mm (SD = 2.2) improvement, on average, in the Wits appraisal and Elnagar et al.[45] reported 6 degrees' (SD = 1.6) improvement in the ANB, with no dental side effects. The dental side effect of the NET3 corrector on the lower arch and the slightly smaller overall skeletal effect makes it inferior (in terms of overall treatment effect) when compared to those purely bone-borne methods. It may be argued that for more severe cases (and where compliance is likely to be good), the BAMP and/or the Hybrid Hyrax-Mentoplate methods would be a better choice.

Clinically, the NET3 corrector was well tolerated by the patients. However, some clinical problems were reported. The most common breakage reported with this appliance was due to the loosening of the PowerScope spring from the nut on the lower left first molar. This problem is potentially related to function and mandibular movement leading to gradual unwinding of the screw on the left side. An effective remedy could be to reverse the threads on the left-hand side screws. A similar effect has been witnessed by the authors when using the Hanks Herbst appliance for Class II correction (but on the right-hand side). There were also two incidences of fracture of the welding between the molar band and the lower nut, and two incidences where the cantilever arm sheared off the maxillary molar bands. Perhaps a more robust band design (especially with CAD/CAM manufacturing[46]) would be possible.

Our study has some limitations including the wide age range of patients as well as the retrospective control group. It is suggested that patients respond more favourable to Class III growth modification treatment when they are younger than 10 years of age.[8] Our results need to be tested in a randomised clinical trial with a larger patient sample from both young and older age groups. Long term follow up of these patients is also necessary.

11.7. Conclusion

The compliance-free NET3 corrector is effective in correcting Class III malocclusion in growing children in the short term and is well tolerated by patients. Correction comes mostly from maxillary skeletal protraction and mandibular dental compensation. Minimal maxillary dental side effects were seen. Effects were comparable yet slightly better than what is achieved with conventional RME-facemask. Further improvement in the design is required to reduce the breakage rate and improve reliability. With further improvement of the design, this appliance could offer a predictable and compliance-free method for managing skeletal Class III malocclusion in mild and moderate cases.

11.8. References

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11.9. List of figures

11.10. List of tables

11.11. Figures

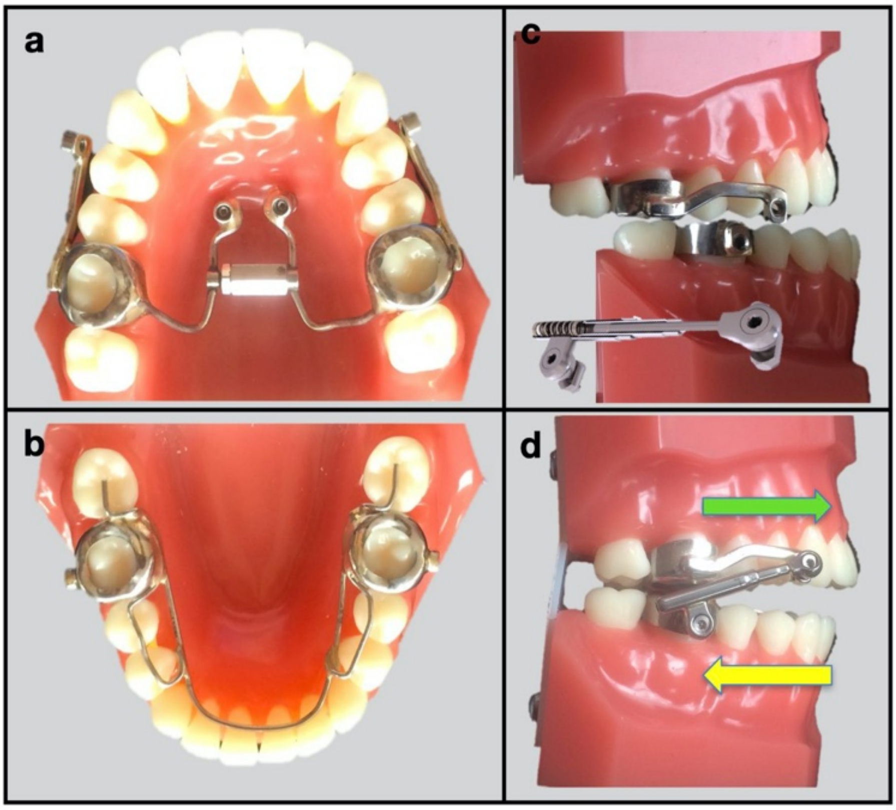

Figure 1. NET3 corrector design. A. Occlusal view of the maxillary arch showing the expansion appliance connected to the miniscrews and the molar bands with cantilever arms; B. Occlusal view of mandibular appliance with modified molar crowns, with the buccal Hanks Herbst nut (American Orthodontics, Sheboygen, WI, USA) with lower lingual arch and rests on the lower second molars (if erupted) and rests on the lower premolars (not bonded); C. Lateral view of the appliance before connecting the modified PowerScope spring (American Orthodontics, Sheboygen, WI, USA) with diagram showing the internal structure of the PowerScope spring; D. Bite corrector activated by connecting the modified PowerScope spring, producing a forward force on the maxilla (green arrow) and backward force on the mandible (yellow arrow).

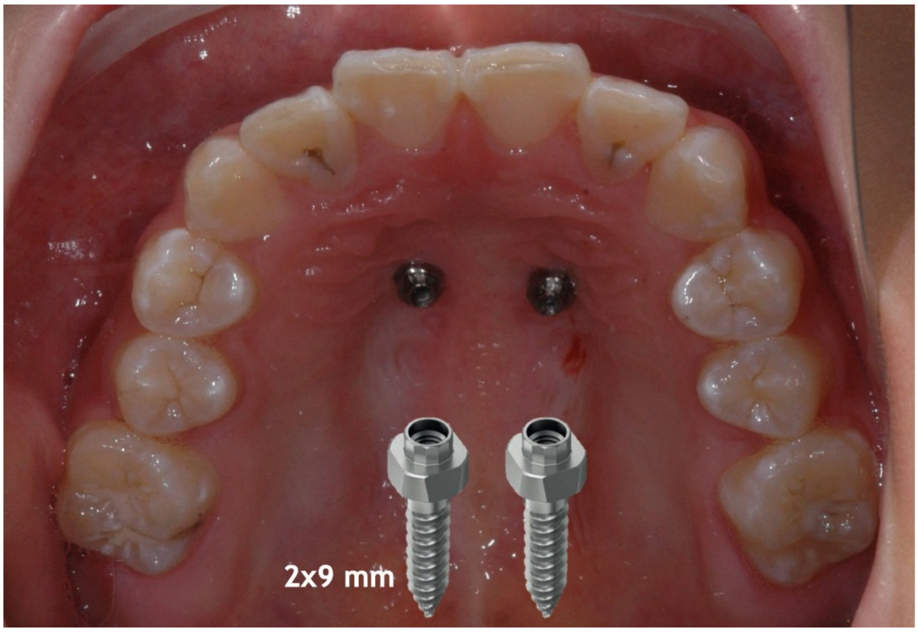

Figure 2. Two Benefit palatal miniscrews (2 x 9 mm; PSM Medical Solutions, Gunningen, Germany) inserted in the anterior palate, paramedian at the third Rugae line.

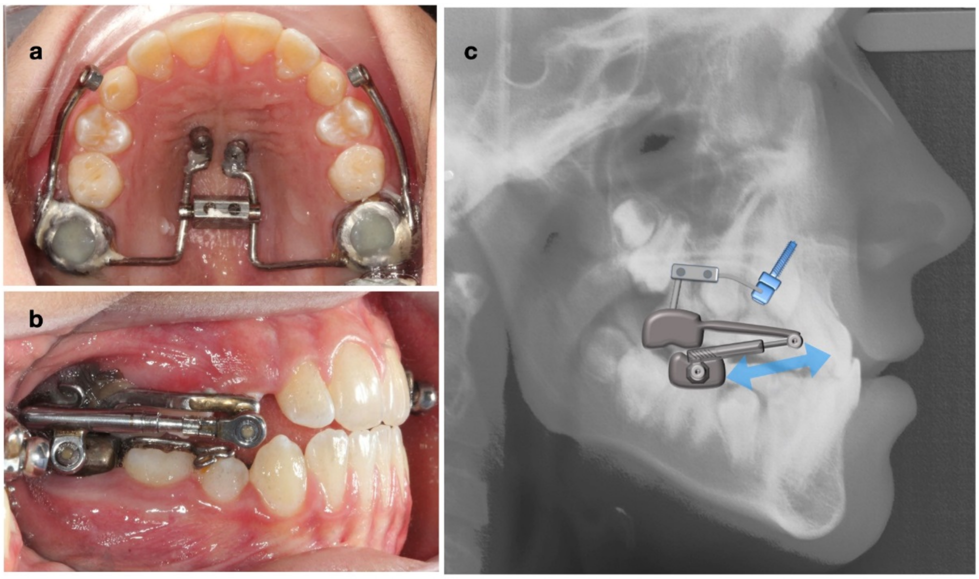

Figure 3. The NET3 corrector setup. A. Maxillary appliance with SuperScrew (The SuperScrew-SuperSpring Co. Los Angeles, CA, USA) and cantilever arms; B. Active appliance with shims or split stops added to activate the spring further; C. Diagrammatic illustration of the biomechanics of the NET3 corrector.

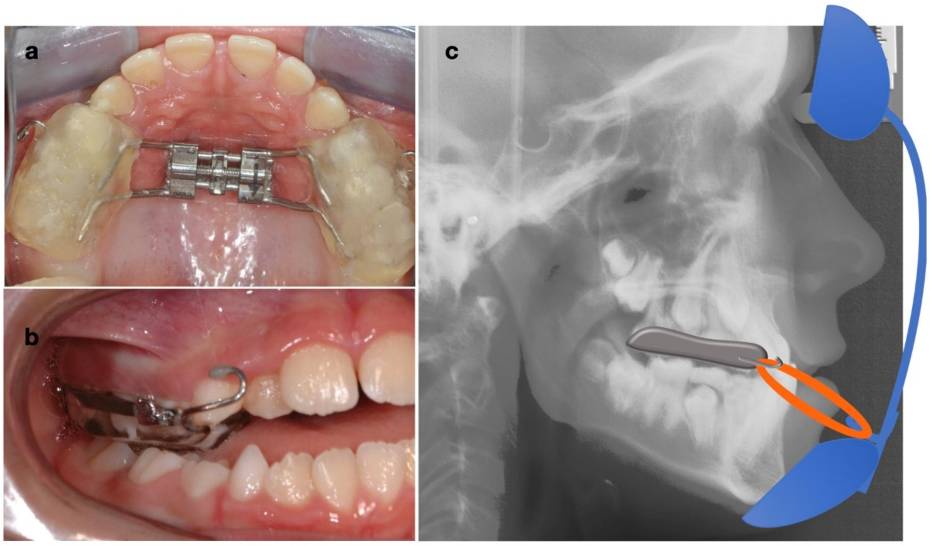

Figure 4. A. Bonded Hyrax appliance with acrylic bite blocks; B. Facemask hooks emerge near maxillary canine for elastic application; C. Facemask elastic force vector at approximately 30 degrees down from the occlusal plane.

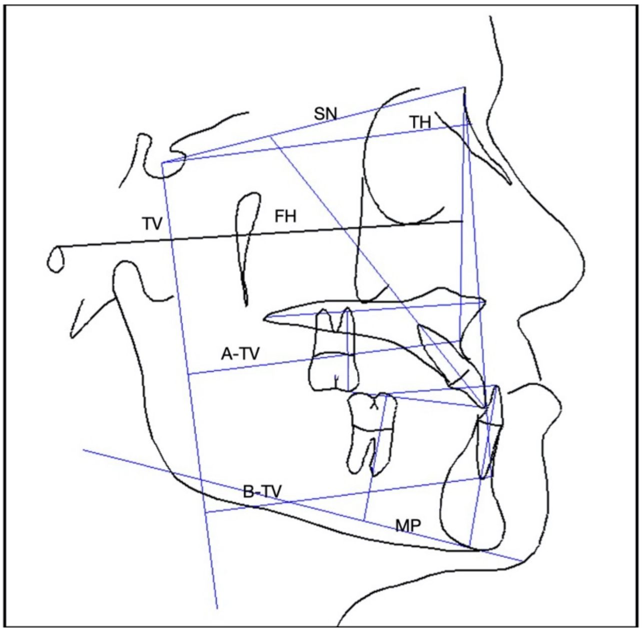

Figure 5. cephalometric measurements and reference lines. SN (Sella-Nasion line). TH (true horizontal line 7 degrees from SN). TV (true vertical line 90 degrees from TH through Sella). A-TV (perpendicular distance from A point to TV). B-TV (perpendicular distance from B Point to TV). FH (Frankfort horizontal line). PP (palatal plane through ANS-PNS). MP (mandibular plane). UOP (upper occlusal plane: maxillary incisal tip to mesiobuccal cusp of first molar. LOP (lower occlusal plane: mandibular incisor tip to mesiobuccal cusp of mandibular first molar). U1 (long axis of the most labial upper incisor). L1 (long axis of the most labial mandibular incisor). U6 (maxillary first molar long axis: mesiobuccal cusp to mesiobuccal root tip). L6 (mandibular first molar long axis: mesiobuccal cusp to mesial root tip).

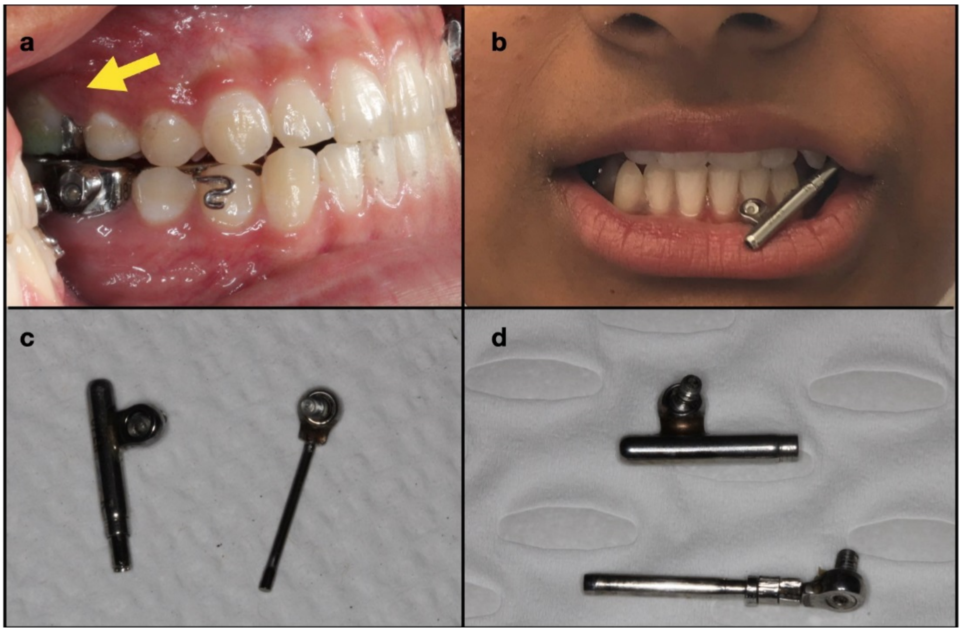

Figure 6. Common breakages in the trial. A. Cantilever arm sheared off the maxillary molar crown; B. Loosening of the left-side bite corrector spring in the lower arch (the most common breakage); C. Fracture of the telescopic arm; D. Separation of the telescoping mechanism.

Figure 7. Treatment progression with the NET3 corrector. A. Before treatment; B. Initial activation of the spring; C. Six months' progress with reactivation of the spring, with the application of split stops or shims to compress the spring; D. Corrected malocclusion with the posterior open bite and distal tipping of the lower molars evident.

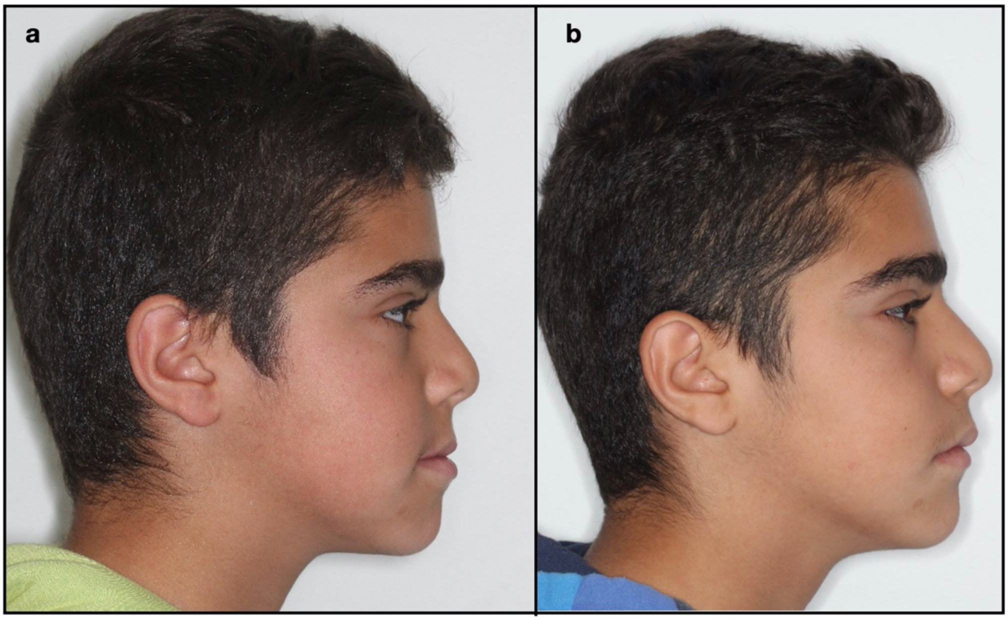

Figure 8. Profile change before (A) and after (B) treatment, with increased facial convexity and reduced chin prominence.

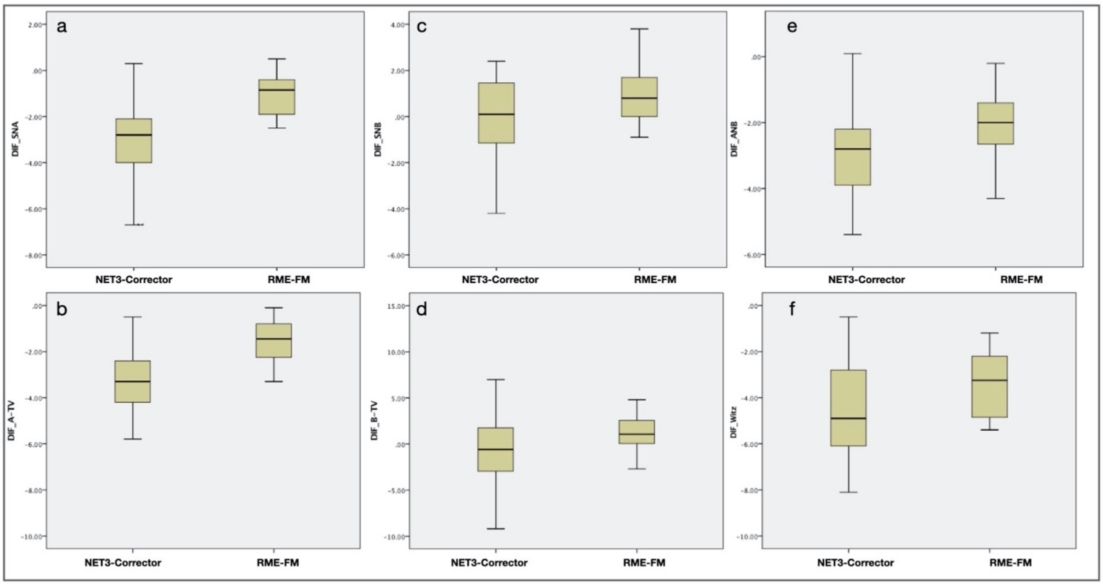

Figure 9. Box plots showing the difference in response between T1 and T2 for the anteroposterior skeletal parameters the x-axis NET3 corrector vs. RME-FM.

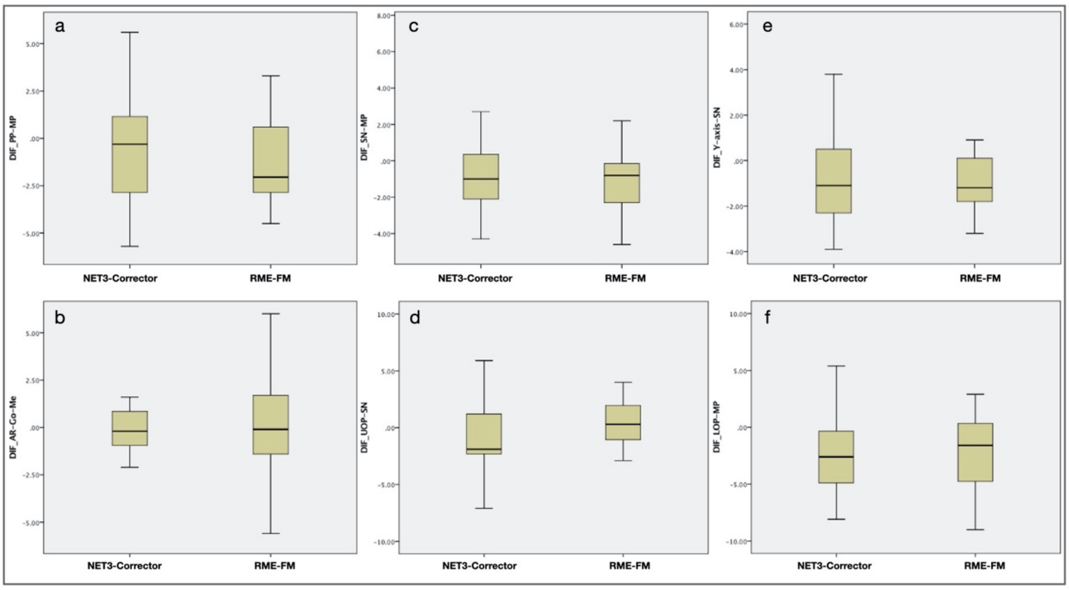

Figure 10. Box plots showing the difference in response between T1 and T2 for the vertical parameters the x-axis NET3 corrector vs. RME-FM.

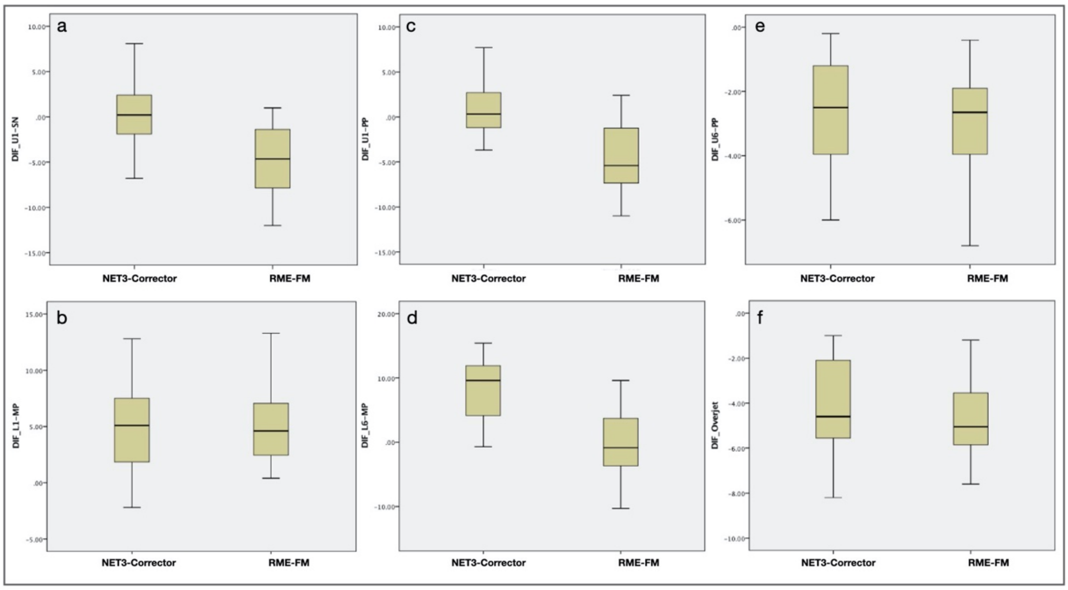

Figure 11. Box plots showing the difference in response between T1 and T2 for dental parameters the x-axis NET3 corrector vs. RME-FM.

11.12. Tables

Table 1. Comparison of the two groups at T1 before treatment.

	NET3-Corrector (n=20)		RME-FM n=20		95% Confidence Interval of the Difference		
	Females: 9, Males: 11		Females: 7, Males: 13				
	Mean	**Std. Deviation**	**Mean**	**Std. Deviation**	**Lower**	**Upper**	***p***
Age at T1 years	11.14	1.17	11.14	2.06	-1.07	1.07	1.00
Tx Duration months	10.6	3.2	12	3.5	-3.6	0.7	0.18
SNA°	79.40	2.76	77.85	3.22	-0.36	3.47	0.11
SNB°	80.47	3.12	79.73	2.91	-1.19	2.67	0.44
ANB°	-1.10	2.04	-1.90	1.56	-0.36	1.96	0.17
Wits mm	-4.44	2.31	-5.00	2.49	-0.97	2.10	0.46
A-TV mm	57.20	2.45	58.21	3.51	-2.95	0.93	0.30
B-TV mm	56.90	5.47	57.96	4.84	-4.36	2.24	0.52
PP-MP°	26.18	6.67	24.47	4.26	-1.88	5.29	0.34
SN-MP°	33.65	6.13	33.82	4.83	-3.70	3.36	0.92
Y-axis-SN°	67.71	3.76	67.21	2.74	-1.61	2.60	0.64
AR-Go-Me°	133.23	5.55	136.41	4.54	-6.43	0.07	0.06
UOP-SN°	18.31	3.04	17.97	4.11	-1.97	2.65	0.77
UOP-PP°	12.37	4.43	10.63	5.14	-1.33	4.82	0.26

LOP-MP°	20.40	3.92	20.60	3.79	-2.66	2.27	0.87
U1-SN°	106.19	6.32	104.25	5.29	-1.79	5.68	0.30
U1-PP°	113.68	5.71	113.61	5.76	-3.60	3.75	0.97
U6-PP°	77.77	4.37	81.00	3.94	-5.90	-0.57	0.02
L1-MP°	87.78	6.25	86.15	5.99	-2.29	5.55	0.41
L6-MP°	81.31	6.07	77.76	5.24	-0.08	7.18	0.06
Overjet mm	-1.50	1.97	-2.11	1.61	-0.54	1.77	0.29
Overbite mm	1.38	2.23	1.51	2.58	-1.68	1.41	0.86

Table 2. Intra Class Correlation Coefficient for the intra-observer reliability

	Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound
SNA°	0.994	0.979	0.998
SNB°	0.993	0.974	0.998
ANB°	0.994	0.98	0.999
Wits mm	0.988	0.847	0.998
A-TV mm	0.984	0.937	0.996
B-TV mm	0.993	0.975	0.998
PP-MP°	0.991	0.967	0.998
SN-MP°	0.987	0.952	0.997
Y-axis-SN°	0.986	0.946	0.997
AR-Go-Me°	0.984	0.945	0.996
UOP-SN°	0.982	0.93	0.996
UOP-PP°	0.981	0.932	0.995
LOP-MP°	0.946	0.804	0.985
U1-SN°	0.994	0.98	0.999
U1-PP°	0.995	0.983	0.999
U6-PP°	0.981	0.934	0.995

L1-MP°	0.868	0.537	0.964
L6-MP°	0.99	0.963	0.997
Overjet mm	0.985	0.948	0.996
Overbite mm	0.989	0.961	0.997

Table 3 Variables used in the lateral cephalometric analysis

	Measurement	Definition
Anteroposterior skeletal relationship	SNA	The angle between the anterior cranial base (Sella to Nasion) and the NA (nasion to point A) line
	SNB	The angle between the anterior cranial base (Sella to Nasion) and NB (nasion to point B) line
	ANB	The angle between the NA and NB lines relates the anteroposterior position of the maxilla to the mandible
	Wits	The distance between AO and BO, the projection of points A and B perpendicularly to the occlusal plane
	A-TV	The distance between A-point and the true vertical line TV
	B-TV	The distance between B-point and the true vertical line
	AB-TV difference	The difference between A-TV and B-TV
Vertical skeletal relationship	PP-MP	The angle between the palatal plane and mandibular plane
	SN-MP	Mandibular plane angel: The angle between the anterior cranial base (Sella to Nasion) mandibular plane

	Y-axis	The angle between the line from Sella to Gnathion SN-Gn and the Frankfurt horizontal plane and indicates the downwards, rearwards or forwards position of the chin in relation to the upper face.
	Ar-Go-Me (gonial angle)	The angle between the Me-Go line and the Go-Ar line
Dental variables	UOP-SN	The angle between the upper occlusal plane and the anterior cranial base line
	UOP-PP	The angle between the upper occlusal plane and palatal plane
	LOP-MP	The angle between the lower occlusal plane and mandibular plane
	U1-SN	Angle between the upper incisor and the anterior cranial base line
	U1-PP	Angle between the upper incisor and the palatal plane
	U6-PP	Angle between the upper first molar and the palatal plane
	L1-MP	The angle between the lower incisor and mandibular plane
	L6-MP	The angle between the lower first molar and mandibular plane
	Overjet	The overjet
	Overbite	The overbite

Table 4. Comparison for each group between T1 and T2 and comparison of differences in changes between the two groups.

	NET3- Corrector (n=20)							RME-FM (n=20)							NET3-Corrector vs RME-FM						
	T1		T2		95% Confidence Interval of the Difference			T1		T2		95% Confidence Interval of the Difference			NET3-Corrector		RME-FM		95% Confidence Interval of the Difference		
	mean	SD	mean	SD	Lower	Upper	p	mean	SD	mean	SD	Lower	Upper	p	Mean	SD	Mean	SD	Lower	Upper	p
SNA°	79.40	2.76	82.54	3.24	-4.04	-2.23	0.00	77.85	3.22	78.90	3.31	-1.46	-0.64	0.00	-3.14	1.94	-1.05	0.87	-3.05	-1.12	0.00
SNB°	80.47	3.12	80.62	3.16	-1.02	0.72	0.72	79.73	2.91	78.77	2.82	0.39	1.54	0.00	-0.15	1.86	0.97	1.22	-2.12	-0.11	0.03
ANB°	-1.10	2.04	1.92	1.89	-3.66	-2.37	0.00	-1.90	1.56	0.12	1.37	-2.47	-1.56	0.00	-3.02	1.38	-2.02	0.97	-1.76	-0.24	0.01
Wits mm	-4.53	2.33	0.00	2.53	-5.59	-3.47	0.00	-5.00	2.49	-1.61	2.05	-4.07	-2.72	0.00	-4.53	2.20	-3.40	1.44	-2.34	0.07	0.06
A-TV mm	57.20	2.45	60.83	2.67	-4.56	-2.70	0.00	58.21	3.51	59.79	3.68	-2.01	-1.14	0.00	-3.63	1.99	-1.58	0.94	-3.05	-1.06	0.00
B-TV mm	56.90	5.47	57.23	3.83	-2.68	2.02	0.77	57.96	4.84	56.90	4.67	0.21	1.91	0.02	-0.33	5.02	1.06	1.81	-3.81	1.03	0.25
PP-MP°	26.18	6.67	26.83	5.55	-2.01	0.71	0.33	24.47	4.26	25.85	3.95	-2.45	-0.31	0.01	-0.65	2.92	-1.38	2.29	-0.95	2.41	0.39
SN-MP°	33.65	6.13	34.19	5.52	-1.60	0.52	0.30	33.82	4.83	34.85	4.19	-1.80	-0.25	0.01	-0.54	2.26	-1.03	1.66	-0.78	1.75	0.44
Y-axis-SN°	67.71	3.76	68.14	3.35	-1.56	0.70	0.44	67.21	2.74	68.27	2.35	-1.64	-0.48	0.00	-0.43	2.42	-1.06	1.24	-0.60	1.86	0.31
AR-Go-Me°	133.23	5.55	133.45	5.36	-1.00	0.56	0.56	136.41	4.54	136.29	3.55	-1.18	1.42	0.85	-0.22	1.66	0.12	2.79	-1.81	1.13	0.64
UOP-SN°	18.31	3.04	19.44	4.20	-2.90	0.65	0.20	17.97	4.11	17.17	4.19	-0.36	1.97	0.17	-1.13	3.80	0.81	2.49	-3.99	0.13	0.07
UOP-PP°	12.37	4.43	12.57	4.36	-2.28	1.89	0.85	10.63	5.14	9.58	4.71	-0.34	2.43	0.13	-0.20	4.46	1.05	2.95	-3.66	1.18	0.31
LOP-MP°	20.40	3.92	22.71	3.78	-3.81	-0.80	0.01	20.60	3.79	22.78	4.02	-3.77	-0.59	0.01	-2.31	3.22	-2.18	3.39	-2.24	1.99	0.91

U1-SN°	106.19	6.32	105.83	5.89	-1.18	1.91	0.63	104.25	5.29	109.20	5.15	-6.73	-3.18	0.00	0.37	3.31	-4.96	3.80	3.04	7.60	0.00
U1-PP°	113.68	5.71	113.22	5.98	-0.92	1.84	0.49	113.61	5.76	118.19	5.53	-6.42	-2.74	0.00	0.46	2.94	-4.58	3.94	2.81	7.27	0.00
U6-PP°	77.77	4.37	80.31	4.89	-3.41	-1.67	0.00	81.00	3.94	84.00	3.93	-3.78	-2.22	0.00	-2.54	1.86	-3.00	1.66	-0.67	1.59	0.41
L1-MP°	87.78	6.25	83.03	6.69	2.72	6.77	0.00	86.15	5.99	81.19	6.82	3.41	6.51	0.00	4.75	4.33	4.96	3.31	-2.68	2.25	0.86
L6-MP°	81.31	6.07	73.60	7.57	5.26	10.16	0.00	77.76	5.24	77.77	5.36	-2.57	2.55	0.99	7.71	5.23	-0.01	5.47	4.29	11.15	0.00
Overjet mm	-1.50	1.97	2.78	1.08	-5.25	-3.29	0.00	-2.11	1.61	2.77	0.85	-5.80	-3.96	0.00	-4.27	2.10	-4.88	1.97	-0.69	1.91	0.35
Overbite mm	1.38	2.23	1.10	1.36	-0.50	1.06	0.46	1.51	2.58	1.77	1.52	-1.31	0.79	0.61	0.28	1.67	-0.26	2.23	-0.72	1.80	0.39

12. Case reports

Treatment and long-term maintenance of two severe skeletal Class III cases using skeletal anchorage

A condensed version of this manuscript is to be submitted for publication to the American Journal of Orthodontics & Dentofacial Orthopedics

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12.2. Abstract

The two case reports show the treatment of severe Class III malocclusions in growing patients with the use of a miniscrew supported maxillary expansion appliance with mandibular symphysial miniplates and Class III elastic traction. This was combined with a protocol of continuous alternating semi rapid maxillary expansion and contraction of 0.25 mm/day alternating weekly for 12 months. The results show significant changes in the growth pattern and correction of the Class III malocclusion with significant maxillary protraction. Retention was then followed through puberty with bone-borne part time elastic wear using CAD/CAM rigid TPA. Treatment protocols and retention regime are discussed.

12.3. Introduction

Severe skeletal Class III malocclusion is considered particularly challenging to manage in growing children. Skeletal Class III malocclusion is defined as a skeletal facial deformity characterized by a forward position of the mandible in relation to the cranial base and/or the maxilla.[1] This can be the result of a maxillary deficiency, mandibular excess or a combination of the two.[2]

Class III problems are relatively uncommon, with prevalence ranging from 3-10% depending on the population studied,[3] which would make severe cases even less common. Individuals with severe skeletal Class III malocclusions often face significant functional,[4] aesthetic[5] and psychological challenges due to an anterior crossbite and concave facial profile, which may cause a social handicap.[5] The malocclusion usually gets worse with growth, and the mandible grows more and for longer than in Class I cases.[6]

Conventional Class III therapy usually uses the protraction facemask combined with maxillary expansion, aiming to stimulate maxillary sutural growth while restraining mandibular growth.[3] However, this has several limitations, especially in severe cases. First, as such therapy is tooth-borne, it is associated with several unwanted dental side effects, such as mesial movement of the maxillary teeth, proclination of the upper incisors, extrusion of the maxillary molars and retroclination of the mandibular incisors.[7-12] In addition, the mesial movement of maxillary teeth can lead to increased anterior crowding.[7] These dental compensations, although undesirable, can help overjet correction in mild and moderate cases. On the other hand, in more severe cases there is already natural dento-alveolar compensation,[13] with proclined upper incisors and retroclined lower incisors. Exaggerating such compensation is undesirable aesthetically and may also force the teeth outside the bony envelope.[14] Second, the appliance shows limited skeletal effects, which makes it difficult to get full resolution in severe cases. Studies show that a maximum of 4-5 mm of skeletal correction can be expected if treatment is carried out before the age of nine,[15] with even poorer results in children past the age of 10 due to increased sutural resistance to protraction with maturation.[15] Third, the extraoral nature of the appliance reduces patient acceptance and makes it unlikely in a severe case (where correction may take longer) that patient compliance will be maintained long enough to achieve full resolution. Finally, maintaining the correction after growth modification is particularly challenging. During puberty, mandibular growth usually accelerates at a rate faster than the maxilla.[6,16,17] This is even more pronounced in Class III subjects, which can challenge earlier correction significantly. Furthermore, the mandible in Class III individuals has been shown to grow for longer during and after puberty than in Class I individuals.[6,16,17] Most appliances used after growth modification are tooth-borne or tooth-tissue-borne, such as the Frankel FR3[18] appliance. Such appliances tend to result in mostly dento-alveolar compensations.[19-21]

Two recent approaches have changed Class III treatment. The first is the introduction of skeletal anchorage in maxillary protraction. This approach was introduced with the use of maxillary miniplates in conjunction with a protraction facemask[22,23], then using intraoral Class III elastics with miniplates in the maxillary zygomatic buttress and in the anterior mandible[24]. The intraoral nature of the treatment improves patient acceptance, while the use of skeletal anchorage eliminates the dental side effects, enhances the skeletal results compared to conventional treatment and also allows effective treatment in older children.[25,26] Wilmes et al. introduced the Hybrid Hyrax[27] with two palatal miniscrews, which can be combined with either a protraction facemask[28,29] or surgical plates[28,30,31] in the mandible for Class III correction. This approach also allows the simultaneous correction of transverse maxillary deficiency, which is often seen in Class III cases.[32]

The second approach is the Alt-RAMEC protocol introduced by Liou[33] in 2005, which aims to activate or disarticulate the maxillary sutures through alternating rapid maxillary expansion and contraction (Alt-RAMEC) of 7 mm per week for nine weeks. This aims to allow more protraction of the maxilla and enable treatment to be effective with more mature children. It displayed double the amount of maxillary advancement when compared to conventional facemask therapy, with stable results after two years.[34] However, the duration for which sutural simulation from the Alt-RAMEC protocol remains is unknown; it is also unclear whether a more continuous sutural stimulation may be of benefit in severe cases.

The following case studies show the long-term management of two severe skeletal Class III malocclusions with a hybrid expander appliance, with mandibular miniplates combined with a modified Alt-RAMEC protocol using continuous semi-rapid alternating maxillary expansion and contraction (**C**alt-**S**RAMEC) to maintain sutural response throughout the treatment. This is followed by a retention protocol utilising skeletal anchorage.

12.4. Case report 1

A young boy aged 8 years and 11 months presented with a severe Class III malocclusion on the skeletal Class III base (Figure 1) with an ANB angle of -5 degrees, a Wits appraisal of -7.5 mm and a reverse overjet of -3 mm (T1; Table 1; Figure 2). Both the child and the parents were quite concerned with the facial appearance associated with the malocclusion. The facial appearance and cephalometric measurements suggested a significant maxillary deficiency. Both upper and lower arches showed reasonably good alignment. The patient was not able to bring the anterior teeth into edge-to-edge contact, and there was no detectable CR-CO discrepancy or functional shifting of the mandible forwards, which indicated a true severe skeletal discrepancy.

The treatment options discussed included traditional maxillary expansion and facemask therapy with guarded prognosis, due to the severity of the skeletal discrepancy. Additionally, the family did not think an extraoral appliance would be practical for 13-16 hours per day, due to the patient's active participation in many sporting activities and after-school engagements. The alternative plan of waiting for growth to be completed and then carrying out orthodontic treatment combined with orthognathic surgery was also not ideal, due to the psychosocial impact which the malocclusion and facial disharmony had on his overall development. A treatment plan was put forward with the aim of improving the skeletal discrepancy. The plan involved the use of a skeletally borne growth modification based on the Hybrid Hyrax-Mentoplate protocol by Wilmes et al., using a hybrid maxillary expander (tooth-bone-borne) with a mandibular symphysial miniplate for Class III traction (Figure 3). To stimulate maxillary sutural response, the plan included a modified Alt-RAMEC protocol of continuous semi-rapid alternating maxillary expansion and contraction (**C**alt-**S**RAMEC) throughout the treatment. It was agreed with the family that treatment may not completely resolve the malocclusion, but would improve facial appearance and function, after which future treatment may be required with or without orthognathic surgery.

12.4.1.The treatment protocol

A hybrid expander (Figure 3) modified from the Hybrid Hyrax[27] designed by Wilmes et al. was used. The 12 mm SuperScrew (The SuperScrew-SuperSpring Co. Los Angeles, CA, USA) was selected instead of the Hyrax screw. Activated with a hex wrench from the front of the mouth, it is easier for parents and patients to use (especially in the constriction part of the Alt-RAMEC protocol) when compared to conventional Hyrax-type expansion mechanisms. Each turn of the SuperScrew, (moving the hex key from incisor to incisor) equates to 1/12 of a millimetre of expansion. Two palatal Benefit mini-implants (2 x 9 mm; PSM Medical Solutions, Gunningen, Germany) were placed paramedian on both sides of the midpalatal suture at the third palatine rugae, following the protocol described by Wilmes et al.[27] The SuperScrew was laser-welded to the Benefit abutments (PSM Medical Solutions, Gunningen, Germany).

After appliance cementation, the patient was instructed to turn the expander one turn a day for two weeks ahead of miniplate insertion. Once the miniplates were placed, the Calt-SRAMEC was started. The patient was instructed to turn the screw once per day (0.17 mm) for one week (expanding), for a total of 1.2 mm per week, and then once a day (0.17mm) for one week (constricting). This was then repeated through the entire first 12-month period of treatment. This is a modification of the original Alt-RAMEC protocol proposed by Dr Eric Liou[33]. The aim of Calt-SRAMEC is to expand and constrict less aggressively by 0.17 mm per day, as opposed to 1 mm per day, but to then sustain this routine for 12 months in order to maintain sutural activation for a longer period of time.

The proprietary Mentoplate (PSM Medical Solutions, Gunningen, Germany) was not available at the time, and conventional surgical trauma plates (Stryker Universal Orthognathic; Stryker, Kalamazoo, MI, USA) were placed in the mandibular symphysis and fixed with three screws. The top of the plate was then converted to hooks using a high-speed carbide bur (Figure 3). Elastics were started with gradually increasing strength, in a manner which was similar to the protocol described by De Clerck et al. The aim was to gradually increase the bone density around the miniplate in order to promote stability (Figure 3). For the first six weeks, ¼” 3.5 oz elastics were used full time and changed twice a day. The elastic force was then increased to 6 oz at six weeks and maintained for three months, then increased to 8 oz until the end of the first year of treatment. At seven months, a mandibular removable appliance with a bite plane was constructed to allow disclusion, aiming to facilitate occlusal correction. The removable appliance was stopped once a positive overjet was achieved, which occurred at 11 months of treatment. Full photos (Figure 4) and a follow-up lateral cephalogram were obtained 14 months after Class III traction was started (T2; Figure 5), when 2 mm of overjet were achieved.

Results showed that the patient developed a positive overjet of 2 mm with reduction of the ANB discrepancy by 5 degrees to 0 ANB (Figure 5; Table 1). The Wits appraisal was reduced from -5 mm to 1 mm, indicating a 6 mm improvement in the skeletal discrepancy.
The correction came mostly from improvement in the SNA angle, which was indicative of improvement in the maxillary position, with some reduction in the SNB angle due to backward rotation of the mandible (Figure 5). The superimpositions (Figure 6a) indicated a significant maxillary advancement with some restraining and backward rotation of the mandible mostly due to vertical maxillary development. Upper incisor inclination remained constant, while mandibular incisors appeared to have uprighted slightly in relation to the mandibular plane (Table 1). Profile improvement was evident (Figure 4).

Due to the positive response but incomplete resolution of the Class III relationship, it was decided to continue the treatment for a further twelve months, and the elastic force was increased to 14 oz. During the second year of treatment, the palatal miniscrews failed after 10 months, but this went unnoticed by the patient for eight weeks. During this time, the elastic traction resulted in mesial movement of the buccal segments, tipping the molars into a Class II relationship and blocking the space for the eruption of the maxillary canines. New records were obtained (Figure 7) marking 26 months of treatment. The cephalometric analysis (T3) showed a further significant improvement in the skeletal pattern, with the ANB normalising at two degrees and the Wits appraisal at 3.7 mm (Table 1). In addition, there was a further uprighting of the lower incisors in relation to the mandibular plane, and little change in the upper incisor position. The maxillary molars tipped mesially by 10 degrees (which is quite significant) due to the failure of the miniscrews.

After a 10-week break, two new palatal miniscrews (Benefit; 2 x 9 mm; PSM Medical Solutions, Gunningen, Germany) were placed and a new appliance designed. This time, a hybrid expander combined with a distalizer (similar to the design by Wilmes et al.,[35]) was constructed (Figure 9). This was intended to distalize the maxillary first molars into Class I and open space for maxillary canines while continuing the Calt-SRAMEC and maintaining Class III elastic wear. Distalization was started at a rate of 0.2 mm/week. At the same time, the Calt-SRAMEC was restarted and elastic wear was resumed using 8 oz elastics (Figure 12). The molars were distalized by approximately 4.5 mm over a five-month period, and space for the upper canines was regained. The elastic wear continued during the distalization period and was maintained after the distalization stopped. A further 12 months of treatment were completed. After a total of 38 months of active treatment, new records were obtained (T4) and the retention phase was started (Figures 10 and 11). Tracing of the lateral cephalogram (Table 1) showed further improvement in the skeletal pattern, with the ANB angle increasing to 2.9 degrees and the Wits appraisal to 3.7mm. Overjet and overbite were also normalised. Space for the maxillary canines was re-established and a molar and canine Class I relationship achieved with good premolar interdigitation. The maxillary incisor inclination actually reduced a little (with a reduction of five degrees), likely due to the upper arch dental distalization (Figure 12a). The maxillary molars were also uprighted by 10 degrees, and the mandibular incisors were maintained.

A CAD/CAM rigid trans-palatal arch (TPA) was then constructed to fit over the palatal miniscrews using the protocol by Graf el al.[36] and bonded to the upper first molars with a buccal hook for night-time elastic wear (Figure 13). The patient was requested to wear the 8 oz elastics at night as a form of active retention. Both maxillary canines erupted into a Class I relationship and it was decided that no further treatment with fixed orthodontic appliances would be needed at that time, but that close monitoring of growth would be required and continued until the cessation of growth. After 24 months of retention, follow-up records were again obtained (T5; Figures 14 and 15). The Class I occlusion was well maintained, and the skeletal pattern improved further, with the ANB angle increasing to 3.4 degrees and the Wits appraisal to 3.4 mm (Table 1; Figure 15), while the incisors remained stable. The progression of the profile can be seen in (Figure 16) and the occlusal progression in (Figure 17). The same retention protocol is planned to be continued until cessation of growth.

12.5. Case report 2

A boy aged 11 years and 9 months (Figure 18) presented with a severe Class III malocclusion on a skeletal Class III base, due to a combination of maxillary deficiency and mandibular excess, with an ANB angle of -3.2 degrees, a Wits appraisal of -8.2 mm and a reverse overjet of -3 mm (T1; Figure 19; Table 2). The lower incisors were retroclined while the maxillary incisors were slightly proclined and spaced, indicating dento-alveolar compensation. There was a family history of Class III malocclusion, the father having presented with a similar malocclusion that had not been treated. Due to the patient's slightly advanced age and the severity of the malocclusion, traditional facemask treatment was not considered as an option. The first option was to wait for growth completion and then consider orthodontic treatment combined with orthognathic surgery. The second option was to consider a phase of growth modification to lessen the skeletal discrepancy and the psychosocial impact of the facial disharmony. The treatment plan was to use the hybrid expander with mandibular miniplates for Class III elastic traction. Maxillary expansion was carried out for only three weeks prior to starting elastic traction.

During the first 12 months of treatment, compliance with elastics was not ideal. However, follow-up lateral cephalometric superimposition (T2; Figure 20a; Table 2) showed that despite the relatively erratic elastic wear, there was some improvement in the skeletal pattern. The ANB angle reduced by 1.8 degrees, and there was a 4.3 mm improvement in the Wits appraisal, with no dental side effects. Nevertheless, the superimpositions showed significant mandibular growth in that first year (Figure 20a). At this stage, a discussion was held with the patient and family in which they were presented with the following options: either to terminate the treatment or to consider restarting the treatment with the CAlt-SRAMEC protocol and better compliance with elastic wear. The patient became very motivated after seeing the cephalometric comparison, so a new phase of treatment was started. A new hybrid expander was made due to a fracture in the molar bands, and the treatment was restarted with the CAlt-SRAMEC protocol as above, the only difference being that elastic wear was started immediately. Six oz elastics were used, and then increased after three months to 8 oz; there was no need for a removable appliance due to the lack overbite. After another 12 months, the follow-up records (T3; Table 2; Figures 20b, 21, 22 and 23c) showed a significant improvement in the Class III pattern, with a change to a positive ANB angle of 1 degree and a positive overjet of 3 mm. There was a 4.6 degree change in the ANB discrepancy and a 6.5 mm improvement in the Wits appraisal over the two-year treatment period. Comparison of the cephalograms from T1 and T3 (Figure 20b) showed a significant improvement of the maxillary position, with restriction of mandibular growth. At 14 years and 8 months it was now decided that elastic wear should continue as a form of active retention, and that the the CAlt –SRAMEC should be discontinued. After a further 12 months, the results appeared to be stable. New records were obtained before the treatment proceeded with fixed appliances to finalise the occlusion (Figure 23c). The cephalometric analysis (T4) showed that in that year, there had been a slight return to the Class III growth pattern. This can be seen in the SNA, which only increased by 1.6 degrees while the SNB increased by 2.1 degrees, resulting in the ANB dropping back to 0.9 degrees from 1.4 degrees (Table 2). A slight increase in the upper incisor inclination was also evident, and the overjet reduced by 1 mm.

The hybrid expander was then removed, and fixed appliances were placed. The objectives were to achieve a good overbite and a Class I interdigitation. In order to increase the overbite, the maxillary occlusal plane was rotated clockwise while advancing the maxillary dental arch. This was achieved using a TPA between the maxillary molars and then running an elastomeric chain from the palatal miniscrews to the TPA directed mesially. The force vector from the chain would be apical to the centre of resistance of the maxillary molars and so lead to clockwise rotation of the maxillary occlusal plane (Figure 24). Class III elastic wear to the miniplates was maintained throughout the fixed appliance treatment. After 18 months of fixed appliance treatment, the patient had a reasonably well interdigitated Class I relationship, with a good overbite (Figure 25). He was now 18 years old and growth had slowed down, but not stopped. The cephalograms (T5) at the completion of the fixed appliance treatment showed that a return to the Class III growth pattern had taken place (Figures 26 and 28a), which was similar to the results of the previous cephalogram. The maxilla continued forward growth with a small increase in the SNA of 0.9 degrees, while the mandible outpaced the maxilla slightly, showing a 1 degree increase in the SNB with a further worsening of the ANB to 0.8 degrees, while the Wits appraisal was reduced to -5.3 mm. The overbite improved with the fixed appliance treatment, with a counterclockwise rotation of the maxillary occlusal plane. There was a slight increase in the upper incisor inclination (Table 2). A similar retention protocol to that used for Case 1 was employed. Records taken after a 12-month retention (T6) period showed a stable occlusal result with a slight Class III tendency on the left-hand side and with minimal skeletal change (Figures 28b, 29 and 30; Table 2). The progression of the profile can be seen in Figure 31 and the progression of the occlusal correction in Figure 23.

12.6. Discussion

It is evident from the above cases that with skeletal anchorage and continuous maxillary expansion and contraction (CAlt-SRAMEC), significant Class III correction may be achieved and maintained in severe Class III cases throughout the pubertal growth spurt, while minimising unwanted dental side effects. The results introduce a number of questions on Class III treatment approaches and highlight the need for more research in this area.

First, in severe Class III cases, it may not be feasible to plan treatment in terms of a phase 1 treatment around the traditional 12-14-month timeframe. Growth modification treatment for such cases could be considered a long-term intervention. This is now possible when skeletal anchorage is being used and the teeth are not at risk of being overloaded. Similar long treatment approaches have previously been used in conjunction with chin cup therapy;[37] however, it is much more cumbersome for patients to use an extraoral appliance long-term than it is for them to wear Class III elastics. Based on the above cases, it was evident that more time was needed to correct the malocclusion than the conventional time frame of 9-14 months reported with facemask wear. This is likely not only due to the severity of the skeletal discrepancy, but also to the absence of dental compensation usually seen with tooth-borne appliances. Dental compensation, in the form of upper incisor proclination, mesial movement of the maxillary dentition and retroclination of the mandibular anterior teeth, would lead to a faster correction of the overjet at the expense of skeletal correction. It was evident that with the extended treatment time, the maxillary growth continued to respond steadily to protraction and eventually corrected the skeletal discrepancy without any dental compensation. Similarly, with the bone-anchored maxillary protraction (BAMP) protocol, longer treatment times were reported when compared to tooth-borne RME facemask therapy.[25]

Second, there seems to be a positive effect on maxillary protraction from continuous expansion and contraction at a slow rate. It is unclear whether a similar result would have been achieved without expansion or without alternating expansion and contraction. Some recent studies suggest that Alt-RAMEC improves the response to maxillary protraction.[38] The original protocol suggested by Liou suggested a more aggressive expansion and contraction routine of 1 mm per day, stopping after 9 weeks.[33] The protocol was initially introduced on a tooth-borne maxillary expansion appliance, which raised concerns about excessive root resorption and/or periodontal damage to the teeth supporting the appliance.[39] On the other hand, finite element analysis of the Hybrid Hyrax[40] shows the loading during expansion is mainly supported by the miniscrews, which may mean that a miniscrew-supported expander could be safer for the teeth with Alt-RAMEC. The protocol used in the above case reports was slower and less aggressive than the original Alt-RAMEC (0.17 mm per day, as opposed to 1 mm per day) and was maintained for much longer (12-24 months as opposed to 7-9 weeks). This may allow the sutural stimulation to be maintained for longer; however, this requires further investigation.

Third, it seems that with skeletal anchorage and good patient compliance, severe Class III cases may benefit from a phase of growth modification to improve the facial appearance and potentially lessen the amount of future surgery, even if the case is not fully corrected. As it appears in the presented cases, the patients experienced dramatic reduction of the skeletal discrepancy with significant improvement in facial profile. It can also be argued that in case of future relapse, the amount of skeletal discrepancy left for future treatment would be much smaller than if no treatment was administered, thus reducing the morbidities associated with future orthognathic surgery (should it be required).

The long-term stability of Class III growth modification treatment remains a challenge. Class III cases are known to resume their original growth pattern once treatment is discontinued[41] and so close follow-up is required. Additionally, studies on the growth of Class III individuals show that their mandibles grow more and for longer than those of Class I individuals.[42] It does appear that in the presented cases, there was a degree of mandibular growth reduction and redirection, especially early on. However, it was also evident in the second case, where mandibular excess was evident in the beginning, that mandibular growth resumed and challenged the stability of the result from the age of 16 to 19 years, while the maxilla remained responsive, but at a slower rate (Table 2).

Success in the long-term management of severe Class III malocclusion using the presented method requires patient commitment and motivation. Compliance with orthodontic treatment can be unpredictable, with patients usually wearing the appliances for 50-65% of the prescribed time.[43] However, some research suggests that the severity of the malocclusion can play a role, and those patients who perceived their malocclusion as more unattractive were more motivated to comply with treatment.[44] In the presented cases, the severity of the malocclusion may have been a motivating factor. A larger study with objective monitoring of compliance would help assess this factor. Such a long treatment, however, can be considered burdensome for some patients and their families. A thorough discussion would be required before initiating treatment to weigh up the costs and benefits of this approach versus a potentially shorter intervention followed by a break which could then be followed by a combined orthodontic and orthognathic surgical approach.

12.7. Conclusion

The above cases demonstrate that skeletal anchorage combined with sutural activation through maxillary expansion and contraction may offer a treatment approach and means for retention in severe skeletal Class III malocclusions. The limits of the technology remain to be explored. With the rising cost of health care and the high cost of orthognathic surgery, further research on earlier intervention with skeletal anchorage in Class III cases is warranted. Retention after growth modification using skeletal anchorage may be an effective means to avoid overloading the dentition and maintain skeletal results.

12.8. References

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12.9. List of figures

12.10. List of tables

12.11.Figures

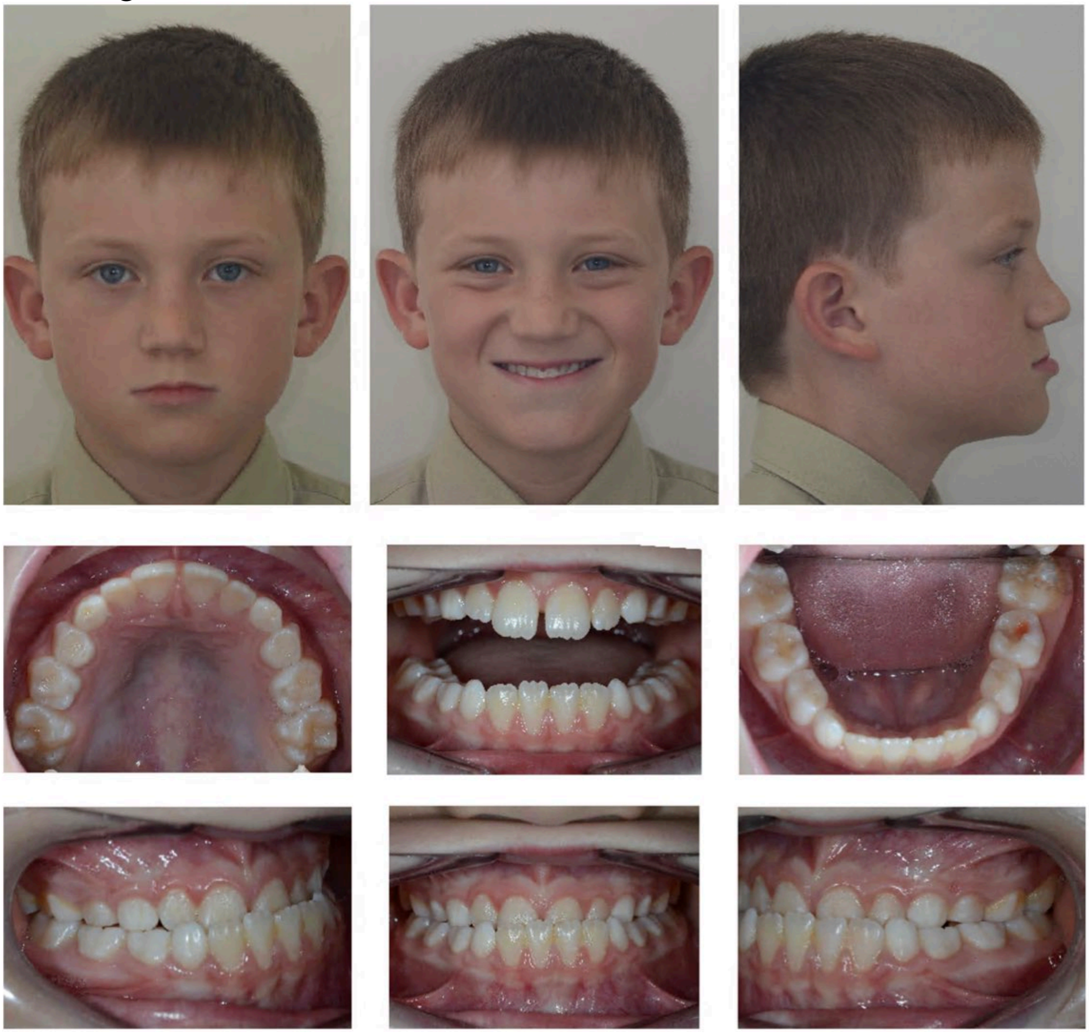

Figure 1. Pre-treatment photos of Case 1, showing a severe Class III malocclusion with anterior crossbite and concave profile.

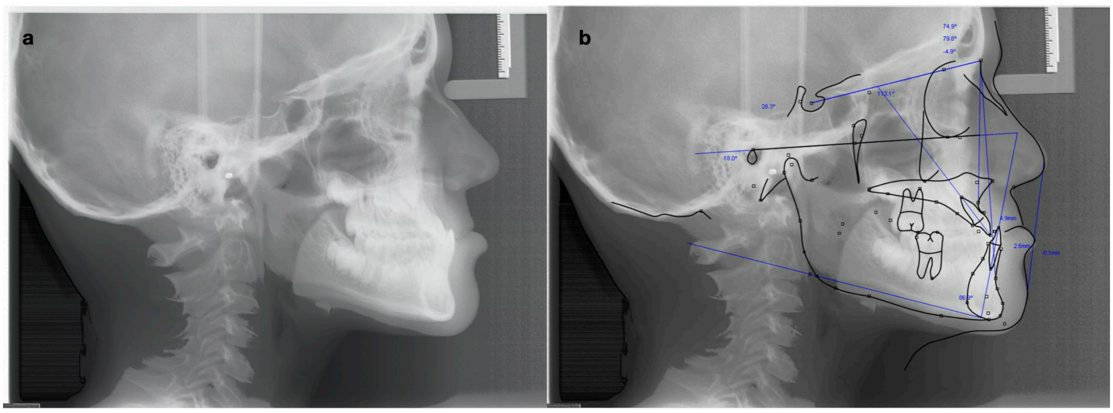

Figure 2. Lateral cephalometric tracing of the pre-treatment radiograph, showing a severe skeletal Class III pattern.

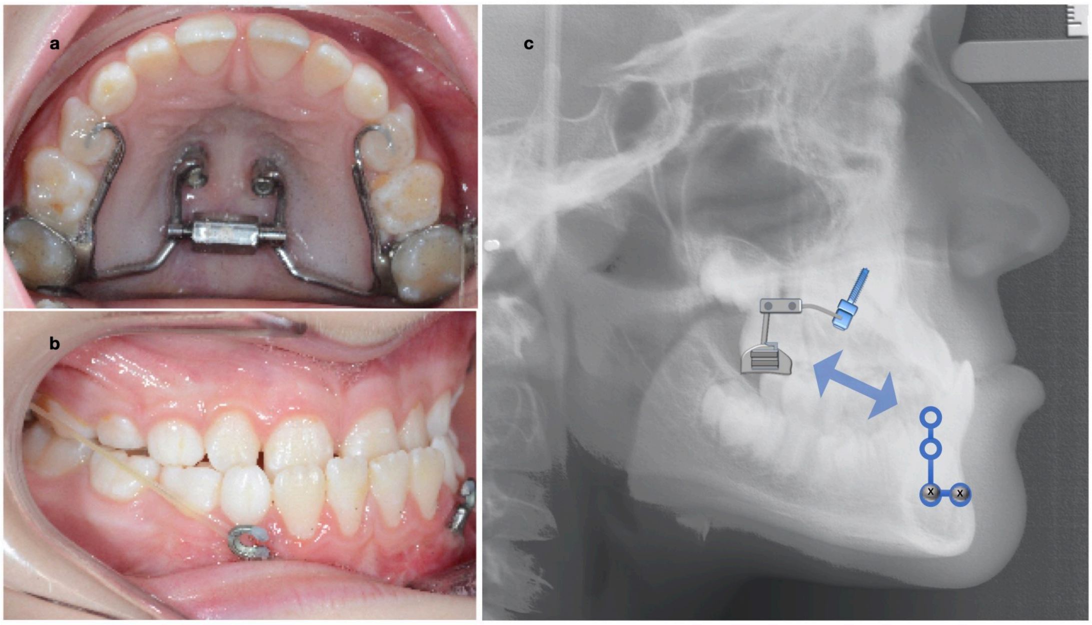

Figure 3. Hybrid expander miniplate appliance in place. A. Hybrid expander with two palatal miniscrews and expansion mechanism with rests extended to the deciduous first molars; B. The head of the miniplate converted into a hook, and elastics worn to the hook on the maxillary first molar band; C. Diagrammatic representation of the mechanics; elastic force vector in blue.

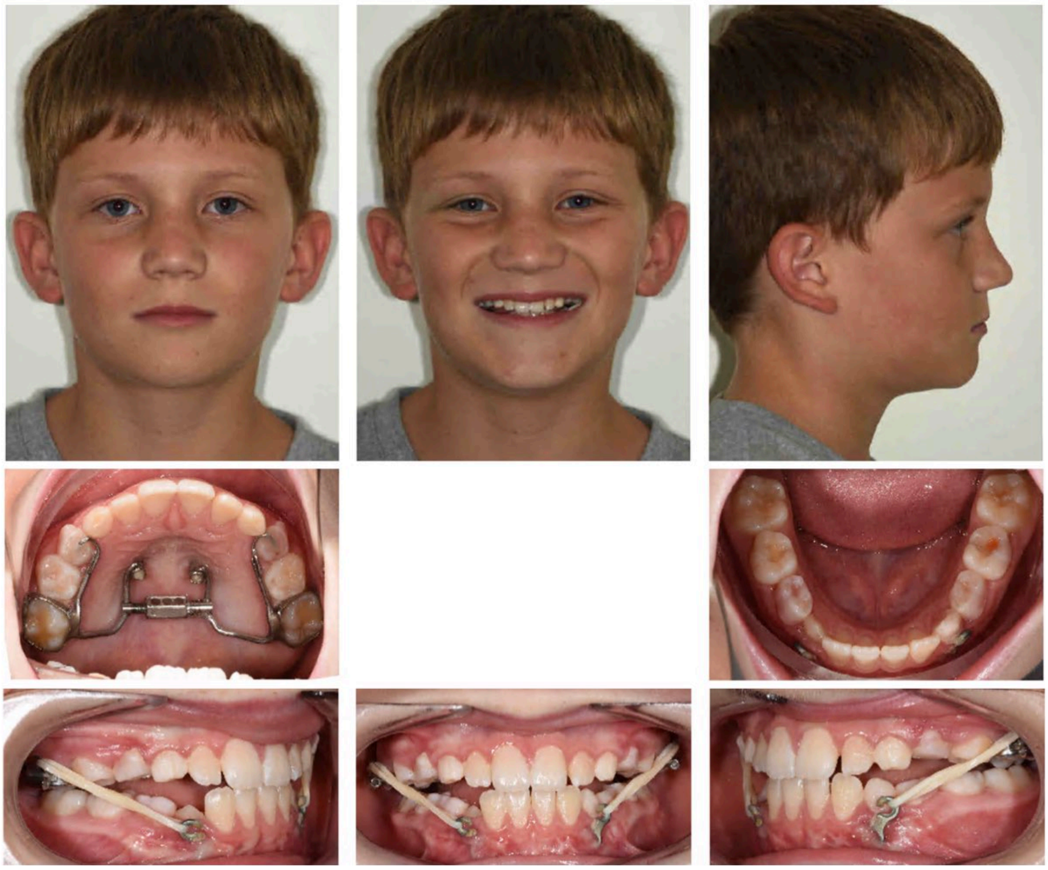

Figure 4. Treatment progress photos after 14 months of treatment, with a small positive overjet achieved and a significant profile improvement evident.

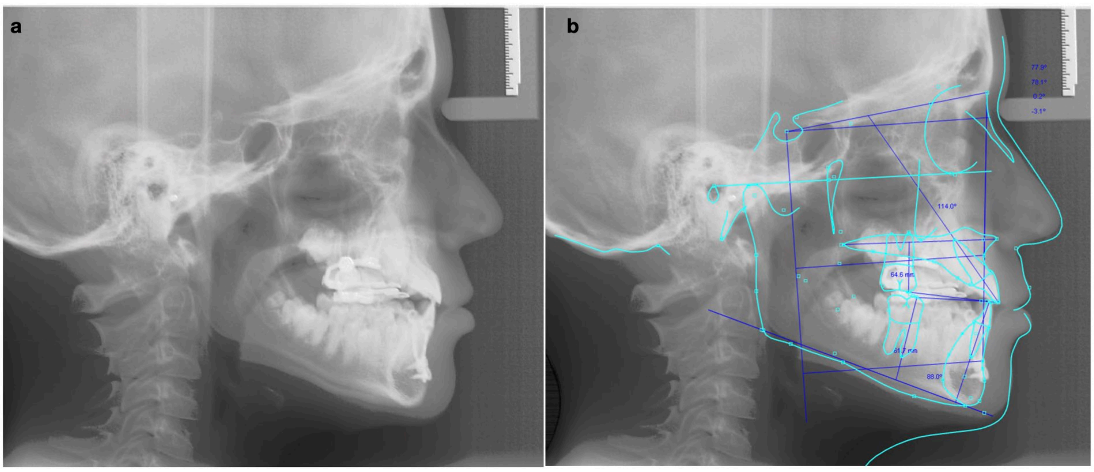

Figure 5. A. Progress lateral cephalogram (T2); B. Lateral cephalometric tracing at T2 after 14 months of treatment.

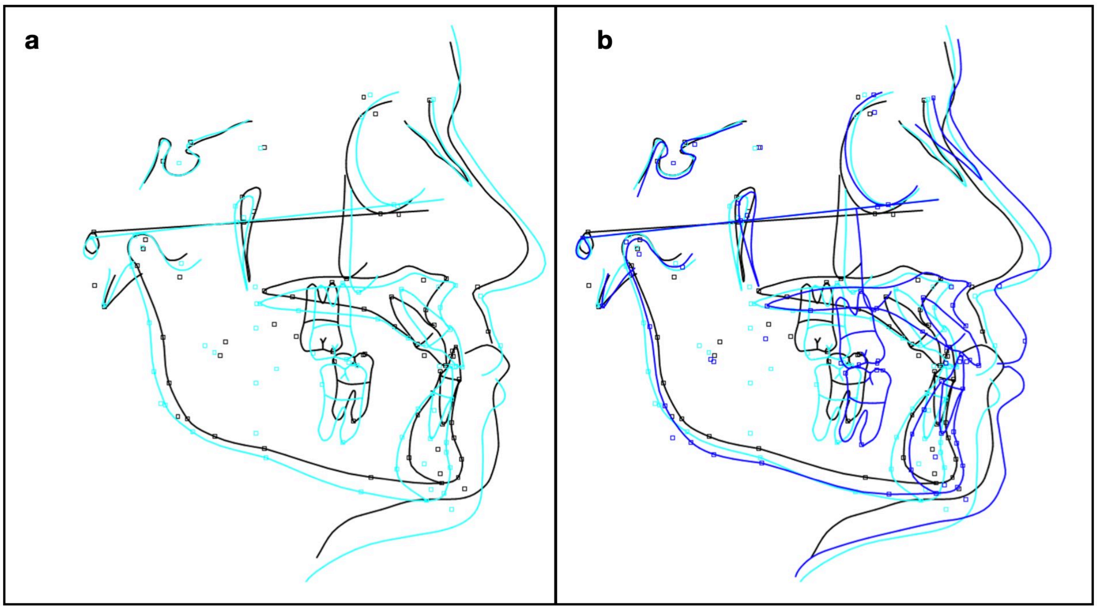

Figure 6. A. Cephalometric superimposition of T1 (black) and T2 at 14 months (light blue); B. Serial cephalometric superimpositions of T1 (black), T2 at 14 months (light blue) and T3 at 26 months (dark blue).

Figure 7. Intraoral photos taken at 26 months, when failure of the two palatal miniscrews was discovered. A. The maxillary buccal segment had migrated mesially and the space for the maxillary canines was lost; B. The maxillary molars were tipped mesially into a Class II relationship and there was loss of space for the maxillary canines.

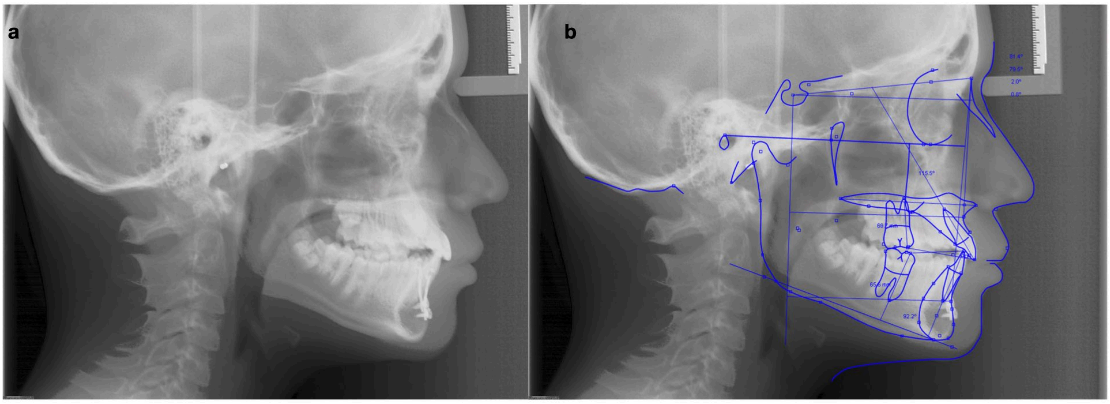

Figure 8. Progress lateral cephalogram (T3); B. Lateral cephalometric tracing at T3 after 26 months of treatment. The mesial tipping of the maxillary molars is evident.

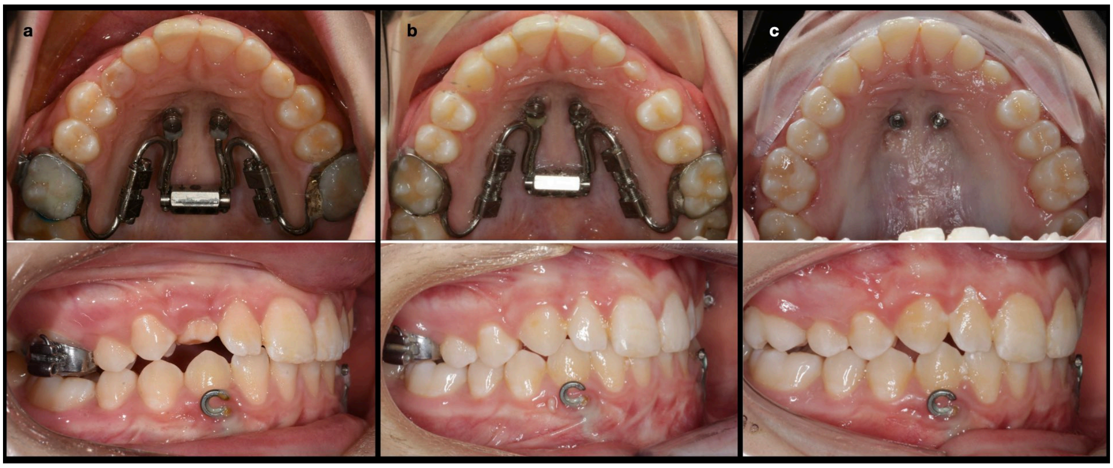

Figure 9. The hybrid expander distaliser in place. A. At the start of expansion and distalisation with molar in Class II; B. Molar distalised into Class I and space reopened for the maxillary canines, while Class III elastic traction was continued; C. Appliance removal and records at 38 months of active treatment.

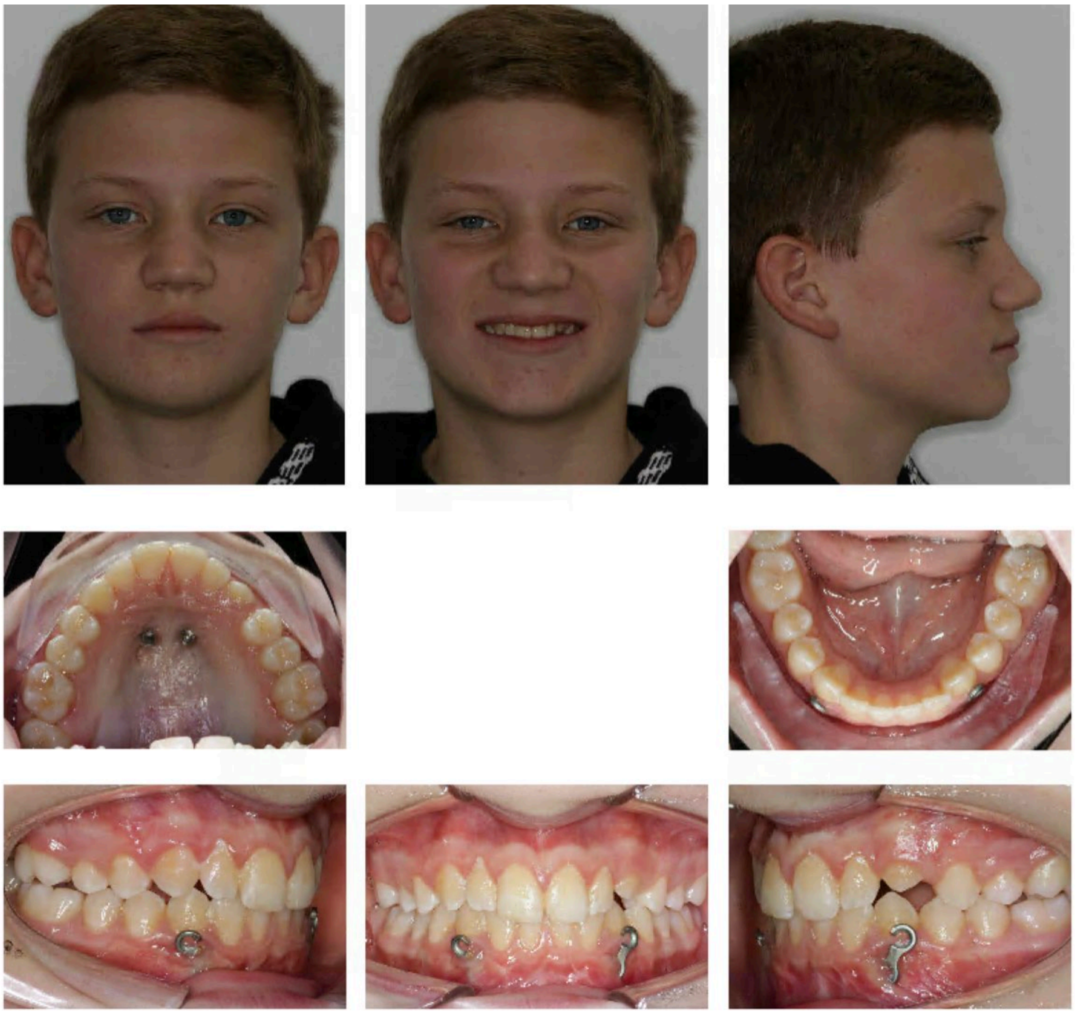

Figure 10. Photos at the end of 38 months of active treatment, with a Class I relationship and well-balanced profile.

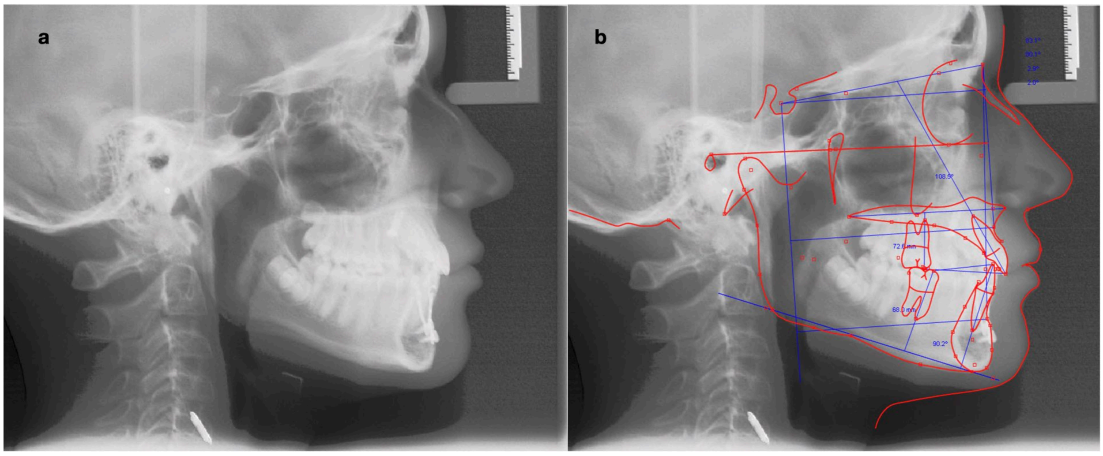

Figure 11. A. Progress lateral cephalogram (T4). B. Lateral cephalometric tracing at T4 after 38 months of treatment and before commencing the retention phase.

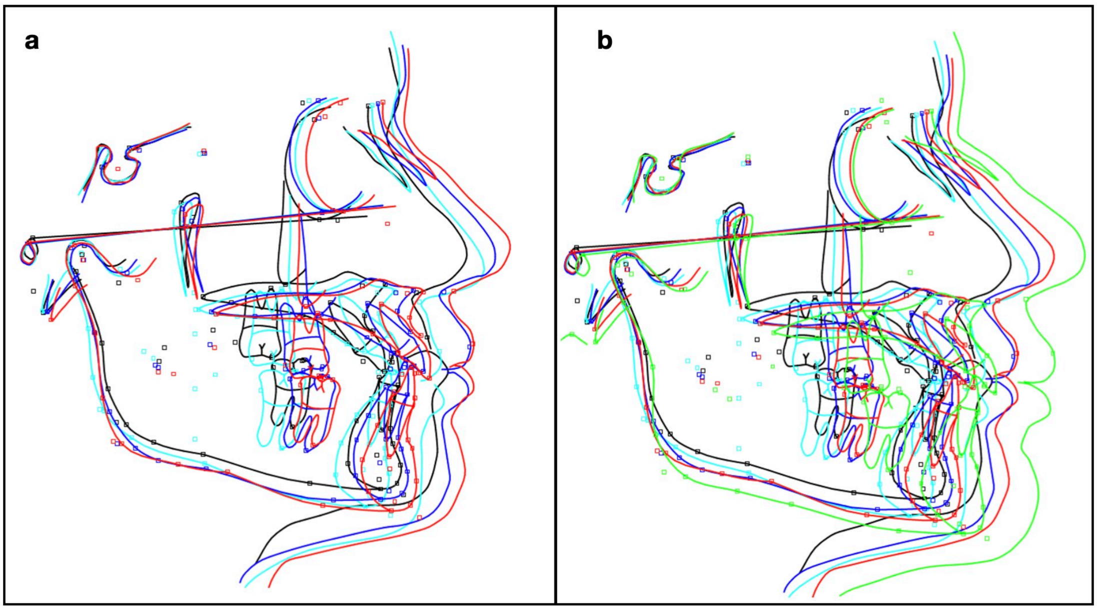

Figure 12. A. Serial cephalometric superimpositions of T1 (black) and T2 at 14 months (light blue), T3 at 26 months (dark blue) and T4 (red) at 38 months of treatment; B. Serial cephalometric superimpositions of T1 (black), T2 at 14 months (light blue), T3 at 26 months (dark blue), T4 (red) at 38 months of treatment and T5 (green) after 24 months of active retention.

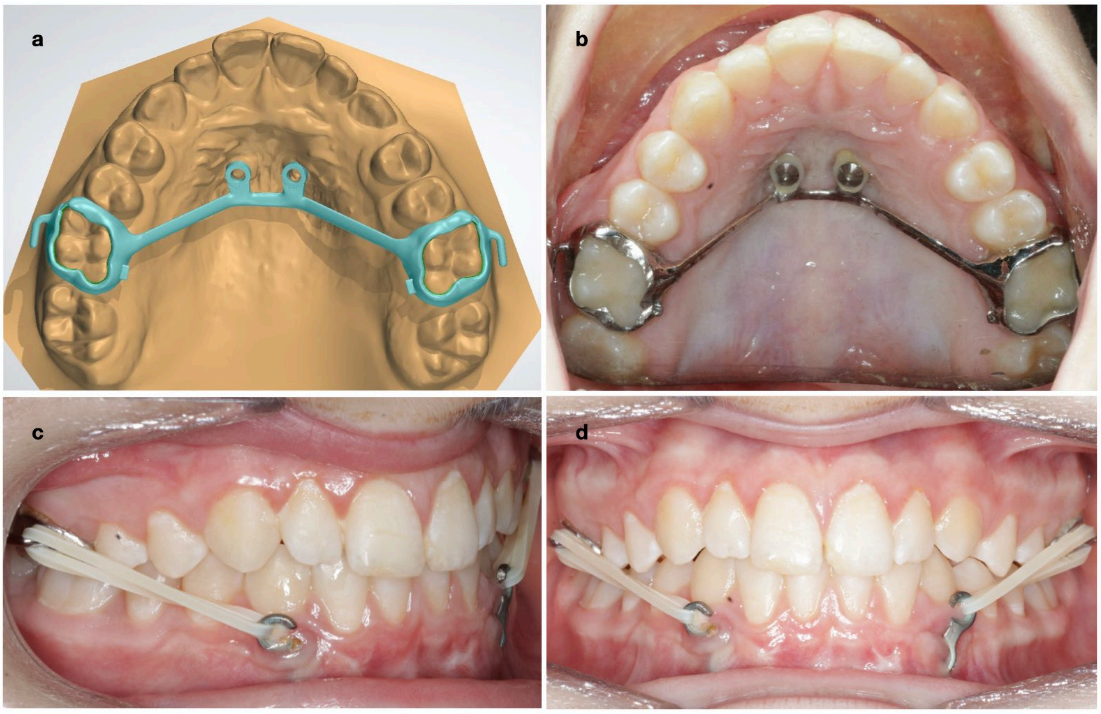

Figure 13. Start of retention phase. A. Digital design of rigid TPA with buccal hooks and rings to fit the miniscrews; B. CAD/CAM TPA cemented and fixed to miniscrews; C and D. Continuation of Class III elastic traction from the mandibular miniplate to the hooks on the TPA for active retention.

Figure 14. Photos taken after 24 months of active retention showing well-maintained Class I relationship, with a balanced profile.

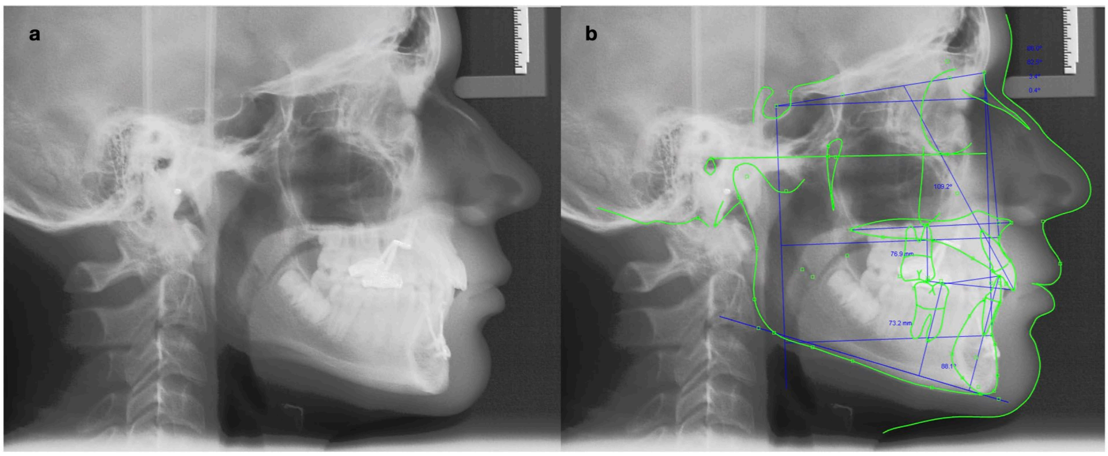

Figure 15. Progress lateral cephalogram (T5). B. Lateral cephalometric tracing at T5 after 24 months of active retention.

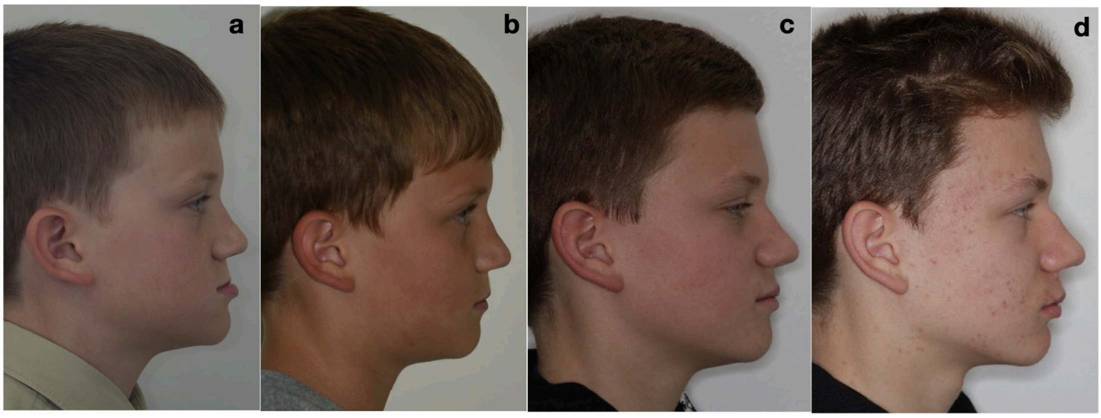

Figure 16. Progression of the profile. A. Pre-treatment; B. At T2 after 14 months of treatment; C. At T4 after 38 months of active treatment and D. At T5 after 24 months of active retention.

Figure 17. Progression of the occlusal correction. A. Start of treatment (T1), beginning elastic traction; B. T2, after 14 months of treatment with positive overjet; B. T3: failure of the palatal miniscrews showing loss of canine space; C. T4: completion of 38 months of treatment and molar distalisation concomitant with Class III traction regaining space for

maxillary canines; D. Commencement of active retention; E. T5, after 24 months of active retention.

Figure 18. Pre-treatment photos of Case 2, showing a severe Class III malocclusion with anterior crossbite, upper anterior spacing and concave profile.

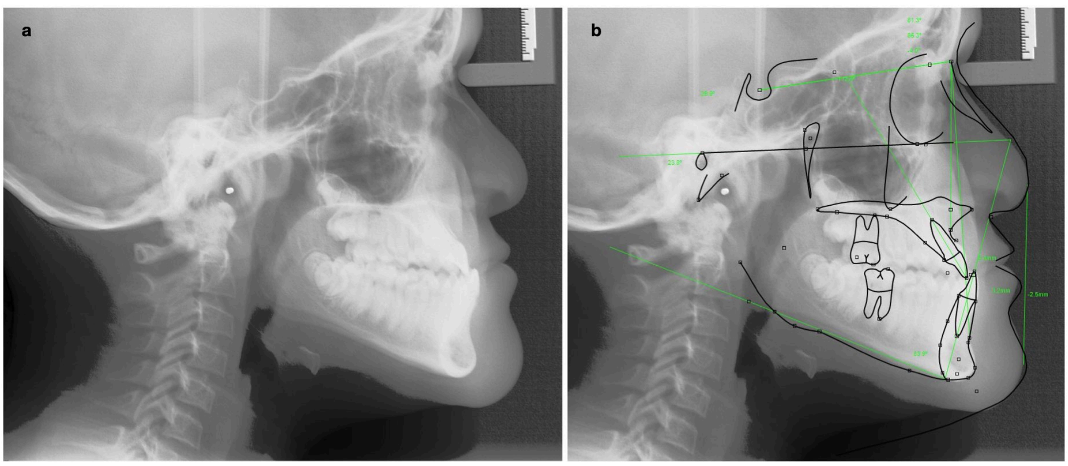

Figure 19. Case 2 lateral cephalometric tracing of the pre-treatment radiograph, showing a severe skeletal Class III pattern.

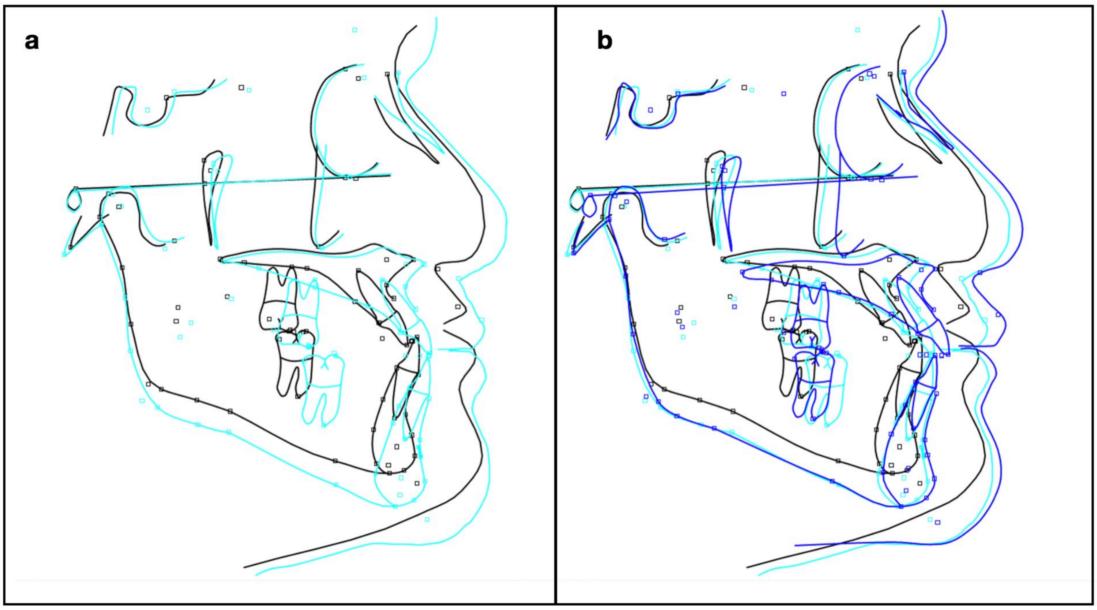

Figure 20. A. Cephalometric superimposition of T1 (black) and T2 at 12 months (light blue); B. Serial cephalometric superimpositions of T1 (black), T2 at 12 months (light blue) and T3 at 24 months (dark blue).

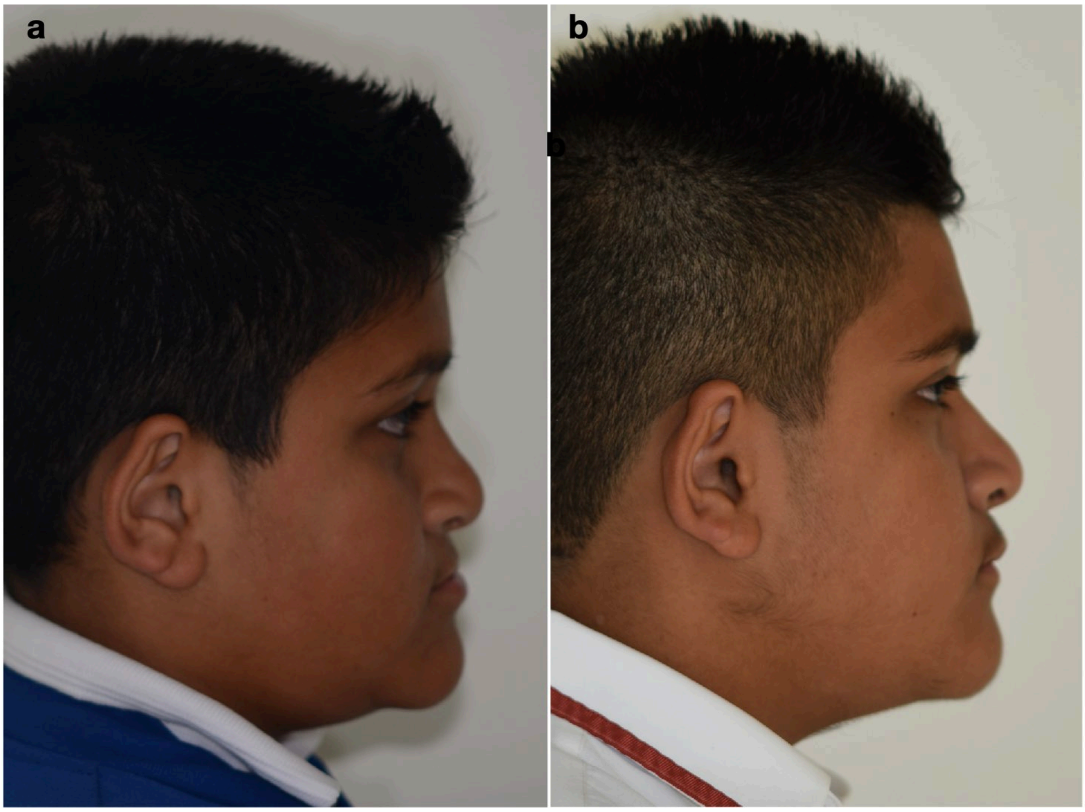

Figure 21. Profile comparison of T1 and T3 after 24 months of treatment. A. Pre-treatment profile; B. T3 profile.

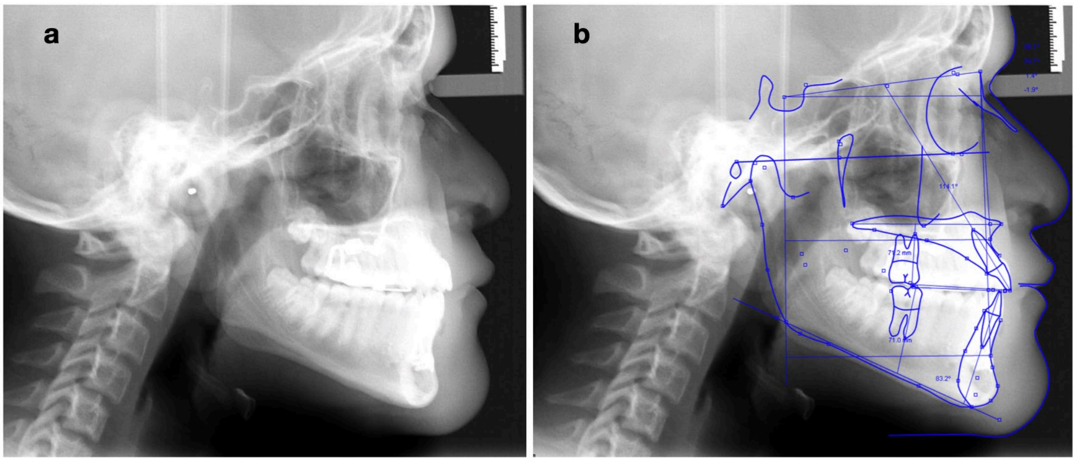

Figure 22. Progress lateral cephalogram (T3). B. Lateral cephalometric tracing at T3 after 24 months of treatment.

Figure 23. Progression of the occlusal correction of Case 2. A. Start of treatment (T1), beginning elastic traction; B. T2: after 12 months of treatment, overjet was still negative; C. T3: after 24 months of treatment, with overjet improved; D. T5, at the completion of 18 months of fixed appliance treatment with a Class I relationship, with good overjet and overbite; E. Commencement of active retention; F. T5, after 12 months of active retention, with a slight Class III tendency evident.

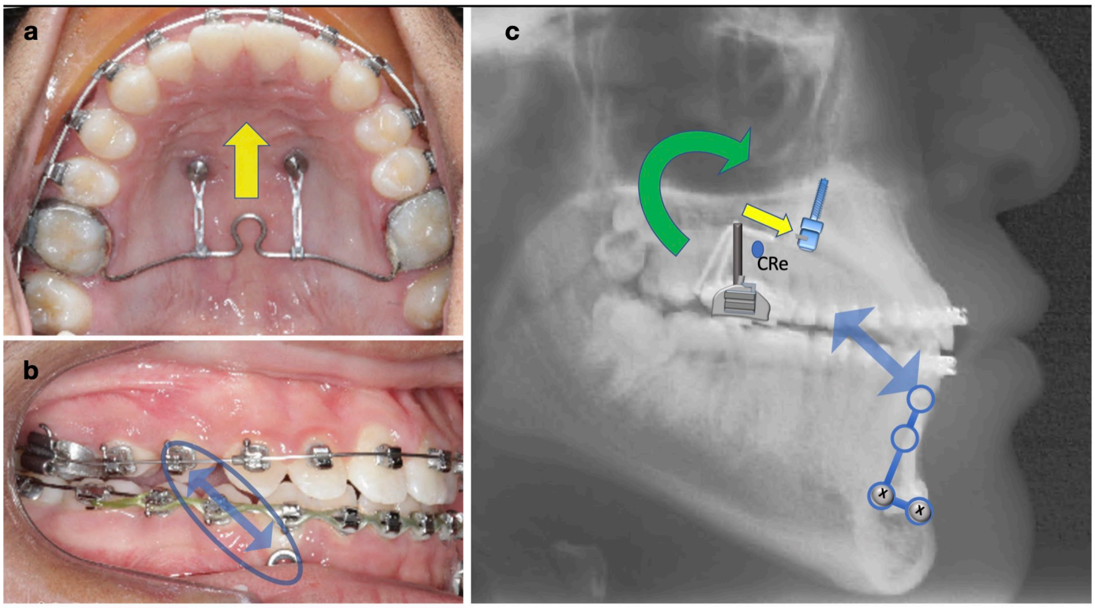

Figure 24. Fixed appliance treatment phase. A. TPA with elastomeric chain mesialising the upper arch; B. Class III elastic force vector during the fixed appliance phase (blue arrow); C. Diagrammatic representation of the biomechanical setup during the fixed appliance phase. The yellow arrow represents the force vector from the elastomeric chain acting apical to the CRe of the maxillary molars and stimulating a clockwise rotation of the maxillary occlusal plane (green arrow). Blue arrow represents the elastic force vector of the Class III elastics, from the mandibular miniplate to the maxillary first premolar.

Figure 25. Progress photos taken after completion of fixed appliance treatment showing the Class I relationship with good overjet and overbite and well-balanced profile.

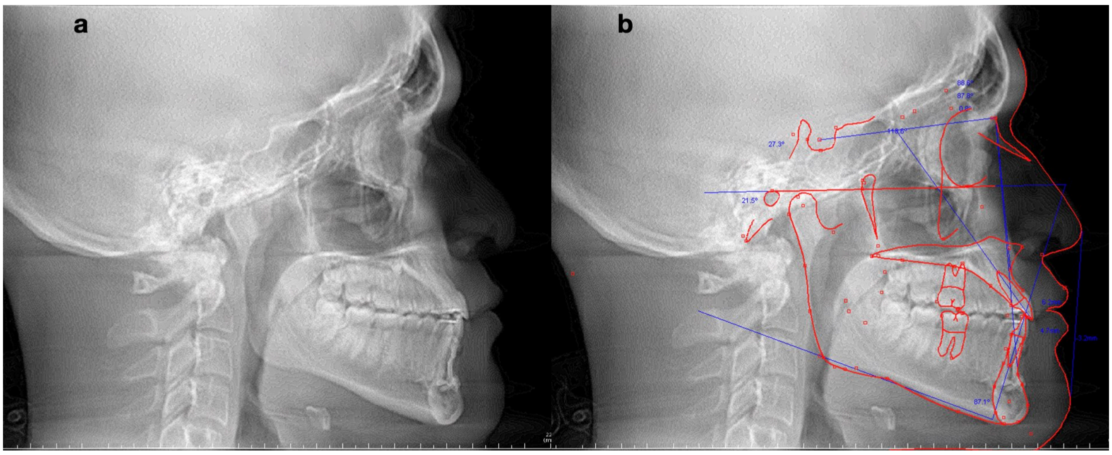

Figure 26. Progress lateral cephalogram. A. T5, at the completion of fixed appliance treatment; B. Lateral cephalometric tracing at T5.

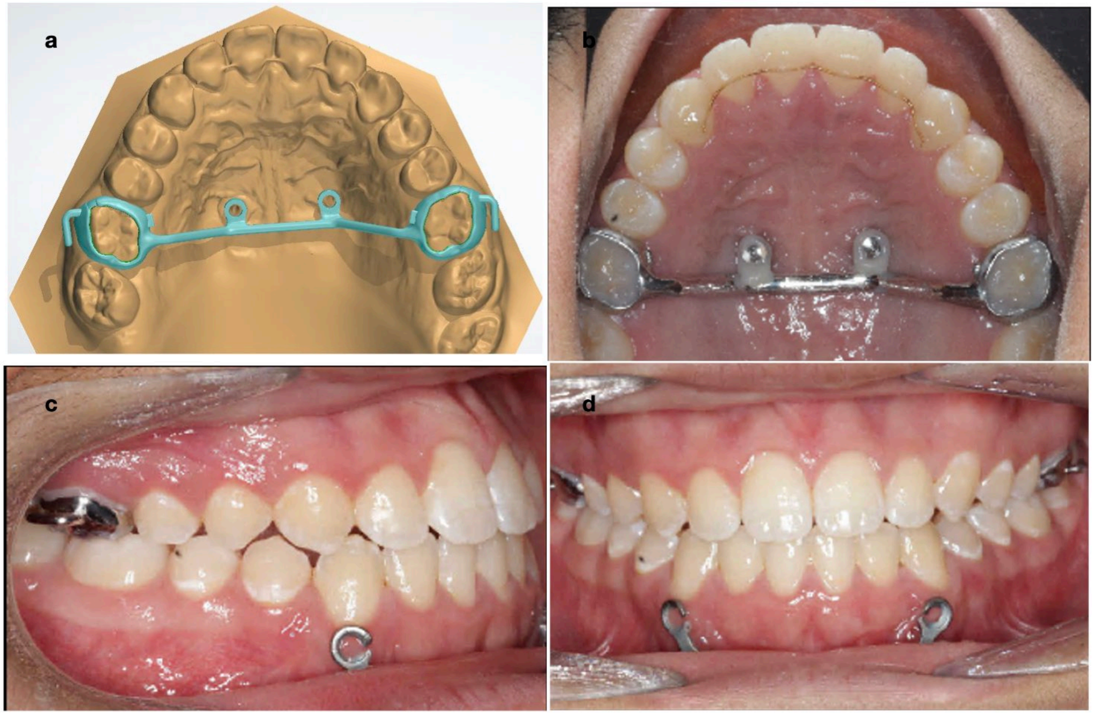

Figure 27. Start of retention phase. A. Digital design of rigid TPA, with buccal hooks and rings to fit the miniscrews; B. CAD/CAM TPA cemented and fixed to miniscrews; C and D. Continuation of Class III elastic traction from the mandibular miniplate to the hooks on the TPA for active retention.

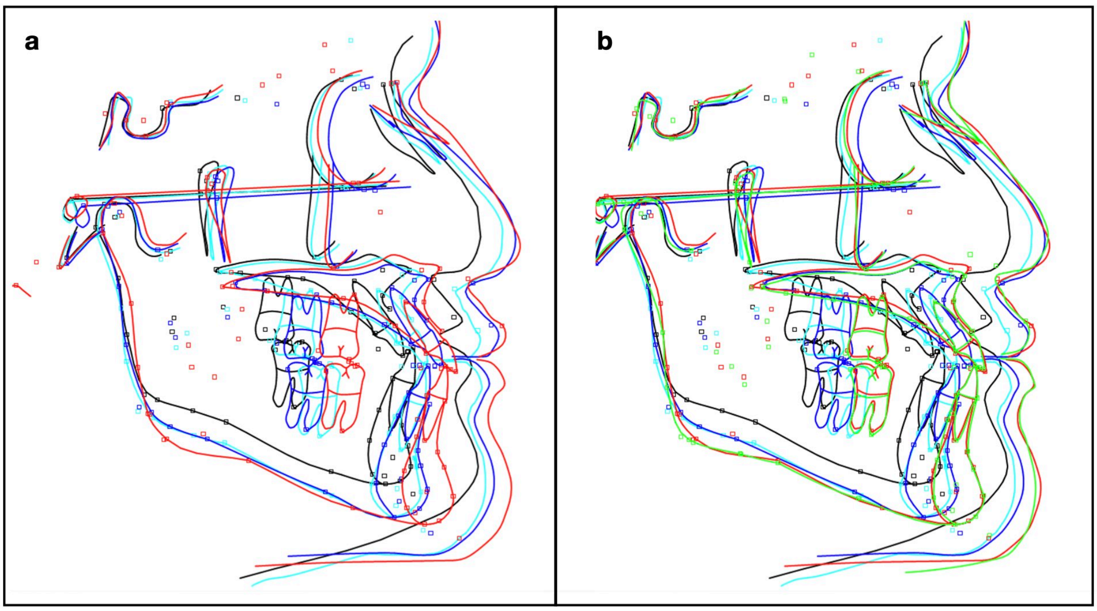

Figure 28. A. Serial cephalometric superimpositions of T1 (black) and T2 at 12 months (light blue), T3 at 24 months (dark blue) and T4 (red) at the end of fixed appliance treatment; B. Serial cephalometric superimpositions of T1 (black), T2 at 12 months (light blue) and T3 at 24 months (dark blue), T4 (red) at the end of fixed appliance treatment and T5 (green) after 12 months of active retention.

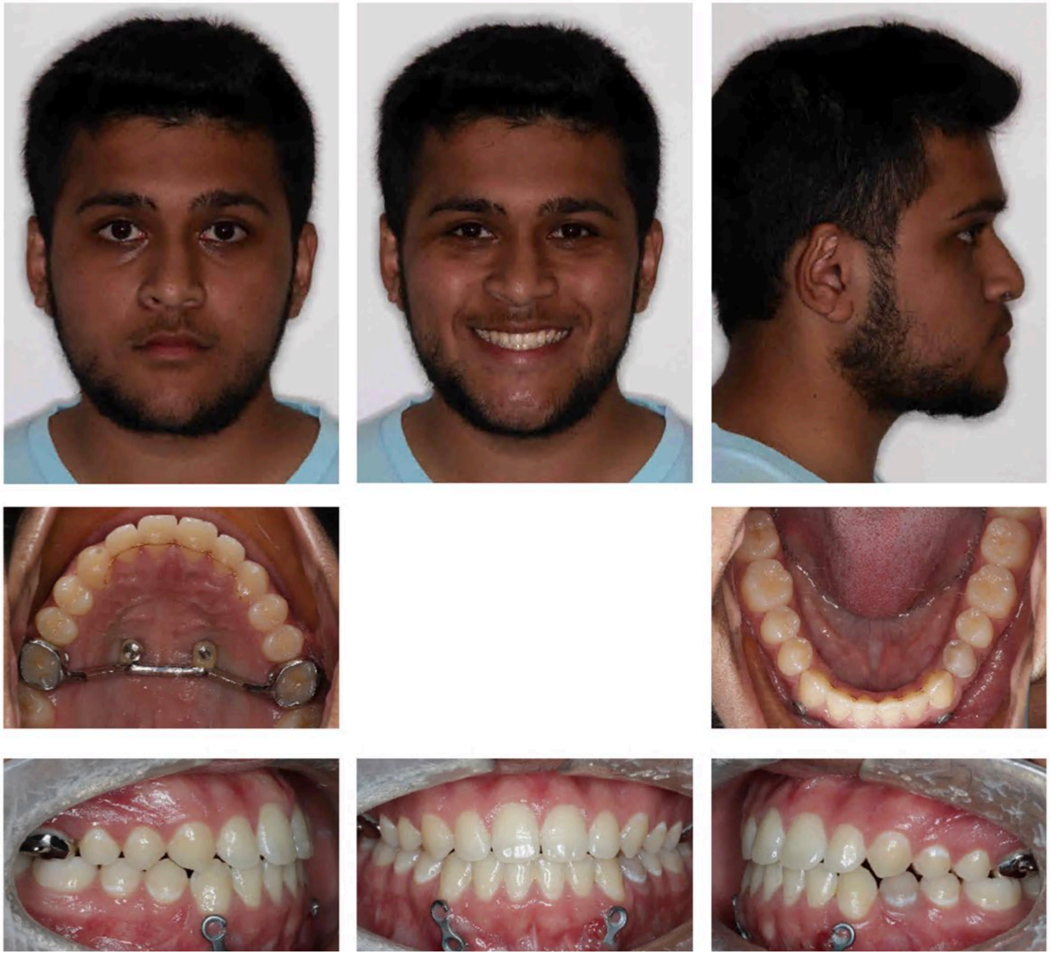

Figure 29. Photos taken after 12 months of active retention, showing the Class I relationship was reasonably well maintained, with slight Class III tendency (especially on the left-hand side), with a balanced profile.

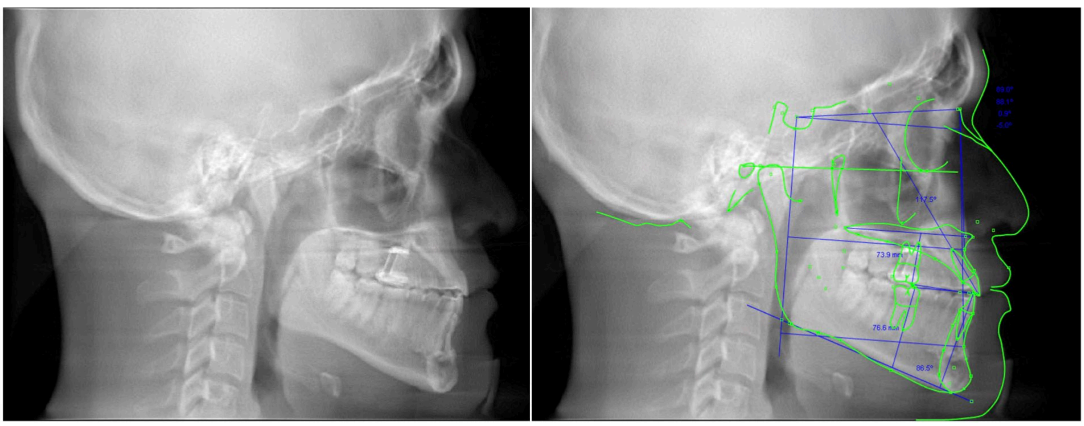

Figure 30. Progress lateral cephalogram (T5). B. Lateral cephalometric tracing at T5 after 12 months of active retention.

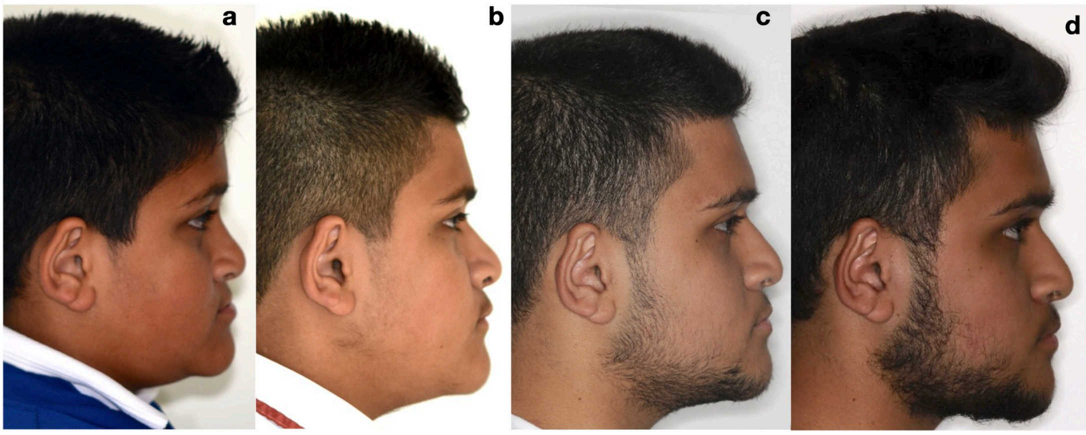

Figure 31. Case 2 progression of the profile. A. Pre-treatment; B. At T3, after 24 months of treatment; C. T4, after 38 months of active treatment; D. T5, after 12 months of active retention.

12.12.Tables

Table 1. Lateral cephalometric Analysis values: T1 before treatment, T2 after 14 months of treatment, T3 after 26 months of treatment after failure of the two palatal miniscrews. T4 after the second hybrid expander with distalizer was removed and total of 38 months of active treatment. T5 retention records after 24 months of active retention.

Case 1 cephalometrics					
	T1	**T2 (14m)**	**T3 (26m)**	**T4 (38m)**	**T5 (24m ret)**
SNA°	74.9	77.9	81.4	83.1	86
SNB°	79.9	78.1	79.5	80.1	82.5
ANB°	-5	-0.2	2	2.9	3.4
Wits mm	-7.6	-1.9	3.7	3.2	3
A-TV mm	60.7	64.6	69.7	72.6	76.9
B-TV mm	63.8	61.7	65.6	68	73.2
PP-MP°	18	22.8	17.6	20.2	19.1
SN-MP°	28.3	31.7	26	28.1	25.7
Y-axis-SN°	62.5	65.3	62.8	63	61.7
AR-Go-Me°	121.8	120.9	121	120.3	121.1
UOP-SN°	16.2	17.7	12.5	11.1	10.4
UOP-PP°	10.6	8.6	7.3	6.5	8.1
LOP-MP°	18.7	17.3	22.6	23.4	24.23
U1-SN°	114.3	114	115.5	108.5	109.2
U1-PP°	124.6	122.9	123.7	116.4	115.8
U6-PP°	86.9	87.4	97.2	86.4	87.8
L1-MP°	85.4	87.8	91.2	90.2	90
-L6-MP°	85.9	83.6	89.1	87	88.6
Overjet mm	-3	2	4.4	4	5
Overbite mm	4.7	0.6	3.2	3.6	4

Table 2 Lateral cephalometric Analysis values: T1 before treatment, T2 after 12 months of treatment, T3 after 24 months of treatment. T4 after 36 months active treatment. T5 at the completion of fixed appliance treatment. T6 retention records after 12 months of active retention.

Case 2 cephalometrics						
	T1	**T2**	**T3 (24m)**	**T4 (36m)**	**T5 (50m)**	**T6 (12m) retention**
SNA°	81.3	83.5	86.1	87.7	88.6	89
SNB°	84.5	84.8	84.7	86.8	87.8	88.1
ANB°	-3.2	-1.4	1.4	0.9	0.8	0.9
Wits mm	-8.2	-3.9	-1.7	-3.7	-5.3	-4
A-TV mm	62.8	67.8	71.2	72.1	73.7	73.9
B-TV mm	66.8	70.4	71	73.8	76.3	76.6
PP-MP°	20	21.2	24.3	24.4	23.5	21
SN-MP°	28.8	30.5	31.9	30.4	28	27
Y-axis-SN°	63	64	63.1	62.5	62	61.1
AR-Go-Me°	129.8	126.3	129	128.4	125.3	126.3
UOP-SN°	13.1	11.8	11.1	12.6	14	11.3
UOP-PP°	6.5	7	3.2	6.1	11.4	7
LOP-MP°	17.1	20	19	19.8	18.6	18.1
U1-SN°	114.7	114.7	114.1	116.2	117.3	117.5
U1-PP°	123.4	124	121.7	122.1	121	122.8
U6-PP°	87.9	87.3	87	86.3	81	82.2
L1-MP°	85	84.1	83	86.5	86.5	86.5
-L6-MP°	77.2	77.8	78	77.6	83.3	82.5
Overjet mm	-2.8	0.8	3	2	2.7	2.2
Overbite mm	2	-1.5	-0.1	-0.2	1.6	1

13. Conclusion and future directions

The treatment of Class III malocclusion in growing children can be considered one of the more challenging treatments in orthodontics. Earlier reports targeted the mandible, aiming to restrain mandibular growth since it was believed that mandibular excess growth was the main culprit in malocclusion.[1-3] In fact, the term ‘mandibular prognathism’ was used synonymously with ‘Class III malocclusion’.[3] Cephalometric studies, however, highlighted clearly that the majority of Class III patients suffered from maxillary deficiency.[4-6]

Numerous appliances directed towards the orthopaedic correction of Class III malocclusion have been studied. These can be broken down into chin cup therapy, Class III functional appliances and maxillary protraction with facemask.

Chin cup therapy aimed to restrain mandibular growth and redirect it.[7-12] However, most long-term reports showed chin cup therapy to be insufficient, with many cases experiencing rebound growth and relapse.[12] Additionally, treatment times were very long, and the protocol was demanding in terms of patient compliance.[7-12] When taking into account the fact that maxillary deficiency is a significant contributor in the greater percentage of Class III cases[4-6] it is understandable that chin cup therapy has fallen out of favour in recent years.

The aim in modern Class III treatment is to stimulate downwards and forwards maxillary growth while restraining and/or redirecting mandibular growth.[13] Several animal and human studies in the 1960s, 70s and 80s showed that sutural growth can be stimulated by protraction and expansion.[14-19] Maxillary expansion and protraction using various iterations of the protraction facemask became a mainstay of Class III treatment.[13]

For the last three decades, the protraction facemask has been used for the management of Class III malocclusion with maxillary hypoplasia.[13] The appliance is usually tooth-borne and can be used with or without maxillary expansion.[20,21] Maxillary expansion is thought to aid in stimulating a better sutural response to protraction forces through disarticulation of the circummaxillary sutures. However, the literature remains divided on this issue.[22-24]

Maxillary protraction with the tooth-borne facemask produces downward and forward maxillary growth with some restraining and backward rotation of the mandible.[20,21]

Nevertheless, there are several undesirable dental side effects, such as mesial movement of the maxillary dentition, extrusion of the maxillary molars and tipping and proclination of the incisors with, counterclockwise rotation of the occlusal plane.[20,21] Additionally, the mesial movement of the maxillary buccal segments can result in increased anterior crowding.[25] The mandibular incisors tend to tip lingually, which can increase crowding.[20,21] These dental side effects are undesirable as they compensate dentally for what is originally a skeletal problem. Additionally, in more severe cases, there is already some natural dento-alveolar compensation[26] and exaggerating it can be aesthetically undesirable. In addition, dental anchorage may be insufficient during the mixed dentition phase, especially the latter parts, during which the shedding of the deciduous molars and the eruption of permanent premolars is taking place.[27] During this phase, the deciduous molars would provide little or no support for heavy orthopaedic forces. The loosening of the teeth in the presence of appliances can make the appliances uncomfortable and reduce compliance with facemask wear, due to the pain which can be caused by pulling on mobile teeth. Further to the dental side effects, the total amount of skeletal correction reported with the tooth-borne facemask is small, especially when attempting to treat more severe cases.[20,22,28,29] The correction is even smaller with older children who are at or closer to the pubertal growth spurt.[25,28]

Additionally, the facemask is a cumbersome extraoral appliance, which can reduce its acceptance by patients. The wear time requirements are also quite high. Most studies have required patients to wear the appliance for 13-16 hours a day,[20,22,24,28] which can be challenging for most children, especially if they engage in extracurricular activities. This also makes the success of the treatment completely dependent on patient compliance, and if compliance is poor, the results are also unsatisfactory.

13.1. Summary of the limitations of conventional tooth-borne facemask therapy:

1. Undesirable dental side effects
2. Poor dental anchorage in the late mixed dentition
3. Small and (in more severe cases) potentially insufficient overall skeletal correction
4. Poor results in older children
5. Demanding wear time protocol

6. Complete reliance on patient compliance
7. Obtrusive and extraoral nature of the appliance.

The work in this project aimed to address and resolve some of the above limitations through the use of three different approaches that utilised skeletal anchorage.

Undesirable dental side effects:

The use of skeletal anchorage with maxillary protraction appears to eliminate many of the unwanted dental side effects on the maxillary dentition.[30-33] In all three applications studied in this project – the use of two palatal miniscrews with the hybrid expander in conjunction with maxillary protraction using either a facemask (HE-FM), Class III elastics with mandibular miniplates (HE-MP) or with the compliance-free NET3 corrector – the maxillary dental side effects were successfully negated. However, this was not the case for the mandibular dental side effects. With the HE-FM and the NET3 corrector, the mandibular incisors still retroclined in a manner similar to that observed with the tooth-borne RME-facemask. In addition, the NET-3 corrector had the effect of tipping the mandibular first molars distally. The use of mandibular miniplates (HE-MP), on the other hand, had the opposite effect. There seemed to be a tendency for the lower incisors to decompensate and advance with this protocol. Similar results were also reported with the BAMP protocol.[30,34] This finding seems unique to the use of miniplates to carry the Class III traction in the mandible, and may be particularly significant for more severe Class III cases, where there is already a significant element of dento-alveolar compensation and exaggerating it would be undesirable. Using the HE-MP protocol may be indicated in such cases over the other methods. However, more research is needed to clarify this point, considering the large standard deviation found in the lower incisor angulation change.

Poor dental anchorage for orthopaedic forces in the late mixed dentition

The use of skeletal anchorage is also aimed to overcome this shortcoming. The design of the HE-MP and the NET3 corrector used in this project do not engage any maxillary teeth other than the maxillary molars. And while the NET3 corrector gains anchorage in the lower arch only from the mandibular first molars, the HE-MP does not engage any lower teeth. This makes either of those treatment protocols a good option in Class III cases where treatment is starting in the late mixed dentition period, when deciduous molars would offer poor anchorage. It also makes it possible, if need be, to combine or overlap the treatment with fixed appliance treatment. This was evident in the second case presented in the long-term follow-up case report, where it was possible to transition into fixed appliance treatment during puberty, while the patient maintained the Class III traction using mandibular miniplates to control mandibular growth. This is in contrast to the use of HE-FM in this project, where all patients were in the early mixed dentition stage, meaning that the appliance also included the deciduous molars and canines. However, the original design of the Hybrid Hyrax by Wilmes et al.[35] only engages the maxillary first molars, and should a hybrid expander be selected to treat a Class III malocclusion in the late mixed dentition using the facemask, the design can easily avoid engaging any teeth other than the first molars.

Small amount of skeletal correction

The amount of skeletal correction is relatively small with tooth-borne RME-facemask treatment and may not be sufficient to completely resolve skeletal problems, especially in more severe cases. Studies typically show an improvement of 0.9-2.5 degrees in the ANB angle and 2-4 mm in the Wits appraisal.[20,22,24,36,37] In addition, the results for facemask therapy seem to be poor in older children.[28,38,39] In this project, it was evident that use of skeletal anchorage significantly enhanced the skeletal response, especially that of the maxilla. When the HE-FM was used, maxillary protraction was approximately two-fold that of patients undergoing tooth-borne facemask RME therapy, while with the HE-MP it was almost threefold. The NET3 corrector also showed greater maxillary protraction than the RME-FM, but to a lesser degree than the other two methods. On the other hand, the RME-FM tended to have a greater effect in terms of reducing mandibular excess, but this was mostly due to the backward rotation of the mandible and an increase in the lower anterior face height. The greater skeletal response was likely due to the direct transmission of protraction forces to the skeletal structure without loss due to tooth movement.

In more severe cases, especially when there is a positive family history of Class III, the HE-MP and the BAMP method can be considered the best options, as they avoid overloading any dental components. Orthopaedic treatment can be conducted and then maintained while fixed appliance treatment is completed during puberty.

Demanding facemask wear time protocol

Achieving good compliance is key to successful facemask therapy. In most studies on the facemask, patients were required to wear the facemask for 13-16 hours every day for a treatment duration of approximately 9-12 months.[20-22,40-42] This wear regimen would be quite demanding and laborious for most children at a young age, especially those engaging in after-school activities and hobbies. This requirement alone could lead to poor acceptance of treatment, as well as poor compliance. Studies on the adherence of patients to medical regimens have shown that treatments requiring greater patient lifestyle changes can lead to poor compliance, and thus poor outcomes.[43] Most studies on the facemask, however, have not objectively measured compliance with prescribed wear times. When compliance was objectively measured using thermal sensors, it was shown that patients wore appliances for 50-65% of the prescribed wear time.[44,45] On average, patients wore the facemask for 8.6 hours of the prescribed 13 hours.[44]

In our first study in this project, patients using the HE-FM were requested to only wear the facemask at bedtime. This is less than commonly requested, yet the skeletal and dental effects were on par with those reported in other studies.[32,33,38,40,41] By limiting facemask wear to bedtime only, the treatment may seem easier to adhere to and can more easily fit into the child's normal routine without too much disruption. This factor alone may result in better acceptance from patients and their families, and potentially result in better overall compliance and more regular facemask wear. Although objective wear time monitoring was not used in this study, it is unlikely that patients would have exceeded the prescribed hours of facemask wear. Children under the age of 11 years are expected to sleep between 10 and 12 hours every night.[46] It can be postulated that since skeletal anchorage increases the efficacy of facemask therapy, sufficient skeletal correction can be achieved with fewer hours of wear. Older children and adolescents sleep fewer hours[47] and so this may be an effective strategy for them.

Further research in this area is very necessary, where the wear time can be objectively measured and then correlated with the actual skeletal response. Such research could shed light on the dose-response ratio to facemask wear and provide good guidelines as to the minimum amount of time for which maxillary protraction needs to be in place to create a response. Furthermore, it would be desirable to assess whether this plateaus with time, or whether the skeletal response is proportional to the time for which the appliances are worn.

The need for patient compliance

Despite the use of skeletal anchorage with the HE-FM enhancing the results and the BAMP[52] and HE-MP protocols increasing patient acceptance by eliminating the extraoral component, both methods are still 100% reliant on the patient adhering to the prescribed wear regimen. This can make the treatment unpredictable. The introduction of the NET3 corrector aimed to address this problem. By using a completely intraoral approach that does not require patient compliance, the NET3 corrector enhances the operator's control over the treatment. The results in terms of skeletal correction and patient tolerance were encouraging. However, there are still some limitations to this approach. Firstly, the lower component is only tooth-borne, and there were significant dental side effects. Although this may be acceptable in mild and moderate cases, this may be quite undesirable in more severe cases. A future improvement and direction for future research could be to consider the use of a compliance-free design in conjunction with mandibular skeletal anchorage. Furthermore, the appliance resulted in more frequent repair appointments than the other two methods. One particular problem was the loosening of the left side spring. This could potentially be remedied by using reverse threaded components for the left side, where the loosening occurred. If this is achieved, the appliance could be much easier to use in everyday practice.

Obtrusive extraoral appliance

One of the main disadvantages of the facemask is its extraoral nature. Especially in modern-day children (as well as their parents), it is initially met with some resistance. With younger children (in whom a good response can be achieved with bedtime wear only) families may be able to accept the treatment more. Nevertheless, there will be children and families who will still reject such treatment. Furthermore, in older children who may not sleep enough hours, a completely intraoral method would be much more attractive and more likely to be accepted. The BAMP protocol, Hybrid Hyrax-Mentoplate and HE-MP protocol (used in this study), as well as the completely intraoral compliance free NET3 corrector, would be attractive options for such cases. Class III traction can be maintained full-time and the results show an excellent skeletal response.

When compared, the HE-MP does offer several advantages over the BAMP method. First, by eliminating the maxillary miniplates, it eliminates four surgical procedures, namely insertion and subsequent removal. Second, it increases the predictability of the maxillary anchorage unit, with the palatal miniscrews having a success rate of over 96%,[48,49] while maxillary miniplates show a much lower success rate, especially in younger children.[50] Third, it can incorporate skeletal maxillary expansion, which is often needed[51] and may also enhance the sutural response to protraction.[20] Finally, the treatment can start earlier, as the L-plates can be placed before the eruption of the mandibular canines. On the other hand, when it comes to long-term retention, the use of the BAMP method may be simpler. Furthermore, there will be no need for any components to be left on the teeth, while long-term retention with HE-MP will require either the expander to be left in place long-term, or for a rigid TPA to be constructed, adding cost and also increasing the potential for tooth damage from cement leakages and decay on the anchorage teeth.

Overall, the use of skeletal anchorage provides significantly better skeletal correction, however clinicians may need to keep in mind that the changes in overjet, when skeletal anchorage is used, is less. Most studies take into account the changes in overjet, ie overcorrection of overjet to 4-5 mm to stop growth modification and if the same is utilised for skeletally anchored growth modification, it may seem to clinicians that treatment with skeletal anchorage takes longer.
In our second study in this project, the average treatment time for HE-MP was two to three months longer than for RME-FM, yet both groups ended up with a similar overjet. In fact, despite the longer treatment time, the HE-MP group showed slightly less improvement in overjet. Similar findings were also reported by De Clerck et al. in their study comparing the BAMP protocol with RME-facemask.[30] The treatment was approximately two months longer with the BAMP method.[30] This can be explained by the lack of dental compensation when skeletal anchorage is used in the mandible. When tooth-borne Class III correction is used, 40-60% of the correction comes from mesial movement of the maxillary molars, proclination of the maxillary incisors and retroclination of the mandibular incisors.[20] This occurs concomitantly with the skeletal correction and thus serves to correct the overjet in a shorter period of time. When skeletal anchorage is being used, the dental compensation is eliminated, and thus the entire overjet correction is achieved through skeletal changes only, which explains the longer duration of such treatment. Additionally, in the HE-MP group the lower incisors

actually advanced slightly with treatment, subtracting even more from the overall overjet correction, as opposed to the retroclination of the lower incisors seen with the RME-FM.

The second factor that may play a role in slower correction with HE-MP is the lack of backward rotation of the mandible. There was no significant reduction in the SNB angle, nor was there an increase in the mandibular plane angle in the HE-MP group. On the other hand, with the facemask, a reduction in the SNB by 1 degree on average contributed significantly to the overall skeletal correction and would have also facilitated overjet correction. This was mainly attributed to the increase in the mandibular plane angle which was caused by backward rotation of the mandible. Additionally, the two long-term case reports showed that the maxilla can continue to respond positively to protraction over a long period of time. Future research could examine the following issues: skeletal response with bone anchorage, how it relates to the duration of treatment, the nature of the changes that occur in early stages of treatment, and how the dentition may change its response with the changing soft tissue pressures that ensue once the anterior crossbite is corrected and tongue and lip posture is altered.

13.2.Clinical recommendations for Class III treatment in growing children

The following table (Table 1) is a summary of clinical recommendations for Class III treatment in growing children based on the findings of this study:

Table 1. Recommendations for management of Class III malocclusion in growing children:

Treatment protocol	**Case severity**	**Age group**	**Clinical considerations**	**Advantages**	**Disadvantages**
Tooth-borne RME-facemask combination (**RME-FM**)	Mild and mild to moderate	6-9 years *Good root support on the maxillary deciduous molars	• Expansion needed • Acceptance of facemask wear 13-16 hours a day	• Minimally invasive	• Extraoral facemask needed • Demanding wear regimen • Compliance-dependent • Undesirable dental side effects • Small total correction • Not effective in older children
Hybrid expander-facemask combination (**HE-FM**; bedtime wear)	Mild, moderate and severe	7-10 years *younger than seven if safe placement of palatal miniscrews possible*	• Expansion needed • Family rejected GA for miniplates placement • Acceptance of wearing facemask to bed *For more severe cases: can be used as a phase 1 treatment, and mandibular miniplates can later be*	• Expansion and protraction both using skeletal anchorage • No need for GA • Procedure completable in the orthodontic office; minimally invasive with few complications • Bedtime wear routine achievable for most young children	• Extraoral facemask needed • Compliance-dependent • Safe placement of the palatal miniscrews may be difficult before the eruption of the maxillary lateral incisors and in very narrow arches • Retroclines the lower incisors

			inserted when safe placement is possible.		• Some backward rotation of the mandible
Hybrid expander-miniplate combination (**HE-MP**)	Moderate and severe cases **Milder cases that reject the facemask*	7-14 years **Younger cases only when all lower incisors erupted*	• Expansion needed • Rejected/ not accepting of facemask/failed to comply with facemask • Active lifestyle • Long-term retention needed (family history of Class III)	• No need for extraoral devices • Expansion and protraction both using skeletal anchorage • Appliances are almost invisible • No dental side effects • Possibility to decompensate the lower incisors • Treatment maintainable long-term without difficulty; good option for severe cases • Full fixed upper and lower appliances usable in parallel • Well tolerated and accepted by older and active children	• Need for GA adds cost, inconvenience and risk • Flap surgery required • More discomfort in early stages • Higher percentage of complications than palatal miniscrews • Compliance-dependent

				• High success rate of maxillary anchorage unit	
Maxillary and mandibular miniplates (**BAMP**)	Moderate and severe cases	11-14 years old **lower canines erupted and maxillary bone dense enough for zygomatic miniplates*	• No expansion needed • Active lifestyle • Possible option for cases with a previous treatment that included expansion • Reasonably well aligned dentition • Long-term retention needed (family history of Class III)	• No need for extraoral devices • Appliances almost invisible • No dental side effects • Possibility of decompensating the lower incisors • Treatment maintainable long-term without difficulty; good option for severe cases • Full fixed upper and lower appliances usable in parallel • Well tolerated and accepted by older and active children	• GA needed • Four flap surgeries to place devices • Only after eruption of the lower canines • Higher failure rate of maxillary miniplates • More discomfort early on • Compliance-dependent
NET3 corrector	Mild and moderate cases	7-14 years old	• Expansion needed • Family or young patient who rejected wearing a facemask	• Compliance-free • Expansion and protraction both	• Skeletal correction slightly less than other

			• Family rejected GA for miniplates placement • Poor compliance with elastics or facemask recorded or expected • Ideally patient local to the clinic for adjustment and repairs	using skeletal anchorage • No need for GA • Procedure completable in the orthodontic office; minimally invasive with few complications	bone-borne methods • Dental compensation in the lower arch • Higher frequency of breakages

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14. Appendix

This is a list of works, published and in press, done in the progression of this project and in relation to the research, however, the candidate was not the first author. The works are included here with the contribution of the author.

14.1. List of Papers

14.2. References

1. Al-Mozany SA, Dalci O, Almuzian M, Gonzalez C, Tarraf NE, Ali Darendeliler M. A novel method for treatment of Class III malocclusion in growing patients. Prog Orthod 2017;18:40.
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14.2.1. Title 1: The application of skeletal anchorage in the correction of anterior open bite and skeletal Class III malocclusion: a paradigm shift.

Description: Overview paper written by the candidate for the Annals of The Royal College of Dental Surgeons as part of the participation in the Convocation in Queenstown New Zealand. Using early

Journal: Annals of The Royal College of Dental Surgeons

Year: 2012

Ann Roy Australas Coll Dent Surg 2012;21:113-119

THE APPLICATION OF SKELETAL ANCHORAGE IN THE CORRECTION OF ANTERIOR OPEN BITE AND SKELETAL CLASS III MALOCCLUSION: A PARADIGM SHIFT

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Abstract

In recent years orthodontic treatment has been revolutionized by the introduction of skeletal anchorage or temporary anchorage devices (TADs). Many malocclusions, which have been previously only treatable through orthognathic surgery, such as skeletal open-bites, can now be managed non-surgically with less biological cost to the patient. Furthermore the recent application of TADs in the treatment of growing skeletal Class III patients is not only minimizing the need for obtrusive appliances, such as head gear and face masks, but it is also proving to deliver better and superior results to conventional growth modi cation protocols with more patient acceptance and less need for compliance. This overview covers the applications of TADs in the treatment of skeletal open bites and skeletal Class III malocclusions with reference to current evidence and clinical case presentations.

Introduction

Temporary anchorage devices have steadily made their way into mainstream orthodontics over the past decade. Although there have been sporadic reports in the literature previously[1,2] it is only recently that the use of skeletal anchorage has made its way into becoming an everyday part of orthodontic practice. Cope in 2007[3] defined them: "*(TAD) or a temporary anchorage device is a device that is temporarily xed to bone for the purpose of enhancing orthodontic anchorage by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether and which is subsequently removed after use* ." They can be divided into two main groups: anchorage plates and miniscrews. Anchorage plates usually involve the elevation of a flap and a surgical plate is secured to the bone using two or more screws with an attachment point for force application protruding through the mucosa into the oral cavity, whereas mini-screws are usually single titanium screws placed transmucosally and in the majority of cases do not require any flaps or incisions. In both cases the TADs are removed after treatment.

The indications for use of TADs in orthodontics are numerous and it can be said they have introduced a paradigm shift in orthodontics greatly expanding the horizon of what is achievable through orthodontic treatment for both adults and children. In many cases they may preclude the need for orthognathic surgery. This can be seen in the management of skeletal anterior open bite and skeletal Class III malocclusions.

Anterior Open bite treatment with skeletal anchorage

Anterior Open bite malocclusion has always been considered one of the more difficult ones to treat in orthodontics. It is present *"where the upper incisor crowns fail to overlap the incisal third of the lower incisor crowns when the mandible is brought into full occlusion"* according to Mizrahi.[4] Skeletal open bites[5] can be defined as a deviation from the normal vertical relationship of the maxillary and mandibular dental arches. The reason for the lack of contact is a deviation in the orientation of the basal bones of the maxilla and mandible in relation to each other,[6] and it can be present combined with a dual occlusal plane. In many cases it is associated with the facial features of the long face syndrome.[7]

Although the aetiology and features of open bite can be variable, traditionally skeletal open bites have been corrected by restricting the vertical development of the molar segment, usually in a growing child, or by attempting to intrude the molar segment. This usually employed obtrusive appliances utilizing extra-oral anchorage such as high-pull headgear[8] (Fig. 1a), vertical pull chin cups[9] or the use of acrylic bite blocks.[10,11] In many cases the results were limited by patient compliance and the difficulty in continuous wear of such devices due to their interference with the patient's daily activities and social interactions. In most adults surgical impaction of the maxilla was the treatment of choice. The treatment usually aimed to intrude the posterior maxillary segment thus allowing mandibular auto-rotation resulting in anterior tooth contact and closure of the open bite. Full fixed appliances with intermaxillary elastics[12] and/or extractions[13] have also been advocated although the treatment camouflaged the skeletal discrepancy through dental movements rather than addressing the skeletal aspect, which sometimes results in less than ideal facial aesthetics.

With the introduction of skeletal anchorage using the TADs as a point of force application, molar intrusion can be achieved reliably using intraoral and compliance free orthodontic mechanics. The molar intrusion allows mandibular autorotation and closure of the open bite without the need for extra oral devices or surgical maxillary impaction. This can be done through maxillary molar intrusion, mandibular molar intrusion or a combination of both. The first published reports on molar intrusion used anchorage plates, fixed to the buccal cortical bone around

* Presented at the Twentiy-first Convocation of the Royal Australasian College of Dental Surgeons, Queenstown, New Zealand, 31 March - 4 April 2012

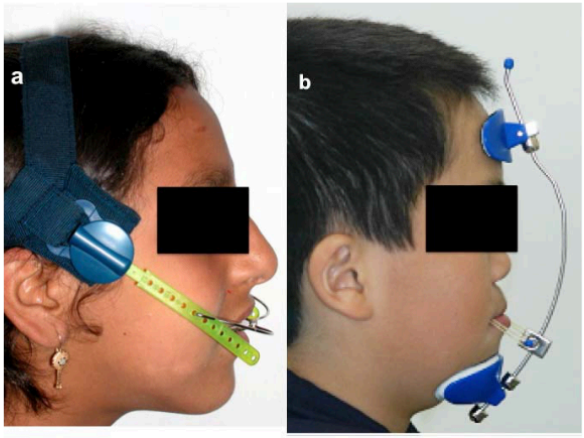

Fig. 1. – Extra-oral anchorage a. High Pull Head Gear b. Face Mask or Reverse Pull Head Gear (RPHG).

the apical regions of the lower first and second molars on both the right and left sides, to intrude mandibular molars for open bite correction.[14] This was followed by several reports on maxillary molar intrusion using anchorage plates placed in the zygoma.[15,16] In all cases the result was successful closure of the anterior open bites. With mini-screws gaining popularity several studies successfully used them as TADs for molar intrusion in open bite treatment[17-19] with placement locations varying from buccal, palatal and combinations of both. Mini-screws offer the advantage of being simpler to insert and remove with less surgery involved compared with surgical plates. Overall the amount of molar intrusion reported varied between 3-5 mm in a treatment duration of 4-10 months depending on the study.[14-19] Almost all of the studies report successful closure of the open bites with various degrees of mandibular auto rotation of 1.7-4 degrees.[14-18]

In a recent prospective clinical study at the University of Sydney, Foot *et al.*[20] treated 16 patients with anterior open bites using mini-screws and a specially designed intrusion spring (the SIS Sydney Intrusion Spring). The SIS aims to provide a specifically designed force application mechanism that is both hygienic, easy to use and does not require frequent reactivation to minimize patient discomfort. The open bite was corrected in all subjects in a period of 4.9 months on average with a mean molar intrusion of 2.9 ± 0.8 mm resulting in a 1.2° ± 1.3° counterclockwise rotation of the mandible. There was also an effect to elongate and upright the upper incisors with no significant extrusion of the lower molars. The authors concluded that the SIS used in conjunction with TADs is an effective means of correcting anterior open bites.

The long-term stability of open bite correction reported in the literature is very variable with some degree of relapse expected regardless of the treatment modality. With traditional orthodontic mechanics[21] relapse was reported in up to 33% of cases while others have reported negligible relapse.[22] Proffit *et al.*[23] examined surgical treatment results up to 3 years post treatment and reported a 10% chance a patient will have 2-4 mm relapse in the overbite. They speculated it might be due to incomplete adaptation of the tongue posture to the correction. Molar intrusion with TADs as treatment for open bites is a relatively new treatment modality, therefore there is little published literature on the long-term stability of the correction. The most comprehensive follow up to date was by Baek *et al.*[24] looking at nine adult patients three years post treatment. They found that molar intrusion relapsed

TABLE 1

Cephalometric analysis (Sydney-Geneva). Most of the vertical parameters highlighted in bold font indicate skeletal open bite patterns.

Parameter	Norms	Value
SNA*	82 ± 4°	74.6°
SNB†	79 ± 2°	69.9°
ANB‡	2.6 ° ± 2.4°	(4.7°)
S-Go'/ N-Me (J%)§	64 %	**57.9%**
N-ANS / ANS-Me¶	45%, 55%	**42.1%, 57.9%**
SN-PP**	8 ± 2°	12.8°
PP-MP††	23 ± 4°	**35.7°**
SN-MP‡‡	31 ± 3°	**48.4°**
SN-OP§§	15 ± 3°	**24.5°**
Gonial angle	122 ± 4°	129.7°
Y axis¶¶	68 ± 4°	**79.5°**
SN-FH***	7.8 ± 2.4°	13.6°
SN-Ba†††	130 ± 4°	128.2°
Witz ‡‡‡	0 ± 2	3.4
1/-SN §§§	103 ± 7°	94.2°
1/-PP	111 ± 6°	106.9°
/1-MP¶¶¶	92 ± 9°	88.8°
1/1	134 ± 13°	128.6°
Overjet	1-3 mm	**5.9**
Overbite	1-3 mm	**-2.5**

* SNA: SN for Sella –Nasion the line represents the anterior cranial base and A for (A-point) the anterior limit of the maxillary base. The angle denotes the relationship between the maxilla and the cranial base in the antero-posterior plane.
† B is B-point for the anterior limit of the mandibular base and SNB is the angle denoting the relationship between the mandible and the cranial base in the antero-posterior plane.
‡ ANB the angle denotes the relationship between the maxilla and mandible in the antero-posterior plane.
§ S-Go'/N-Me (J%) ratio between Sella-Gonion, distance denoting posterior face height, and Nasion-Menton, the distance denoting the anterior face height.
¶ N-ANS/ANS-Me ratio between upper anterior face height and lower anterior face height where ANS is anterior nasal spine.
** SN-PP angle between the cranial base line and PP palatal plane.
†† PP-MP angle between mandibular plane and palatal plane.
‡‡ SN-MP angle between cranial base line and mandibular plane usually a strong indicator of the vertical skeletal pattern.
§ §SN-OP angle between anterior cranial base line and occlusal plane.
¶¶ Y axis angle between Frankfurt Horizontal plane and Sella-Gnathion line is a good indicator on the vertical skeletal pattern.
***SN-FH angle between anterior cranial base and Frankfurt horizontal plane.
††† SN-Ba cranial base angle (between anterior and posterior cranial base).
‡‡‡ Witz appraisal denotes the antero posterior relationship between maxilla and mandible as evident on the occlusal plane.
§§§ 1/-SN upper incisor angle to the cranial base.

Fig. 2. – Pretreatment photos: Extra oral views showing long a face with increased lower anterior face height and retrognathic profile. The smile line is canted with more gingival display on the right hand side on smiling. Intra oral views showing open bite from 13-23 of 2-3 mm with Class II buccal segments.

by 0.45 mm after 2.39 mm of intrusion on average over the three-year period. Furthermore the overbite was increased in treatment by an average of 5.56 mm and relapsed by only 1.2 mm over the retention period. They concluded that molar intrusion with TADs was a valid treatment modality providing long-term stability comparable with conventional orthodontics and orthognathic surgery. Their results also indicate the need for over correction during treatment as well as perhaps some form of active retention.

Case reports

Case 1: 19 year old female presented with Class II malocclusion with an anterior open bite (Fig. 2), an increased lower anterior face height and a long face, as evident from the increased mandibular plane angle and vertical skeletal parameters (Fig. 3) (Table 1). There was also a slight cant in her smile line with more gingival exposure on smiling on the right hand side (Fig. 2). When surgical maxillary impaction was declined by the patient, molar intrusion using mini-screws was planned in both maxilla and mandible followed by full fixed appliances with the extraction of all third molars. The objective was to intrude the molar segments thus allowing mandibular autorotation to achieve anterior tooth contact eliminating the open bite and improving the vertical facial proportions at the same time. In order to prevent molars from tipping buccally with the intrusive forces a rigid transpalatal bar was constructed between the maxillary first molars with rested on the second molars (Fig. 4). In addition a 4 mm clearance between the bar and the palatal mucosa was left in order to allow room for intrusion without palatal impingement. In the lower arch a rigid lower lingual bar connecting the mandibular first molars with rests on the second molars was cemented (Fig. 4). Sectional fixed appliances were also bonded on the premolars and second molars to unite the buccal segments. Five TADs were placed in total. One mini-screw was placed on the buccal side between the second premolars and first molars in all four

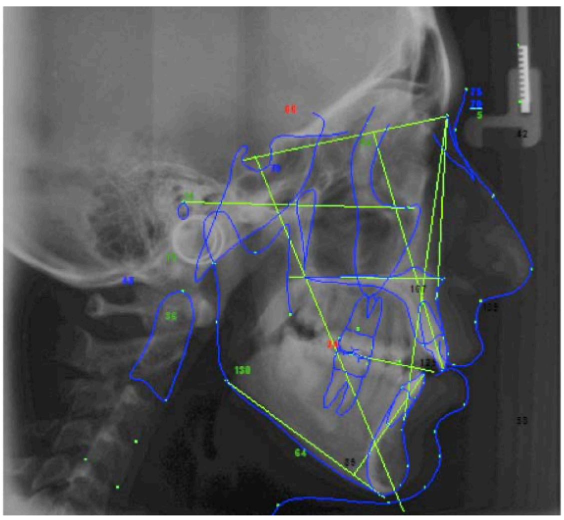

Fig. 3. – Cephalometric tracing showing increase in most vertical parameters and a tendency towards a skeletal Class II pattern.

Fig. 4. – Appliance placement with a rigid transpalatal bar and rigid lower lingual arch with rests on second molars. TADs (mini-screws) placed between the first molar and second premolar in all four quadrants and one mini-screw placed in the mid palate. Nickel titanium coil springs attached TADs to the molar teeth with 150 g of intrusive force and secured with flowable resin composite to minimize cheek irritation.

quadrants and one mini-screw was placed in the midpalate (Fig. 4). The TADs were immediately loaded by connecting NiTi coil springs with a force of 150g buccally and palatally attached to the first molars. The intrusion period continued for a period of 10 months in which a positive overbite of 5 mm was achieved (Fig. 5b). Full fixed appliances were then placed and the TADs were passively tied to the first molars to maintain the molar intrusion. Superimposition of lateral cephalometric tracings after molar intrusion using Bjork's stable structures[25] shows successful maxillary and mandibular molar intrusion with subsequent mandibular auto rotation (Fig. 6). Profile photographs also demonstrated a significant profile improvement with improved chin projection and a more pronounced soft tissue chin appearance following the reduction of the lower anterior face height (Fig. 5). Treatment was continued with fixed appliances correcting the smile line and finishing with a Class I molar and canine relationship with normal overjet and overbite. Fixed retainers were placed in the maxillary and mandibular anterior segments (Fig. 7) and the patient was also issued with clear vacuum formed retainers for night time wear.

From the above it appears that TADs in open bite treatment offer a predictable method for the correction of open bites with limited need for patient compliance and with completely intraoral mechanics. It also allows the correction of skeletal open bites without the midfacial changes associated with maxillary impaction surgery, which are not always desirable.

However it must be emphasized that the application of TADs does not provide a universal solution for open bite malocclusion problems and that diagnosis and assessment of the aetiology behind the open bite is of paramount importance for success and long-term stability of the outcome but is beyond the scope of this manuscript. Factors such as thumb sucking habits and abnormal tongue posture must be addressed as a priority. Furthermore it needs to be

Fig. 5. – Showing progression of treatment: A. Pretreatment B. After 10 months of intrusion overcorrection with 5 mm overbite and a posterior open bite. Improved profile with more pronounced chin projection. C. Treatment completed.

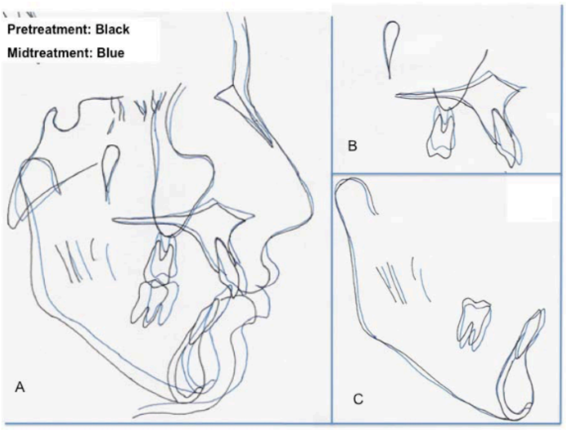

Fig. 6. – Superimposition of lateral cephalometric tracings A. Stable structures of the cranial base showing mandibular autorotation with increased forward projection of the chin. B. Maxillary regional super imposition showing maxillary molar intrusion and maxillary incisor flaring. C. Mandibular regional superimpositon showing mandibular molar intrusion.

remembered that facial balance and harmony are the main aim of modern orthodontics and dentofacial orthopaedics and should be the main guiding parameters behind decision-making. Particular attention must be paid to the smile line and incisal/gingival display at rest and on smiling in order to decide whether molar intrusion will indeed provide the desired effect. TADs and molar intrusion present a new treatment modality that should be used when indicated by the facial and occlusal goals.

Class III correction with skeletal anchorage:

Correction of skeletal Class III malocclusion is among the more challenging malocclusions to treat in the orthodontic office. Class III malocclusion according to Angle[26] occurs when the lower teeth occlude mesial to their normal relationship with the maxillary teeth the width of one premolar or more. Skeletal Class III maloccusion occurs when the mandibular base is more mesial than the normal in relation to the maxilla and this can be due to a deficient maxilla, prognathic mandible or a combination of both.[27] It is generally believed that the majority of Class III malocclusions will have an element of maxillary deficiency as a common feature.[28] Treatment modalities in growing children have typically aimed to stimulate sutural growth of the maxilla, restrain the growth of the mandible or attempt a combination of both.

Treatment timing for Class III malocclusion in growing children is considered paramount[29] as patency of the sutures is necessary for successful maxillary protraction. Maxillary sutures become more complex with age making protraction less effective.[30] Therefore it has been advocated that treatment using reverse pull head gear (RPHG) or a protraction face mask (Fig. 1b) should be employed early between ages 7-10 years old to utilize the growth potential of the maxillary sutures. It is believed that simultaneous rapid maxillary expansion aids in activation of the circummaxillary sutures or to somewhat "disarticulate" the maxilla, although the evidence in this regard is equivocal.[31,32] In addition to the importance of treating early, success with RPHG is highly dependent on patient compliance usually involving the use of the cumbersome extra-oral appliance for 14-16 hours per day for a period of 10-12 months.[30] The protraction facemask therapy leads to both dental and skeletal effects including desirable forward movement of the maxilla but also downward and backwards movement of the mandible with proclination of the maxillary incisors and retroclination of the mandibular incisors, which are considered undesirable dental compensations that detract from the skeletal correction.[30]

The amount of forward movement of the maxilla (A-point) and therefore skeletal correction is significantly higher if treatment is done early, before age 10, ranging around 2-3 mm, while the benefits of treatment is greatly reduced for older children dropping to 1-2 mm after the age of 10 years.[31]

In recent years two treatment modalities have changed the face of Class III growth modification treatment. The first was when Liou *et al.*[33] introduced a protocol of alternating rapid maxillary expansion and contraction (ALT RAMEC) prior to maxillary protraction. The aim of the technique was to improve the efficiency of the treatment through disarticulation of the maxilla by repeated cycles of expansion and contraction thus facilitating maxillary protraction. In addition he used an intra-oral compliance free spring thereby eliminating the need for RPHG and the compliance issues associated. The results were very impressive, with a forward movement of the maxilla (A-point) of 5.8 mm over a period of 2-3 months. This amount of maxillary forward movement is almost 2-3 fold what the literature[29-31,34] on RPHG demonstrates and in one third of the treatment time. In addition he treated patients who were considered late in terms maxillary protraction at 11.5 years old and the results were stable two years after treatment.

DeClerk *et al.*[35] introduced another treatment modality. The technique applies Class III intermaxillary elastics to titanium mini-plates placed in the zygoma and the anterior mandible to correct maxillary deficiency. The group[36] compared the results of their treated patients with what is expected from

Fig. 7. – Appliances at start of protraction. From *Al-Mozany et al. (with permission).*[38]

untreated Class III controls and found on average 4 mm more of maxillary forward movement and 2 mm of restrained mandibular growth. This was almost double the amount produced by RPHG treatment.[29-31] In addition the results were achieved in a group of children who were 11 years old, which would be considered past the ideal time for RPHG treatment.[29-31] They[37] then compared the mini-plate and Class III elastics protocol with a sample of cases treated with RPHG and found that the skeletal anchorage group showed on average 2-3 mm more maxillary advancement while the effects on mandibular growth were comparable with those of the RPHG. Furthermore the vertical control with the skeletal anchorage group was better with no backwards rotation of the mandible and no lower incisor retroclination. The technique does not involve any tooth borne appliances.

A recent prospective study[38] at the University of Sydney examined the effects of combining both Alt-RAMEC and skeletal anchorage with Class III elastics in the treatment of skeletal Class III maxillary deficiency in growing children. In order to eliminate the need for flap surgery and general anaesthesia the study used mini-screws instead of anchorage plates. A group of 14 (7 male and 7 female) Class III patients with maxillary deficiency aged 12.5 years on average were treated with Alt-RAMEC and TADS with Class III elastics. Two mini-screws were inserted on either side of the mid-palatine suture and two mini-screws were inserted into the anterior mandible between the canines and lateral incisors. The palatal TADs[39] were attached to a modified bonded rapid palatal expander and the lower TADs were fixed to a modified bonded lingual arch (Fig. 8). The maxilla was then expanded at 1 mm/day for a period of seven days followed by constriction of the maxilla at 1 mm/day for 7 days. This protocol was repeated for nine weeks. Following this Alt-RAMEC protocol intermaxillary Class III elastics (Fig. 8)

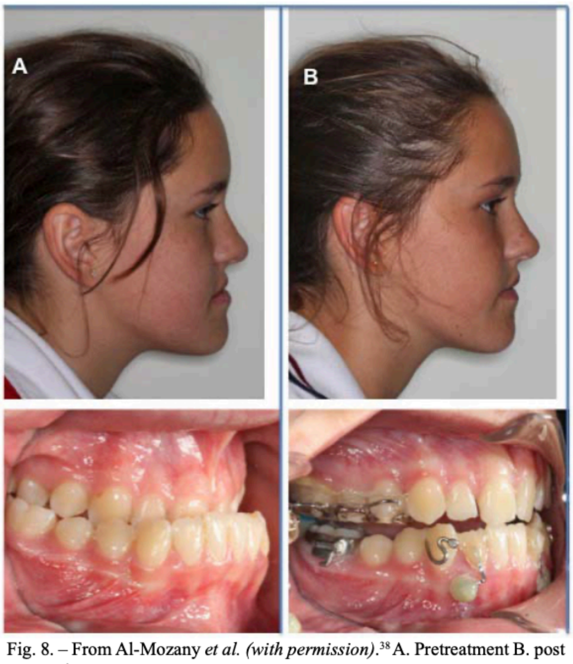

Fig. 8. – From Al-Mozany *et al. (with permission)*.[38] A. Pretreatment B. post protraction.

were worn 24 hours per day and protraction was ceased when an overjet of 2 mm was achieved. The results were promising with the 2 mm overjet achieved in all subjects after an average of 8.6 weeks. The maxilla moved forward by 3.3 mm on average (Fig. 9), twice as much as what would be expected at this age with RPHG and in only a third of the treatment time.[29-31] The results are also comparable with those achieved by the De Clerck[35] protocol with less treatment duration. However, there were dental compensations experienced such as proclination of maxillary incisors and retroclination of mandibular incisors as well as backward rotation of the mandible. This can be attributed to the fact that the appliances were tooth borne and indirectly supported by skeletal anchorage and the inherent flexibility of the wires used would have allowed some dental movement. Nevertherless, the combination of Alt-RAMEC with TADs and Class III elastics for the correction of Class III malocclusions appears very promising. It offers an alternative to conventional RPHG that is completely intraoral with improved patient acceptance. In addition to offering superior results in shorter duration it also allows effective treatment for patients who previously would be considered too old to benefit fully from RPHG therapy. However long term stability of the changes still need to be evaluated. This study is part of an ongoing project at the University of Sydney aiming to improve the efficiency and efficacy of Class III correction in growing individuals.

From the above it appears that the incorporation of TADs in orthodontic treatment has significantly changed the way modern orthodontic treatment is approached. TADs have widened the possibilities of what can be done with orthodontic treatment alone. They have enabled the elimination of many cumbersome and obtrusive appliances as well as reduced the need for patient compliance in many aspects of treatment, making treatment simpler and more predictable. It can also be said that the research so far has merely scratched the surface in the field of skeletal anchorage.

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14.2.2. Title 2: A novel method for treatment of Class III malocclusion in growing patients[1]

Description: This was prospective clinical trial done as part of the Doctor of Clinical Dentistry (DClin Dent) of Dr Saad Al-Mozany. The candidate at the time served as a lecturer in the department of Orthodontics and supervisor for the research project. He contributed in the study design and to the design and mechanics of the appliances used.

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Progress in Orthodontics

RESEARCH Open Access

A novel method for treatment of Class III malocclusion in growing patients

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Abstract

Background: Management of Class III malocclusion is one of the most challenging treatments in orthodontics, and several methods have been advocated for treatment of this condition. A new treatment protocol involves the use of an alternating rapid maxillary expansion and constriction (Alt-RAMEC) protocol, in conjunction with full-time Class III elastic wear and coupled with the use of temporary anchorage devices (TADs). The aim of this study was to evaluate the dento-skeletal and profile soft tissue effects of this novel protocol in growing participants with retrognathic maxilla.

Methods: Fourteen growing participants (7 males and 7 females; 12.05 ± 1.09 years), who displayed Class III malocclusions with retrognathic maxilla, were recruited. Pre-treatment records were taken before commencing treatment (T1). All participants had a hybrid mini-implant-supported rapid maxillary expansion (MARME) appliance that was activated by the Alt-RAMEC protocol for 9 weeks. Full-time bone-anchored Class III elastics, delivering 400 g/side, were then used for maxillary protraction. When positive overjet was achieved, protraction was ceased and post-treatment records were taken (T2). Linear and angular cephalometric variables were blindly measured by one investigator and repeated after 1 month. An error measurement (Dahlberg's formula) study was performed to evaluate the intra-examiner reliability. A paired-sample t test ($p < 0.05$) was used to compare each variable from T1 to T2.

Results: Treatment objectives were achieved in all participants within 8.5 weeks of protraction. The maxilla significantly protracted (SNA 1.87°± 1.06°; Vert.T-A 3.29± 1.54 mm $p < 0.001$), while the mandibular base significantly redirected posteriorly (SNB −2.03° ± 0.85°, Vert.T-B − 3.43± 4.47 mm, $p < 0.001$ and $p < 0.05$ respectively), resulting in a significant improvement in the jaw relationship (ANB 3.95°± 0.57°, $p < 0.001$; Wits 5.15± 1.51 mm, $p < 0.001$). The Y-axis angle increased significantly
(1.95° ± 1.11°, $p < 0.001$). The upper incisors were significantly proclined (+ 2.98°± 2.71°, $p < 0.01$), coupled with a significant retroclination of the lower incisors (− 3.2°± 3.4°, $p < 0.05$). The combined skeletal and dental effects significantly improved the overjet (5.62± 1.36 mm, $p < 0.001$) and the soft tissue Harmony angle (2.75° ± 1.8°, $p < 0.001$).

Conclusions: Class III elastics, combined with the Alt-RAMEC activation protocol of the MARPE appliance, is an efficient treatment method for mild/moderate Class III malocclusions. The long-term stability of these changes needs further evaluation.

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Background

The incidence of Class III malocclusions ranges from 0.8–12% [1–3]. The etiology of Class III malocclusions can be categorized as either genetic or environmental in origin [3]. The craniofacial characteristics of the Class III malocclusion may be attributed to both a positional and a dimensional disharmony of numerous components of the craniofacial skeleton involving the cranial base, the maxilla, and/or the mandible [4–6]. Ellis and McNamara [7], in their cephalometric sample of 302 adult participants with Class III malocclusions, found that 45.5% of their sample had maxillary retrusion.

Treatment modalities range from dentofacial orthopedic treatments using protraction facemasks [8] and camouflage orthodontic treatments to a combined orthodontic jaw surgery. The extra-oral protraction face mask (PFM) is the most efficient appliance for short- to long-term use [9–11]. Rapid maxillary expansion (RME), in conjunction with PFM, has been claimed to disrupt circummaxillary sutures, which in turn might enhance the skeletal effects [12]. By contrast, some evidence has suggested that RME provides no benefit to the outcomes of PFM [13].

An elaboration of the RME protocol, in which the maxilla is alternately expanded and constricted (Alt-RAMEC) in a weekly cycle, has been demonstrated to produce a more pronounced "disarticulation" effect that allows for a significant amount of maxillary protraction in a considerably reduced amount of time [14]. A well-designed randomized clinical trial demonstrated that PFM combined with the Alt-RAMEC protocol resulted in significant maxillary protraction (0.93 mm, 95% CI, − 1.65, − 0.20; $p = 0.013$) with minimal unwanted clockwise rotation of the mandible ($p < 0.05$) when compared with patients who underwent treatment with conventional PFM and RME [15]. A case-controlled clinical trial showed no statistically significant differences in the cephalometric variables among participants who had their facemask protraction commenced during an Alt-RAMEC phase when compared with those whose maxillary protraction started at the end of the Alt-RAMEC cycle [16].

The modern incorporation of skeletal anchorage into the discipline of orthodontics has led to its utilization in the orthopedic treatment of Class III malocclusions. The use of surgical plates has eliminated the need for the cumbersome part-time extra-oral headgear appliance, and the protraction is maintained full-time. A recent systematic review suggested that maxillary protraction anchored with a bone-anchorage device induces more maxillary advancement with minimal dental side effects when compared with tooth-anchored appliances [17]. Although efficient protraction of the maxilla has been confirmed following the use of surgical plates coupled with intermaxillary Class III elastics, their insertion is undertaken under general anesthesia, unlike temporary anchorage devices (TADs), which are usually placed under local anesthesia [18].

No previous study has investigated the effectiveness of the use of the Alt-RAMEC protocol in conjunction with TAD-supported Class III elastic wear for protraction of the maxilla. The aim of this study was to test the null hypothesis that this new treatment protocol will provide no statistically significant dento-skeletal and profile soft tissue changes.

Methods

Participants

The study was registered with the Australia New Zealand (ANZ) Clinical Trial Registry (ACTRN:12610000220066, Ethical approval Number: X10-010). All participants from the treatment waiting list of the Orthodontic Department at Sydney Dental Hospital were screened. Initially, 42 growing participants were identified with Class III malocclusions. Of these 42 selected participants, 14 (7 males and 7 females; 12.05 ± 1.09 years) met the inclusion criteria. As the study is a case series analytical study, no sample size calculation was undertaken. The inclusion criteria were:

- Participants at Cervical Vertebral Maturational (CVM) Stage 2 or 3 and
- Participants with clinically diagnosed retrognathic or hypoplastic maxilla, anterior crossbite, and dental Class III molars and canines.

Participants with previous orthodontic/orthopedic treatment or congenital abnormalities were excluded. All records (T1) were taken in the centric relation (CR) before commencing the intervention. A senior clinician (OD) re-examined the participants to confirm the inclusion criteria. Written informed consent was obtained from the parents or guardians.

Treatment protocol

Appliance setup phase

Each participant had four TADs inserted under local anesthesia (2% lignocaine with 1:80,000 adrenalin); two were para-medial palatal TADs and two were mandibular TADs that were inserted between the canine and the lateral incisor (Fig. 1a). Before placement of the TADs, the prospective implant site was swabbed with 0.12% chlorhexidine solution.

In the lower arch, self-drilling 1.6 × 6 mm Aarhus™ (MediconeG, American Orthodontics) TADs were placed at an approximately 30° apical angle. Insertion was complete when the head of the TAD was flush with the labial mucosa. The TADs chosen for the palatal placement

Fig. 1 a Implant placement sites and **b** appliances loaded with two elastics per side

were 2 × 9 mm Mondeal™ (GAC) TADs. The area of the palatal TAD placement was marked with a periodontal probe. Pilot 1.5-mm holes were then created using a surgical hand-piece (speed 800 rpm) under sodium chloride irrigation until engagement was achieved. The palatal TADs were then placed using a contra-angle handpiece (torque setting of 35 Ncm, speed 30 rpm). A minimum clearance of 5 mm between the two palatal TADs was chosen to enable the placement of the impression caps. Healing caps were then placed on the palatal TADs, and a 0.12% chlorhexidine mouth rinse was prescribed for daily use (Savacol, alcohol-free, Colgate).

One week later, molar bands were fitted around the lower first molars, and alginate impressions were then taken to construct a modified lingual arch (MLA). At the same visit, the palatal healing caps were removed and transfer impression copings were placed onto them for the subsequent transfer-coping polyvinylsiloxane (PVS) maxillary impressions. A medium-bodied PVS impression was injected around the transfer abutments, whereas the impression tray was filled with a heavy-bodied PVS. An impression of the maxillary arch was taken with the transfer abutments in place. After impression-taking, the laboratory mini-implant analogues were positioned on the impression transfer abutments. The three-dimensional relationships of the TADs in the oral cavity were thus duplicated on the plaster model.

Laboratory stage

A hybrid mini-implant-assisted rapid maxillary expander (Hybrid MARPE), using a Hyrax-screw that produces 0.25 mm per quarter turn, was then constructed. Ball clasps (Romanium, Dentaurum) were embedded at the region of the first premolars and first molars (Fig. 2a). The Hybrid MARME was cemented with a glass ionomer cement (GIC) on day 28 of the TAD insertion.

The MLA was constructed from 1 mm romanium wire (Dentaurum, Australia) and cemented with GIC on day 28 after the TAD insertion. The lingual cleats that extended from the MLA were bonded onto the lingual surfaces of the anterior teeth with a composite resin to hold the lower arch as one unit (Fig. 2b).

Fig. 2 a Hybrid MARPE and **b** MLA appliance design

Alt-RAMEC phase

The participant was instructed to expand the hybrid MARME by 1 mm/day for 7 days (2 turns in the morning and 2 turns in the evening). One week later, all participants presented for expansion assessment; if satisfactory, the participant was then instructed to constrict the maxilla by unwinding the hybrid MARME by 1 mm/day (2 turns in the morning and 2 turns in the evening) for 7 days. This cycle was repeated until week 9. After 9 weeks of alternating expansion and contraction, the mobility of the maxilla was subjectively and manually assessed. This was done by supporting the forehead and bridge of the participant's nose with one hand and holding the maxillary incisors with the other. The maxilla was then moved in an anterior and posterior direction to detect the mobility of the maxilla. When sufficient mobility "disarticulation" was achieved, the second phase (the protraction phase) of treatment commenced.

Maxillary protraction phase

A 0.019″ × 0.025″ stainless steel (SS) wire was bent to fit passively into the crossheads of the lower TADs on both sides and was secured with a flowable composite to the labial surface of the lower incisors. Two full-time heavy intra-oral elastics per side, producing a total of 400 g/side, were prescribed. The participant was instructed to change the elastics once a day. One of these elastics ran in the long-closing Class III configuration, from the posterior ball clasps on the hybrid MARPE to the "S" hook. The other one ran in the short-closing Class III configuration, from the anterior hook on the hybrid MARPE to the MLA (Fig. 1b). This configuration was adopted to prevent counterclockwise rotation of the maxilla.

The participants were then assessed at 2-week intervals until a + 2-mm overjet was achieved. Once the overjet was corrected, the appliances were removed, and post-treatment records were then taken (T2).

Cephalometric analysis

One investigator blindly traced all the cephalograms using the Dolphin software. In addition to measuring the overjet changes as a primary outcome, the secondary outcomes included skeletal, dental, and soft tissue cephalometric measurements, as well as some of the recently described stable basicranial linear horizontal measurements [19] (Fig. 3 and table 1). The intra-examiner reliability was assessed by repeating all the cephalometric measurements after 1 month.

Statistical analysis

The cephalometric data were analyzed statistically using the Statistical Package for Social Sciences (SPSS, ver. 17.0, SPSS Inc., Chicago, Illinois). The sample was normally distributed for most parameters, as determined using the Kolmogorov Smirnov test; hence, a paired-sample t test ($p < 0.05$) was used to compare each variable from T1 to T2. An error measurement (Dahlberg's formula) study was performed to evaluate the intra-examiner reliability.

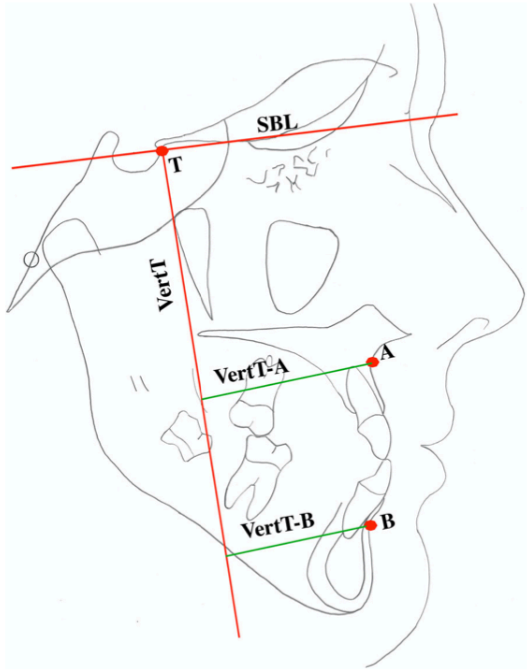

Fig. 3 Horizontal skeletal measurements. Point T: The most superior point of the anterior wall of the sella turcica at the junction with tuberculum sellae, Vert T: Line perpendicular to SBL and passing through point T, Vert T-A: Horizontal distance traced from the perpendicular line from Vert T to point A, and Vert-B: Horizontal distance traced from the perpendicular line from Vert T to point B

Results

One mandibular TAD was lost but was replaced during the Alt-RAMEC phase. Another participant fractured the buccal attachment on the MLA, but this was repaired during elastic loading. Regardless, the aims of the treatment intervention were achieved in all participants over a period of 8.5 weeks of protraction (range 8–9 weeks) (Fig. 4).

Method errors were not statistically significant ($p > 0.05$), for both linear and angular measurements, at 0.98 mm and 0.87°, respectively. The pre-expansion (T1) and post-protraction (T2) cephalometric measurements are summarized in Table 1.

At the skeletal level, both angular (Sella-Nasion to A (SNA) 1.87± 1.06 mm) and linear (Vert.T-A 3.34 ± 1.54 mm) measurements of the anteroposterior position of the maxilla showed a significant protraction ($p < 0.001$).

Table 1 Skeletal, dental, and soft tissue changes from T1 to T2

	T1	T2		T2-T1			
Variables	Mean	SD	Mean	SD	Mean	SD	*p* value
Anteroposterior changes							
SNA (°)	78.37	2.49	80.24	2.92	1.87	1.06	0.000
Vert. T-A (mm)	46.23	8.8	49.57	8.93	3.34	1.54	0.000
SNB (°)	82.11	3.19	80.09	3.53	− 2.02	0.85	0.000
Vert. T-B (mm)	39.57	14.69	36.14	12.95	− 3.43	4.47	0.013
ANB (°)	− 3.75	2.89	0.2	2.77	3.95	0.57	0.000
Wits appraisal (mm)	− 9.63	2.5	− 4.47	2.67	5.16	1.51	0.000
Vertical changes							
Mid-facial height (N-ANS) (mm)	52.27	2.99	54.95	2.35	2.68	1.53	0.447
Lower facial height (ANS-ME) (mm)	69.44	4.76	72.63	5.34	3.19	2.21	0.000
Upper facial height ratio (N-ANS/N-ME) (%)	44.3	1.88	43.13	1.91	− 1.17	1.21	0.003
Lower facial height ratio (N-ME/ANS-ME) (%)	55.67	1.99	56.87	1.91	1.2	1.24	0.003
Y-axis (°)	67.38	3.6	69.33	4.08	1.95	1.11	0.000
Dentoalveolar changes							
Upper incisors inclination (UI-SN)(°)	104.51	6.6	107.49	6.24	2.98	2.71	0.001
Lower incisors inclination (LI-MP)(°)	84.82	4.97	81.61	3.64	− 3.21	3.4	0.004
Inter-incisal angle (IIA) (°)	135.29	7.17	133.88	5.94	− 1.41	4.55	0.268
Overjet (OJ) (mm)	− 2.89	1.41	2.74	1.11	5.63	1.36	0.000
Overbite (OB) (mm)	1.57	1.92	0.36	1.46	− 1.21	1.89	0.033
Soft tissue profile changes							
Harmony (H) angle (n-me-ls)(°)	6.36	4.47	9.12	3.97	2.76	1.8	0.0001

Similarly, the mandible position was significantly improved (Vert.T-B − 3.43± 4.47 mm, $p < 0.05$; Sella-Nasion to B (SNB) − 2.02 ± 0.85, $p < 0.001$). A marked improvement was evident in the ANB angle (3.95° ± 0.57°, $p < 0.001$) and Wits measurement (5.16± 1.5 mm, $p < 0.001$). The significant increase in the Y-axis (1.95° ±1.22°, $p < 0.001$), coupled with a significant increase in the lower third (ANS-Me) of 3.19± 2.2 mm ($p < 0.001$), indicated a clockwise rotation of the mandible. However, no significant increase was noted in the middle facial height (N-ANS) (0.32± 1.53 mm, $p = 0.45$).

At the dental level, the upper incisors proclined significantly (UI-PP = 2.98° ± 2.71°, $p < 0.005$) coupled with a significant retroclination of the lower incisors (LI-MP = 3.2°± 3.4°, $p < 0.05$). The combined dental and skeletal changes led to a significant improvement in the overjet and overbite, at 5.62 ± 1.36 mm ($p < 0.001$) and − 1.21± 1.89 mm ($p < 0.05$), respectively.

Furthermore, cephalometric soft tissue profile analysis showed a significant increase in the H angle, at 2.76± 1.8 ($p < 0.001$).

Discussion

The recommended starting age for maxillary protraction therapy for a good orthopedic effect is the prepubertal stage [20–23]. Nevertheless, the participants in this study (aged 12.05 ± 1.09 years) responded positively, with a mean treatment time of approximately 8.5 weeks.

The Alt-RAMEC protocol was utilized to produce a more pronounced disarticulation of the maxilla than can be obtained using conventional maxillary expansion [14]. The mean maxillary protraction was significantly greater than the outcomes reported in the previous literature [21, 24, 25]. This could be attributed to a combination of the disarticulation effect of the Alt-RAMEC protocol and/ or the full-time utilization of the heavy Class III elastics which were partially tooth-bone-anchored. Similarly, the anteroposterior mandibular position was significantly improved secondary to the intervention, again probably due to the full-time utilization of the Class III elastics. The argument might be made that the changes in the SNB and therefore ANB were surpassed as a result of the elimination of mandibular functional displacement secondary to the intervention however the main aim of our class III correction was to improve the maxillary position nevertheless taking records at the RCP could induce another inherent pseudo-increase in the facial height.

A posterior rotation of the mandible and an increase in the anterior facial height are common treatment

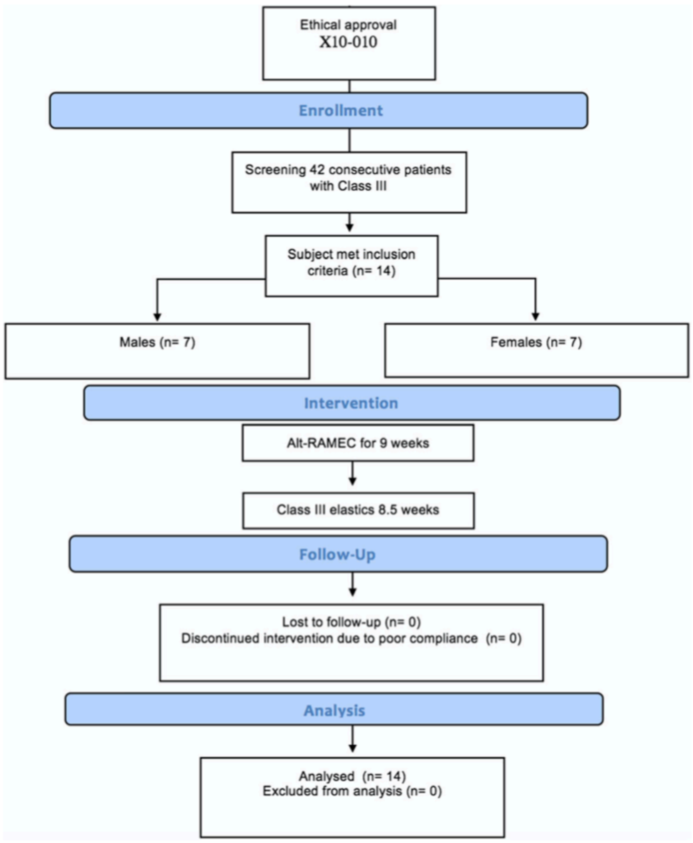

Fig. 4 Trial flow chart

biomechanical effects of the PFM treatment [21, 25–27]. Similar changes were observed in this study in the form of significant increases in the lower facial height and Y-axis.

The maxillary protraction protocol partially utilized the dentition for the transmission of the forces to the underlying skeletal structures, including the maxilla and the mandible. This led to the unwanted effects represented by proclination of the upper incisors and retroclination of the lower incisors, as reported in other studies [28, 29]. Therefore, correction of the malocclusion was due to the combination of skeletal and dentoalveolar effectst.

The skeletal and dentoalveolar changes observed in our study resulted in an overall normalization of the unesthetic facial concavity. This was seen as a significant reduction in the H angle of these participants. For a clinical demonstration, the treatment records are presented for one of the participants enrolled in this study (Fig. 5).

Limitations of the study and future research

An argument can be made that the wide standard deviation of SNA angles could increase the level of uncertainty. This might be attributed to individual variations in response to the treatment and/or errors in tracing.

One of the aims of using TADs in our treatment protocol was to reduce the unwanted dentoalveolar side effects; however, proclination of the upper incisors and retroclination of the lower incisors were unavoidable. This could be a result of the inherent flexibility of the vertical arms that connect the lower TADs to the mandibular incisors, as this may have allowed wire flexion under the effect of the heavy inter-maxillary elastics, thereby allowing for retroclination of the lower incisors. Similarly, the arms that connect the palatal TADs to the acrylic pads of the hybrid MARPE may have flexed under the protractive effect of the Class III elastics, allowing for proclination of the maxillary incisors.

One of the difficulties in using this treatment protocol is the delicateness of implant appliance placement, as the slightest error in appliance impression/construction makes it difficult to issue the expander with palatal TADs. An alternative would be to design a new hybrid MARPE system that would permit the cementation of

Fig. 5 Records for patient 5

the expander with hooks for class III elastic placement first, followed by insertion of the TADs. Another drawback of this novel treatment approach is participant compliance with performing the expansion and constriction of the maxilla and the daily interchange of the elastics. Future developments may involve an expander that expands and contracts itself, as per a particular protocol, plus the development of intra-oral nickel titanium springs to minimize the participant's compliance. Alternatively, magnets can be used to provide the protractive forces.

The authors acknowledge that the sample size of this study is too small to comment on the validity of the use of this novel approach in treating Class III malocclusion compared to other established methods. A future direction of the study would be to compare this treatment modality with other treatment approaches using a long-term randomized clinical trial.

Conclusions

Bone-anchored Class III protraction using MARPE and miniscrew supported lower lingual arch and Alt-RAMEC protocol, is an efficient first phase treatment for Class III malocclusions. Correction was achieved through a combination of skeletal, and dentoalveolar effects. However, a long-term randomized clinical trial with a larger sample size is recommended for verification.

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Authors' contributions
SA treated the patients. SA, OD, CG, and NT participated in the design and coordination of the study, carried out the sample collection, and made substantial contributions to analysis and interpretation of data. MA made substantial contributions to the interpretation of data and was involved in revising the study critically. AD conceived the study, participated in the design and coordination of the study, and made substantial contributions to analysis and interpretation of data. All authors drafted the manuscript and read and approved the final manuscript.

Ethics approval and consent to participate
The study was registered with the Australia New Zealand (ANZ) Clinical Trial Registry (ACTRN:12610000220066, Ethical approval Number: X10-010).

Consent for publication
Written informed consent was obtained from the patients for publication of this research and accompanying images.

Competing interests
The authors declare that they have no competing interests.

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RESEARCH

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Early Class III treatment with Hybrid-Hyrax – Facemask in comparison to Hybrid-Hyrax-Mentoplate – skeletal and dental outcomes

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Abstract

Background: Protraction of maxilla is usually the preferred and more commonly used treatment approach for skeletal Class III with a retrognathic maxilla. The aim of this study was the comparison of the skeletal and dental effects of two skeletally borne appliances for maxillary protraction: a) Hybrid-Hyrax in combination with facemask (FM), b) Hybrid-Hyrax in combination with Mentoplate (ME).

Methods: Thirty four Patients (17 facemask, 17 Mentoplate) were investigated by means of pre- and posttreatment cephalograms. The two groups matched with regard to treatment time, age gender and type of dentoskeletal deformity before treatment.

Results: Both groups showed a significant forward movement of A-point (FM GROUP: SNA + 2.23° ± 1.30°— *p* 0.000*; ME: 2.23° ± 1.43°— *p* 0.000*). B-Point showed a larger sagittal change in the FM Group (SNB 1.51° ± 1.1°— *p* 0.000*) compared to the ME group (SNB: – 0.30° ± 0.9°— *p* 0.070). The FM group showed a significant increase of the ML-NL + 1.86° ± 1.65° (*p* 0.000*) and NSL-ML + 1.17° ± 1.48 (*p* 0.006*). Upper Incisor inclination did not change significantly during treatment in both groups as well as the distance of the first upper Molar in relation to A-point.

Conclusion: Both treatments achieve comparable rates of maxillary protraction, without dentoalveolar side effects. Skeletal anchorage with symphysial plates in the mandible provides greater vertical control and might be the treatment of choice in high angle patients.

Keywords: Class III, Facemask, Mini-plates, Skeletal anchorage, Rapid maxillary expansion

Background

Morphological features of skeletal class III malocclusion may comprise mandibular prognathism, maxillary retrognathism or a combination of both. Cross-sectional studies revealed a prevalence of class III patients with a retrusive maxilla between 32 and 63%, depending on the investigated population, ethnicity, and sex [1–3]. In these patients, protraction of the deficient maxilla represents a causal treatment approach [3–11].

Sagittal orthopaedic forces to protract the maxillary complex were commonly applied to the upper dental arch [6, 12, 13]. This approach incurred well-known side effects such as proclination of the upper front teeth, bite opening, mesial movement of the lateral segments, and constriction of unerupted canines [14–18].

New skeletal anchorage concepts involving surgical mini-plates or mini-implants have been developed to address these problems [19–21]. Directing orthopaedic forces directly into the bony structures of the midface promised a significant reduction of dental side effects as well as an enhancement of skeletal response. To further increase orthopaedic treatment effects, some maxillary protraction protocols include rapid maxillary expansion (RME) in order to stimulate the midface sutures [12, 18, 22]. Interestingly, systematic reviews and meta-analyses representing a high level of evidence either advocate or dismiss the positive effect of RME [10, 23–25]. RME can be carried out purely bone-borne or with a combination of dental and skeletal anchorage using mini-implants in the anterior palate (Hybrid-Hyrax).

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Traditionally, maxillary protraction has been performed by extraoral traction using various types of facemasks [26, 27]. The associated skeletal treatment effects have been documented extensively in numerous clinical studies: advancement and anterior rotation of the maxilla, sagittal growth inhibition and posterior rotation of the mandible, and increase of the vertical dimension [28–30].

As an alternative, skeletal anchorage in the lower jaw eliminates the need for extraoral devices, which might have a positive effect on patient's acceptance and compliance. The Mentoplate, which was used for maxillary protraction in one study group, is inserted subapical to the lower incisors and can be inserted prior to canine eruption [31].

The aim of this retrospective study was to investigate the skeletal and dental effects of two skeletally borne appliances for maxillary protraction: (a) Hybrid-Hyrax in combination with facemask (FM) and (b) Hybrid-Hyrax in combination with Mentoplate (ME) (Fig. 1). The null hypothesis was that there is no difference regarding the skeletal and dental effects between the different treatment modalities.

Methods

Initially, a group of 50 consecutively treated patients was considered for this study.

Inclusion criteria were as follows:

- Moderate/severe class III: WITS ≤ – 2.0 mm
- Age ≥ 7 years to ≤ 12 years
- Treated according to a standardised protocol (see below)
- Lateral cephalograms before and after treatment
- Anterior crossbite or incisor edge-to-edge relationship, class III molar relationship

Exclusion criteria were as follows:

- Craniofacial anomalies
- Systemic diseases
- Forced or functional bite

Thirty-four patients (17 facemask, 17 Mentoplate) fulfilled the inclusion/exclusion criteria. The group compositions can be found in Tables 1 and 2.

Table 1 Group allocation

	Male	Female	Total
Facemask	8	9	17
Mentoplate	7	10	17
Total	15	19	34

Chi-square 0.500 n.s

Treatment protocol

A Hybrid-Hyrax device fitted on two paramedian mini-implants in the anterior palate (2 × 9 mm, Benefit, PSM, Tuttlingen, Germany) for RME was used in all patients. RME was performed activating the Hyrax screw by 90° turns four times a day, resulting in an expansion of 0.8 mm per day (Fig. 2).

The Mentoplate (PSM, Tuttlingen, Germany) was surgically inserted at the department for oral surgery under local anaesthesia 2 weeks prior to RME. Protraction was started simultaneously with RME in both groups.

The FM group was instructed to wear 400 g elastics on each side for 14–16 h per day [6, 11, 32]. The force vector of the elastics, between the FM and the Hybrid-Hyrax, was adjusted to have an inclination of 20–30° relative to the occlusal plane (Fig. 3). The ME group was instructed to wear 200 g elastics on each side, between the Hybrid-Hyrax and the Mentoplate, for 24 h per day. Cl. III elastics were worn with an inclination of 10–15° relative to the occlusal plane (Fig. 4).

Cephalometric analysis

Digital pre- (T0) and posttreatment cephalograms (T1) (Sirona Orthopos XG plus; Bensheim, Germany) were calibrated and analysed. Measurements and superimpositions according to stable cranial structures the anterior border of Sella and median border of the orbital roof were performed by the same operator using the Software ImageCollector. Blinding of the operator was only possible for the pre-treatment cephalograms, since the Mentoplate was still in place in all of the post-treatment radiographs.

Cephalometric landmarks and planes and their definitions are presented in Fig. 5 and Table 3. Fifteen

Fig. 1 Exemplary presentation of a patient wearing a facemask (left) and a Mentoplate (right)

Table 2 Age distribution

	Age
Facemask	8.74 ± 1.20
Mentoplate	9.43 ± 0.95
T test	0.072 n.s.

randomly selected cephalograms were retraced on two different occasions within a 2-week interval by one examiner. The intraclass correlation coefficient (ICC) ranged between 0.93 and 0.98.

Statistics

Statistical analysis was carried out using SPSS (IBM, Version 23). Measurements were tested for normal distribution using the Shapiro-Wilk test. Depending on these tests, statistical comparison of mean values was carried out using parametric or non-parametric tests, respectively. Intra-group differences were identified using Student's *t* test for dependent samples or Wilcoxon test. Differences between the groups were tested using *t* test for independent samples or Mann-Whitney *U* test. The confidence interval was set to 95%.

Results

Treatment time, age and gender distribution did not show significant differences between the groups. (Tables 1, 2 and 4). Initial cephalometric values revealed did not differ significantly at T0 (Table 3).

The skeletal effects for each group are shown in Tables 5 and 6. The differences between the groups are shown in Table 7.

Anterior and posterior crossbites were corrected in all individuals. Neither implant or plate failures nor breakages of the appliances occurred.

Discussion

The main goal of early class III treatment of patients with maxillary retrognathia is to achieve maxillary protraction and growth restriction of the mandible without undesirable side effects such as mesial migration of the upper dentition and vertical skeletal changes.

Various different strategies exist to achieve these objectives:

- The BAMP (Bone anchored Maxillary Protraction) protocol [19]
- The Miniscrew Implants/Facemask combination [33, 34]
- Two miniplates laterally to the aperture piriformis in conjunction with a facemask [35]
- The Hybrid-Hyrax Facemask/Mentoplate combination [31, 36]

which was examined in this retrospective study. The groups were comparable regarding their skeletal pattern, age, sex, and treatment time. The review of the confidence interval show, that a sufficient number of patients were evaluated. The significant differences are thereby supported by alpha and beta errors.

Maxillary protraction was carried out successfully in both groups, leading to a significant improvement of the maxillary position. In both groups, similar changes were induced regarding the SNA-Angle during a comparable treatment period (SNA + 2.23°), and a significant improvement of the WITS-appraisal (FM Group 4.81 mm, ME 4.14 mm) was found. These changes comply with the reported treatment effects on SNA with range of 1–3° achieved by maxillary protraction [8–10, 37]. The values we found are slightly higher than those of conventional RME and FM therapy. In a controlled clinical study, Westwood et al. found increases of 1.6° in SNA and 4.3 mm in the Wits appraisal [7]. A meta-analysis of conventional maxillary protraction reported a mean increase of SNA by 1.4° [24].

Many clinicians favour the use of RME to open the midface sutures to improve the skeletal effect. The RME/FM protocol demonstrates superior maxillary protraction when performed in the early mixed dentition

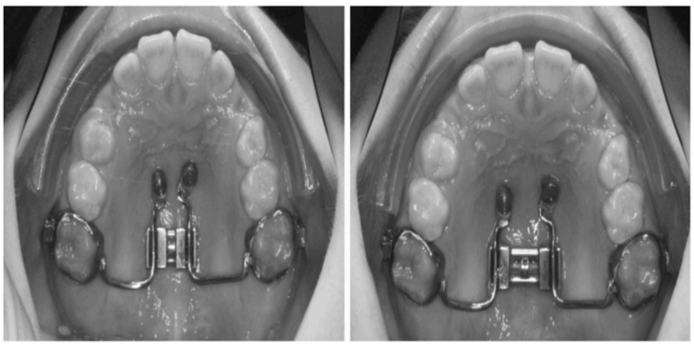

Fig. 2 Hybrid-Hyrax- before and after maxillary expansion

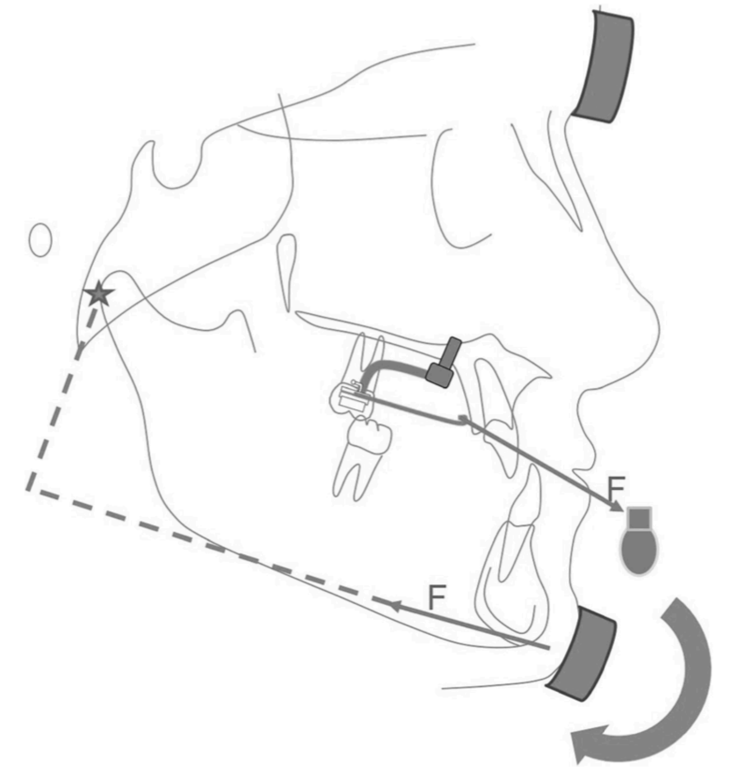

Fig. 3 Schematic diagram of the facemask

[6, 18]. Consequently, the timing of treatment seems to be of paramount importance. Current evidence seems to be slightly in favour to combine RME and maxillary protraction during early Class III treatment, which gave reason to perform RME in all patients included in this study [24].

Mini-plate anchored maxillary protraction as described by de Clerck showed good skeletal effects in the late mixed or early permanent dentition [38, 39]. Since the Mentoplate is inserted in the subapical region of the lower incisors, awaiting the eruption of the lower canines is not necessary, allowing for an earlier onset of treatment [31, 40]. Currently, it is not very clear whether early and late onset of treatment using purely bone-borne protraction devices is more effective.

The skeletal effect in the maxilla seems to be improved, if the orthopaedic forces are applied directly to the maxillary bone with the help of skeletal anchorage instead of using tooth-borne appliances [39, 41, 42]; also, a reduction of dental side effects can be observed. The usual side effects occurring during protraction with tooth-borne appliances such as proclination of the incisors, space loss for the canines and mesial migration of the molars could not be observed in both study groups. Therefore, the majority of the overjet correction (FM group 3.51 mm, ME group 3.06 mm) was due to favourable skeletal changes rather than dentoalveolar compensation.

For protraction of the maxilla, heavy forces of 400 up to 1500 g are recommended with FM therapy, to facilitate a sufficient orthopaedic effect [43]. For purely bone-anchored protraction protocols, lighter forces are recommended. De Clerck used an initial force of 100 g, which is gradually increased to 250 g, with a recommended full time wear of the Cl. III elastics. In this study, 200 g were used over the whole treatment time. Intraoral elastics can be worn full time without affecting the patient facial appearance, which might be a key to increase patient's compliance. Subjective wear time analysis revealed a FM wear time of 14 h per day [14, 18, 44, 45]. In a case study, an objective wear time measurement showed an average wear time of 9 h a day [46]. Apparently, the recommended heavy forces in conventional appliances stem from the limited wear times of these extraoral devices. In contrast, purely intraoral skeletally anchored devices can be worn over a longer period of time during a day, thus producing a comparable skeletal effect at lower force levels. As in all other studies, it

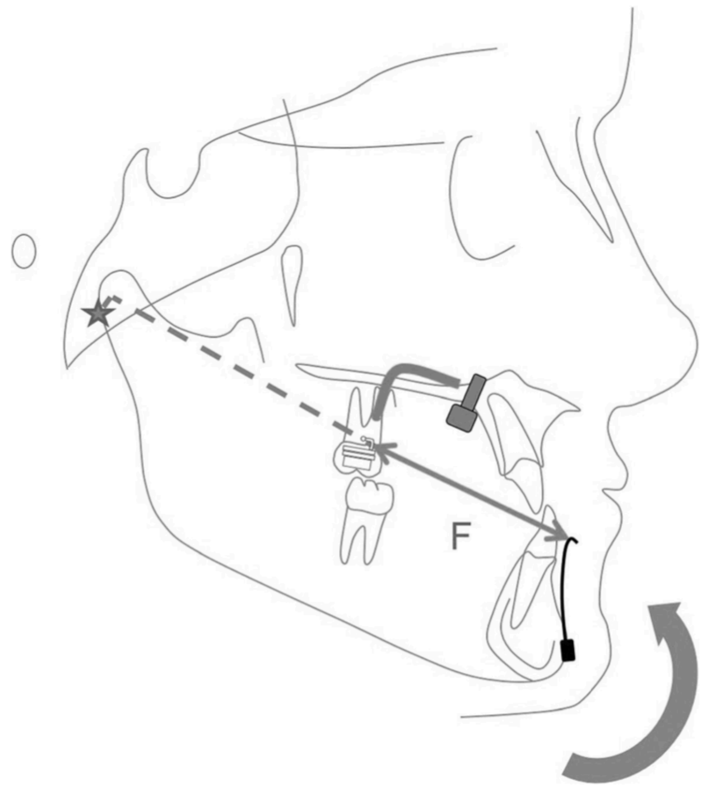

Fig. 4 Schematic diagram of the Mentoplate

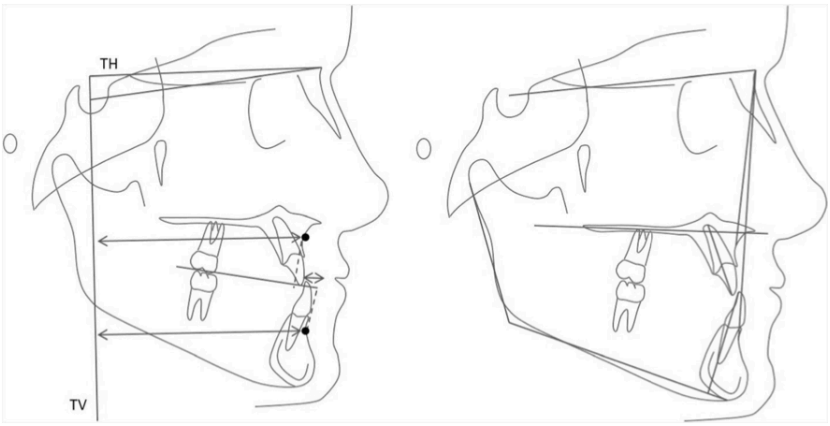

Fig. 5 Cephalometric analysis, left sagittal linear measurements (TH—true horizontal; TV—true vertical); right angular measurements

Table 3 Cephalometric values; comparison of initial values before treatment

Variables	Facemask T0	Mentoplate T0	p values	CI 95%	
SNA°	79.41 ± 2.86	79.23 ± 3.08	0.865	− 1.90	2.26
SNB°	80.51 ± 3.26	80.09 ± 3.05	0.703	− 1.79	2.63
ANB°	− 1.10 ± 1.98	− 0.86 ± 1.83	0.714	− 1.58	1.09
WITS mm	− 5.39 ± 1.47	− 5.83 ± 1.35	0.369	− 0.55	1.43
ATV mm	59.99 ± 2.99	59.42 ± 4.97	0.685	− 2.29	3.45
BTV mm	59.32 ± 4.78	58.24 ± 7.04	0.604	− 3.13	5.29
ABTV mm	0.67 ± 3.16	1.18 ± 2.88	0.629	− 2.62	1.61
ML-NL°	26.06 ± 5.44	27.87 ± 6.18	0.371	− 5.88	2.26
ML-NSL°	32.65 ± 6.27	34.95 ± 6.94	0.317	− 6.93	2.32
NSL-NL°	6.58 ± 2.93	7.08 ± 3.74	0.812(MWU)	− 2,85	1,85
AR-GO-ME°	126.92 ± 7.05	128.10 ± 4.99	0.643	− 6.23	3.95
MOK-A mm	26.37 ± 2.21	26.43 ± 1.93	0.929	− 1.51	1.39
U1-PP°	108.19 ± 7.85	110.36 ± 6.79	0.396	− 7.30	2.96
L1-ML°	86.87 ± 6.27	86.52 ± 6.93	0.892(MWU)	− 4,27	4,97

MWU Mann-Whitney *U* test

Table 5 Skeletal and dental treatment effects in the facemask group

Variables	Facemask T0	Facemask T1	p values	CI 95%	
SNA°	79.41 ± 2.86	81.66 ± 2.92	0.000*	1.60	2.90
SNB°	80.51 ± 3.26	79.02 ± 3.27	0.000*	− 2.06	− 0.91
ANB°	− 1.10 ± 1.98	2.65 ± 2.34	0.000*	3.00	4.49
WITS mm	− 5.39 ± 1.47	− 0.57 ± 1.51	0.000*	4.02	5.52
ATV mm	59.99 ± 2.99	62.42 ± 3.47	0.000*	1.71	3.13
BTV mm	59.32 ± 4.78	57.52 ± 5.05	0.002*	− 2.81	− 0.74
ABTV mm	0.67 ± 3.16	4.90 ± 3.60	0.000*	3.30	5.14
ML-NL°	26.06 ± 5.44	27.95 ± 6.12	0.000*	1.03	2.74
ML-NSL°	32.65 ± 6.27	33.79 ± 6.11	0.149	0.37	1.90
NSL-NL°	6.58 ± 2.93	5.84 ± 3.96	0.148 (W)	− 0.27	1.76
AR-GO-ME°	126.92 ± 7.05	127.33 ± 6.92	0.001*	0.19	0.61
MOK-A mm	26.37 ± 2.21	26.30 ± 2.19	0.246	− 0.05	0.19
U1-PP°	108.19 ± 7.85	107.04 ± 6.92	0.473	− 2.16	4.47
L1-ML°	86.87 ± 6.27	83.04 ± 4.26	0.028* (W)	− 6.99	− 0.67

W Wilcoxon
*significant at $p < 0.05$

would have been most desirable being able to objectively measure the exact wear times of the elastics for maxillary protraction.

As mentioned above, the skeletal effects found in the FM and ME groups on the maxilla where comparable. This was not true for the mandible where a significant decrease of the SNB angle was found. Analysis of the vertical cephalometric measurements revealed a significant opening of the interbase angle (ML-NL) in the FM group which was mainly caused by a posterior rotation of the mandible. In other words, B point effectively moved down and backwards in the FM-group, which might be due to the chincap effect of the facemask [4]. Consequently, the skeletal effect on the mandible in the FM-group is more of a vertical nature, described by a posterior rotation of the mandible (Fig. 3). In contrast, the B-point remains stable in the ME-group (Fig. 4). These findings were consistent with those of Cevidanes and other authors, who reported a greater vertical control and less opening rotation of the mandible when applying forces to symphyseal plates [38, 39, 47]. The gonial angle decreased significantly in the ME-group, which might be due to changes in the direction of condylar and ramus growth [48].

Table 4 Treatment time

	Treatment time in years
Facemask	0.79 ± 0.26
Mentoplate	0.87 ± 0.25
T test	0.362 n.s.

The results represent short-term observation within the limitations of a retrospective study. Further observation of these patients would be desirable to be able to draw long-term conclusions of these treatment modalities.

Conclusions

Both treatment options achieve comparable rates of maxillary protraction, without dentoalveolar side effects. The Mentoplate can be inserted before eruption of the mandibular canines allowing an early onset of

Table 6 Skeletal and dental treatment effects in the Mentoplate group

Variables	Mentoplate T0	Mentoplate T1	p values	CI 95%	
SNA°	79.23 ± 3.08	81.47 ± 3.15	0.000*	1.49	2.97
SNB°	80.09 ± 3.05	79.79 ± 3.20	0.070	− 0.42	0.97
ANB°	− 0.86 ± 1.83	1.68 ± 1.55	0.000*	2.20	3.20
WITS mm	− 5.83 ± 1.35	− 1.69 ± 1.32	0.000*	3.74	5.05
ATV mm	59.42 ± 4.97	62.09 ± 5.03	0.000*	1.90	3.44
BTV mm	58.24 ± 7.04	58.50 ± 7.24	0.973	− 0.91	0.88
ABTV mm	1.18 ± 2.88	3.59 ± 2.91	0.000*	2.16	3.17
ML-NL°	27.87 ± 6.18	27.97 ± 6.05	0.869	− 1.26	1.07
ML-NSL°	34.95 ± 6.94	34.40 ± 6.87	0.055	− 0.01	1.11
NSL-NL°	7.08 ± 3.74	6.44 ± 3.56	0.229	− 0.44	1.73
AR-GO-ME°	128.10 ± 4.99	125.14 ± 8.36	0.000*	− 3.96	− 1.94
MOK-A mm	26.43 ± 1.93	26.32 ± 1.86	0.054	0.00	0.22
U1-PP°	110.36 ± 6.79	110.78 ± 5.12	0.752	− 3.22	2.37
L1-ML°	86.52 ± 6.93	85.97 ± 6.22	0.556	− 1.41	2.52

*significant at $p < 0.05$

Table 7 Group differences between the facemask and Mentoplate group

Variables	Facemask (ΔT0 – T1)	Mentoplate (ΔT0 – T1)	*p* values	CI 95%	
SNA°	2.23 ± 1.30	2.23 ± 1.43	0.995	– 0.96	0.95
SNB°	– 1.51 ± 1,13	– 0.30 ± 0.98	0.002*	– 1.95	– 0.47
ANB°	3.75 ± 1.45	2.54 ± 0.99	0.008*	0.33	2.08
WITS mm	4.81 ± 1,38	4.14 ± 1.25	0.147	– 0.25	1.59
ATV mm	2.38 ± 1,42	2.67 ± 1.49	0.557	– 1.31	0.72
BTV mm	– 1.87 ± 2,08	0.26 ± 1.75	0.003*	– 3.47	– 0.78
ABTV mm	4.24 ± 1.78	2.41 ± 0.99	0.001*	0.82	2.84
ML-NL°	1.89 ± 1.65	0.12 ± 2.11	0.005*	0.61	3.27
ML-NSL°	1.17 ± 1.48	– 0.55 ± 1.09	0.001*	0.80	2.63
NSL-NL°	– 0.72 ± 1.99	– 0.49 ± 2.06	0.501 (MWU)	– 1.64	1.19
AR-GO-ME°	0.40 ± 0.41	– 2.96 ± 1.96	0.000*	2.36	4.35
MOK-A mm	– 0.07 ± 0.24	– 0.11 ± 0.22	0.624	– 0.12	0.20
U1-PP°	– 1.15 ± 6.45	0.57 ± 5.49	0.407	– 5.91	2.46
L1-ML°	– 3.84 ± 6.13	– 0.56 ± 3.83	0.081 (MWU)	– 6.85	0.29

MWU Mann-Whitney *U* test
*significant at $p < 0.05$

class III treatment. The need to wear a facemask is eliminated. Hence, it can be alternative if patients refuse to wear a facemask. Skeletal anchorage with symphyseal plates in the mandible provides greater vertical control and might be the treatment of choice in high angle patients.

Availability of data and materials
Please contact the author for data request.

Authors' contributions
JW took part in designing the study, wrote the main draft of the manuscript, and performed statistical analysis. MN took part in the study design and statistical analysis and critically revised the manuscript. NET critically revised the manuscript and aided in cephalometric data analysis. BW took part in designing the study and helped to draft the manuscript. DD participated in the design of the study, aided in the statistical analysis, and critically revised the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate
The study was approved by the local Ethical Committee.
Study ID: 6047R.
Registration-ID: 2017074350.

Consent for publication
Written informed consent was given for publication of the photos and individual person's data.

Competing interests
Benedict Wilmes is promoting and lecturing for PSM, the manufacturer of the Benefit system. The other authors declare that they have no competing interests.

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14.2.4. Title 4: Is there an ideal insertion angle and position for orthodontic mini-implants in the anterior palate? A CBCT study in humans[3]

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ORIGINAL ARTICLE

AJO-DO

Is there an ideal insertion angle and position for orthodontic mini-implants in the anterior palate? A CBCT study in humans

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Introduction: Orthodontic mini-implants are frequently used to provide additional anchorage for orthodontic appliances. The anterior palate is frequently used owing to sufficient bone quality and low risk of iatrogenic trauma to adjacent anatomical structures. Even though the success rates in this site are high, failure of an implant will result in anchorage loss. Therefore, implants should be placed in areas with sufficient bone quality. The aim of the present study was to identify an optimal insertion angle and position for orthodontic mini-implants in the anterior palate. **Methods:** Maxillary cone-beam computed tomographic (CBCT) scans from 30 patients (8 male, 22 female, age 18.6 ± 12.0 years) were analyzed. To assess the maximum possible length of an implant, a 25-reference-point grid was defined: 5 sagittal slices were extracted along the median plane and bilaterally at 3 mm and 6 mm distances, respectively. Within each slice, 5 dental reference points were projected to the palatal curvature at the contact point between the cuspid (C) and first bicuspid (PM1), midpoint of PM1, between PM1 and PM2, midpoint of PM2, and between PM2 and the first molar (M1). Measurements were conducted at −30°, −20°, −10°, 0°, 10°, 20°, and 30° to a vector placed perpendicular to the local palatal curvature. Statistical analysis was conducted with the use of R using a random-effects mixed linear model and a Tukey post hoc test with Holm correction. **Results:** High interindividual variability was detected. Maximum effective bone heights were detected within a T-shaped area at the midpoint of PM1 and contact point PM1-PM2 ($P < 0.01$). Within the anterior region a posterior tipping was advantageous, whereas in the posterior regions an anterior tipping was beneficial ($P < 0.01$). In the middle of the median plane, tipping did not reveal a significant influence. No gender- or age-related differences were observed. **Conclusions:** Within the limitations of this study, optimal insertion positions were found within a T-shaped area at the height of PM1-PM2 in the anterior palate. In general, a posterior tipping was beneficial at anterior positions, and an anterior tipping appeared beneficial at posterior positions. High interindividual variation was found and should be carefully considered by the clinician. (Am J Orthod Dentofacial Orthop 2019;156:345-54)

Orthodontic treatment with the use of fixed appliances requires sufficient anchorage. In the past decade, orthodontic mini-implants have become popular because they provide additional skeletal anchorage and increase the overall treatment spectrum.

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All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
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Several studies have demonstrated their efficacy for en masse retraction, Class III therapy, space closure, and many other applications[1-4] for both adults and children.[5] The anterior palate has become a favored insertion site owing to the ability to place implants with larger dimensions, thus offering greater stability.[6,7] Despite the advantages and frequent use, there are risks and complications associated with the insertion of mini-implants, such as trauma to dental roots, nerve involvement, perforation into the nasal or maxillary sinus, and anchorage loss.[8] The latter may occur when implants become loose owing to insufficient bone quality or inflammation.[9]

Because sufficient bone quality in the anterior palate is crucial to obtain appropriate implant stability, it has been evaluated in several studies.[9-24] Several reports suggest that bone quality is superior within a T-shaped zone encompassing the anterior palate and the median suture.[25-27]

At this stage there are contradictory reports on the suitability of the median suture posterior to the second rugae. Pronounced interindividual variances have been reported,[28] and one study with a very large sample size reported on bone height decreases posterior to the second rugae.[20] In addition, most studies evaluated bone height perpendicular to the occlusal plane, which is in contrast to the clinical recommendation to place the mini-implants perpendicular to the palatal curvature, making measurements perpendicular to the occlusal plane of limited relevance for the clinician. The ideal insertion angle at different positions in the palate may be more clinically relevant.

The aim of the present investigation was to measure bone thicknesses perpendicular to the palatal curvature with angles varying from −30° to +30° at different positions within CBCT images, and to classify potential locations based on their suitability for orthodontic mini-implants. As a second aim, sex- and age-related differences were evaluated.

MATERIAL AND METHODS

This cross-sectional study included a total of 30 patients (22 female subjects, mean age 20.1 ± 13.1 years; and 8 male subjects, mean age 13.5 ± 5.0 years). All patients had been treated at the Department for Orthodontics, Universitätsklinikum, Düsseldorf, Germany).

The inclusion criterion was that a cone-beam computed tomographic (CBCT) scan was obtained in the years 2010-2014 with the use of the Pax-Duo 3D (Orange Dental, Biberach, Germany) at 90 kV, 3.0-5.5 mA, 24 s exposure time, and 0.2 mm isotropic resolution.

The exclusion criteria were syndromes or craniofacial malformations, pathologic processes in the maxilla, missing teeth in the maxilla, and palatally displaced teeth.

The study protocol was approved by the local Ethical Committee (IRB number 5418). No informed consent was required, because all CBCT images had been obtained in the past, they were clinically justified, and the data were anonymized before the investigation.

Alignment of the CBCT scans according to the occlusal plane and the median-sagittal plane was performed with the use of Osirix for Mac OS (version 5.8.2, 32 bit; Pixmeo Bernex, Switzerland). Measurement positions were constructed by means of the following steps. (1) Extraction of sagittal slices along the midpalatal suture, 3 mm lateral and 6 mm lateral, were extracted. (2) Transversal reference lines were constructed perpendicular to the midpalatal suture. These reference lines were located in such a way that they passed through the contact points between the canines and the first premolars (C-PM1), between the first and the second premolars (PM1-PM2,) and between the second premolar and the first molar (PM2-M1). Thus, they enabled projection of the dental landmarks to the measurement grid. (3) Additional reference lines (dental projections) were constructed at the central aspect of the 2 bicuspids, ie, PM1 and PM2. These reference points were constructed by computing the midpoint of the vector from C-PM1 to PM1-PM2 and the midpoint of the vector from PM1-PM2 to PM2-M1. (4) A measuring grid consisting of 25 measuring points (intersections of sagittal and transverse reference lines) was generated (Fig 1). All measurements were performed within the 5 sagittal slices at the respective dental projections after export of the respective slices.

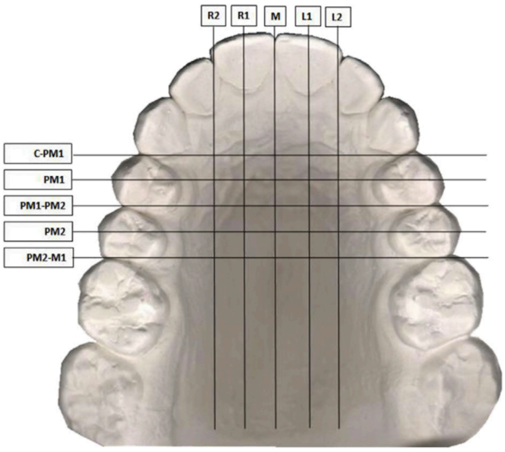

Fig 1. Visualization of the measuring grid (occlusal view): Effective bone height and BV/TV were measured at 25 measuring points at different angulations. For each sagittal view, the respective slices were extracted from the volumetric CBCT data sets, ie, R2/L2 (left and right 6 mm paramedian slices), R1/L1 (right and left 3 mm paramedian slices), and M (median slice). Measurements were performed at the interproximal contact of canine and first bicuspid (C-PM1), first bicuspid (PM1), interproximal contact of the 2 bicuspids (PM1-PM2), second bicuspid (PM2), and interproximal contact to the first molar (PM2-M1).

All morphometric measurements were performed with the use of the ImageJ software program (version 2.0.0-rc-39/1.50 b; National Institutes of Health, US)

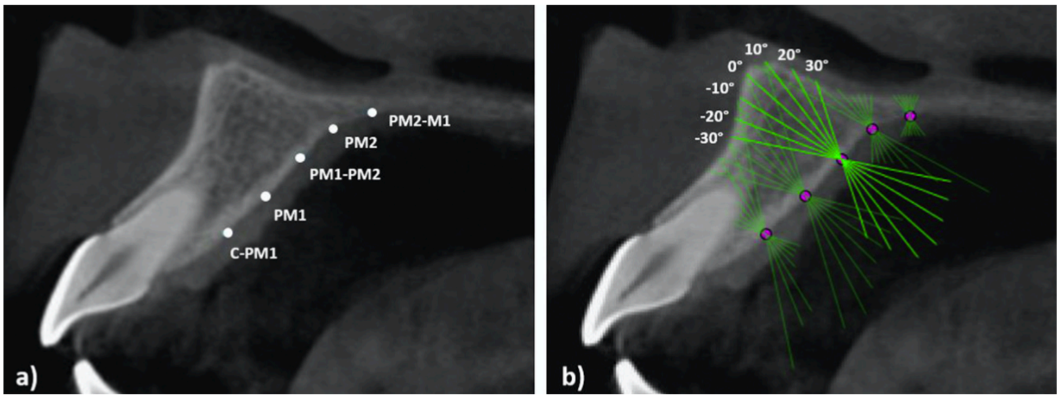

Fig 2. Examples for sagittal slices extracted from CBCT to perform effective bone height and bone fraction (BV/TV) measurements at different angulations: **a,** Projections of the measurement points (C-PM1, PM1, PM1-PM2, PM2, and PM2-M1) to the palatal bone plate at a paramedian slice. **b,** Measurement of effective bone height (and BV/TV) was performed at 7 different angulations (−30° to 30°). 0° is equivalent to a perpendicular insertion.

for Mac OS. All reference points were identified at each slice (Fig 2, *a*) and a tangent was matched to the bony margin of each reference point. All measurements (see below) were performed perpendicular (0°) to the tangent and subsequently with an angulation of −30°, −20°, −10°, 10°, 20° and 30° (Fig 2, *b*).

Effective bone heights were measured between the cortical margins from the palate and the nasal or maxillary sinus with the use of the measurement line tool in ImageJ. If the measurement line intersected with tooth roots or the incisive canal, the measurement was stopped at the respective anatomic positions.

Bone fraction (BV/TV), defined as the relative amount of calcified bone (%) within a region of interest (ROI; 5 mm thickness), was obtained with the use of the volume fraction tool in the ImageJ plugin BoneJ. A subset of 22 CBCTs were found eligible for this analyses, whereas the remaining scans had to be excluded because of artefacts from mini-implants located in the anterior palate.

Because CBCT is usually not calibrated, ie, gray values do not exactly correspond with the respective Hounsfield units, a histogram normalization was required. To achieve normalization, the respective minimum (air) and maximum (enamel) gray values were measured in each sagittal slice (Fig 3, *a*) and set as minimum and maximum gray values.

To segment bone tissue, the lower threshold level was set to 33% (Fig 3, *b*), because this value provided the most consistent segmentation. BV/TV was measured at each reference point along the respective measurement line and the above-mentioned angulations with the use of a thickness of 5 mm (Fig 3, *c*). If the ROI was not entirely surrounded by bone, eg, because of intersection with the nasal cavity, it was cranially shortened until it contained bone tissue only.

After assessment of effective bone height at different insertion angles and the respective BV/TV values, the data were pooled by insertion position and classified as follows: green (high suitability): effective bone height >6.5 mm, BV/TV > 0.4 mm, no intersection of the measurement line with tooth roots or incisal canal; yellow (moderate suitability): effective bone height 5.0-6.5 mm, no intersection of the measurement line with tooth roots or incisal canal; or red (low suitability): effective bone height <5.0 mm or intersection with tooth root or incisive canal.

In all locations classified as "green" or "yellow," best insertion angles were identified by comparison of locally available effective bone heights.

Statistical analysis

The statistical analysis was performed with the use of R.[29] For descriptive purposes, data were summarized with the use of boxplots. Because data were partially dependent (multiple measurements per patient), a linear mixed effects (LMER) model was used for statistical comparison (random effect: patient; fixed effects: age and sex, or angle, sagittal position, and transversal position). To assess if qualitative differences existed between the mixed model against a model without the factors in

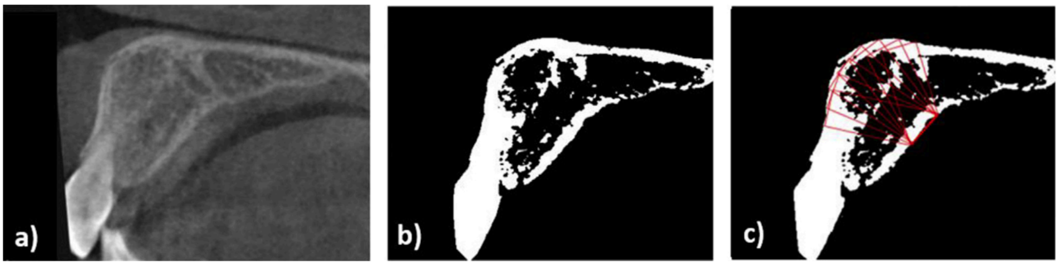

Fig 3. Measurement of bone fraction (BV/TV), **a,** Sagittal slices were used to evaluate BV/TV values. **b,** Bone segmentation was performed after calibration according to the individual minimum (air) and maximum (enamel) gray values of the respective slice and a threshold level of 84 in the 8 bit image. **c,** Example for BV/TV evaluation at PM1-PM2 for each angulations (−30° to 30°) within a region of interest of 5 mm thickness around the measurement line (not shown). The values were exported as percentages.

question, analysis of variance (ANOVA) was conducted. Post hoc comparisons were performed with the use of Tukey multiple comparison test and the Holm P value correction method.

The suitabilities of different measurement positions were classified based on the findings from the mixed model and the proximity to tooth roots and the incisal canal. Finally, the local impact of the insertion angle at each reference point was assessed by computing the linear mixed effects model for 1 random effect (insertion angle) and 1 fixed effect (patient). This model was compared against a model without this factor by means of ANOVA. The results were assumed to be significant at $P < 0.05$.

RESULTS

The association between effective bone height and patient age and sex was tested by means of ANOVA comparing an LMER with the effects of interest (fixed effects: age and sex; random effect: patient) against a model without these effects (random effect: patient only). This analysis revealed no significance ($P = 0.81$), meaning that age and sex could not explain the differences of bone thicknesses.

Descriptive analyses showed distinct variability of available effective bone height at different insertion points and angles. Paramedian effective bone heights were generally higher than median positions, increasing from C-PM1 to PM1. They remained higher for posterior insertion angles at PM1-PM2 and decreased toward PM2 and PM2-M1. PM1 revealed the greatest effective bone height at paramedian positions of 8.38 ± 3.75 mm (3 mm paramedian) and 8.42 ± 3.70 mm (6 mm paramedian), whereas the greatest effective bone height at median positions was found at PM1-PM2 (6.35 ± 3.09 mm; Fig 4).

BV/TV decreased from anterior to posterior positions and had similar values in median and paramedian positions. Adjacent to the incisal canal, BV/TV was negligible (Fig 5).

The ANOVA revealed significance for the LMER with the factors sagittal position, transversal position, and insertion angle ($P < 0.001$). These factors remained significant when the model was reduced to single factors only ($P < 0.01$). This means that both the insertion positions and respective angles could explain the differences of the effective bone heights. The post hoc multiple comparison test yielded significant differences between all sagittal insertion points ($P < 0.01$), and between median and lateral points at 3 mm, as well as between median and lateral points at 6 mm ($P < 0.001$). However, no significant differences were identified between lateral points at 3 and 6 mm ($P = 0.25$ to $P = 1.0$).

For each location in the measurement grid, the optimal local insertion angles (when available) were computed by means of ANOVA and Tukey post hoc multiple comparison test (Supplementary Table, available at www.ajodo.org). Significant differences in effective bone height for different angulations were detected for all paramedian and median C-PM1 positions. In these positions, a posterior inclination was most beneficial. A posterior angulation was also most beneficial at the median and paramedian PM1 (6 mm lateral, right site only).

The greatest effective bone height was found for an anterior angulation at the paramedian PM1-PM2 and PM2-M1 points and at all PM2 points.

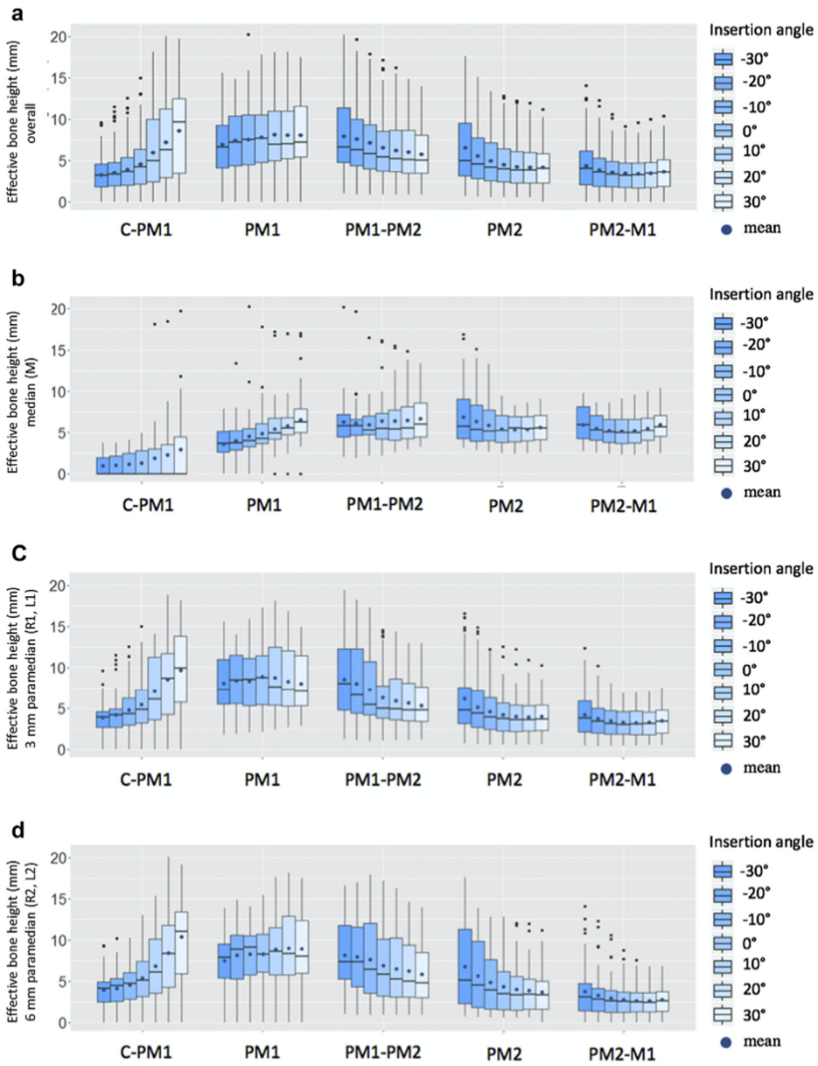

Fig 4. Boxplots showing the medians and interquartile ranges for effective bone height measurements **(a)** overall (pooled values) and at **(b)** median (M), **(c)** 3 mm paramedian (pooled R1 and L1 values), and **(d)** 6 mm paramedian (pooled R2 and L2 values).

The ANOVA revealed significance for the LMER with the factors sagittal position, transversal position, and insertion angle ($P < 0.001$) and remained significant when reducing the model to 1 factor only ($P < 0.001$). The post hoc multiple comparison test yielded significant differences between the median plane (M) against all of the paramedian planes (R2, R1, L1, L2; $P < 0.001$) as well as between L2 toward L1 and between L2 toward R1 ($P < 0.01$). Furthermore, there was a significant difference in bone fraction at the insertion points PM2 and PM2-M1 against every other sagittal insertion points ($P < 0.001$). At these points, BV/TV was lower compared with the remaining positions.

The insertion points and their classification are shown in Figure 6. All PM1-PM2 insertion points and

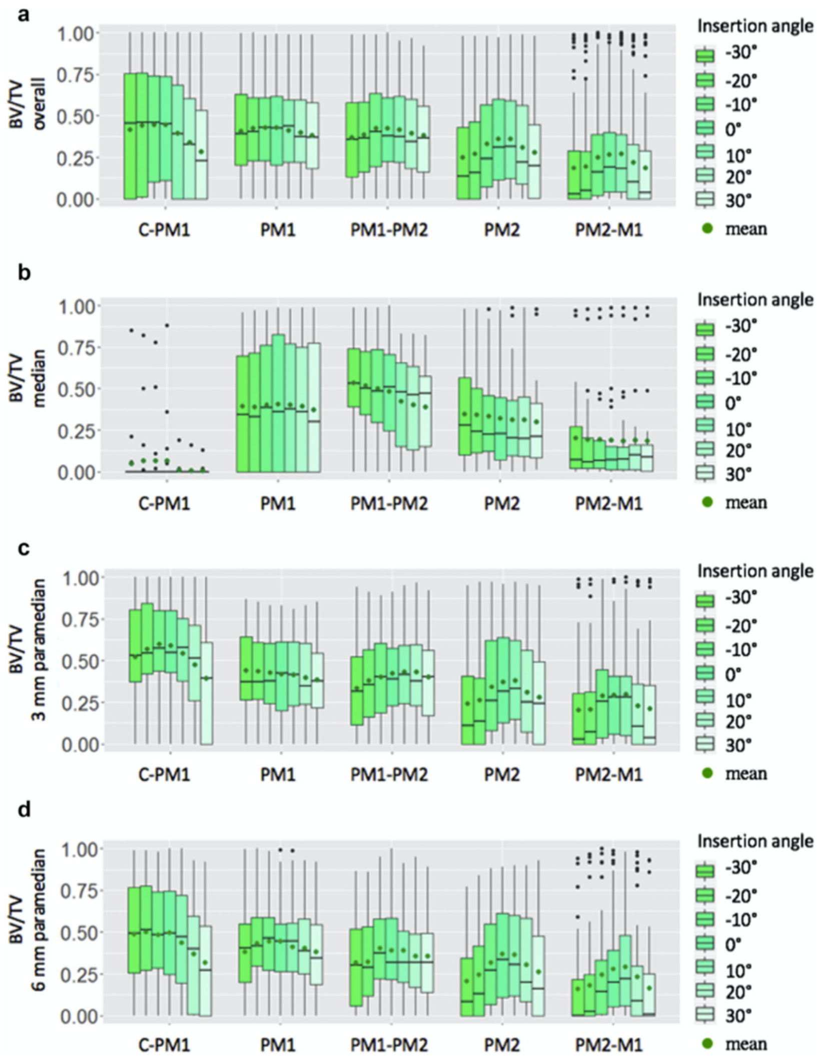

Fig 5. Boxplots showing the bone fraction values (BV/TV) **(a)** overall (pooled values) and at **(b)** median, **(c)** 3 mm paramedian, and **(d)** 6 mm paramedian.

all paramedian PM1 insertion points were classified as "green." The median insertion points PM1, PM2, and PM2-M1 were classified as "yellow." The L1/L2 and R1/R2 paramedian insertion points PM2 and PM2-M1 were classified as "red" owing to a low mean effective bone height. The anterior C-PM1 insertion points were classified as not suitable due to risk of damage of the anterior tooth roots and incisal canal. The optimal insertion angle (maximum effective bone height) is included in Figure 6 for all points classified as "green" or "yellow."

DISCUSSION

This study aimed to assess if specific insertion angles are beneficial for orthodontic mini-implants in the anterior palate. The overall potential benefit of a specific

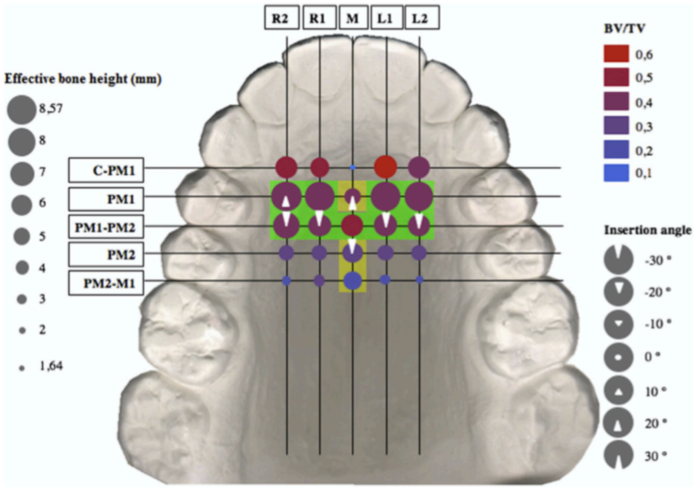

Fig 6. Orientation map of the anterior palate summarizing the effective bone height and bone fraction measurements from all patients at the respective positions. For each point, effective bone height and bone fraction values obtained at different angles were pooled and encoded by the point diameter or color, respectively. The insertion angle offering the greatest effective bone height at each point is indicated by white triangles. The eligibility of potential mini-implant insertion areas was classified as follows: *green* = ideal (effective bone height >6.5 mm and BV/TV > 0.4); and *yellow* = limited (effective bone height 5.0-6.5 mm). The paramedian C-PM1 values were not classified as ideal or limited owing to high variability among patients and thus high risk of root damage.

angle was tested as well as for specific common paramedian and median locations. Potential locations and angles were then classified based on the quantity of bone support for orthodontic mini-implants. As a secondary outcome, sex- and age-related differences were evaluated.

To evaluate which insertion angle would be most beneficial, differences in effective bone height and densities at different sagittal and transversal locations were evaluated. Our analysis confirmed previous findings of greatest bone thicknesses and bone fraction values between the first and second premolars at the palatal suture and a decrease of effective bone height in a posterior direction.[20,21] Effective bone heights reached maximum values slightly anterior and lateral to the first premolars at both the 3 mm and the 6 mm paramedian positions, whereas height and bone fraction values decreased at both paramedian positions more posteriorly. This is similar to previous findings.[17,30]

At positions anterior to the first premolar, the risk of touching to nasopalatine nerve was highest, which is in agreement with another recent investigation.[31]

A significant impact of the insertion angle on primary stability of mini-implants has been reported previously.[32] In addition, this investigation shows that the insertion angle also affects the available effective bone height for implant insertion. However, our analyses revealed that the insertion angle is relevant only at specific positions, namely, at the most posterior and anterior median positions but not at the region of highest median bone availability.

For paramedian insertion lateral to the second premolar and contact point PM1-PM2, the insertion angle also proved to be significant, whereas bone thickness was in general too low for placements more posteriorly. For median and paramedian placement, 30° to 20° tipping of the implant to the posterior proved to be most effective at the anterior positions. In contrast, anterior tipping of −30° yielded the best bone support at the posterior median and paramedian positions (Fig 6).

As a secondary outcome, age- and sex-related differences in effective bone height and bone fraction were evaluated. Conflicting findings have been reported in the literature regarding differences in bone quality or height with respect to age,[10,11,15,21,33-35] in agreement with our present study. This finding could be explained by the fact that subjects included in the previous studies were rather young (18.6 ± 12 years on average in our study). From an osteologic

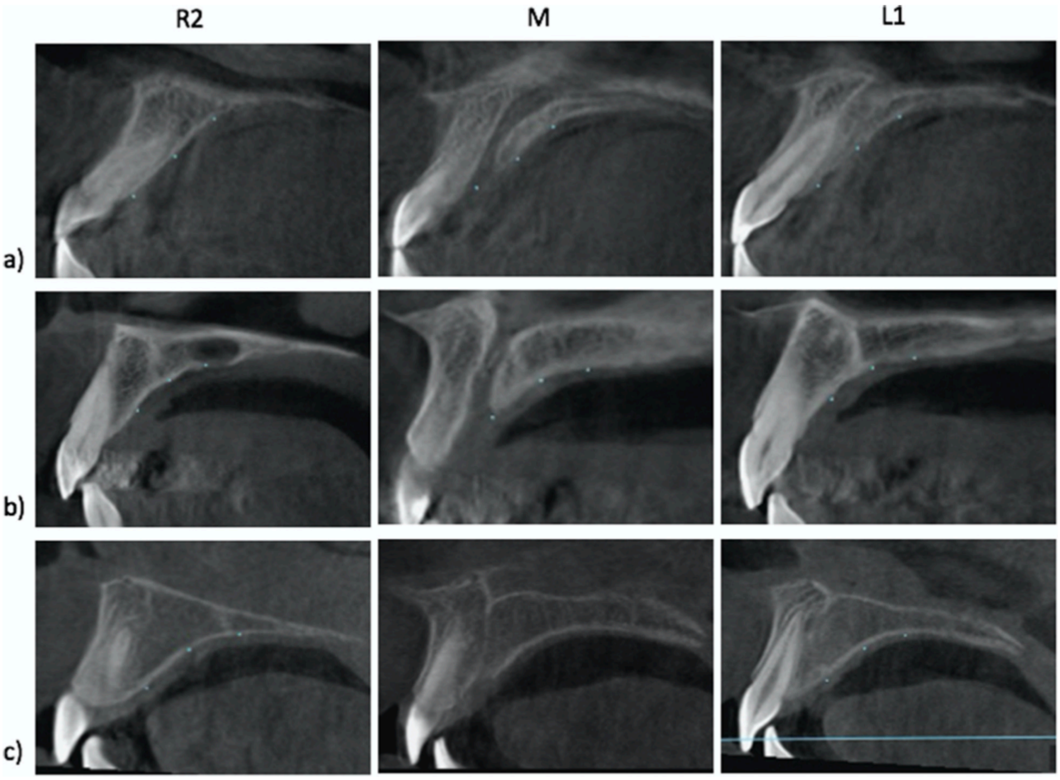

Fig 7. CBCT slices of patients showing examples for minimal, median, and maximum effective bone height values in the right 6 mm paramedian (R2), median (M), and left 3 mm paramedian (L1) slices. **a,** Patient with least effective bone height values (female, 15 y): effective bone height of 0 mm at C-PM1 (R2), PM1 (R2), and at C-PM1 (M). **b,** Patient with median effective bone height values (female, 39 y): effective bone height of 13 mm at PM1-PM2 (R2), 7 mm at PM1, PM1-PM2, PM2, and PM2-M1 (M), and 13 mm at PM1-PM2 (L1). However, effective bone height decreased to 0 mm at R2 at PM2-M1 and at C-PM1 (M). Effective bone height still amounted to 7 mm for anterior angulations at PM1-PM2 (L1). **c,** Patient with greatest effective bone height values (male, 13 y): effective bone height of 20 mm at PM1 (M) and 18 mm at C-PM1 (R2) and PM1 (L1).

perspective, peak bone mass occurs in the late twenties or early thirties,[36] so age-dependent changes may only be observed if a greater age range is examined.

Controversial findings have also been reported on association between sex and effective bone height. Whereas significant associations were found in a few studies,[15,17,33] no significant differences were identified in studies by Gracco et al,[21] Ryu et al,[10] Stockmann et al,[37] and Sumer et al,[34] also in agreement with the present investigation. However, the conflicting findings may be explained by subject age, because studies comparing bone samples from patients of different ages reported significant sex-dependent differences for postmenopausal women compared with older men.[38,39]

Different methods to assess palatal effective bone height have been reported in the literature. Two-dimensional measurements with the use of lateral cephalograms are of limited relevance owing to superimposition of anatomic structures. Bone height morphometry results can vary significantly between values obtained from lateral cephalograms and volumetric images.[40] Therefore, analysis of CBCT images is a common practice to evaluate bone availability in the anterior palate.[31,33,34] Insertion angles and effective bone height have been evaluated with respect to different reference planes, of which the sagittal and coronal planes from CBCT have been used in most cases.[31,40] In contrast, we aligned all of the data sets to the occlusal plane before analysis to allow consistent alignment of the CBCT images for comparison. The slices were extracted either at the median or the paramedian plane. Because implant placement is recommended to be performed perpendicular to the palatal surface, we considered effective bone height in this direction to be most relevant for the clinician. Therefore, implant placement perpendicular to the palatal surface was defined as the default 0° position, and bone support after tipping the implant from −30° to the anterior to +30° to the posterior was also evaluated.

Bone fraction measurements on CBCT images have been described as problematic due to the huge variance of gray values and missing or inaccurate Hounsfield units in CBCT.[41,42] In the present investigation, before the determination of the bone fraction, each sagittal slice was normalized by setting air to 0 and the enamel to 255. By this approach, the bony structures could be accurately identified independently from their actual gray value in the respective slice. To provide consistent calibration and comparability, all images were obtained with the use of the same CBCT machine.

Variability of effective bone height between individuals was very high (Fig 7), in agreement with previous studies.[9,13,17,23] Given the high variability of the amount of bone in the investigated regions, the question arises whether results are reliable enough to justify general recommendations for palatal implant insertion sites and angles. Some authors support this notion,[14,21,37] whereas a systematic review of literature concluded that bone availability may be too low in some cases to achieve sufficient implant stability for maximum anchorage and that individual assessment is required.[43] Varying bone qualities were also observed in autopsy material from 22 subjects, but the majority of samples provided sufficient bone for temporary skeletal anchorage.[35,44] However, the present study confirmed that individuals with a very low effective bone height of <2 mm do exist, and it is likely that these individuals would be prone to implant failure. Whether identification of these subjects is possible from lateral cephalograms or the type of clinically visible palatal curvature needs to be evaluated in future studies.

Limitations of this study were that only sagittal tipping of the implant was investigated whereas lateral tipping may also be relevant in median as well as paramedian positions. Figure 6 illustrates the investigated insertion positions and angles as a map. However, only the insertion angle providing maximum bone support was selected instead of all angles that revealed significance. The impact of tipping of the implant was tested for maximum bone support only, even though bone fraction also affects implant stability. Bone fraction was tested only at the specific locations, because we considered that the clinician will first look for maximum bone and then check the bone fraction at the specific locations.

CONCLUSIONS

This investigation supports the assumption of a T-shaped area located in the anterior palate providing superior bony support for orthodontic mini-implants.[26,27] However, this region may be slightly narrower and smaller than previously suggested. Optimal bone support existed only lateral to the first premolar for paramedian and extended to the second premolar for median placements. For paramedian and median placements at posterior locations, anterior tipping of the implant was found to be beneficial. For an anterior median placement, posterior tipping appeared advantageous. Age- or sex-related differences could not be observed, but variance among the subjects was generally high. Future studies are needed to identify patients at high risk of insufficient palatal bone support that may require CBCT before implant placement.

SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajodo.2018.09.019.

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14.2.5. Title 5: Miniscrews vs Miniplates[4]

The textbook chapter titled "Miniscrew vs Miniplates" reviews the various applications of skeletal anchorage in orthodontics and dentofacial orthopaedics and discussed the areas where it is advantageous to use miniscrews and areas where it is advantageous to use miniplates. It discussed the merits and demerits sighting the relevant literature and illustrating using clinical cases and diagrams. The candidate co-authored the chapter through literature review, writing of the chapter, design of the majority of the figures and table, referencing, clinical cases and writeup.

Book title: Temporary Anchorage Devices in Clinical Orthodontics

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Miniscrews vs. Miniplates

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46.1 Introduction

Although early reports on orthodontic use of miniplates and miniscrews were published in the 1980s [1, 2], it was not until the late 1990s that they started to make their way into the orthodontic mainstream. While early reports on the use of miniplates focused on movement of the entire dental arch to correct skeletal malocclusions such as anterior open bites with molar intrusion [3–5], the early applications of miniscrews revolved more around intra-arch mechanics for maximum anchorage [6, 7].

Both methods are now widely used and some controversy exists regarding which one is superior for skeletal anchorage. As with most treatment modalities, techniques, and materials, there might be advantages and disadvantages for each method, so this chapter aims to explore the merits and indications which may favour one technique over the other from ease of use, patient comfort, success rate, and practicality for different applications.

46.2 Insertion and Patient Comfort

Compared to miniscrews, the placement of miniplates is a more invasive procedure, requiring flap surgery and sutures [8]. In addition, a second surgery is required for their removal. In most cases, the procedure is referred to surgeons, with very few orthodontists in a position to place them. This makes the procedure not only more invasive, but also likely to be more expensive and inconvenient for the patient who has to visit different specialists. In contrast, the placement of miniscrews is usually flapless and minimally invasive. The instrument setup is fairly simple and the placement is technically less demanding compared to that required for miniplates. Furthermore, most orthodontists can place miniscrews in their office, making it a more convenient and less expensive approach.

Post-operative discomfort and pain are also less with miniscrews [9]. In fact, only 50% of miniscrew patients reported pain one hour post operatively in contrast to 100% of miniplate patients. In addition, the intensity of the pain as reported on a visual analog scale (VAS) was more severe at 66.4 with miniplates compared to 19.5 with miniscrews. For comparison, a day of orthodontic treatment is rated at 40–50. The discomfort also lasts for up to a week longer with miniplates.

Although comfort and simplicity are important, it is also important to consider the mechanical aspects of orthodontic treatment and the efficacy of delivering the desired outcomes. Practical considerations are important when deciding between the two anchorage options, and the additional discomfort, cost, and inconvenience may still be justified in cases where miniplates offer superior clinical outcomes. Proponents of miniplates say they are more reliable and offer higher success rates than interradicular miniscrews.

46.3 Advantages of Miniplates

Miniplates have the advantage of being away from the dental arch, thus avoiding root interference. This makes them a very good choice in cases where larger movements are required, especially if they will include the entire dental arch. The screws should be placed in a part of the maxilla and/or mandible with good bone quality, allowing for movement of the entire arch but avoiding root interference.

Temporary Anchorage Devices in Clinical Orthodontics, First Edition. Edited by Jae Hyun Park.

Additionally, the forces, when needed, can be directly applied to the skeletal structures for growth modification treatment as has been demonstrated in skeletal Class III treatment [10]. By using two or more screws to fix the miniplates, the screws act in tandem, distributing the load on more than one screw and thus potentially increasing the stability and success of the miniplates. Overall, the reported success rates for miniplates are higher than those of interradicular miniscrews in the literature.

The main disadvantage of miniscrews is the fact that placement is usually interradicular, which can increase the risk of root injury and, more importantly, can make the movement of an entire arch difficult because eventually there will be root interference and subsequent failure [11].

In addition, a single miniscrew is more susceptible to failure when used with intermittent inter-arch elastic traction. However, when two or more miniscrews are consolidated with stainless steel wires or plates, the stress distribution on each individual screw is much less, thus increasing their success rate (Figure 46.1). However, it is rare to see screws used in tandem in the alveolus because it can be difficult to find sufficient interradicular space in two adjacent interdental sites.

On the other hand, with the more recent introduction of palatal miniscrews that allow a suprastructure to be placed such as the Benefit system [12, 13], miniscrews in the palate gain some of the stability advantages of miniplates. In fact, by using two or more screws in tandem with a supragingival plate (Beneplate), midpalatal miniscrews gain stability similar to a miniplate without the need for flap surgery. The use of the anterior palate allows miniscrews to be placed in an area with excellent cortical bone, and the modular system then allows the two screws to be used in tandem for various applications.

46.4 Which are Better – Miniscrews or Miniplates?

A comparison between miniplates and miniscrews is only of value clinically if the two systems are to be used to treat a similar malocclusion and the reasons for using them are the same. In the following paragraphs, the main applications of skeletal anchorage will be explored and the merits and demerits of miniscrews vs. miniplates will be discussed based on the clinical application.

46.4.1 Open Bite Treatment

The treatment of skeletal anterior open bite with molar intrusion and counterclockwise mandibular rotation is perhaps one of the earliest reported applications of skeletal anchorage in orthodontics (Figure 46.2). By intruding either the maxillary molars, mandibular molars or both, the open bite closes through mandibular autorotation. Umemori et al. [3] reported on two cases of severe skeletal anterior open bite treated with mandibular molar intrusion using miniplates in the posterior mandible. They also showed nine

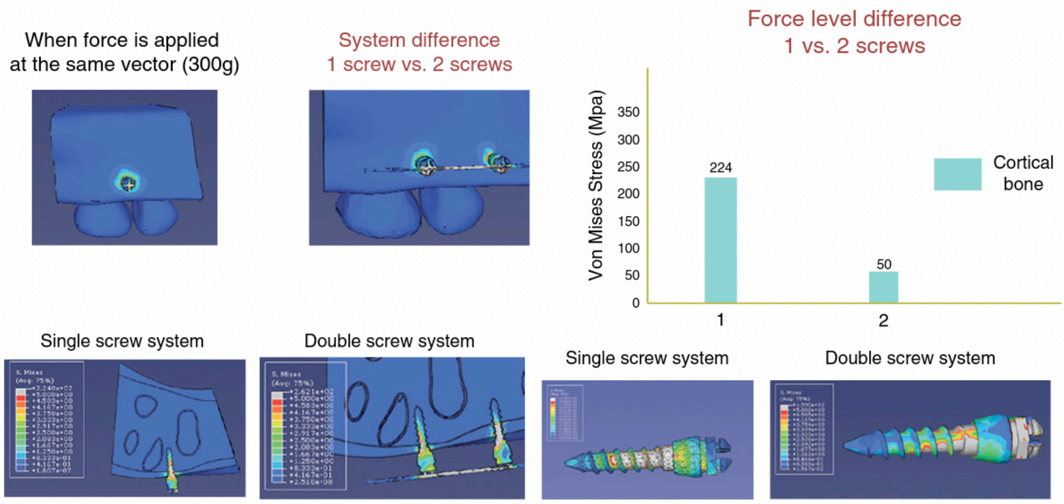

Figure 46.1 Finite element modelling (FEM) showing the difference in stress concentration when a single miniscrew is used, vs. when two miniscrews are connected with a stainless steel wire. Stresses on the cortical bone are significantly reduced when two screws are loaded in tandem.

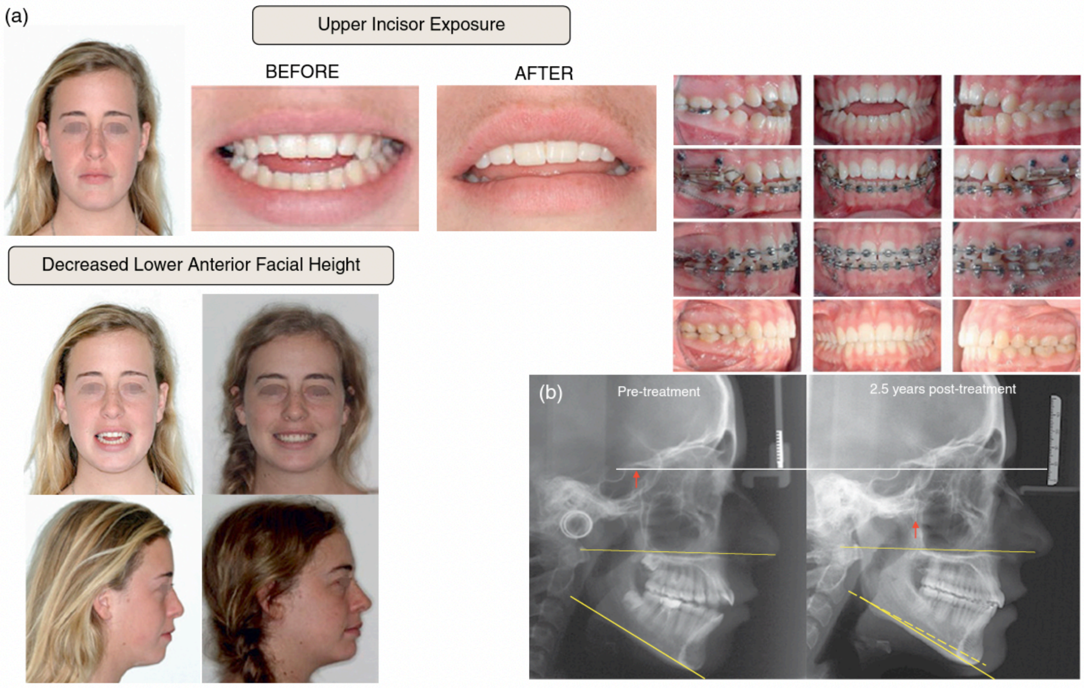

Figure 46.2 (a) Anterior open bite and Class II malocclusion treated using posterior miniscrews. (b) Initial and 2.5 years post-treatment lateral cephalograms showing correction of the skeletal and dental open bite and Class II malocclusion.

cases [14] with two years post-treatment stability. Sherwood et al. [5] used miniplates in the zygomatic buttress to intrude maxillary molars and for anterior open bite correction, and a similar approach was taken by Erverdi et al. [4]. However, similar results in open bite treatment have also been achieved with maxillary miniscrews [15–17]. It has been reported that open bite correction and stability was very similar when treated with miniplates and/or miniscrews as compared with surgical posterior maxillary impaction [18]. However, TADs are not recommended for treating very severe open bite cases. The molar intrusion vector has the effect of expanding and tipping the molars buccally, which usually needs to be controlled by either a transpalatal/lingual appliance, factoring sufficient buccal root torquing moment in the archwires, or by placing a miniscrew palatally with an intrusive force (Figures 46.3 and 46.4).

An approach recently introduced with anterior palatal miniscrews may offer a good alternative with fewer screws while maintaining the screws in ideal bone and controlling molar intrusion with the “mousetrap” appliance (Figure 46.5) [19].

The use of mandibular miniscrews as an alternative to miniplates for mandibular molar intrusion may prove slightly more challenging than in the maxilla. If miniscrews are placed far enough gingivally to allow for sufficient range of the activation of the intrusion mechanics, this would place the screws in unattached gingiva where there is greater likelihood of irritation, gingival overgrowth, and failure. Additionally, it is a site that poses difficulty in miniscrew placement due to limited access and a very high bone density, which may require predrilling. On the other hand, miniplates can be placed away from the dentition while allowing sufficient range for activation. Unfortunately, if the end of the miniplate emerges from the unattached gingiva or is located in the retromolar area of the mandible, this often causes irritation and infection (Figure 46.6).

One clear indication for miniplates in open bite treatment is anterior open bite cases associated with a skeletally narrow maxilla. These are often treated with surgically assisted rapid palatal expansion (SARPE). Often, this requires stage 1 surgery prior to maxillary impaction after leveling, aligning, and decompensation. However, considering that molar intrusion can largely mimic the effect of maxillary impaction, combining molar intrusion with SARPE may reduce the total surgery required. In this case, miniplates can be placed in the zygoma above the osteotomy line. The miniplates are bent with a bayonet-shaped bend to allow room for the maxillary expansion at the

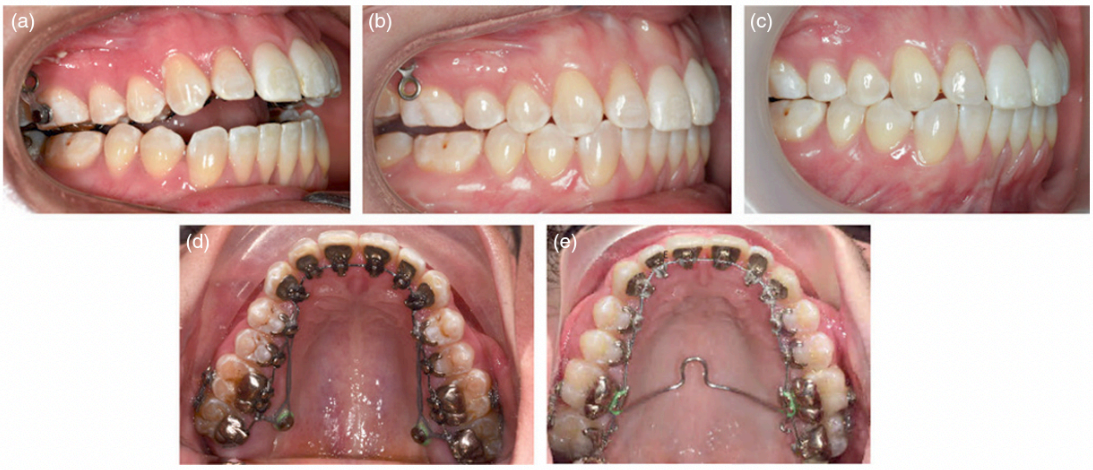

Figure 46.3 (a–c) Anterior open bite treated with maxillary molar intrusion using maxillary miniplates. (d) Palatal miniscrew used to counteract the buccal tipping moment generated by the buccal miniplate. (e) Transpalatal bar used to counteract the buccal tipping moment generated by intrusive force from the buccal miniplate.

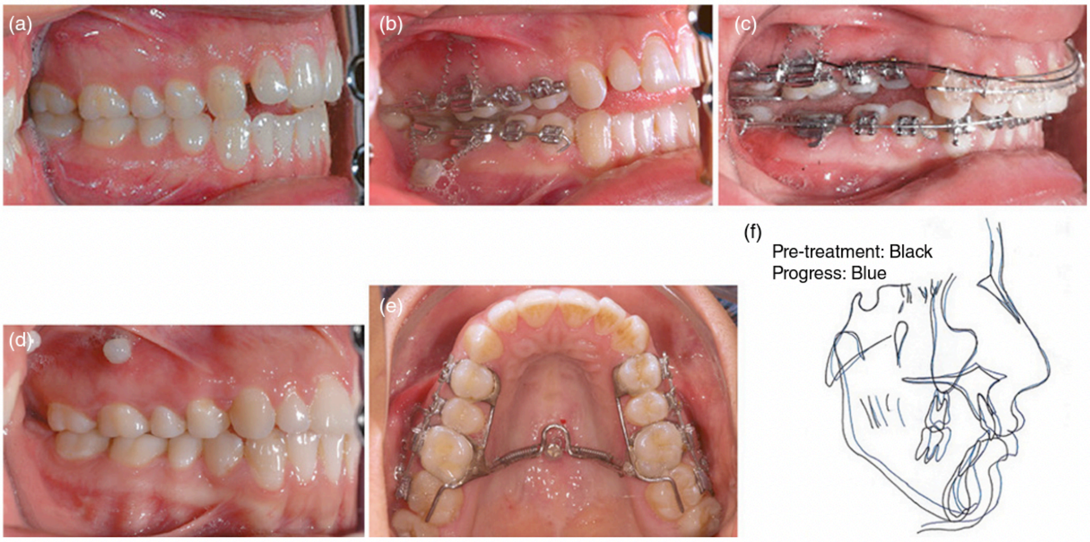

Figure 46.4 (a–d) Anterior open bite treated with miniscrews and maxillary and mandibular molar intrusion. (e) Transpalatal bar used to counteract the buccal tipping moment generated by the intrusive force on the buccal miniscrew. A palatal miniscrew is also used. (f) Lateral superimposition showing mandibular counterclockwise rotation, closing the open bite and increasing chin projection.

osteotomy site. Following the expansion, the miniplates can then act as anchorage for molar intrusion. The regional acceleratory phenomena (RAP) that follow the osteotomy are also likely to accelerate the molar intrusion, resulting in rapid correction of the anterior open bite. However, miniscrews cannot be placed above the osteotomy line, so there is no miniscrew option in this scenario.

In conclusion, it can be argued that when maxillary molar intrusion is desired, miniscrews offer a reliable and less invasive approach, but miniplates are essential in

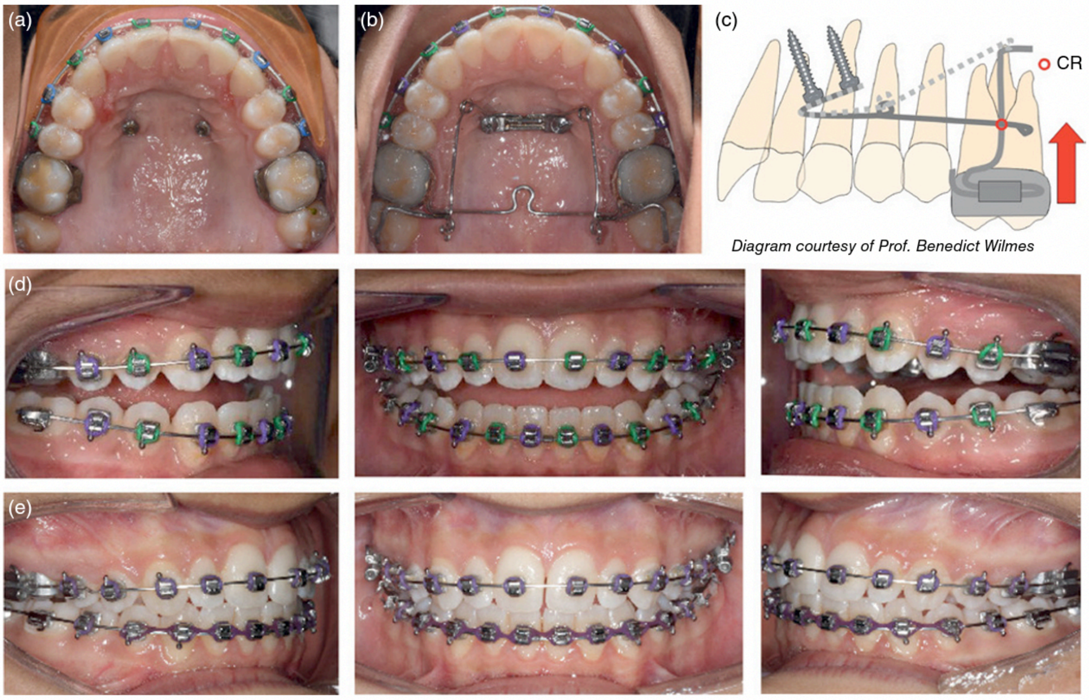

Figure 46.5 (a) Trans-sagittal palatal miniscrews in the anterior palate. (b) The "mousetrap" appliance. Composed of a transpalatal arch (TPA) between the first molars with an occlusal rest on the second molars. The TPA receives the intrusive force from 0.7 mm steel wire spring welded to a miniplate connecting the two palatal miniscrews. (c) Diagram showing the force vectors of the mousetrap appliance. Source: Courtesy of Prof. Benedict Wilmes. (d, e) The progress of open bite correction with the "mousetrap" spring.

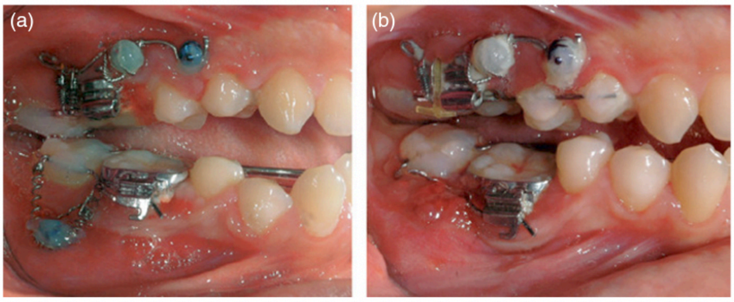

Figure 46.6 (a) Miniscrew placed in the unattached gingiva for mandibular molar intrusion. (b) Mucosal irritation and infection from the miniscrew.

cases where SARPE and posterior intrusion are used at the same time because the anchorage units need to be above the osteotomy cuts, and in cases where mandibular molar intrusion is required, miniplates are the better choice.

46.4.2 Class II Treatment and Molar Distalization

Class II correction is one of the most common treatments provided in an orthodontic office. Until recently, headgear was frequently used to distalize the maxillary molars.

However, most clinicians now prefer to use skeletal anchorage because it eliminates the obtrusiveness of extraoral appliances. In addition, molar distalization is indicated in cases where crowding has occurred in the maxillary arch due to mesial drifting of the posterior teeth. Distalizing appliances, such as the pendulum appliance, have the side effect of proclining the anterior anchorage segment, so the true distalization ends up being very small [20, 21], but with skeletal anchorage, true distalization becomes possible and predictable.

Sugawara et al. [22] used zygomatic anchorage plates to distalize the upper arch for Class II correction. Interradicular maxillary miniscrews have also been used [23], but the major limitation with interradicular miniscrews is root interference. As distalization progresses, the roots of the teeth will eventually touch the miniscrews, leading to root damage, or more likely, miniscrew failure [11]. This means either the miniscrews have to be removed and placed in a different site or an alternative means of anchorage will have to be used with tooth movement. Miniplates, however, do not have this limitation and provide very good 3D control without any root interference or impact from existing crowding (Figure 46.7).

Miniscrews in the anterior palate offer a reliable and less invasive option for Class II correction. Several distalization appliances are now available that allow maxillary molar distalization as well as distalization of the entire maxillary arch without root interferences. A distalizing appliance can be used on two palatal miniscrews to avoid root interference [24–26]. The use of two miniscrews in the anterior palate in tandem allows excellent stability with the advantage of minimal surgery as compared to bilateral skeletal miniplates (Figure 46.8). The main disadvantage is that this appliance may impede speech more than a buccally placed anchorage plates.

In conclusion, it can be argued that for the purpose of maxillary molar distalization and/or maxillary arch distalization for Class II correction anchorage miniplates are an

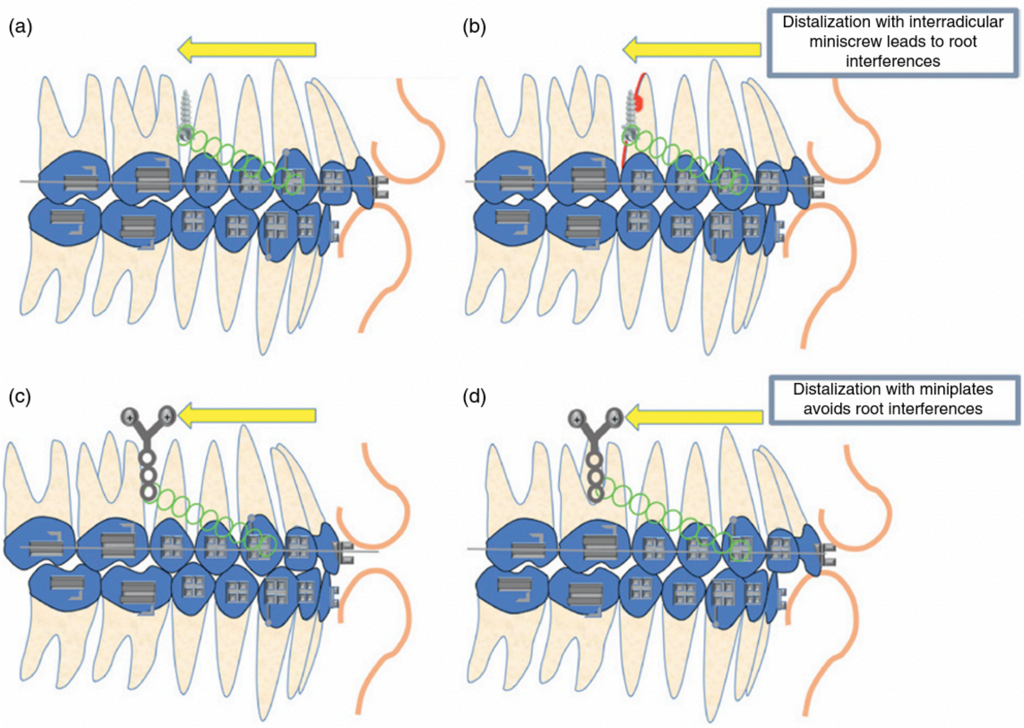

Figure 46.7 Diagrammatic representation of mandibular molar distalization scenarios with miniscrews vs. miniplates. (a, b) Use of miniscrews for maxillary arch distalization eventually results in root interference with the miniscrew. (c, d) Miniplates are above the roots so distalization of the entire arch can proceed without root interference.

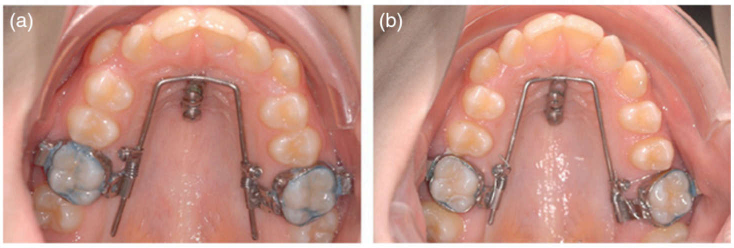

Figure 46.8 Before (a) and after (b) distalization. Beneslider for molar distalization using two anterior palatal miniscrews in tandem through a "Beneplate." This method allows arch distalization without root interference. *Source:* Courtesy of Prof. Benedict Wilmes.

unnecessarily invasive option when distalizers with miniscrews in the anterior palate can offer similar treatment outcomes with minimal surgery and discomfort. Miniplates should be reserved for cases when a midpalatal miniscrew is not possible under any circumstance.

46.4.3 Class III Treatment

The applications of skeletal anchorage in Class III treatment can be divided into applications for orthopedic correction of skeletal Class III cases and those where dental movement is used to correct or camouflage a Class III malocclusion.

46.4.3.1 Dental Class III Correction and Camouflage Treatment

In many adult cases, Class III malocclusion can be corrected through mandibular arch distalization using skeletal anchorage. Similar to Class II treatment, distalization of the entire mandibular arch with interradicular miniscrews poses a problem with root interference, especially if the amount of distalization exceeds the space between the miniscrews and the roots of the teeth mesial to it. Miniplates in the posterior mandible can be of greater use, especially if the third molars are to be extracted concomitantly [27]. This allows the third molars to be extracted and the miniplates to be placed in one surgical procedure, thus greatly reducing the surgical burden on the patient (Figure 46.9).

46.4.3.2 Buccal Shelf Screws

The placement of miniscrews in the mandibular buccal shelf has been proposed as a good alternative to correct Class III malocclusion and severe lower crowding by lower molar distalization and retraction [28]. The buccal shelf provides an extra-alveolar site for safe miniscrew placement. With an initial failure rate of 7%, the buccal shelf screws can be an attractive alternative to miniplates in the mandibular arch. The buccal shelf screw is a 2.0×12 mm long stainless steel miniscrew placed in the mandibular buccal shelf [29]. Analysis of adult cone-beam computed tomography (CBCT) scans has shown that cortical bone thickness buccal to the distal root of the mandibular second molars provides adequate bone for placement of buccal shelf screws [30]. Although predrilling may be required due to the high bone density, flap surgery is not required, so this procedure can be performed by the orthodontist. Due to the minimal width of attached mucosa at the second molars, buccal shelf screws are likely to be in the movable mucosa. However, based on a retrospective study of more than 1600 subjects, this does not seem to be a major problem [29]. Although more technically demanding than traditional interradicular miniscrews, it does offer a good alternative to mandibular arch distalization.

In conclusion, it can be said that in Class III correction, where the entire mandibular arch is being distalized, miniplates have a significant advantage over interradicular miniscrews, especially if the third molars need to be extracted. On the other hand, buccal shelf miniscrews offer a viable alternative and require less surgery to place.

46.4.4 Class III Growth Modification

In recent years, the orthopedic treatment of Class III malocclusion in growing children has been revolutionized by the use of skeletal anchorage. It allows true orthopedic correction of maxillary deficiency without the dental side effects seen with traditional tooth-borne facemask therapy, problems such as mesial migration of the maxillary posterior teeth and flaring of the maxillary incisors. Some authors have applied protraction facemasks directly to miniplates in the anterior maxilla. Their results showed significant skeletal corrections without dental side effects common with conventional facemask therapy [31]. However, similar results can also be achieved using miniscrew-supported maxillary expansion as has been demonstrated with the hybrid hyrax appliance, and it is less

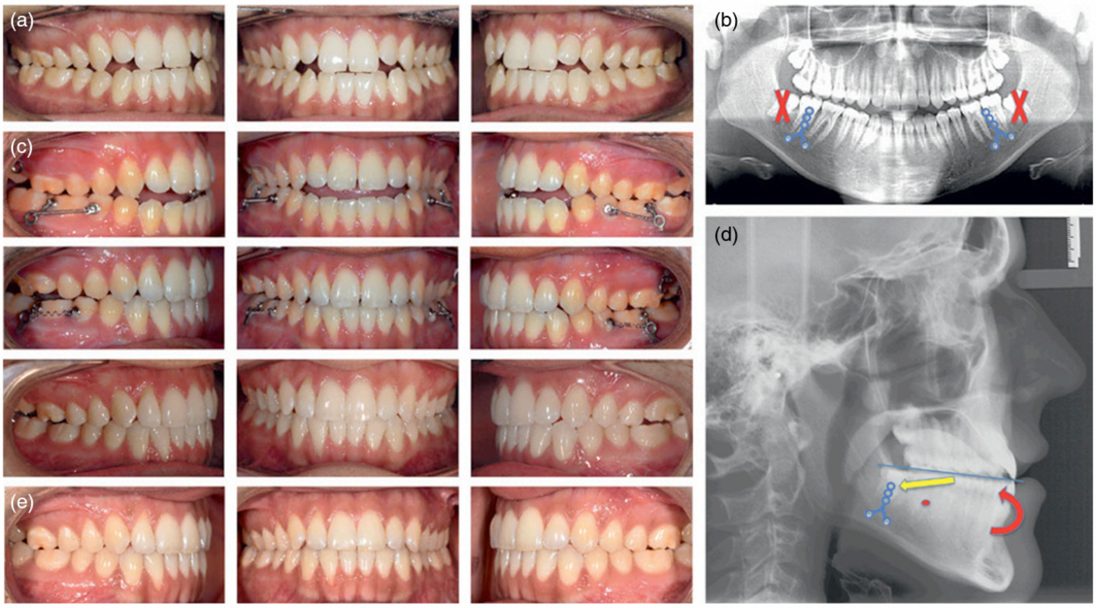

Figure 46.9 Class III malocclusion with anterior open bite treated with mandibular arch distalization using miniplates and lingual appliances. (a) Pre-treatment. (b) Miniplate insertion was done at the same time as third molar extraction. (c) Treatment progression with distalization using NiTi coil spring from the miniplate. (d) Force vectors for mandibular arch distalization and change in the orientation of the mandibular occlusal plane. (e) The 1.5 year post-treatment results are stable.

invasive and clinically simpler to apply [32]. Additionally, maxillary expansion [32] and/or molar distalization [33] for crowding can be combined in the same appliances. By placing two miniscrews trans-sagittally in the anterior palate, miniscrews can serve as anchorage for both expansion and protraction of the maxilla.

However, facemask acceptance and compliance are a major challenge, especially with older children. De Clerck et al. [10] introduced the use of miniplates in the zygomatic area and in the mandibular symphysis with the purely intraoral use of Class III elastics. This is likely to be better accepted by patients and allows for a fully bone-borne appliance with almost full-time Class III traction. The results showed significantly more skeletal correction as compared to untreated controls with evidence of dental decompensations not seen before with tooth-borne appliances [34]. However, De Clerck's design does not include maxillary expansion (Figure 46.10).

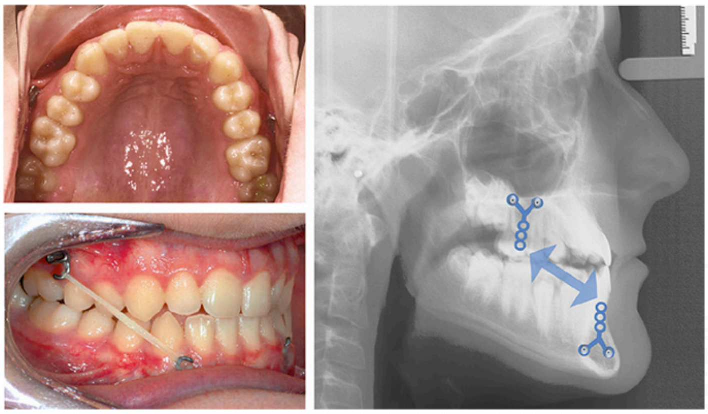

Figure 46.10 Miniplates in the mandible and maxilla for Class III growth modification with intermaxillary elastics.

In some cases, maxillary expansion is included in Class III treatment due to transverse maxillary deficiency, but in most cases, expansion is thought to activate the circum-maxillary sutures, making them more responsive to maxillary protraction forces. Some authors have gone so far as to alternate maxillary expansion and contraction (Alt-RAMEC) to further enhance the maxillary sutural response [35]. The use of palatal miniscrews to support the repeated expansion and contraction should also reduce the risk of root damage to the dentition from the cyclic loading [36]. Recent studies have reported great success when miniscrew-supported maxillary expansion is combined with miniplates in the anterior mandible (Figure 46.11) [37, 38]. And the results were similar to those where a bone-borne protraction facemask was used (Figure 46.12) [39].

In conclusion, it can be argued that in cases where maxillary protraction is desired, whether it be with a facemask or Class III elastics from mandibular symphysial miniplates, this can be achieved with palatal miniscrews rather than miniplates. The placement of the miniscrews allows the expansion as well as protraction to be bone-borne so the surgical intervention is minimal, especially considering this is for young children. Because of the invasive nature of the surgery to place maxillary miniplates, the need for a second stage surgery to remove them, and the increased discomfort following the operations, it can be argued that

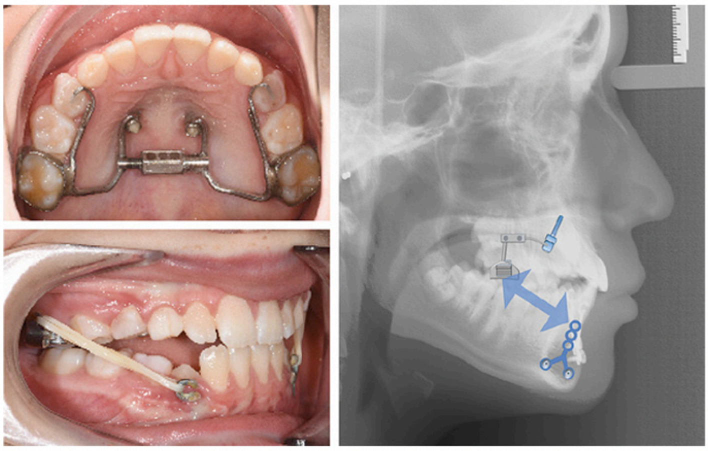

Figure 46.11 Class III growth modification with hybrid expander in the maxilla and miniplates in the mandible using intermaxillary elastics. The use of palatal miniscrews allows bone-borne expansion and the palatal miniscrews act as anchorage for the protraction force indirectly transmitted through the molar hooks.

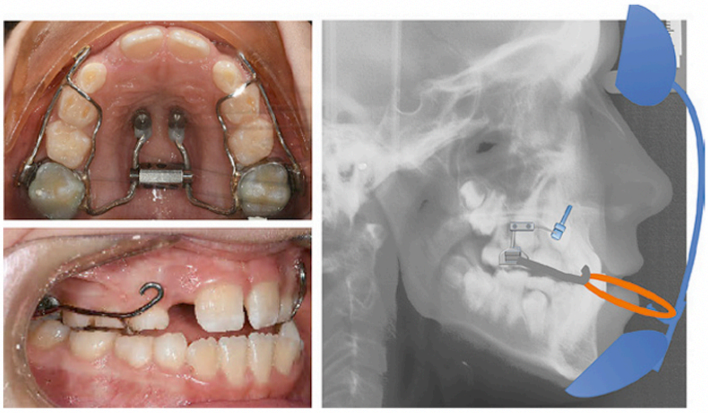

Figure 46.12 Class III growth modification using hybrid expander. Palatal miniscrews are used as anchorage for expansion, then for maxillary protraction using a facemask.

for the purpose of maxillary protraction, the use of minimally invasive miniscrews in the anterior palate achieves the same outcome with a reduced burden on the patient. Although bilateral zygomatic miniplates require at least four to six screws, miniscrew expansion requires only two palatal miniscrews, and in addition to that, the design can be combined with skeletal protraction as well as molar distalization in cases with crowding [40].

Unfortunately, the same is not true for the mandibular correction. Growth modification is often performed in the mixed dentition. The placement of interradicular miniscrews is unpredictable in this age group. First, failure rates are known to be higher in the alveolar process of children. Second, there are limited sites for safe insertion of miniscrews due to the presence of developing teeth. A miniplate, however, can be placed away from the developing teeth in areas of good bone density. Furthermore, in cases where only the permanent lower incisors have erupted, miniplates, coined "mentoplates," can be placed apical to the incisor roots in the anterior symphysis.

46.5 Intra-arch Mechanics

Since their introduction, miniscrews have been used extensively to bolster anchorage against unwanted tooth movement, especially in extraction cases where maximum anterior retraction is required or cases where maxillary or mandibular molars need to be protracted to close the space of missing teeth. Although miniplates can also be used for such cases, it might seem excessive to use them where the simpler miniscrews can achieve the same results. It can be argued that for the sake of intra-arch mechanics where maximum anchorage is required, miniscrews are more than sufficient and miniplates should be considered only when miniscrews are contraindicated.

46.6 The Special Case for "Surgery-first" Orthodontics

Surgery-first orthodontics allows for cases requiring combined orthodontic and orthognathic surgical treatment to

Table 46.1 Miniscrews and miniplates: clinical applications and authors' recommendations.

Clinical application	The primary choice of TADs	Additional considerations
Open bite treatment		
Maxillary molar intrusion	Buccal interradicular miniscrews Palatal interradicular miniscrews in the palatal slope Anterior palatine miniscrews with indirect anchorage (e.g. "mousetrap" appliance)	Miniplates can be used in select cases, especially when third molar extraction is planned, as it can be done simultaneously
Mandibular molar intrusion	Miniplates offer a larger range of intrusion. It can be done simultaneously with third molar extraction when indicated	Buccal shelf miniscrews offer a good range of intrusion in some cases Interradicular buccal miniscrews can be used in selected patients with adequate attached gingiva
Maxillary arch distalization	Palatal miniscrews in the anterior palate for distalization with no root interference (e.g. Beneslider) Palatal interradicular miniscrews in the palatal slope for shorter range distalization (There is more space between roots palatally than buccally)	Miniplates can also offer an alternative, especially if third molars will be extracted simultaneously Buccal miniscrews offer a limited range of distalization due to root interference
Mandibular arch distalization	Miniplates offer a good range of distalization with no root interference. Ideally installed together with extraction of third molars Buccal shelf miniscrews can offer a similar range of distalization with no root interference	Palatal miniscrews with Class III elastics can be considered, however, they depend on compliance Interradicular buccal miniscrews for short-range distalization due to root interference
Class III orthopedic growth modification	Palatal miniscrews in the anterior palate with expansion and facemask Palatal miniscrews in anterior palate with expansion and mandibular miniplates	Zygomatic or anterior maxillary miniplates can be used with a facemask, however, they are much more invasive Zygomatic miniplates with mandibular anterior miniplates and Class III elastics if expansion is not needed
Intra-arch mechanics for maximum anchorage	Miniscrews in interradicular areas offer adequate anchorage for almost all intra-arch mechanics	Miniplates should be reserved for cases when there is inadequate bone quality in the alveolus or insufficient interradicular space for miniscrew placement

have their surgery done first before orthodontic preparation and decompensation is commenced [41]. The advantages of this surgery-first approach include immediate improvement in facial esthetics, in contrast to the gradual worsening that can occur with the decompensation in the traditional approach, and it usually results in faster treatment [42]. This is partially due to the post-operative regional acceleratory phenomenon as well as the elimination of muscle pressures and occlusal forces. Following surgery, dental decompensation needs to be performed, so placement of miniplates at the same time as the surgery provides the required anchorage to correct the dental and occlusal relationships with movement of the entire arch in many cases. This is a good indication for miniplates, as they will be placed at the surgery and will be away from the dentition, allowing movement without root interference [41, 43].

46.7 Conclusions

It can be concluded that, overall, miniscrews are much less invasive and require a simpler procedure for use. However, there are areas where the mechanical advantages offered by miniplates make both treatment modalities an integral part of the orthodontic skeletal anchorage armamentarium (Table 46.1).

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