EVALUATION OF THE EFFECTIVENESS OF THE REMOVABLE MANDIBULAR RETRACTOR WITH SLOW MAXILLARY EXPANSION COMPARED TO THE BONE-ANCHORED INTERMAXILLARY TRACTION WITH RAPID MAXILLARY EXPANSION IN THE CORRECTION OF SKELETAL CLASS III MALOCCLUSION ASSOCIATED WITH MAXILLARY CONSTRICTION IN GROWING PATIENTS: A RANDOMIZED CONTROLLED TRIAL

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LIST OF ABBREVIATIONS

ANZCTR	Australian New Zealand Clinical Trials Registry
BAIMT	Bone-anchored intermaxillary traction
BAMP	Bone-anchored maxillary protraction
BSI	British Standard Institute
CBCT	Cone-beam computed tomography
CCT	Randomized controlled trial
CI	Confidence interval
CO	Centric occlusion
CR	Centric relation
CT	Computed tomography
DIFF	Difference
FM	Face Mask
FR III	Frankel functional regulator III appliance
G	gram
GIC	Glass ionomer cement
ICCs	Intraclass correlation coefficients
ICW	Inter-canine width
IMPA	Incisor mandibular plane angle
IMW	Inter-molar width
LMDist	Left molar distance
M	Mean
MARME	Micro-implant Assisted Rapid maxillary expansion
MAX	Maximum

MD	Mean difference
MDN	Median
MIN	Minimum
MM	millimeter
MOH	Ministry Of Health
MP	Miniplates
OB	Overbite
OJ	Overjet
ORTA	Orthodontic intermaxillary removable traction appliance
PROMs	Patient-reported outcome measures
QH	Quad-helix
RCT	Randomized controlled trial
RMDist	Right molar distance
RME	Rapid maxillary expansion
RMR	Removable mandibular retractor
RP	Removable plate
RPE	Rapid palatal expansion
RPFM	Reverse Pull Face Mask
RTB	Reverse Twin-Block
RTBLP-RME	Reverse twin block with lip pads and rapid maxillary expansion
SAFM	Skeletal-anchored facemask
SD	Standard deviation
SME	Slow maxillary expansion
SPSS	Statistical Package for the Social Sciences

SRMR	Semi-rapid maxillary expansion
SS	Stainless steel
TADs	Temporary anchorage devices
TMJ	Temporomandibular joint
TPA	Trans palatal arch
UCG	Untreated control group
URA	Upper removable appliance
USM	Universiti Sains Malaysia

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PENILAIAN KEBERKESANAN ANTARA RETRAKTOR MANDIBULA BOLEH TANGGAL DENGAN PENGEMBANGAN PERLAHAN MAKSILA BERBANDING DENGAN ALAT TRAKTOR INTER MAKSILA BERANKORKAN TULANG DENGAN PENGEMBANGAN PANTAS MAKSILA DALAM PEMBETULAN MALOKLUSI RANGKA KELAS III BERSERTA MAKSILA KONSTRIKSI DI KALANGAN PESAKIT YANG SEDANG MEMBESAR: PERCUBAAN TERKAWAL SECARA RAWAK

ABSTRAK

Percubaan terkawal secara rawak ini bertujuan untuk menilai keberkesanan dan kebolehterimaan daya tarikan intermaksilari berankorkan (BAIMT) dengan pengembangan maksila pesat (RME) berbanding dengan retractor mandibular boleh tanggal (RMR) dengan pengembangan maksila perlahan (SME) dalam pembetulan kelas rangka. III maloklusi yang dikaitkan dengan penyempitan maksila dari segi masa rawatan. Selain itu, perubahan rangka sagittal dan melintang, perubahan dento-alveolar dan tisu lembut, dan Ukuran Hasil yang Dilaporkan Pesakit (PROM) juga dinilai. Sampel akhir terdiri daripada 26 pesakit (13 lelaki, 13 perempuan), berumur antara 12-15 tahun yang ditugaskan kepada dua kumpulan secara rawak: kumpulan BAIMT dengan RME (14 pesakit, umur min 14.09±1.12 tahun) dan kumpulan RMR dengan SME (12 pesakit, min umur 13.04±1.46 tahun). Selepas pembetulan maloklusi dalam satah sagittal dan melintang, pesakit menjalani fasa pengekalan selama 3 bulan. Sefalogram lateral dan anteroposterior dan tuangan pergigian diambil dari semua pesakit yang mengambil bahagian pada dua masa penilaian: sebelum permulaan rawatan, dan pada akhir fasa pengekalan. Tambahan pula, tahap kesakitan, ketidakselesaan, kemerosotan fungsi, dan rasa malu dinilai menggunakan soal selidik piawai yang diedarkan kepada pesakit pada lima masa penilaian: (T1)

selepas satu hari permulaan rawatan aktif, (T2) selepas satu minggu (T3) selepas empat minggu, (T4) selepas 3 bulan, dan (T5) selepas 6 bulan. Pekali korelasi intrakelas (ICC) digunakan untuk menentukan kebolehulangan kaedah yang digunakan, iaitu kebolehpercayaan intra-pemerhati (atau ralat rawak), manakala ujian-t berpasangan digunakan untuk menentukan sebarang ralat sistematik. Taburan data bagi semua pembolehubah kajian pada mulanya diuji menggunakan ujian normaliti Shapiro-Wilk. Selepas itu, ujian-t dua sampel, atau rakan bukan parametriknya, ujian Mann-Whitney U, digunakan untuk mengesan kepentingan perbezaan antara kedua-dua kumpulan berkenaan tempoh rawatan, data cephalogram dan tuangan gigi. Bagi data soal selidik PROM, ujian Khi kuasa dua telah digunakan. Untuk semua pembolehubah, nilai ICC berada dalam julat korelasi yang sangat baik. Keputusan menunjukkan bahawa tempoh kedua-dua fasa pengembangan dan rawatan aktif adalah jauh lebih rendah dalam kumpulan BAIMT dengan RME berbanding kumpulan RMR dengan SME($p<0.001$). Analisis cephalometric lateral menunjukkan perbezaan yang signifikan antara kedua-dua kumpulan hanya mengenai Co-Gn ($p=0.039$) dan ANS-Me ($p=0.008$) yang memihak kepada RMR dengan SME. Walau bagaimanapun, tiada perbezaan ketara ditemui antara kedua-dua kumpulan berkenaan pembolehubah yang dikaji pada kedua-dua cephalogram anteroposterior dan tuangan gigi ($p>0.05$). Mengenai penilaian PROM, tahap kesukaran pertuturan adalah jauh lebih tinggi dalam kumpulan RMR dengan SME berbanding yang lain hanya pada T1 ($p=0.006$). Sebaliknya, sekatan pergerakan mandibula adalah lebih besar dalam kumpulan BAIMT dengan RME berbanding yang lain hanya pada T2 ($p=0.042$). Kedua-dua BAIMT dengan RME dan RMR dengan SME mampu membetulkan maloklusi Kelas III yang dikaitkan dengan penyempitan maksila pada

pesakit yang membesar dengan gigi kekal dengan membuat perubahan rangka, gigi dan tisu lembut yang serupa.

EVALUATION OF THE EFFECTIVENESS OF THE REMOVABLE MANDIBULAR RETRACTOR WITH SLOW MAXILLARY EXPANSION COMPARED TO THE BONE-ANCHORED INTERMAXILLARY TRACTION WITH RAPID MAXILLARY EXPANSION IN THE CORRECTION OF SKELETAL CLASS III MALOCCLUSION ASSOCIATED WITH MAXILLARY CONSTRICTION IN GROWING PATIENTS: A RANDOMIZED CONTROLLED TRIAL

ABSTRACT

This randomized controlled trial aimed to evaluate the effectiveness and acceptability of the bone-anchored intermaxillary traction (BAIMT) with rapid maxillary expansion (RME) in comparison with removable mandibular retractor (RMR) with slow maxillary expansion (SME) in the correction of skeletal class III malocclusion associated with a maxillary constriction in terms of treatment time. Moreover, sagittal and transverse skeletal changes, dento-alveolar and soft tissue changes, and Patient-Reported Outcome Measures (PROMs) were also assessed. The final sample consisted of 26 patients (13 males, 13 females), ages ranging 12-15 years who were assigned to two groups randomly: BAIMT with RME group (14 patients, mean age 14.09±1.12 years) and RMR with SME group (12 patients, mean age 13.04±1.46 years). After correction of malocclusion in the sagittal and transverse planes, patients underwent a 3-month retention phase. Lateral and anteroposterior cephalograms and dental casts were taken of all patients participating at two assessment times: before the beginning of the treatment, and at the end of the retention phase. Furthermore, the levels of pain, discomfort, functional impairment, and shyness were evaluated using a standardized questionnaire that was distributed to

the patients at five assessment times: (T1) after one day of the beginning of the active treatment, (T2) after one week (T3) after four weeks, (T4) after 3 months, and (T5) after 6 months. Intraclass correlation coefficients (ICCs) were applied to determine the reproducibility of the employed method, i.e. intra-observer reliability (or random error), whereas paired t-tests were applied to determine any systematic error. The data distribution for all study variables was initially tested using the Shapiro-Wilk normality test. Thereafter, Two-sample t-test, or its nonparametric counterpart, the Mann-Whitney U test, was used to detect the significance of the differences between the two groups regarding treatment duration, cephalogram data, and dental cast. For PROM questionnaire data, the Chi-square test was used. For all variables, Intraclass correlation coefficients values were in the range of excellent correlation. The results showed that the duration of both expansion and active treatment phase was significantly lower in BAIMT group compared to the RMR group ($p<0.001$). Sagittal skeletal and soft tissue analysis showed a significant difference between the two groups only regarding Co-Gn ($p=0.039$) and ANS-Me ($p=0.008$) in favor of RMR with SME. However, no significant differences were found between the two groups regarding the variables studied on both the anteroposterior cephalograms and dental casts ($p>0.05$). Regarding Patient-Reported Outcome Measures assessment, the speech difficulties level was significantly greater in the RMR group compared to the other one only at T1 ($p=0.006$). In contrast, mandibular movement restriction was significantly greater in the BAIMT with RME group compared to the other one only at T2 ($p=0.042$). Both BAIMT with RME and RMR with SME are capable of correcting Class III malocclusion associated with a maxillary constriction in growing patients with permanent dentition by making similar skeletal, dental, and soft tissue changes.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Skeletal Class III malocclusion is regarded as one of the most complex issues to address in orthodontics (Kamel et al., 2023). ts etiology can originate from various developmental factors, including dental, skeletal, or a combination of both. The treatment approach is determined by the patient's age and the severity of the malocclusion (Umale et al., 2016). Many cases necessitate early intervention for a majority of patients (Ngan and Moon, 2015). A significant benefit of treating Class III malocclusion early is the potential to avoid surgical procedures, thereby decreasing the associated morbidity (Woon and Thiruvenkatachari, 2017). Reports indicate that skeletal Class III malocclusion affects over 7% of the global population, with even higher prevalence rates in Southeast Asians, ranging from 12.58% to 26.67% (Hardy et al., 2012). Overall, the high prevalence of Class III malocclusion can significantly impact the quality of life for a large segment of the Malaysian population (Bichara et al., 2016). In the management of skeletal Class III malocclusion, various treatment choices exist. These include early orthopedic intervention while the individual is growing, orthodontic techniques for camouflage, and orthognathic surgery once growth is completed (Alhammadi et al., 2022, Woon and Thiruvenkatachari, 2017). However, selecting the right treatment and timing the intervention can be difficult. Treating skeletal Class III malocclusion presents challenges due to diverse mandibular growth patterns, a plethora of treatment choices, a notable risk of relapse, as well as irreversible alterations post-orthodontic extractions (Taraji et al., 2023). Conversely, various methods have been implemented for treating Class III cases through growth modification during the

primary and mixed dentition stages, such as the use of face masks. (Delaire et al., 1976, Lee et al., 2012), the chin cup (Graber, 1977, Chatzoudi et al., 2014), Frankel III Appliance (Fränkel, 1970, Levin et al., 2008), class III Bionator (Garattini et al., 1998) and the removable mandibular retractor (RMR) (Proffit et al., 2003, Saleh et al., 2013b). Several studies have demonstrated the effectiveness of the RMR in altering the growth patterns of Class III deformities during both early and late mixed dentition (Baccetti and Tollaro, 1998, Saleh et al., 2013b). A recently introduced method is the bone-anchored intermaxillary traction (BAIMT) system, which utilizes mini-plates that are placed on the upper and lower jaws for the attachment of Class III intermaxillary elastics (De Clerck et al., 2009, De Clerck et al., 2012, Majanni and Hajeer, 2016). Jamilian and Showkatbakhsh simplified this procedure afterward using mini-screws in the lower jaw instead of mini-plates for attaching Class III intermaxillary elastics (Jamilian and Showkatbakhsh, 2010, Jamilian et al., 2011).

On the other hand, many instances of mild to moderate skeletal Class III malocclusion are linked to disturbances in both vertical and transverse dimensions, with maxillary constriction being particularly significant (Mergen et al., 1999). Maxillary constriction is a prevalent orthodontic issue that can occur at any age (Mergen et al., 1999, Bucci et al., 2016). The occurrence of unilateral or bilateral maxillary constriction, with or without accompanying dental crowding, is common in individuals with skeletal Class III malocclusions (Bucci et al., 2016, Pinheiro et al., 2014). Maxillary expansion is considered the optimal approach for addressing this skeletal deformity of the maxilla to restore a normal transverse occlusal relationship (Bucci et al., 2016, Pinheiro et al., 2014). This skeletal expansion involves increasing the maxillary width by utilizing the opening of the palatal suture (Bucci et al., 2016, Martina et al., 2012). Various kinds of maxillary expanders can be utilized based on

the force applied and the expansion frequency: rapid maxillary expansion (RME) options include the Hyrax expander and the Hass type expander, while slow maxillary expansion (SME) options consist of removable palatal expansion appliances and quad-helix appliances (Bucci et al., 2016, Martina et al., 2012).

1.2 Problem statement and study rationale

Noticeable features of Class III malocclusion can result in unfavorable aesthetics for children, prompting parents to pursue orthodontic treatment at an early age (Oltramari-Navarro et al., 2013). The timing of this treatment is a critical factor in its success (Woon and Thiruvenkatachari, 2017). Certain studies indicate that the preferred age for initiating orthodontic therapy for Class III malocclusion is prior to the age of ten (Baccetti and Tollaro, 1998, Kim et al., 1999, Keles et al., 2002, Vaughn et al., 2005, Anne Mandall et al., 2012, Woon and Thiruvenkatachari, 2017). However, other research has suggested that age does not significantly impact treatment outcomes, particularly if growth has not yet been completed (Kapust et al., 1998, Atalay and Tortop, 2010). Hence, there is no strong evidence indicating that early treatment is advantageous (Woon and Thiruvenkatachari, 2017).

There have been numerous studies examining the effectiveness of removable and fixed appliances in the management of class III malocclusion (Jamilian et al., 2011, Majanni and Hajeer, 2016, Saleh et al., 2013b). RMR has been identified as a straightforward, simple, and effective functional appliance for treating Class III patients in both stages of deciduous and mixed dentitions, and it is well-received by children (Majanni and Hajeer, 2016, Saleh et al., 2013b). Nonetheless, contemporary literature suggests that while functional appliances can address class III malocclusion in growing patients, their effects are primarily dentoalveolar, with little or no influence on the skeletal pattern (Zere et al., 2018).

To address these limitations, bone-anchored maxillary protraction (BAMP) was proposed, facilitating both maxillary protraction and hindrance of lower jaw growth with minimal alterations in dentoalveolar level. Consequently, BAMP is now widely utilized in the treatment of skeletal class III malocclusion (Kamath et al., 2022). However, previous clinical studies that have investigated the effectiveness of BAMP or what is also known as bone-anchored intermaxillary traction (BAIMT) in growing class III patients have compared the effectiveness of this method with untreated control groups (De Clerck et al., 2010, Kamel et al., 2023, Mandall et al., 2024) or with a face mask (Cevidanes et al., 2010, Hino et al., 2013, de Souza et al., 2019). However, only one published randomized controlled trial (RCT) compared the effectiveness of the BAIMT system with an intraoral functional device (Majanni and Hajeer, 2016). This RCT found that BAIMT seemed to demonstrate greater effectiveness in addressing growing patients suffering from mild to moderate malocclusion of Class III compared to the RMR appliance (Majanni and Hajeer, 2016). However, class III cases that require rapid maxillary expansion were excluded from the previous trial, and it was not taken into account that the presence of unilateral or bilateral maxillary constriction with or without dental crowding is widespread with class III skeletal problems (Bucci et al., 2016, Pinheiro et al., 2014).

Based on the findings of a recent systematic review, dental changes are more evident with RMR, while skeletal changes are more noticeable with BAIMT. Moreover, BAIMT showed higher levels of patient acceptability in comparison with RMR appliances. However, the appliance's acceptability improves over time (Devi and Subramaniyan, 2022). The previous findings do not provide sufficient evidence to form a strong conclusion and additional trials will be necessary to achieve consistent and reliable outcomes (Devi and Subramaniyan, 2022). Furthermore, after

reviewing the published literature, no previous RCT that has compared the efficacy of the RME-assisted BAIMT treatment and the slow maxillary expansion (SME)-assisted RMR treatment in growing patients with Class III malocclusion and skeletally constricted maxilla was found.

After reviewing the published literature, there was only one RCT that compared the effectiveness of BAIMT system with the Removable Mandibular Retractor (RMR) in growing patients suffering from class III malocclusion in the late mixed dentition (Majanni and Hajeer, 2016). One of the limitations of the previous study is that patients who needed RME were excluded from the research sample.

in our study, RME was applied in the BAIMT group and SME in the RMR group, while no expansion (either rapid or slow) was applied in their study (Majanni and Hajeer, 2016).

no previous RCT has investigated the effectiveness of the RMR in addressing Class III malocclusion in this age group of patients (permanent dentition aged 12-15 years.)

After reviewing the literature, no previous study was found that investigated the dental effects (related the maxillary first molars right and left mesial movement) associated with RMR treatment.

After reviewing the published literature, only two RCTs were found that studied the PROMs associated with orthodontic treatment of skeletal Class III malocclusion. (Saleh et al., 2013a) in early mixed dentition and (Majanni et al., 2020) in late mixed dentition.

Therefore, the current RCT aimed to compare the efficacy of the mini-screw-based BAIMT system in conjunction with rapid maxillary expansion (RME) and the removable mandibular retractor (RMR) in conjunction with slow maxillary expansion (SME) in the treatment of growing maxillary-constricted Class III patients between 12 - 15 years.

1.3 Objectives of the study

1.3.1 General objective

Evaluation of the effectiveness and acceptability of the bone-anchored intermaxillary traction (associated with rapid maxillary expansion) in comparison with removable mandibular retractor (associated with slow maxillary expansion) in the correction of skeletal class III malocclusion associated with a maxillary constriction in growing patients between 12 - 15 years.

1.3.2 Specific objectives

1. To compare the treatment time of the bone-anchored intermaxillary traction (associated with rapid maxillary expansion) in comparison with removable mandibular retractor (associated with slow maxillary expansion) in the correction of skeletal class III malocclusion associated with a maxillary constriction in patients between 12 - 15 years.

2. To compare the sagittal and transverse skeletal changes following the correction of skeletal class III malocclusion associated with BAIMT (with RME) in comparison with a maxillary constriction using RMR (with SME) in patients between 12 - 15 years.

3. To compare the short-term dento-alveolar changes following the correction of skeletal class III malocclusion associated with BAIMT (with RME) in comparison

with a maxillary constriction using RMR (with SME) in patients between 12 - 15 years.

4. To compare the short-term changes of soft tissue following the correction of skeletal class III malocclusion associated with BAIMT (with RME) in comparison with a maxillary constriction using RMR (with SME) in patients between 12 - 15 years.

5. To assess the levels of pain, discomfort, and impairment of mandibular movement caused using the BAIMT (with RME) in comparison with the RMR (with SME) in patients between 12 - 15 years.

1.4 Research Hypotheses

There are five research hypotheses tested in this research:

1) **Null hypothesis (H0):** There is no significant difference in the treatment time of the two procedures in the correction of skeletal class III malocclusion associated with a maxillary constriction.
2) **Null hypothesis (H0):** There are no significant differences in the sagittal and transverse skeletal changes following the correction of skeletal class III malocclusion associated with a maxillary constriction between the two groups.
3) **Null hypothesis (H0):** There are no significant differences in the short-term dento-alveolar changes following the correction of skeletal class III malocclusion associated with a maxillary constriction between the two groups.
4) **Null hypothesis (H0):** There are no significant differences in the short-term soft tissue changes following the correction of skeletal class III

malocclusion associated with a maxillary constriction between the two groups.

5) **Null hypothesis (H0):** There are no significant differences in the levels of pain, discomfort, and impairment of mandibular movement associated with the correction of skeletal class III malocclusion associated with a maxillary constriction between the two groups.

1.5 Research questions

1. What is the difference in the treatment time between BAIMT (with RME) and RMR (with SME) in the correction of skeletal class III malocclusion associated with maxillary constriction in growing patients?

2. What are the differences in the sagittal and transverse skeletal changes between BAIMT (with RME) and RMR (with SME) in the correction of skeletal class III malocclusion associated with maxillary constriction in growing patients?

3. What are the differences in the short-term dento-alveolar changes between BAIMT (with RME) and RMR (with SME) in the correction of skeletal class III malocclusion associated with maxillary constriction in growing patients?

4. What are the differences in the short-term soft tissue changes between BAIMT (with RME) and RMR (with SME) in the correction of skeletal class III malocclusion associated with maxillary constriction in growing patients?

5. What are the differences in the levels of pain, discomfort, and impairment of mandibular movement between BAIMT (with RME) and RMR (with SME) in the correction of skeletal class III malocclusion associated with maxillary constriction in growing patients?

CHAPTER 2

LITERATURE REVIEW

2.1. Class III malocclusion

2.1.1 Definition of Class III malocclusion

In 1899, Edward Angle classified malocclusion into three categories depending on the relationship between the upper and lower first molars and their alignment relative to the occlusal line. Angle's Class III malocclusion is characterized by the anteriorly placed mandibular first molar concerning the maxillary first molar (Angle, 1899).

The relationship of Class III incisor is defined according to the British Standard Institute (BSI) as one in which the edge of the mandibular incisor is positioned anteriorly to the cingulum plateau of the maxillary incisors, with overjet being reduced or reversed (Institution, 1983).

2.1.2 Prevalence of Class III Malocclusion

The malocclusion prevalence shows great variation across various regions of the world, among diverse ethnic groups, and amidst different races (Umale et al., 2016). The prevalence of Class III malocclusion according to the systematic review by Hardy et al. has been reported to range from 0% to 26.7% for different populations worldwide (Hardy et al., 2012). This wide range in prevalence can be attributed to several factors such as race, geographical area of the studied population, gender, age, and the study design, including sample size and inclusion criteria (Hardy et al., 2012). However, the greatest incidence of Class III malocclusion is located in Asian communities reaching 15.80%, whereas the lowest prevalence was found in India with a percentage of 1.19% (Hardy et al., 2012, Ismail et al., 2017). Chinese

population shows a prevalence of angle class III malocclusion of 15.69%, while the Japanese population shows a relatively lower prevalence ranging between 4% and 5% (Soh et al., 2005, Ishii et al., 1987, Reed, 2011). For the Malaysian population, the occurrence of class III malocclusion was discovered to be 34.1% according to a recent study by Ismail and his colleagues (Ismail et al., 2017). In the Caucasian population, the prevalence of class III ranges from 1-4% (Ngan, 2005). Moreover, Hispanic populations show more prevalence of Class III malocclusions when compared to the African or Caucasian populations (Reed, 2011). On the other hand, Class III malocclusion prevalence in the United States accounts for only approximately 1% of the entire population and 5% of orthodontic patients (Jaradat, 2018).

2.1.3 Etiology of Class III malocclusion

Maxillary hypoplasia and retrognathism or mandibular prognathism, or both, can be the cause of Class III malocclusion. This means that there is a potential anatomical heterogeneity of this malocclusion type where one or both jaws may be affected either in sagittal length or in position relative to the other. Furthermore, according to familial aggregation studies, the factors of familial environment or genetics can play a significant role in the Class III malocclusion etiology (Ngan and Moon, 2015, Otero et al., 2014). The factors causing class III malocclusion are divided into two main groups: genetic and environmental factors. Researchers disagree about the effect of each group since it is often difficult to separate them (McDonald and Ireland, 1998). It has been found that 60% of American society has malocclusion caused by a combination of causative factors, while about 5% of cases of malocclusion are caused by specific factors (Proff et al., 2008).

- Genetic factors:

There is a common belief that heredity influences the dimensions and growth patterns of the jaws. It is supported by some studies that proved the critical role of genetic factors in the pathogenicity of class III malocclusion (Nakasima et al., 1982, Singh, 1999). Singh found high correlation rates between parents and their offspring regarding malocclusion class (Singh, 1999). Therefore, the role of genetic factors must be considered in malocclusion treatment (Nakasima et al., 1982).

The indirect effect of genetic factors of class III malocclusion is also investigated in previous studies, which contained numerous cases of cleft lip and palate, congenital loss of some permanent teeth, and syndromes such as Curzon syndrome (Chang et al., 2006, Li et al., 2011). These cases were associated with an early fusion of cranial sutures and early development of the upper jaw while the lower jaw was normal (Chang et al., 2006, Li et al., 2011).

The Habsburg royal family is the most famous example of heredity factors. The family's distinguishing features included a prognathic mandible, and consequently a malocclusion of class III. Of the 40 royal family members for whom records were available, 33 showed a prognathic lower jaw. (Jacobson et al., 1974, Jaradat, 2018). Moreover, in 1970, some research conducted by Litton and his colleagues studied class III anomalies in families of 51 individuals. They reached the conclusion that there was an association between genetic inheritance in siblings and offspring and class III malocclusion characteristics (Litton et al., 1970, Jaradat, 2018).

- Environmental factors:

Numerous environmental factors have been proposed to play a role in the class III malocclusion development.

Breathing: the patient suffering from oral breathing and large tonsils is forced to push the tongue forward continuously to secure the airway, causing the advancement of the lower jaw (Daher et al., 2007).

Bad habits: such as the habit of pushing the lower jaw forward in some children in an attempt to imitate their parents causing anterior crossbite (Chang et al., 2006). Other habits such as nail-biting and upper lip sucking can interfere with the pathogenesis of class III malocclusion, where the abnormal position of the lower jaw can cause a constant tightening of the articular condyle away from its cavity, inducing excessive growth of the lower jaw (Proff et al., 2008).

Forced occlusion: where the untreated anterior sliding of the lower jaw becomes a real protrusion of the lower jaw (Kapur et al., 2008).

Dental disorders: The delayed replacement of deciduous teeth in the upper jaw leads the permanent upper incisors to erupt palatally, while the birth loss of the upper teeth leads to a decreased length of the upper jaw relative to the lower jaw (Joshi et al., 2014).

Facial trauma: The surgical operations of the upper jaw and the middle face, and the traumas at an early age result in scars that could cause obstruction or lack of maxillary growth (Joshi et al., 2014).

Hormonal disorders: Some hormonal disorders of the pituitary and thyroid gland are associated with Class III malocclusion. For example, excessive growth

hormone secretion after puberty leads to asymmetric growth of facial bones causing limited growth in the sub-condylar region, as in patients with osteomyelitis (Yagi et al., 2004).

In the early stages of childhood, thyroid hormone deficiency causes an increase in the size of the tongue, leading to a mandibular protrusion and consequently to Class III malocclusion (Proff et al., 2008).

2.1.4 Classification of Class III malocclusion

Class III malocclusion was classified depending on the etiology or origin into the following types according to Moyers (Moyers, 1988):

1. **Dental Class III malocclusion:** Class III dental relationships and a normal skeletal relationship between the two jaws but the defect is located at the upper incisors and/or lower incisors, i.e. protrusion of the lower incisors or/and retrusion of the upper incisors or both (Moyers, 1988).

2**. Functional Class III malocclusion:** when the lower jaw slides during mandibular closure being forced to a mesial or anterior position relative to the upper jaw. However, in the mandible rest position, the relationship between both jaws is normal. Moyers attributed the cause of this anterior shift to a neuromuscular factor (Moyers, 1988).

Some researchers have mentioned the following diagnostic features of the functional class III malocclusion: no family story; an average length of the upper jaw, an average length of the lower jaw, a palatal inclination of the upper incisors with a labial inclination of the lower incisors, and a normal facial profile close to a straight profile (Rabie and Gu, 2000).

3. **Skeletal Class III malocclusion:** It is either due to an overgrowth of the mandible, underdevelopment of the maxilla, or a combination of both in the sagittal plane. Moyers showed that most cases of skeletal class III malocclusion are caused by underdevelopment of the maxilla and middle face (Moyers, 1988).

The prognathism of the lower jaw is caused by a positioning disorder of the lower jaw relative to the base of the cranium, while the retrognathism of the upper jaw is mainly caused by a decrease in the length of the base of the upper jaw (Dietrich, 1970, Ellis and McNamara, 1984).

The skeletal class III malocclusion may be associated with a decrease in the length of the anterior cranial base, a decrease in the vertical growth of the upper jaw, a decrease in the angle of the lower jaw, as well as, a concave profile with a decrease of the o facial convexity angle (Mouakeh, 2001).

2.1.5 Features of Class III malocclusion

• Sagittal dimension: Mandibular vs maxillary contribution

Class III patients typically display a concave facial profile. This may be attributed to maxillary retrognathism, mandibularprognathism, or a mix of both issues. Ellis and McNamara revealed that the most common skeletal relationship among class III patients is a combination of maxillary retrognathism and mandibular prognathism, accounting for 30% of cases. This is followed by maxillary retrognathism (19. 5%) and mandibular prognathism (19. 1%) (Ellis and McNamara, 1984).

Staudt and Killaridis discovered that in 47. 4% of class III cases, the mandible played a considerable role either in terms of size or position. Looking at the cases from another perspective, those with a solely maxillary involvement, either in a

retruded position or due to a deficiency in size, accounted for 19. 3%Furthermore, only 8.7% of the patients had contributions from both jaws (Staudt and Kiliaridis, 2009).

Recent research indicates that class III malocclusion can arise from pure mandibular prognathism (19.1% - 45.2%), pure maxillary retrognathism (19. 5% - 37. 5%), or a mix of both (1. 5% - 30%) (Kamath et al., 2022, Ahmed et al., 2024).

Baccetti et al. investigated gender differences amongst patients of class III malocclusion. However, they stated that class III was linked to a level of substantial sexual dimorphism in craniofacial parameters, particularly starting from the age of 13. However, during the circumpubertal and post-pubertal periods, female Class III patients displayed notably smaller linear measurements with regard to the maxilla, mandible, and anterior facial heights compared to their male counterparts (Baccetti et al., 2005).

Proff et al. found that in subjects with Class III skeletal growth patterns, the length of the mandible relative to the anterior cranial base is increased, while the length of the maxilla is not consistently affected in these cases (Proff et al., 2008).

• Transverse dimension

Chen et al. compared between untreated class III patients group and class I control group regarding the dental arches development and the skeletal maxillary-mandibular bases. They used cephalometric radiographs to measure the maxillary skeletal base width, bi-antegonial widths, and maxillary and mandibular intermolar widths yearly during the ages of 10 to 14 years. It was discovered that the maxillary skeletal base widths were notably narrower in the class III group compared to the class I group. In contrast, no significant differences were found in the bi-antegonial

widths. However, the class III group showed statistically significantly smaller widths of inter-molar in the maxillae in comparison with the class I group. In contrast, nonsignificant differences between the two examined groups regarding the mandibular intermolar widths (Chen et al., 2008).

• Vertical dimension

Concerning the vertical dimensions of class III patients, Staudt and Kiliaridis reported that patients with class III malocclusion have more hyper-divergent vertical dimensions, with increased heights of the lower anterior face (Staudt and Kiliaridis, 2009).

Baccetti et al. observed that in individuals with class III malocclusion, increasing in the vertical facial proportions transpired during both the pubertal growth spurt and at late developmental stages (Baccetti et al., 2007b).

• Dental features

In individuals with skeletal class III, there is a tendency for the teeth to compensate for the skeletal discrepancy in the sagittal plane between the arches. In 42. 1% of instances, the upper incisors are proclined, whereas the lower incisors are retroclined in 26. 3% to 68. 4% of cases (Jaradat, 2018).

2.1.6 Evaluation of Class III malocclusion

The dissimilarity between a skeletal and dental crossbite incorporates:

Dental assessment: When the incisors show a relation of edge-to-edge, and the lower incisors are being retroclined, one must consider the presence of a compensated Class III malocclusion. However, along with functional assessment,

clinical assessment should be conducted on the under-jet in conjunction with the Class III molar of angle relationship (Brizuela et al., 2024).

Functional assessment: An evaluation is conducted to analyze the connection between the mandible and maxilla to identify any disparities in centric relation (CR) or centric occlusion (CO) (Brizuela et al., 2024).

Profile Assessment: A study on facial proportions, chin, and positioning of the face (Brizuela et al., 2024).

Cephalometric Assessment: Identify both the maxillary and the mandibular position (Brizuela et al., 2024).

2.1.7 Treatment of a Class III malocclusion

2.1.7(a) Treatment timing

Skeletal class III malocclusion is known to appear early in life and rarely improves spontaneously, and it is associated in many cases with skeletal maxillary constriction (Baccetti et al., 2007b). Early intervention in cases of skeletal class III, especially in the mixed dentition phase or before the pubertal growth phase, is considered a preferred treatment option (Cha, 2003). Determining the appropriate time for therapeutic intervention in skeletal class III cases depends on the age, and the phase of dentition (Baccetti et al., 2006). In many cases, there is a need for additional diagnostic methods such as hand-wrist radiographs to assess the skeletal age accurately (Perinetti et al., 2017). Although class III malocclusion in growing patients is diagnosed at an early age, a very early intervention decision or delaying the treatment time until reaching a better stage of growth or dentition is considered a critical decision (Baccetti et al., 2007b, Perinetti et al., 2017). Choosing the appropriate timing of treatment is the main factor of treatment success (Cha, 2003).

Some studies have said that the ages before ten years are the best time of intervention to obtain skeletal effects (Baccetti and Tollaro, 1998, Kim et al., 1999, Battagel and Orton, 1995). In contrast, other studies have demonstrated that the effect of age on the treatment results has been little (Atalay and Tortop, 2010, Kapust et al., 1998).

The main goal of early intervention in cases of class III malocclusion is to secure a good oral environment and conditions for better growth and occlusal relationships, as well as to, obtain better facial aesthetic characteristics (Campbell, 1983). The early intervention may reduce the severity of class III malocclusion which prevents the patient from undergoing surgical treatment later (Zere et al., 2018). Turpin has suggested a set of positive and negative factors that affect the growth and development of class III malocclusion (Table 2.1) and proposed that early treatment intervention for class III cases should be taken into consideration if the patient has positive factors (Turpin, 1981, Zere et al., 2018). In contrast, patients with negative factors should be delayed until the growth is completed (surgical treatment) (Turpin, 1981). In some cases, the patients must be informed that early orthodontic intervention may not give satisfactory results, and they may need a surgical intervention later (Turpin, 1981).

Table 2.1 The positive and negative factors of Turpi for decision-making for interception of the developing of Class III malocclusion.

Positive factors	Negative factors
Mild skeletal disharmony	Severe skeletal disharmony
No familial prognathism	Familial pattern established
A young patient with remaining growth	Growth completed
Anteroposterior functional shift	No anteroposterior shift
Convergent facial type	Divergent facial type
Good facial esthetics	Poor facial esthetics
Symmetrical condyle growth	Asymmetrical growth of condyle
Good cooperation expected	Poor cooperation expected
(Turpin, 1981)	

The most important cephalometric measurements that predict the success of the early intervention in cases of class III malocclusion involve (Turpin, 1981):

ANB ((<−2°) – (−3°)), Wits appraisal (for nonsurgical therapy:−2 to −6 mm, for a result of compromised orthodontic: −6 to −9 mm), along with maxillomandibular differential and gonial angle, fall within the normal range.

2.1.7(b) Growth modification and orthopedic treatment

Growth modification is recommended for developing patients with skeletal disharmony of Class III malocclusion (Zere et al., 2018). The objective of orthopedic addressing for skeletal Class III discrepancies is to manage and/or guide the growth of the mandible and maxilla, aiming to enhance or rectify the skeletal imbalance. This approach enables future treatment of these patients through orthodontic camouflage alone, eliminating the necessity for orthognathic surgery. Certain functional appliances target the mandible, while others are more geared towards the maxilla (Reed, 2011, Zere et al., 2018). The modification of growth in Class III malocclusion can be attained through the utilization of both extraoral and intraoral appliances (Azamian and Shirban, 2016).

• Extraoral Appliances

1. **Chin Cap:**

The chin cup considered one of the orthodontics' oldest devices for addressing class III malocclusion, has been applied in patients with mandibular prognathism before reaching puberty (Jaradat, 2018).

It has been observed that treatment using a chin cup appliance does not hinder the growth of the mandible, but instead guides it vertically, causing the mandible to

rotate backward. These changes in the mandibular growth direction aid in enhancing Class III cases(Uner et al., 1995).

According to the findings of the previous systematic reviews, there is a significant consensus in research that the use of chin cup treatment can be effective as an early intervention for addressing developing Class III malocclusion, as indicated by favorable short-term results (Chatzoudi et al., 2014, Mousoulea et al., 2016). However, there are many reasons for discontinuing the chin cup as a choice of treatment including the need to wear these appliances throughout growth to achieve successful treatment. Furthermore, to achieve orthopedic effects, a substantial amount of force is needed, ranging from 600 to 800 grams, which may lead to temporomandibular joint issues. One more reason to discontinue this treatment is that the beneficial outcomes of treatment using the chin cup appliance were frequently not sustained because of the latent mandibular growth. (Reed, 2011).

2. Face Mask (FM):

Protraction face mask (also known as reverse headgear) is one of the most common interceptive appliances used as an interception treatment for developing skeletal Class III malocclusion with maxillary deficiency (Watkinson et al., 2013, Ngan, 2005).

In 2017, Smyth and Ryan conducted a review assessing the early therapy facemask in patients suffering from Class III malocclusion. However, the review included studies on children aged 7 to 12 years who underwent orthodontic treatment by fixed or removable appliances. Furthermore, addressing the reverse overjet was considered as the primary outcome (Smyth and Ryan, 2017). The review stated that there is moderate evidence to indicate that early therapy utilizing facemask results in

short-term improvement in skeletal and dental effects (Smyth and Ryan, 2017). These findings were in line with the outcomes of a systematic review published recently and found that the effects of FM therapy were stable in the short-term follow-up period (Raghupathy et al., 2023). It also revealed that the long-term effects of FM treatment remained stable for the maxilla. However, the growth of the mandibular in a horizontal and unfavorable direction continued until the adolescent growth spurt (Raghupathy et al., 2023).

FM has various clinical applications. Furthermore, there are several options available of FM. The orthodontist might choose either a Petit or Delaire type as the extraoral component of the FM. Additionally, orthodontists have the option to choose between skeletal and dental anchorage, or they may decide to proceed with protraction, with or without expansion (Azamian and Shirban, 2016). Nevertheless, there exist certain restrictions when using a face mask, which include patient compliance and parental control. These limitations can present challenges in utilizing extraoral devices (Nanda and Kierl, 1992). Additionally, other constraints involve the dentoalveolar effect, limited forward advancement of the maxilla (2-3 mm over 9-12 months), and the potential for relapse due to mandibular growth (Bowman, 2008, Rabie and Gu, 2000).

3. Headgear for Mandibular Arch:

Baccetti et al. (Baccetti et al., 2007a) and Rey et al. (Rey et al., 2006) applied the mandibular cervical headgear in developing patients exhibiting Class III resulting from mandibular prognathism. This treatment option leads to lower molar distalization, as well as the redirection of mandibular growth (Azamian and Shirban, 2016).

The most important results of systematic reviews that evaluated the effect of extraoral appliances in the management of Class III malocclusion are summarized in Table 2.2

Table 2.2 The findings of the systematic reviews that evaluated extraoral appliances effect in Class III malocclusion management

Authors	Aim	Appliance	Number and type of studies included	Total number of participants	Results
(Watkinson et al., 2013)	Evaluation of the orthodontic treatment effects for prominent lower anterior teeth in children and adolescents.	Orthodontic fixed appliance, chin cup, facemask, reverse headgear, bone-anchored appliance, or any other intra-oral or extra-oral appliance used to correct the prominent mandibular anterior teeth.	**Inclusion Criteria:** RCTs **Eligible:** 7 RCTs **Total:** 7	Not reported	One study reported a mean difference (MD) of 4.10 mm in overjet favoring the facemask over untreated controls. Regarding the ANB angle, three studies showed a statistically significant MD in favor of the facemask. One study reported that improvements in both overjet and ANB were still existing 3 years post-treatment. Two trials compared the chin cup with an untreated group. Both of them reported a statistically significant improvement in ANB. Moreover, one study reported an improvement in the Wits appraisal.
(Chatzoudi et al., 2014)	Evaluation of chin cup clinical effectiveness in growing patients presenting Class III malocclusion and/or open bite.	Chin cup alone or in combination with removable dis-occlusion or transversal expansion appliances	**Inclusion Criteria:** RCT, Prospective CCT, observational study. **Eligible:** Four prospective CCTs, one observational study. **Total:** 5	120 treated 64 control	Following chin cup treatment, the SNB and gonial angles decreased significantly, while ANB, Wits appraisal, SN-ML, N-Me, and overjet increased in comparison with untreated patients. However, no statistically significant differences were found regarding the rest of the variables.

Table 2.2 Continued

Authors	Aim	Appliance	Number and type of studies included	Total number of participants	Results
(Cordasco et al., 2014)	Estimation of the short-term efficacy of facemasks on the correction of Class III malocclusion.	Orthopaedic facemask	**Inclusion Criteria:** Only RCT studies **Eligible:** Three RCTs **Total:** 3	92 treated 63 controls	ANB increased by 3.66°; SNA increased by 2.1°, and SNB decreased by 1.54°. The results also showed that palatal plane angulation changes significantly during treatment, averaging −0.82° ($p = 0.04$; $Z = 2.01$). Moreover, significant clockwise rotation of the mandibular plane was found with a standard mean difference of 1.51° ($p < 0.01$; $Z = 3.28$).
(Yepes et al., 2014)	Determination of the optimal magnitude, duration, and direction that should be used in facemask treatment.	Protraction facemask	**Inclusion Criteria:** systematic review, meta-analysis, clinical trial, cohort, case-control, and cross-sectional studies **Eligible:** 12 Cohort studies, 2 RCTs **Total:** 14	483	Concerning magnitude, values ranging from 180 to 800 g per side were reported. Regarding force vector direction, there were values between 20° and 30° below or parallel to the occlusal plane. While the duration of use was ranging from 10 to 24 hours daily.