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MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

AETIOLOGY AND MANAGEMENT OF CLASS III MALOCCLUSION

Trabalho submetido por
Mariana Baptista Zanforlin
para a obtenção do grau de Mestre em Medicina Dentária

setembro de 2022

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Trabalho orientado por
Profª Doutora Iman Bugaighis

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This dissertation is dedicated to all that helped and supported me during this journey.

In special to my son Lucas, my husband Bernardo,

and all my close family and friends.

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And to my parents, especially my mother, who helped beyond measure to make this possible.

ABSTRACT

Class III malocclusion is characterized by a complex three-dimensional facial skeletal disparity between maxillary and mandibular growth patterns along with varying degrees of dentoalveolar and soft tissue compensations. In terms of severity, this malocclusion ranges from dentoalveolar abnormalities or functional anterior mandibular displacement to true skeletal problems with substantial maxillomandibular discrepancies. In addition, this condition can be aggravated by vertical growth problems.

Skeletal Class III malocclusions can be a result of retrognathic maxilla with a normal mandible both in position and in size, or prognathic mandible with a normal maxilla both in position and in size or a combination of retrognathic maxilla with prognathic mandible.

Although not very prevalent, skeletal Class III malocclusion represents a huge challenge in terms of therapeutic approach and post-treatment stability. Hence, to determine a realistic and appropriate management and the ideal treatment timing, it is essential to establish an accurate diagnosis. Moreover, a thorough understanding of craniofacial growth and development is required to estimate the remaining growth, especially when growth modification is envisioned.

The aim of this literature review was to provide an overview of Class III malocclusion, with emphasis on its aetiology and components. Evidence based approach and critical appraisal of the relevant literature in English and Portuguese languages between the years 1899 – 2021 were performed. Several search engines were employed such as Pubmed, google scholar Scielo, B-on, the Cochrane data base and relevant books on the subject. The following keywords were used throughout the research process: Class III malocclusion, aetiology, treatment, mandibular prognathism.

RESUMO

A maloclusão de Classe III caracteriza-se por uma complexa disparidade esquelética facial tridimensional entre o padrão de crescimento maxilar e mandibular, apresentando diferentes graus de compensações dentoalveolares e de tecidos moles. Em termos de gravidade, esta maloclusão varia desde anormalidades dentoalveolares ou deslocamento mandibular anterior funcional a verdadeiros problemas esqueléticos com discrepâncias maxilomandibulares substanciais. Além disso, esta condição pode ser agravada por problemas verticais de crescimento.

As maloclusões de Classe III esquelética podem ser resultado de uma maxila retrognata com uma mandíbula normal, tanto em posição como em tamanho, ou mandíbula prognata com uma maxila normal tanto em posição como em tamanho ou numa combinação de ambas.

Embora não muito prevalente, a maloclusão de Classe III esquelética representa um enorme desafio em termos de abordagem terapêutica e estabilidade pós-tratamento. Assim, para determinar uma terapia realista e adequada e o *timing* ideal para o tratamento, é essencial estabelecer um diagnóstico preciso. Além disso, é necessária uma compreensão aprofundada do crescimento e desenvolvimento craniofacial para estimar o crescimento remanescente, especialmente quando se pretende uma intervenção esquelética.

Esta dissertação tem como objetivo proporcionar uma visão geral da maloclusão de Classe III, com ênfase na sua etiologia e características. Foram realizadas abordagens baseadas em evidências e avaliação crítica da literatura relevante em língua Inglesa e Portuguesa entre os anos 1899 - 2021. Várias plataformas de busca foram utilizadas, como Pubmed, o académico do Google Scielo, B-on, Cochrane e livros relevantes sobre o assunto. As seguintes palavras-chave foram usadas durante todo o processo de investigação: maloclusão classe III, etiologia, tratamento, prognatismo mandibular.

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LIST OF ACRONYMS

Alt-RAMEC - Alternate Rapid Maxillary Expansion and Constriction
BAMP - Bone Anchored Maxillary Protraction
CO - Centric Occlusion
CR - Centric Relation
CVM - Cervical Vertebral Maturation
FOP – Functional Occlusal Plane
FR-III - Frankel Functional Regulator III
GTVR - Growth Treatment Vector Response
GWAS - Genome Wide Association Studies
MEAW - Multiloop Edgewise Arch Wire
mm - millimetres
N - Nasion
Or - Orbitale
PFM - Protraction Facemask
Po - Porion
Pog - Pogonion
Pog' - soft tissue Pogonion
RME - Rapid Maxilla Expansion
RTB - Reverse Twin-Block
S - Sella
SARPE - Surgical Assisted Rapid Palatal Expansion
TAD - Temporary Anchorage Device
TMJ - Temporomandibular Joint

I. INTRODUCTION

1. Literature review

Class III malocclusion is a high complex maxillofacial disorder, being considered by a large majority one of the greatest challenges in orthodontic management. This malocclusion can be related to a mandibular protrusion, maxillary retrusion or a combination of both (Clemente et al., 2018; Wendl et al., 2017).

Numerous predisposing characteristics might impact the prevalence of Class III malocclusion, such as ethnicity and regionality. Studies report an interval of global prevalence ranging from 0% to 26.7% for different populations (Woon &, Thiruvenkatachari, 2017; Zere et al., 2018). The highest prevalence was observed in Chinese and Malaysian populations at 15.7% and 16.6% respectively (Hardy et al., 2012). This wide range of occurrence, as well as disparities in percentages may have occurred due to ethnic variations among examined samples, setting of the investigation (school, dental or orthodontic clinics), timing of investigation and inclusive criteria (dental or skeletal) (Zere et al., 2018).

Class III malocclusion aetiology can be attributed to a plethora of factors related to both genetic inheritance and environment (Xue et al., 2010; Zere et al., 2018). Family heritage can have a high impact on the craniofacial skeletal size and shape. Recently, Genome-Wide Association Studies (GWAS) identified 53 genes linked to skeletal Class III malocclusion. The majority of those identified genes were related to cartilage and bone growth and development, whereas a small number was associated to skeletal muscle development (Gershater et al., 2021).

Severity of Class III malocclusion can vary significantly, being classified into three types according to Ngan & Moon (2015): dentoalveolar, pseudo and skeletal, making the diagnosis, the treatment timing and the type of management a challenge. Management of Class III malocclusion relies mainly on accurate diagnosis and the developing stage of the subject.

Treatment of Class III malocclusion might vary between comprehensive treatment or camouflage of the underlying malocclusion. This is undertaken in one or two phases of treatment and might require surgical intervention after growth completion. In some cases, a decision might be taken to delay the orthodontic treatment until the growth ceases and then undertake orthognathic surgical correction of the skeletal malocclusion with pre and post orthodontic phases (Proffit et al., 2018).

Numerous investigators recommended interceptive treatment during prepubertal growth to provide an appropriate dentoskeletal growth environment. Early intervention might lower the chance of future complex orthodontic treatment or orthognathic surgery (Woon & Thiruvenkatachari, 2017). On the other hand, this can be a dilemma as problems may still arise before the maxillary and mandibular growth cessation. Furthermore, long-term results of treatment might vary according to the individual course of growth (Zere et al., 2018). The results of such treatment are not always predictable, especially when the underlying aetiology is genetic in origin, where the mandible continues to grow and the only viable options will be orthognathic surgery or camouflage. The severity of Class III malocclusion in nongrowing individuals determines which of these approaches is more appropriate for the patient (Eslami et al, 2018).

Hence, the patient's age, main complaint and malocclusion severity, alongside with clinical examination and cephalometric analysis, are essential to establish precise diagnosis and consequently adequate and realistic treatment (Eslami et al, 2018).

Patients with moderate to severe skeletal Class III malocclusion may suffer from masticatory movements abruptness and discontinuity, with a decreased ability to chew food affectively. Furthermore, Class III malocclusion has been associated to oral health related disorders, such as myofascial pain, gastroesophageal reflux disease and myogenic temporomandibular disorders. In addition, due to visually unappealing traits, this malocclusion can lead to mental health problems, impacting self-esteem and compromising the quality of life (Gershater et al, 2021).

2. Research methodology

This literature review aimed to critically appraise the relevant literature published in English and Portuguese on the aetiology and orthodontic/orthognathic treatment options of Class III malocclusion using the following research engines, between 1899 and 2021:

Pubmed, google scholar Scielo, B-on, the Cochrane data base and relevant books on the subject. The key words used in this research process were: Class III malocclusion, aetiology, treatment, mandibular prognathism.

3. Aim of the literature review

This literature review provides an overview of Class III malocclusion, focusing on aetiology, components, and management to establish an accurate diagnosis and appropriate treatment.

II. LITERATURE REVIEW

1. Classification of malocclusion

A malocclusion represents a variation from what is considered aesthetically or functionally acceptable. Therefore, a thorough understanding of craniofacial growth and development and what defines an ideal occlusion is fundamental for an orthodontist. This knowledge will form the grounds for an appropriate management approach (Houston, 1992).

Various attempts to define the ideal occlusion have been made in the literature. Edward Angle (1899) was the first to develop a relevant concept of occlusion. He used the relative anteroposterior position of the first permanent molars to define normal occlusion and the dental arch relationship. Moreover, according to Angle (1899), establishing a good cuspal interdigitation is crucial to allow mutual support for the teeth in function.

Lawrence Andrews (1972) described six characteristics that should be present to have an ideal occlusion. These requirements are known as the six keys of normal occlusion (Table 1), which are currently employed by orthodontists to guide reaching the correct tooth position in terms of both aesthetics and dental health.

Table 1- Six keys of normal occlusion (Adapted from Cobourne and DiBiase, 2015).

ANDREW'S SIX KEYS OF OCCLUSION

KEY 1	Key 1 Molar relationship – the distal surface of the distal marginal ridge of the upper first permanent molar occludes with the mesial surface of the mesial marginal ridge of the lower second molar. The mesiobuccal cusp of the upper first permanent molar falls within the groove between the mesial and middle cusps of the lower first permanent molar.
KEY 2	Key 2 Crown angulation or mesiodistal tip – the gingival portion of the long axis of each tooth crown is distal to the occlusal portion of that axis. The degree of tip varies with each tooth type.
KEY 3	Key 3 Crown inclination or labiolingual/buccolingual torque – for the upper incisors the occlusal portion of the crowns labial surface is labial to the gingival portion. In all other crowns, the occlusal portion of the labial or buccal surface is lingual to the gingival portion.

KEY 4	Key 4 Rotations – there should an absence of any tooth rotations within the dental arches.
KEY 5	Key 5 Spacing - there should an absence of any spacing within the dental arches.
KEY 6	Key 6 Occlusal plane – the occlusal plane should be flat.

Angle (1899) defined the classification of malocclusions into classes I, II, and III based on the upper and lower first permanent molars inter-relationship in sagittal direction and the teeth alignment relative to the occlusion line (Figure 1).

In an ideal occlusion, the mesiobuccal cusp of the maxillary first permanent molar occludes in the buccal groove of the mandibular first permanent molar and the teeth are aligned on a smooth curved line of occlusion. (Angle, 1899; Littlewood & Mitchell, 2019; Proffit et al., 2018). Therefore, this anteroposterior position was the basis upon Angle (1898) defined his classification (Figure 1):

- Class I: normal molar relationship with teeth that are rotated or positioned incorrectly, resulting in an improper occlusion line.
- Class II: mandibular first molar occludes distally to the maxillary first molar, divided into maxillary incisors being either proclined or retroclined.
    - Division 1: maxillary incisors are labially inclined; and
    - Division 2: maxillary incisors are retroclined.
- Class III: mandibular first molar occludes mesially to the maxillary first molar.

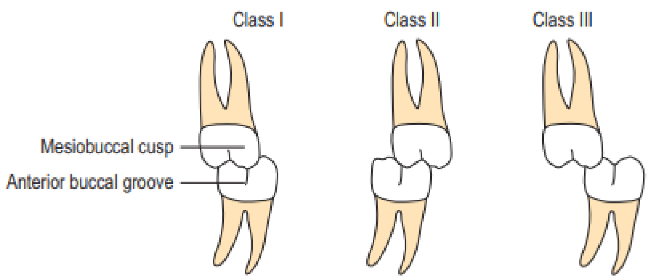

Figure 1 - The Angle molar classification (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 5, Copyright Elsevier).

In clinical practice, the severity of molar relationship can be described using tooth units, with increments of a half or even a third unit of classes relationship (Figure 2) (Cobourne and DiBiase, 2015).

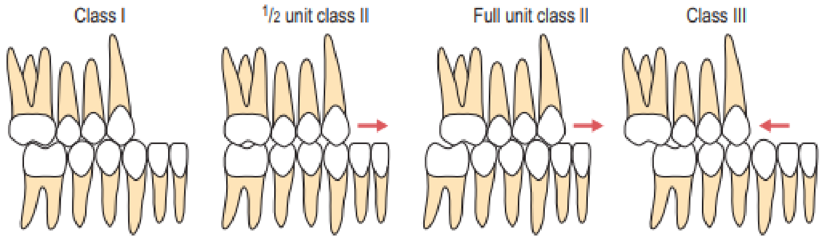

Figure 2 - The buccal segment occlusion can be defined in relation to the degree of mesial or distal occlusion and this is usually measured in units of tooth space (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 5, Copyright Elsevier).

Another anteroposterior occlusal classification is related to the canine relationship (Figure 2) (Cobourne and DiBiase, 2015; Proffit et al., 2018):

- Class I: upper permanent canine occludes directly in the embrasure between lower canine and first premolar.
- Class II: upper permanent canine occludes in front of the embrasure between lower canine and first premolar.
- Class III: upper permanent canine occludes behind the embrasure between lower canine and first premolar.

The severity of the upper and lower canine inter-relationship can also be expressed in terms of tooth units (Figure 2) (Cobourne and DiBiase, 2015).

In addition, there is a further relevant and useful classification related to the lower incisor's edges relationship with the upper central incisors' cingulum plateau, which will reflect the underlying skeletal base relationship. This classification is also divided into classes I, II (divisions 1 and 2) and III (Figure 3) (Cobourne and DiBiase, 2015; Proffit et al., 2018):

- Class I: the mandibular incisor tips occlude below the cingulum plateau of the maxillary incisors.
- Class II: the mandibular incisor tips occlude posterior to the cingulum plateau of the maxillary incisors. This classification is further subdivided into:

  - Division 1: upright or proclined maxillary incisors with increased overjet; and
  - Division 2: retroclined maxillary incisors with a normal or increased overjet.
- Class III: the mandibular incisor tips occlude anterior to the cingulum plateau of the maxillary incisors.

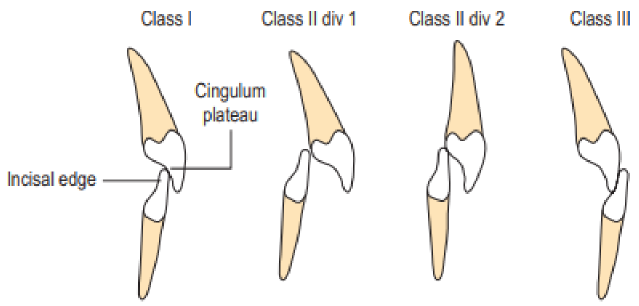

Figure 3 - Incisor classification (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 6, Copyright Elsevier).

For patients with an underlying skeletal discrepancy, a specific malocclusion classification system was established, which in most cases correspond to the dental classification system, yet both must be evaluated individually (Houston, 1992).

Skeletal classification is based on sagittal maxillomandibular relationship and is also categorized into classes I, II and III patterns. Skeletal Class I relationship is considered the ideal sagittal position between maxilla and mandible, reflecting a straight or slightly convex profile. Skeletal Class II relationship is a result of prognathic maxilla or retrognathic mandible or combination of both, which leads to a convex profile depending on the extent of the discrepancy. On the other hand, skeletal Class III relationship occurs due to prognathic mandible or retrognathic maxilla or combination of both, leading to a concave facial profile (Figure 4) (Houston, 1992).

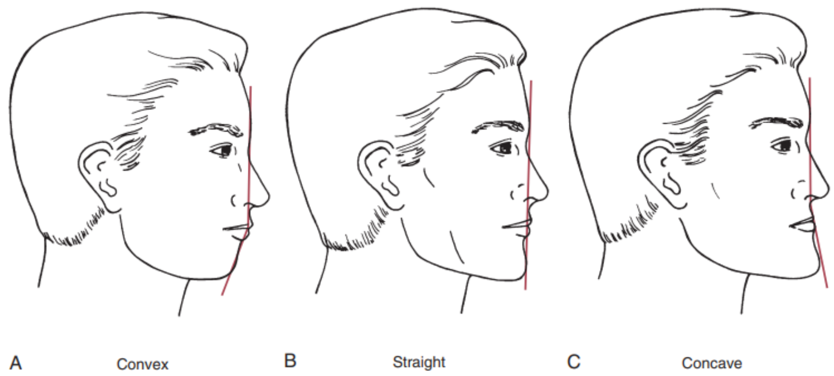

Figure 4 - Facial profile based on sagittal maxillomandibular relationship (A) A convex facial profile indicates a Class II jaw relationship (B) A straight or slightly convex profile is normal and usually reflects a normal jaw relationship. (C) A concave profile indicates a Class III jaw relationship (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 155, Copyright Elsevier).

2. Craniofacial growth and development

Orthodontists are actively involved in the development of not just the dentition but the complete dentofacial complex. A thorough understanding of craniofacial growth and development is essential for orthodontists to be capable of evaluating the developmental status and assessing the remaining growth. Individual differences in growth varies depending on sex, ethnicity and heredity (Proffit et al., 2018).

Furthermore, malocclusion can be prevented in specific situations by understanding how occlusion varies during growth and development. Early intervention might provide the proper environment for normal occlusion to develop (Kim et al., 2009).

The face develops forward and downward away from the cranial base as it grows larger. The calvarium, cranial base, maxilla, and mandible all grow at different times and at different rates and are influenced by many genetic and environmental variables. A balanced pattern of face development is required for a harmonious facial form. Alteration in facial development can lead to variations in facial form and jaw relationships (Littlewood & Mitchell, 2019).

The growth of the brain determines facial development in the first few years of life. The calvarium, eyes, and the bone orbits that surround and protect the eyes are all rapidly growing. This slows until around the age of seven, when the growth of this area is nearly completed. Compared to an adolescent or an adult, a child's face occupies a substantially smaller area of the skull (Littlewood & Mitchell, 2019; Proffit et al., 2018).

The 'pubertal growth spurt' is a period of accelerated development during puberty. Although there is significant variation in the timing of the pubertal growth spurt, this is reported to occur around the age of 10–12 years old in girls and 12–15 years old in boys. The maxilla follows a pattern of growth closer to neural growth and declines to adult levels around the age of 12 whereas the mandible develops in a manner that is more intimately linked to the rest of the body (somatic growth) (Littlewood & Mitchell, 2019; Proffit et al., 2018).

Somatic growth accelerates throughout puberty and continues until about the ages of 16 for girls and 18–20 for boys, when development slows to adult levels. Facial growth never entirely ends, but it slows down to adult levels, resulting in minor long-term alterations (Littlewood & Mitchell, 2019).

The cranial base develops by endochondral ossification. The brain is responsible for the majority of cranial base growth, with half of postnatal growth completed by the age of 3. As the brain increases in size, sutural infilling and remodelling is present alongside with synchondroses; cartilaginous growth sites in the cranial base. Also, the spheno-occipital synchondrosis contributes significantly to the development of the cranial base during childhood, fusing at ages 11-14 in females and 14-16 in males (Littlewood & Mitchell, 2019; Proffit et al., 2018).

Growth at the spheno-occipital synchondrosis, which is located between the anterior cranial base and the Temporomandibular Joint (TMJ), influences the overall skeletal pattern, being responsible for lengthening the cranial base and consequently moving the TMJs and the lower jaw further back, away from the maxilla. Therefore, anteroposterior growth at this synchondrosis site affects the anteroposterior relationship of the jaws, which is also influenced by the cranial base format and angle. A Class III skeletal pattern is more likely to be produced by a small or acute angle while a larger or more obtuse angle produces a class II skeletal pattern (Figure 5) (Littlewood & Mitchell, 2019; Proffit et al., 2018).

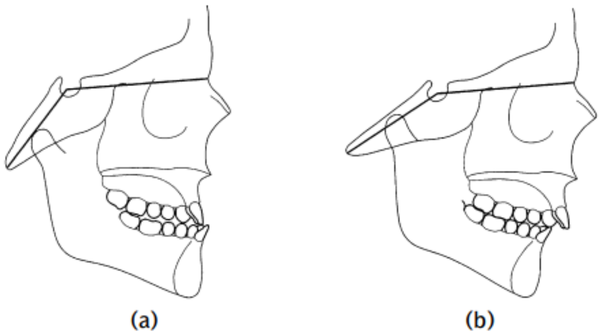

Figure 5 - (a) Acute cranial base angle associated with Class III skeletal pattern. (b) obtuse cranial base angle associated with a Class II skeletal pattern (from *An Introduction to Orthodontics*, Littlewood & Mitchell, 2019, 5th edition, page 42, Copyright Laura Mitchell and Simon Littlewood, 2019, reproduced with permission of the Licensor through PLSclear).

The nasomaxillary complex interconnectedly includes the maxilla, zygomatic, palatal, vomer, ethmoid and nasal bones, with a further linkage through sutures to the anterior cranial base. The maxillary complex develops postnatally entirely through intramembranous ossification and its growth influences upper teeth position relative to the lower teeth, as well as the final maxillary position and facial appearance. There are two primary mechanisms responsible for this complex growth (Figure 6): (1) passive displacement, which is caused by cranial base growth pushing the maxilla forward; and (2) active growth of the maxillary sutures. Most of the development after the age of 7 years, when cranial base growth stops, is attributed to active growth at the maxillary sutures and surfaces (Pinzan et al., 2006; Proffit et al., 2018).

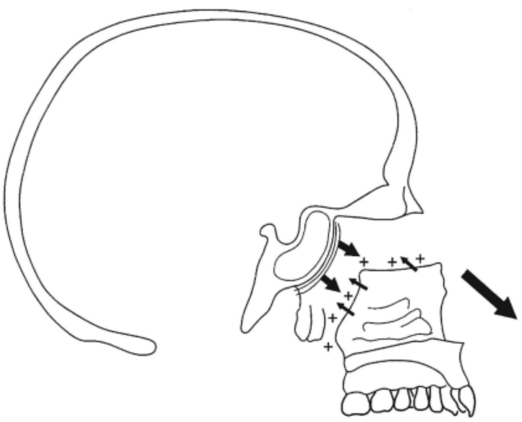

Figure 6 - Forward and downward displacement of the maxilla complex associated with deposition of bone at sutures (from *An Introduction to Orthodontics*, Littlewood & Mitchell, 2019, 5th edition, page 43, Copyright Laura Mitchell and Simon Littlewood, 2019, reproduced with permission of the Licensor through PLSclear).

Forward displacement of the maxillary complex permits the maxilla to develop backwards, lengthening the dental arch posteriorly in the area of the tuberosities and allowing permanent molars to emerge. Downward growth is also resulted by drift of the hard palate and vertical development of the alveolar processes as the teeth erupt and complete root formation. Additionally, the two halves of the maxilla are displaced and infilled at the mid-palatal suture, resulting in lateral expansion (Littlewood & Mitchell, 2019; Proffit et al., 2018).

The shape of the bones of the midfacial skeleton is maintained and developed by complex patterns of surface remodelling. Surface alterations, such as apposition or resorption, can either add to or remove from growth at the sutures. In fact, the maxilla expands downward and forward due to bone apposition in both the tuberosity area and the superior and posterior sutures, concurrently with the resorption in the anterior surfaces of the bone (Mattos & Quintão, 2003; Proffit et al., 2018).

Different than the nasomaxillary complex, both endochondral and periosteal activities are crucial in mandible growth. In addition, the temporomandibular joint displacement caused by cranial base growth plays a minor role (Proffit et al., 2018).

Cartilage covers the mandibular condyle surface at the temporomandibular joint, occurring hypertrophy, hyperplasia and endochondral replacement. The other areas of the mandible are formed and developed by direct surface apposition (modelling) (Figure 7) (Proffit et al., 2018).

The mandible angle and the coronoid process format evolve in response to forces from the attached muscles. The alveolar processes contribute to vertical growth with the eruption of the teeth. Further, the mandible is dislocated forward by the growth of the tongue. As the ramus remodels, it moves backward, lengthening the dental arch posteriorly and creating room for the permanent molars to emerge. Remodelling enlarges the width of the mandible posteriorly and the chin appears to be more prominent after mandible lengthening and remodelling (Figure 7) (Littlewood & Mitchell, 2019; Slaviek, 2002).

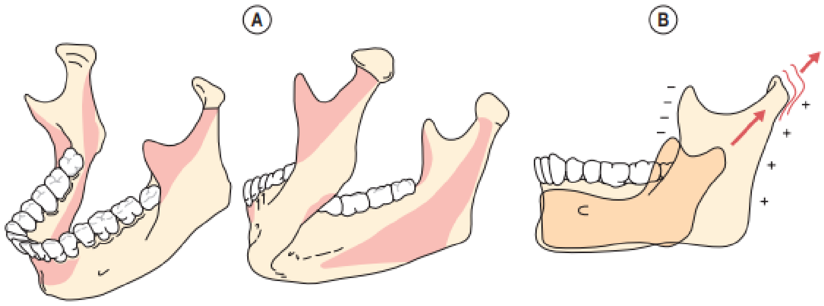

Figure 7 –Mandibular growth. (A) Surface remodelling. Resorptive surfaces are represented by dark shading and depository surfaces are unshaded (B) Elongation of the condyle (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 93, Copyright Elsevier).

Predict how the facial growth of any individual child will progress helps to plan future orthodontic treatment. Although attempts to predict future facial growth from cephalometric radiographs measurements have had mixed results, assessment of height and secondary sex characteristics can also be used to determine if the patient has commenced and completed pubertal growth spurt, being crucial when growth modification therapy is considered (Littlewood & Mitchell, 2019).

The stage of bones maturation on hand–wrist radiographs have been used to indicate the onset of puberty, yet the association with jaw growth has been found to be weak. More success has been achieved by assessing cervical vertebrae maturation on lateral cephalograms. Even using these additional examinations, it is still not viable to determine facial growth rate and extent precisely (Littlewood & Mitchell, 2019).

Information on growth and development in different types of malocclusions and dentoskeletal disharmonies is required to determine appropriate therapy and to predict growth patterns in patients with the same type of malocclusion (Littlewood & Mitchell, 2019; Proffit et al., 2018).

3. Class III malocclusion

3.1. Prevalence of Class III malocclusion

The prevalence of Class III malocclusion varies significantly among and within different ethnic groups, races, and geographic regions, with studies showing an interval of global prevalence ranging from 0% to 26.7% for different populations (Tables 2 and

3) (Hardy et al., 2012; Woon & Thiruvenkatachari 2017; Zere et al., 2018). The highest prevalence was observed in Chinese and Malaysian populations at 15.7% and 16.6% respectively while Indian populations showed the lowest prevalence, 1.19% (Hardy et al., 2012). This wide range of prevalence, as well as rate disparities was potentially driven by ethnic variations from examined samples, setting of the investigation (school, dental or orthodontic clinics), timing of investigation, inclusive criteria (dental or skeletal) (Zere et al., 2018).

Further, from a global viewpoint, the Middle East presented a prevalence of 10.18% for its population, being 1.3% for Israeli Arabs, 15.2% for Iranians, from 10.30% to 11.5% for Turkish and from 4% to 11.38% for Egyptians (Hardy et al., 2012).

Hispanics showed a higher degree of prevalence of Class III than Caucasians or Africans. For Caucasians, the reported prevalence ranged between 3% and 5%. While for Africans, the observed prevalence rate was 4.59%, varying between 1% and 16.8% for countries like Nigeria, Kenya and Tanzania. Further, Americans and Mexican Americans presented prevalence rates of 9.1% and 8.3%, respectively (Ast et al., 1965; Goose et al., 1957; Huber & Reynolds, 1946; Massler & Frankel, 1951; Newman, 1956).

Prevalence of 5% was observed in Latin population and from 2% to 6% in European population**.** A range from 3% to 5% has been observed for the United Kingdom and Scandinavia white population, with around 6% for Sweeden (Prabhat et al., 2013; Thilander & Myrberg, 1973).

The Class III malocclusion incidence was about 5% for Caucasian Americans while for US African-American population was from 3% to 6%. Similar researches of different ethnicities found that Class III malocclusion was prevalent in roughly 3% of Brazilians, 14% of Syrians, 3,7% in Libyans and 9.4% of Saudi Arabians (Bugaighis and Karanth, 2013; Da Silva Filho et al., 1990; Mouakeh & Sulaiman, 1996; Toms et al., 1989).

Table 2- Reported prevalence of Class III malocclusion globally and in different continents (Adapted from Zere et al., 2018).

Continents	Prevalence (%)
Globally	0-26.7
East Asian	4-14
Southeast Asian	15.80
African	4.59
Middle eastern	10.18
Indian	1.19
European	4.88 (2-6)
Northern European	0.8-4.2
American	5

Table 3- Reported prevalence of Class III malocclusion among different nationality groups (Adapted from Zere et al., 2018).

Nationality	Prevalence (%)
Chinese	15.69
Malaysian	16.59
Japanese	2.3-14
Korean	9-19
Taiwanese	1.65
Indian	0-4.76
Israeli Arabs	1.30
Iranians	15.20
Turkish	10.30
Egyptians	11.38
Tanzanian	1.81-19.72
Nigerian	1.22-11.79
United Kingdom	3-5
Scandinavian	3-5
Swedish	6

Brazilian	3-5
Saudi Arabian	9.40
African Americans	3-6
European Americans	0.80
Latino Americans	9.10
Mexican Americans	8.30
Italians	5
German	2.80
Belgian	6
British	2.0
Danish	4.30
Polynesian	5.50
Syrian	14.0
Lebanese	5.10

3.2. Aetiology of Class III malocclusion

Class III malocclusion, like other malocclusions and dentofacial deformities, has a complex and multifactorial aetiology, being caused by a distortion of normal development. Class III malocclusion manifests from a conjunction of the environment with innate or inherited hereditary elements (Xue et al., 2010; Zere et al., 2018).

According to Proffit et al. (2018), when assessing malocclusion, the factors impacting aetiology should be evaluated within three main areas: specific causes, heritage and environment, with an interaction of the last two being responsible for most malocclusions.

Until recently, studies with monozygotic (identical) and dizygotic (fraternal) twins contributed to understanding the extent of influence of genetic aspects on the occurrence of malocclusion, noting that environmental influence is not always the same (Townsend et al, 2008).

Family heritage can have a high impact on the craniofacial skeletal size and shape. Genome-Wide Association Studies (GWAS) identified 53 genes linked to skeletal Class

III malocclusion. The majority of those genes were related to cartilage and bone growth and development, whereas a small number was associated to skeletal muscle development (Gershater et al., 2021).

Further, researches have evidenced that inheritance has a major influence on mandibular growth, being mandibular prognathism recurred over multiple generations. The heritage nature of mandibular prognathism was first observed by Strohmayer in 1937 as reported by Wolff et al. in their dissertation of the Hapsburg family (Ngan &, Moon, 2015).

Controversy exists over Class III malocclusion transmission patterns. Some researchers state that the transmission is autosomal recessive (Huang et al.,1981), while others assert that it is autosomal dominant with penetrance, either complete or incomplete (Cruz et al., 2008). There is a third line that believes in the polygenic transmission (Dehesa-Santos et al., 2021; Zere at al., 2018).

Environmental factors also contribute to Class III malocclusion, such as habits related to the mandibular posture. These alter the position of the mandibular condyle in the fossa, and a consequential forward final spatial position of the mandible (Ngan & Moon, 2015; Rakosi & Schilli, 1981).

Altered shape and size of the pharyngeal airway such as enlarged tonsils can also lead to Class III malocclusion. According to Grippaudo et al (2016), upper airway obstruction causes mouth breathing, which may alter the pattern of craniofacial growth and result in malocclusion. A mouth breather child might have an open mouth posture, a low-positioned tongue, and excessive mandibular development. Additionally, the absence of tongue pressure on the palate can result in a Class III malocclusion with a decreased or inverted overjet, and a sagittal and transverse maxillary skeletal deficit.

Srinivasan and Chitharanjan (2013) and Ihan Hren and Barbic (2016) asserted that the development of soft tissue has a significant influence on the development of hard tissue. This functional matrix hypothesis was highlighted previously by Moss (1962). Therefore, the mandible and maxillary growth might be influenced by the tongue posture and size, which are important etiological variables in the development of malocclusions. According to Primozic et al. (2013), Class III individuals have a significantly lower tongue posture compared to Class I individuals. Additionally, premature loss of the first molars, trauma, irregular eruption of permanent incisors and early loss of deciduous incisors can also contribute to Class III malocclusion (Harris, 1993).

Specific factors, such as congenital anatomic defects (cleft lip and cleft palate), can lead to Class III malocclusion as well (Proffit et al., 2018). Moreover, according to Cobourne and DiBiase (2015) and Sugawara et al. (2016), Class III malocclusion can be aggravated by overproduction of growth hormone, an issue that can lead to gigantism in children or acromegaly in adults.

3.3. Component of Class III malocclusion

Class III malocclusions can be classified into true Class III malocclusion, pseudo-Class III malocclusion and Class III subdivision:

- True Class III malocclusion refers to skeletal Class III with bilateral Class III molar relationship and anterior crossbite or edge to edge incisal relationship (Cobourne and DiBiase, 2015).
- Pseudo-Class III malocclusion refers to skeletal class I with bilateral class I molar relationship and anterior crossbite or edge to edge incisal relationship due to functional anterior mandibular displacement (Rabie and Gu, 2000).
- Class III subdivision (asymmetry) refers to Class III molar relationship on one side (subdivision) and class I molar relationship on the other (Janson et al., 2010).

Several factors can result into True Class III malocclusions (Figure 8) (Zere et al., 2018):

1. retrognathic maxilla and a normal mandible in size and in position (25%);
2. prognathic mandible and a normal maxilla in size and in position (18.7%);
3. retrognathic maxilla and prognathic mandible in combination (22.2%).

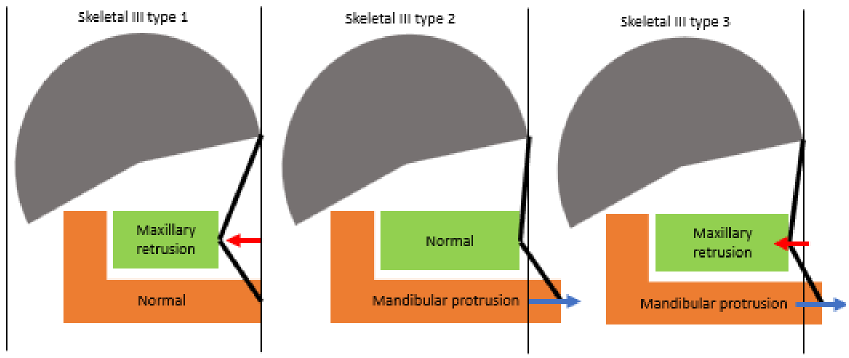

Figure 8 - Types of true Class III malocclusion (Adapted from www.indiandentalacademy.com).

Skeletal characteristics such as diminished saddle angle, shortened cranial posterior and anterior base, and enlarged gonial angle lead to Class III malocclusion, as they all are aspects of a forward positioning of the glenoid fossa (Baccetti et al., 1997; Innocenti et al., 2009; Ngan et al., 1997; Zegan et al., 2015).

Posterior crossbite is another typical feature of skeletal Class III malocclusion, which is often present due to the transverse skeletal deficiency of the maxilla or due to its relative anteroposterior position in relation to the mandible (Cobourne and DiBiase, 2015; Proffit et al., 2018).

Class III malocclusion is associated with a wide range of vertical skeletal proportions. A backward opening rotation pattern of facial growth lessens overbite and accentuates lower face height, leading to a less mandibular forward projection, whereas a forward rotating pattern results in a greater prominence of the chin (Littlewood & Mitchell, 2019). Additionally, mandibular prognathism is related to increased lower facial height, while maxillary retrusion is normally associated with decreased lower facial height (Cobourne et al., 2012).

It can be observed several dental features in Class III individuals, including Class III molar and canine relationship and Class III incisor relationship with edge-to-edge bite or anterior crossbite (Cobourne et al., 2012; Guyer et al., 1986; Zere et al., 2018).

Maxillary and mandibular incisors tend to be inclined towards each other by soft tissues, resulting in a less severe incisor relationship than the skeletal discrepancy. Hence, dental compensation may occur in Class III malocclusions due to anterior oral seal, being achieved by lip contact and moulding the upper and lower labial segments towards each other. However, in patients with increased vertical skeletal proportions the lips are more likely to be incompetent and anterior oral seal is frequently achieved through tongue-to-lower-lip contact, resulting in less dental camouflage (Littlewood & Mitchell, 2019).

Class III malocclusion exhibits soft tissue characteristics such as an obtuse nasolabial angle and a concave facial profile (Jin-jong, 2008). In addition, the lower lip may be full with a thin upper lip (Cobourne and DiBiase, 2015; Guyer et al., 1986).

Pseudo-Class III malocclusion is related to a deflection of the mandible forward as a result of premature dental contacts, allowing full intercuspation. In Centric Relation (CR) it can be observed a Class I skeletal pattern, orthognathic profile and Class I molar relationship, while in Centric Occlusion (CO) there will be a Class III skeletal and dental pattern (Rabie & Gu, 2000).

Class III malocclusion severity varies significantly, making the diagnosis, the timing of treatment and the type of management a challenge. Management of Class III malocclusion relies mainly on accurate diagnosis and the developing stage of the subject.

Taking into account this severity variance, two types of classifications are presented in literature. Classification based on overjet, including (Proffit et al., 2006):

- Mild Class III: 0mm
- Moderate Class III: -1 to -2mm
- Severe Class III: -3 to -4mm
- Extreme: > - 4mm

There is another classification, which is based on the magnitude of the ANB angle and includes (Kerr et al., 1992):

- Mild Class III: > -2º
- Moderate Class III: -2º to -4º
- Severe Class III: < -4º

4. Diagnosis of Class III malocclusion

Class III malocclusions range in severity from dentoalveolar abnormalities or functional anterior mandibular displacement to real skeletal problems with substantial maxillomandibular discrepancies. Additionally, the condition can be aggravated by vertical growth problems. A systematic approach to diagnose Class III malocclusions may assist in determining the appropriate treatment and the ideal time to begin therapy, identifying patients who may benefit from early orthodontic treatment. This is represented in the diagnosis and treatment schematic presented in Figure 16 in the Treatment Planning section (Ngan, 2006; Zere et al., 2018).

The proper diagnosis entails patient interview, examination and the collection of adequate records. This can be achieved via the assessment of dental and medical history, orthodontic records and cephalometric analysis, as well as clinical examination (extra and intra oral) (Cobourne and DiBiase, 2015).

The maxillomandibular position, as well as if the jaws are proportionately positioned in the anteroposterior dimension, should all be considered when assessing the profile. Place the patient in natural head position and draw an imaginary line extending from the upper lip base to the nasal bridge, then draw another imaginary line from the upper lip base down to the chin. As a result, in young individuals a straight or concave profile implies a skeletal Class III jaw relationship (Ngan, 2004).

There must also be an analysis of the transverse dimension in order to assess dental or facial asymmetries. In addition, it is crucial to examine the TMJ, oral musculature, and intraoral hard and soft tissue (Zere et al., 2018).

For dental assessment, it is important to check if the Class III molar relationship coexist with a negative overjet. According to Ngan (2006), a positive overjet or edge-to-edge incisors relation associated with retroclined lower incisors usually denotes a Class III malocclusion compensated form.

Orthodontic records are required to support diagnosis, monitoring of growth and development, as well as for medico-legal purposes. They provide an accurate representation of the patient before starting orthodontic treatment, show progress of the chosen therapy and enable interaction between orthodontists, patient and other healthcare professionals. Orthodontic records include study models, clinical photographs and radiographs (Cobourne and DiBiase, 2015).

In terms of cephalometric assessment, it may provide useful information to assist establishing the aetiology of malocclusion and planning treatment. It may also be helpful to monitor growth with serial cephalometric radiographs in order to optimize the planning and timing of treatment. However, the additional radiation dosage to the patient must be justified, and alternate growth monitoring techniques that do not require ionizing radiation should be employed wherever possible (Cobourne and DiBiase, 2015; Ngan, 2004; Ngan, 2006).

The skeletal pattern is frequently cephalometrically established via the relationship between the maxilla and mandible with the cranial base (line from Sella - S to Nasion - N) by means of angles SNA (81º ± 3º) and SNB (78º ± 3º), where points A and B denotes maxillary and mandibular basal bone (Figure 9 and Table 4). Reduced SNA angle and increased SNB angle are indicators of retrognathic maxilla and prognathic mandible, respectively (Zegan et al., 2015). Further, ANB angle (ANB = SNA – SNB) measures the position of the maxilla relative to the mandible, being classified as indicated in table 5 (Cobourne and DiBiase, 2015, Littlewood & Mitchell, 2019).

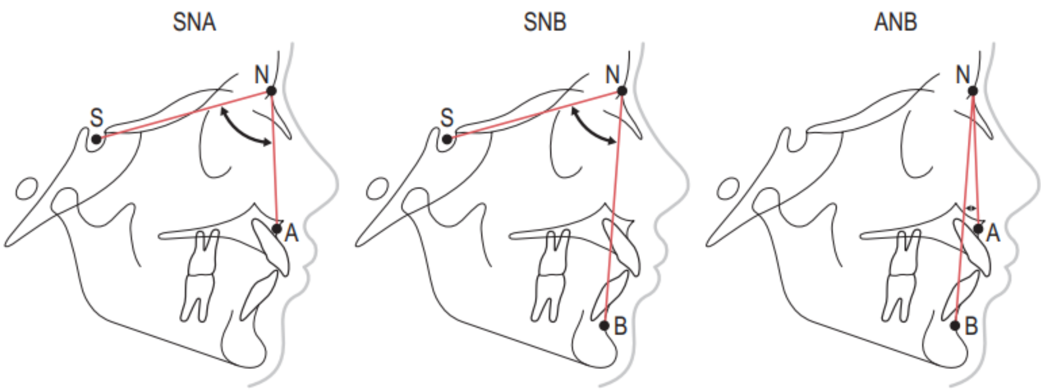

Figure 9 - Types of SNA, SNB and ANB angles (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 199, Copyright Elsevier).

Table 4- Cephalometric normal values for different racial groups (Adapted from Cobourne and DiBiase, 2015).

Cephalometric value	Caucasian	African-American	Arabic	Japanese
SNA	81 ± 3	87 ± 5	81 ± 4	82 ± 3
SNB	78 ± 3	82 ± 4	78 ± 3	79 ± 3
ANB	3 ± 2	5 ± 2	3 ± 2	3 ± 2

Table 5- Classification of anteroposterior skeletal pattern using the ANB angle (Adapted from Littlewood & Mitchell, 2019).

Classification of ANB angle	
ANB < 2^o	Class III
2^o ≤ ANB ≤ 4^o	Class I
ANB > 4^o	Class II

The disadvantage of employing these measurements is that angles SNA and SNB are affected by changes in nasion position (especially anteroposterior shifts), consequently impacting ANB (Figure 10). Furthermore, modifications in incisor root position may have an impact on points A and B (Ngan & Wei, 2004; Stellzig-Eisenhauer, 2002).

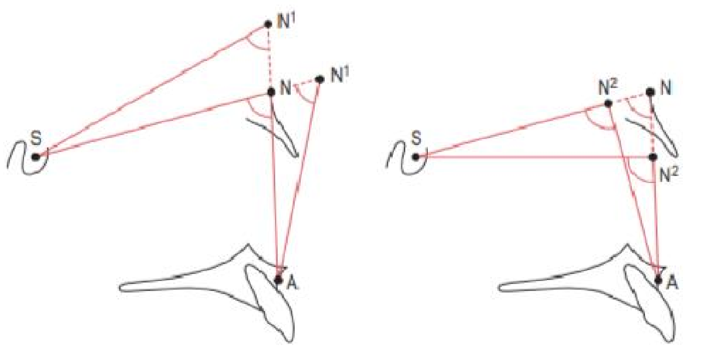

Figure 10 - Anterior or superior positioning of nasion (N1) will reduce the SNA angle, while posterior or inferior positioning (N2) will increase the SNA angle. Both these changes will influence the ANB angle (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 200, Copyright Elsevier).

Another popular cephalometric technique for evaluating anteroposterior jaw relations arises from the McNamara analysis. A line is drawn inferiorly from the Nasion perpendicular to the Frankfort plane (from Porion- Po to Orbitale- Or) and this can be used to estimate maxillary and mandibular positions using point A and Pogonion (Pog), respectively (Figure 11 and table 6) (McNamara, 1984; Ngan & Wei, 2004; Stellzig-Eisenhauer, 2002).

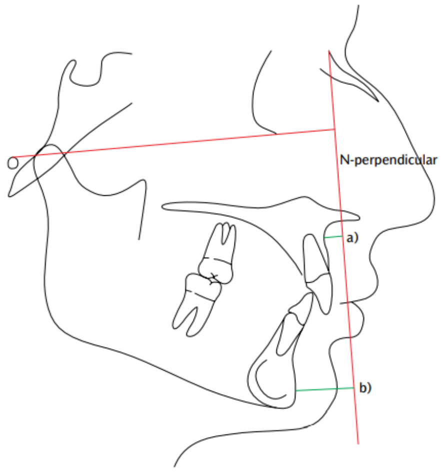

Figure 11 - Anterioposterior skeletal relationship assessed using nasion perpendicular (from *An Introduction to Orthodontics*, Littlewood & Mitchell, 2019, 5th edition, page 78, Copyright Laura Mitchell and Simon Littlewood, 2019, reproduced with permission of the Licensor through PLSclear).

Table 6- Classification of anteroposterior average values for anteroposterior assessment using nasion perpendicular (Adapted from Cobourne and DiBiase, 2015).

	Composite norm
Point A to nasion perpendicular	0 mm (mixed dentition)
Point A to nasion perpendicular	+1 mm (adult)
Pogonion to nasion perpendicular	-8 to -6 mm (mixed dentition)
Pogonion to nasion perpendicular	-2 mm to -4 mm (adult)

The main drawback of using the nasion perpendicular arise from location of the Frankfort plane and the potential variation in the position of the nasion. Alternatively, a method that avoids the cranial base and nasion, such as the Wits analysis, can be utilized, especially when the cephalometric results conflict with the clinical assessment (Oltramari et al., 2005).

Wits analysis compares the relationship of the maxilla and mandible with the occlusal plane, which is a line drawn between the cusp tips of the molars and premolars (or deciduous molars), known as the FOP. Perpendicular lines from both point A and point

B are drawn to the FOP providing points AO and BO. Then, the distance between AO and BO is calculated (Figure 12). According to Ngan & Wei (2004), the average values are −1 mm (± 1.9 mm) for males and 0 mm (± 1.77 mm) for females. Additionally, in Class III discrepancy, BO is significantly ahead of AO.

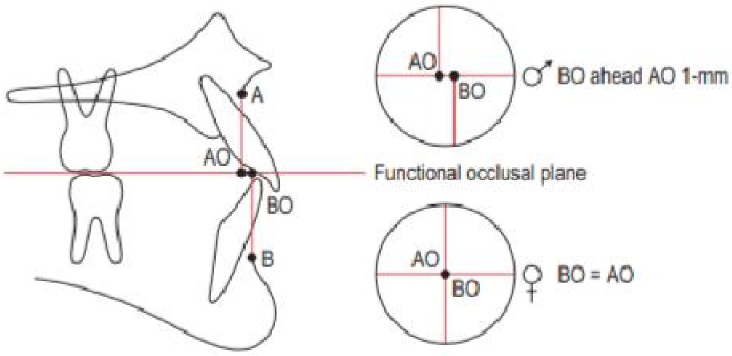

Figure 12 - Wits method. BO should lie 1mm ahead of AO for males, while AO and BO should coincide for females (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 201, Copyright Elsevier).

The Wits analysis downside is the difficulty in locating the FOP, which reduces its accuracy and reproducibility. A minor variance in the angulation of the FOP can noticeably influence the relative positions of AO and BO (Ngan & Wei, 2004).

Careful analysis of soft tissues is crucial, especially when changes in incisor position are intended and when diagnosis and planning are being executed prior to orthognathic surgery. A lateral skull cephalometric radiograph shows the soft tissue profile, and numerous techniques for measuring it have been described, including nasolabial angle, Ricketts' E-line and Holdaway line (Guyer et al., 1986).

The nasolabial angle is formed between the upper lip and base of the nose and should be between 90° and 110°. A high or obtuse nasolabial angle suggests a retrusive upper lip, which might be associated with Class III malocclusion, whereas a low or acute angle is related with lip protrusion. Lip protrusion varies according to ethnicity, with Africans presenting more protrusion than Caucasians (Guyer et al., 1986; Littlewood & Mitchell., 2019). In addition, the Ricketts' E-line is a line drawn from tip of the nose to soft tissue Pogonion (Pog') (Figure 13). In a balanced face, the upper lip should be 4 mm and the lower lip 2 mm behind this line, which is age-related, as the lips are prone to become more retrusive with age (Guyer et al., 1986).

Further, the Holdaway line is a line drawn from Pog' to the upper lip. In a well-proportioned face, this line, if extended, should bisect the nose (Figure 13) (Guyer et al., 1986). The H angle is another measurement that can be driven from the Holdaway line in conjunction with the facial plane (the line between the soft tissue nasio and the soft tissue chin), meaning that its values are influenced by the skeletal convexity. According to Holdaway, a balanced face has a H angle ranging from 7^{o} to 15^{o}, with decreased values associated with Class III malocclusion (Littlewood & Mitchell., 2019).

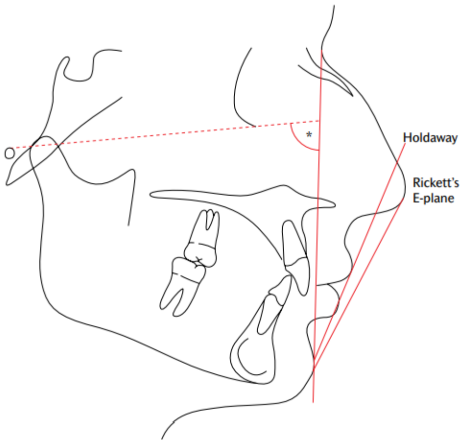

Figure 13 - Ricketts' E-line and Holdaway line (from *An Introduction to Orthodontics*, Littlewood & Mitchell, 2019, 5th edition, page 81, Copyright Laura Mitchell and Simon Littlewood, 2019, reproduced with permission of the Licensor through PLSclear).

5. Assessment of growth and prognosis in Class III patients

Knowledge about growth trends is critical for successful planning and prediction of treatment outcome and long-term stability in Class III patients under development.

Early interceptive treatment has always been discussed between orthodontists and patients. Due to the non-predictable nature of growth, it is recognized that some problems will not be resolved until development is complete, with long-term outcomes depending on individual's growth tendency, regardless of treatment approaches. However, early intervention has been practiced with increasing interest as an attempt to allow normal skeletal growth, reducing the extent or severity of future orthodontic treatment and avoiding orthognathic surgery (Woon &, Thiruvenkatachari, 2017).

An evaluation of skeletal age is frequently required when planning orthodontic treatment, since it is crucial to determine how much skeletal growth is remaining and the adolescent growth spurt in order to establish the best treatment timing. According to Wells et al. (2006), growth modification therapy is more likely to be successful if it is done before the pubertal growth spurt.

Formerly, hand and wrist radiographs were widely used to estimate skeletal age by visually assessing the stages of bone calcification in the hand, wrist and fingers. Nevertheless, there was concern about the radiation exposure required to obtain the radiographs (Alkhal et al., 2008). As a result, the British Orthodontic Society declared the evaluation of skeletal age from hand and wrist radiographs to be contraindicative (Isaacson &Jones, 1994).

Another method to measure skeletal age is based on the cervical vertebrae as observed in cephalometric radiograph (the Cervical Vertebral Maturation - CVM method) (Figure 14). Because cephalometric radiographs are frequently taken for orthodontic patients, this method has the benefit over hand–wrist radiographs in that no additional radiation exposure are required. Moreover, CVM is a stronger predictor for the time of the adolescence growth spurt than chronologic age, according to the existing data. However, caution has to be taken in Class III malocclusion due to mandibular prognathism, as the mandibular growth tend to continue one year more than in class I individuals (Baccetti et al, 2007; Proffit et al., 2018). In addition, Baccetti et al. (2005) suggested that maximum mandible growth occurs in CS3 to CS4 and minimum amount in CS5- CS6 (Figure 15).

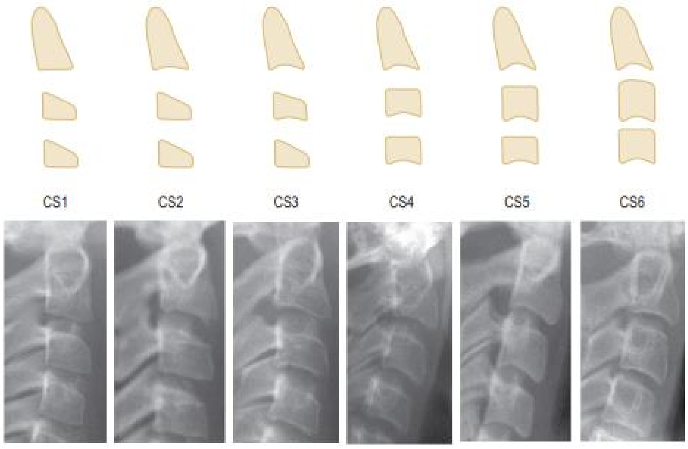

Figure 14 - Schematic representation of cervical vertebrae maturation based upon morphology of C2-4 bodies. CS1, the lower borders of C2-4 are all flat and both C3 and C4 are trapezoid; CS2, a concavity is present in the lower border of C2, while C3 and C4 remain trapezoid; CS3, concavities are present in the lower borders of C2 and C3, the bodies of C3 and C4 may be either trapezoid or rectangular horizontal; CS4, concavities are present in the lower border of C2, C3 and C4, the bodies of C3 and C4 are rectangular horizontal; CS5, concavities in the lower borders of C2, C3 and C4 are still present, at least one of C3 or C4 is now square; CS6, concavities in the lower borders of C2, C3 and C4 are still present, at least one of C3 or C4 is now rectangular vertical in shape. (From *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 104, Copyright Elsevier).

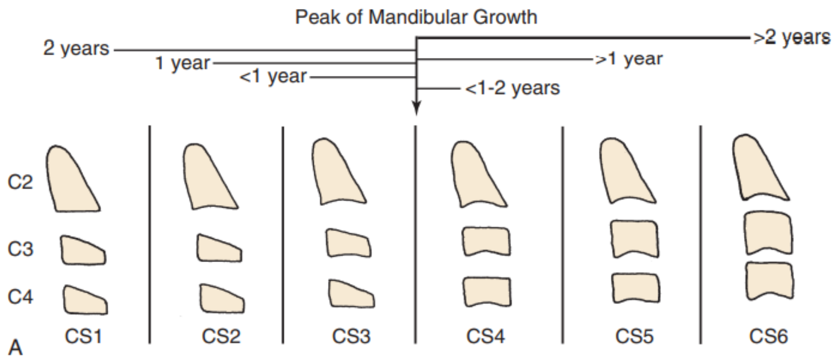

Figure 15 - Vertebral ages calculated from the image of the cervical vertebrae seen in a lateral cephalometric radiograph. Diagrammatic drawings and relationships of the stages to the peak of mandibular growth (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 68, Copyright Elsevier).

Several researchers have used morphological factors and cephalometric analysis of the patient's cephalogram as an attempt to predict Class III malocclusion prognosis. Björk (1969) used this concept to establish seven indicators of mandibular rotation excessive growth during the early developmental stage. These are: the condylar head's inclination; the mandibular canal's curvature; the shape of the lower border of the mandible; the width of the symphysis; the interincisal angle; the intermolar angle; and the anterior lower face height (Björk, 1969; Ngan, 2006; Zere et al., 2018).

Even with the identification of these seven indicators, predicting mandibular growth remains a challenge. This is likely due to the fact that mandibular growth varies greatly in several aspects, such as timing, amount and direction. Furthermore, the evaluation is based on one cephalogram without taking into consideration the growth factor during or between phase one and phase two treatment (Björk, 1969; Zere et al., 2018).

Ngan (2002) proposed the use of a Growth Treatment Vector Response (GTVR) analysis to predict if patients who have had early protraction facemask treatment in the mixed dentition will require either a second phase of orthodontic camouflage or orthognathic surgery. He suggests the use of serial cephalometric radiographs of patients taken a few years apart after facemask therapy, and the use of a GTVR analysis to improve the success of predicting mandibular growth. The diagnostic procedure is usually performed during the early mixed dentition, once a patient is diagnosed with maxillary deficiency. Following the use of maxillary expansion and a protraction facemask, the patient remains under observation for 3-4 years to assess growth. A GTRV analysis will then be performed during the early permanent dentition to support clinicians to decide whether the malocclusion can be camouflaged by orthodontic treatment (GTRV > 0.38), or a surgical intervention is required after growth is complete (GTRV < 0.33) (Ngan & Wei, 2004; Ngan, 2005; Ngan, 2006; Zere et al., 2018).

6. Treatment planning in Class III malocclusion

Several aspects need to be considered when planning treatment: age, sex, facial pattern, family history, patient's main concerns and their expectation and motivation of treatment. Further, patient´s perspective on their occlusion and facial appearance must be considered, since it will have a substantial impact on whether an orthognathic surgical approach is acceptable (Littlewood & Mitchell, 2019).

The severity of the skeletal pattern should be evaluated in all three planes of space; antero-posteriorly, transversely, and vertically, being the major difficulty of prognosis in orthodontic treatment (Proffit et al., 2018).

Another important aspect to be assessed is future growth pattern and amount, both antero-posteriorly and vertically. As the maxilla achieves full growth before the mandible, average growth will tend to worsen the relationship between the arches, and if growth is unfavourable, deterioration can be anticipated. Additionally, infants with enlarged vertical skeletal dimensions will usually keep growing vertically, with increases in mandibular length being split between anteroposterior and vertical projection. As a result, there will be less mandibular prognathism but an increased lower facial height with reduced overbite (Littlewood & Mitchell, 2019).

Incisor relationship is another feature that should be observed. When patients are capable of achieving edge-to-edge incisor contact, it increases the prognosis for treatment with orthodontic camouflage. Moreover, a normal or increased overbite is beneficial in Class III malocclusions, as sufficient maxillary and mandibular incisors vertical overlap following treatment is essential for stability (Littlewood & Mitchell, 2019; Proffit et al., 2018).

Orthodontic management of Class III malocclusion may intent to enhance dentoalveolar compensation. Hence, if significant dentoalveolar compensation is already present, increasing it further probably will not be an aesthetic or stable therapy option (Littlewood & Mitchell., 2019).

The degree of crowding in the upper and lower arches should also be evaluated in cases of Class III malocclusion, as this will help to determine the optimal management plan, such as extraction or gain of space. Crowding can be observed to a larger extent in the superior arch compared to the inferior arch. When looking at patients with a high degree of Class III skeletal pattern, surgery as an ultimate approach must not be discarded, especially prior to any permanent tooth is extracted (Littlewood & Mitchell., 2019; Proffit et al., 2018).

Ngan et al. (1997), described a diagnostic scheme which assists to determine the severity of Class III malocclusion and consequently to elaborate the treatment planning (Figure 16).

Figure 16 - Diagnostic and treatment scheme (Adapted from Zere et al., 2018).

7. Management

7.1. Management of developing Class III malocclusion

Class III malocclusion can develop in early years of life (deciduous dentition), where craniofacial structures growth can be permanently affected by functional alterations (Björk, 1969; Ngan & Moon, 2015). Therefore, the objective of early orthodontic treatment may include the following (Ngan & Wei, 2004; Ngan, 2005; Zere et al., 2018):

1. To improve skeletal discrepancies and provide a more favourable environment for future growth.
2. To avoid irreversible changes in soft tissue or dental structure throughout time. Class III malocclusion is usually associated with an anterior crossbite which can lead to abnormal wear of incisors, dental compensation of upper and lower incisors and gingival recession, if left untreated.
3. To improve occlusal function. Early intervention may help in eliminating CO/ CR discrepancies de-risking potential antagonistic growth.
4. As a way of facilitating phase II treatment (if necessary). For patients with mild to moderate Class III, intervention at early stages may discard a surgery requirement. Even when surgery is subsequently required, early intervention will potentially diminish the surgical extent.
5. To improve aesthetics of the face, and consequently infant psychosocial development (Flanary et al., 1990; Fleming, 2017; Stricker et al., 1979).

Turpin (1981) established a list of positive and negative factors (Table 7) to help determine when a developing Class III malocclusion should be intercepted. Turpin suggested that early treatment should be considered for a patient who presented with positive characteristics, whereas, for those with negative characteristics, management should be postponed until growth has ceased. Patients have to be aware that surgery might be required at a later date, even after an early successful interceptive therapy (Ngan, 2005; Zere et al., 2018).

Table 7- Positive and negative factors for decision making for interception of developing Class III malocclusion (Adapted from Ngan, 2005; Zere et al., 2018).

Positive factors	Negative factors
Good facial aesthetics	Poor facial aesthetics
Mild skeletal disharmony	Severe skeletal disharmony
No familial prognathism	Familial pattern established
Anteroposterior functional shift	No anteroposterior shift
Convergent facial type	Divergent facial type
Symmetrical condylar growth	Asymmetric growth of condyle
Young subject with remaining growth	Growth completed
Good cooperation expected	Poor cooperation expected

According to Ngan et al. (2014), there are 3 types of Class III malocclusion in mixed dentition, which may require different managements:

1. dental: incorrect inclination of upper or lower incisors;
2. pseudo: anterior positioning of the mandible as a result of premature dental contacts deflecting the mandible anteriorly, allowing the patient to achieve full intercuspation;
3. skeletal: true skeletal maxillomandibular discrepancy.

The combination of clinical and cephalometric data assists to determine the types of Class III malocclusion that should be managed in the mixed dentition and which interceptive strategy is most effective (Zere et al., 2018).

7.1.1. Management of dentoalveolar anterior crossbites

The management of non-skeletal anterior crossbites aims to establish proper anteroposterior relationship by shifting only dental elements under the assumption of normal skeletal relationship. Frequently, a constricted maxillary arch is presented along with the anterior crossbite. In those cases, a transversal maxillary expansion is required to correct the anterior crossbite (Chang & Chang, 2009).

Correction of dentoalveolar anterior crossbite can be achieved with the use of removable (active Hawley) and fixed (inclined plane, 2 by 4) appliance. According to Zere et al. (2018), there will be an increased success rate of treatment if the existing proclination of the maxillary incisors is minimal and there is adequate overbite at end of treatment to sustain correction.

Further, the presence of premature contact with an associated mandibular displacement can result in anterior and/or posterior crossbite. It is important to eliminate these premature contacts to diminish the risk of the crossbite (anterior and/or posterior) being perpetuated from the primary into the mixed and permanent dentitions. In addition, it lessens the possibility of a dentoalveolar problem to progress into a skeletal one. Therefore, in case of pseudo-Class III malocclusion, early interceptive treatment should be implemented (Littlewood & Mitchell., 2019).

7.1.1.1. Inclined plane

An inclined plane can be used in deciduous dentition or early mixed dentition (Chang & Chang, 2009; Zere et al. 2018), being recommended for patients with:

1. retroclined upper anterior teeth with an anterior crossbite with or without functional displacement;
2. well-aligned lower anterior teeth without proclination;
3. normal to deep overbite;
4. there is enough space in dental arch for labial movement of the upper incisors.

The implementation is made by using temporary cement to attach the inclined plane on the mandibular anterior teeth (Figure 17). This appliance corrects the malocclusion by tipping maxillary teeth labially whereas mandibular teeth are inclined to a lesser extent in lingual direction. Prakash and Durgesh (2010), recommended the establishment of an acrylic inclined plane with a 45° angle from the lower tooth's long axis (Figure 18).

Figure 17 - Inclined plane appliance (from Anterior Crossbite Correction in Early Mixed Dentition Period Using Catlan's Appliance: A Case Report, Prakash and Durgesh, 2010, Copyright 2011).

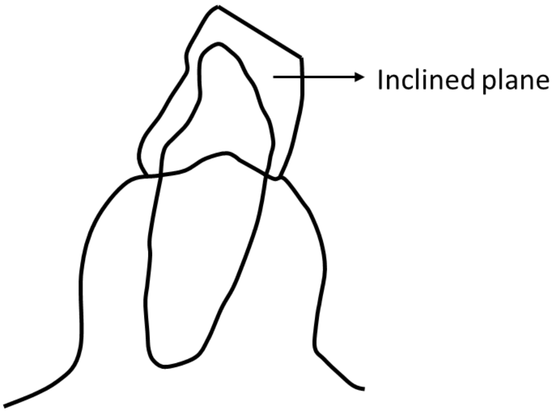

Figure 18 - An acrylic inclined plane with a 45-degree slope against the lower tooth's long axis (Adapted from *Anterior cross-bites in primary mixed dentition-pedo*, 2012, https://www.slideshare.net/PARTHPMT/anterior-crossbites-in-primary-mixed-dentitionpedo).

The advantage of using an inclined plane is that it can correct dental anterior crossbite rapidly (within 3–4 weeks) without requiring patient cooperation. However, the drawback is the possibility of occurring anterior open bite if the appliance is cemented for more than six weeks. It may also interfere with the speech (Graber, 1988; Prakash and Durgesh, 2010).

7.1.1.2. Active Hawley appliance

A removable Hawley appliance is used to correct anterior dentoalveolar crossbite by tipping movement in the mixed dentition stage (Littlewood, 2017). The use of this appliance can direct an anterior tooth in crossbite over the bite with an activated palatal spring or screw, if there is sufficient space (Figure 19). A posterior or anterior bite planes are incorporated in the design of the Hawley appliance (based on the mandibular growth direction), to avoid occlusal interference during the correction of the crossbite. Hawley appliance has also retentive components to ensure the correct placement of active components, like Adam’s clasp as an example (Figure 20). Additionally, the usage of a retentive appliance is not difficult, improving cooperation (Cobourne and DiBiase, 2015).

In terms of stability, reaching a positive overbite on the corrected teeth will be key to prevent relapse. Moreover, Hawley appliance (without activation) can also be utilised as a retainer to ensure correction is maintained. Drawbacks of this appliance are the limitation to movements of tipping and its reliance on patient collaboration (Littlewood, 2017).

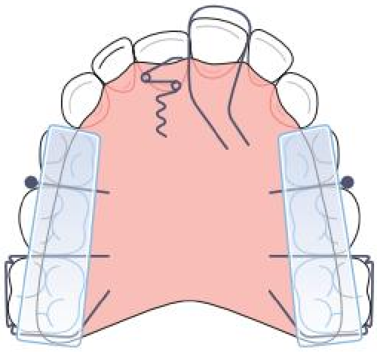

Figure 19 - Removable Hawley appliance with spring active component and a posterior bite plane to raise the bite (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 270, Copyright Elsevier).

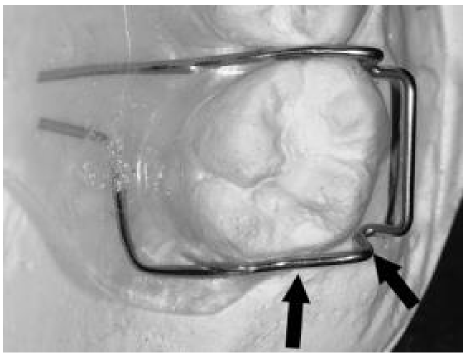

Figure 20 - Retentive component (Adam’s clasp) (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 264, Copyright Elsevier).

7.1.1.3. "2 by 4" appliance

Fixed appliance is used in mixed dentition or early permanent dentition in order to treat dentoalveolar anterior crossbite and to align ectopic incisors (Mckeown and Sandler, 2001; Zere et al., 2018). It is frequently referred to as a "2 by 4" appliance since it is bonded on the two first permanent molars and the four incisors (Chang & Chang, 2009; Ngan et al., 2014; Wiedel & Bondemark, 2015; Wiedel et al., 2016). According to Mckeown and Sandler (2001), continuous archwires is indicated, providing complete control of the anterior dentition as well as an adequate arch form. Further, this therapy can be combined with anterior cross elastics and/or molar bite block disocclusion.

Fixed appliance usually performs well, with a consistent outcome. Compared to removable appliance, fixed device allows apical, bodily and rotational movement. Moreover, this therapy is faster and less expensive and has reduced speech impact. However, at first patients may experience discomfort chewing and biting with the use of this appliance (Ash & Ramfjord, 2009; Wiedel & Bondemark, 2015; Wiedel & Bondemark, 2016).

7.1.2. Growth modification and orthopaedic management

Skeletal discrepancy will dictate the implementation of growth modification therapies. The primary goal would be to correct or at least improve the discrepancy so that orthodontic camouflage alone is sufficient in the future, eliminating the need of orthognathic surgery. This can be achieved with the use of functional, bone-anchored appliances, protraction facemask or chin cup therapy (Zere et al., 2018).

7.1.2.1. Functional appliances

Functional appliances are employed to alter the skeletal pattern via increasing maxilla growth or restricting or redirecting mandible growth, being the best treatment results achieved when they are used in the early mixed dentition period. The Frankel Functional Regulator III appliance (FR-III) and the Reverse Twin-Block appliance (RTB) are two functional appliances regularly used to manage Class III malocclusion (Zere et al., 2018).

7.1.2.1.1. Frankel Functional Regulator III (FR-III)

The FR-III appliance is fabricated with the mandible positioned posteriorly and rotated open. Utilising pads keeps the upper lip forward (Figure 21). These pads are positioned apart from the maxilla to extend the periosteum and promote maxillary anterior growth (Graber et al., 2016). The objective of the vertical opening is to increase eruption of upper posterior teeth in forward and downward direction (Proffit et al., 2018).

Figure 21 - Frankel functional regulator III appliance (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 440, Copyright Elsevier).

According to Levin et al. (2008), who evaluated retrospectively the cases treated by Frankel himself. The authors found a significant change in maxillary size and position of the treated cases with skeletal Class III malocclusion who wore the FR-III appliance full-time for an average of 2.5 years and then part-time in retention for 3 years compared to controls. In addition, they observed an improved mandibular position combined with more lingual lower incisor bodily position, increasing patients' overjet. However, other studies show little true forward movement of the maxilla (Yang et al., 2014). Instead, most of the occlusal relationship improvement is from dental changes; proclination of upper incisors, and retroclination of lowers incisors. Moreover, it is noted that the chin had rotated downward and backward, which enhances maxillomandibular relationship (Mittal et al., 2017; Shastri et al., 2015; Ulgen et al., 1994).

FR-III facilitates the molar relationship to shift from Class III to Class I by allowing the eruption of the upper molars and their mesial movement without impacting the lower molars vertically and anteroposteriorly. In addition, a rotation of the occlusal plane as the upper molars erupt more than the lowers also improve this change (Proffit et al., 2018).

Proffit et al. (2018) suggest that if this appliance is used, long treatment retention periods and excellent compliance are required in order to maintain the correction. Further, according to Ko et al. (2004), long-term stability of this appliance depends on patients' future growth.

7.1.2.1.2. Reverse Twin-Block appliance (RTB)

RTB is a functional appliance used in mixed dentition for managing Class III malocclusion (Figure 22) (Seehra et al., 2012). There are cases reporting the use of RTB in permanent dentition, yet they are limited (Singh et al., 2018).

Figure 22 - Reverse twin-block appliance (from Singh, H., Kapoor, P., Sharma, P., Maurya, R. K., Mittal, T. (2018). Skeletal Class III correction in permanent dentition using reverse twin block appliance and fixed mechanotherapy. *Saudi Dental Journal*, 30(4):379-388.).

The appliance consists of blocks that promote maxilla forward movement and restrict temporarily mandibular development, using the occlusal force (Singh et al., 2018). However, several researches suggest that the improvement of occlusal relationships occurs principally due to dentoalveolar changes; retroclination the lowers incisors, and proclination of upper incisors, resulting in establishment of a positive overjet and overbite (Kidner et al.,2003; Mittal et al., 2017; Shastri et al., 2015).

Additionally, according to Singh et al. (2018), the use of RTB assists to eliminate mandibular displacement, to guide the permanent dentition into favourable occlusal relationship and also to camouflage mandibular growth with clockwise rotation of the mandibular base.

7.1.2.2. Chin cup therapy

Chin cup therapy is used to treat developing Class III malocclusion in primary and early mixed dentition, where prognathic mandibular growth is mild to moderate in nature

(Figure 23) (Thilander, 1965). It is observed that this appliance does not hinder mandibular growth; rather, it shifts the direction vertically, causing the chin to rotate downward and backward, making it less noticeable while increasing anterior face height. Class III malocclusion with sagittal mandibular growth pattern will be improved after these changes in direction, while chin cup therapy should be avoided in Class III cases with vertical growth pattern. Furthermore, because the appliance presses on the lower lip and teeth, one consequence could be the recession of labial gingiva and the retroclination of the lower incisors. (Uner et al., 1995; Zere et al., 2018).

Figure 23 - Chin cup appliance (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 450, Copyright Elsevier).

Chin cup can be divided into two types: occipital pull, which is employed for patients with mandibular protrusion; and vertical pull, that is employed in patient with steep mandibular plane angle and excessive anterior facial height (McNamara & Brudon, 1995). Additionally, the majority of reported studies recommend an orthopaedic force magnitude of 300–500g bilaterally, 14 hours per day (Proffit et al., 2018; Zere et al., 2018).

The traditional view of chin cup therapy is that heavy force applied directly at the condyles would correct excessive mandibular growth by inhibiting condylar growth (McNamara & Brudon, 1995). More recent studies show, according to Proffit et al. (2018), that the treatment goal should be to redirect mandibular growth by applying a lighter force below the condyles, which is more acceptable for patients and equally effective (Figure 24).

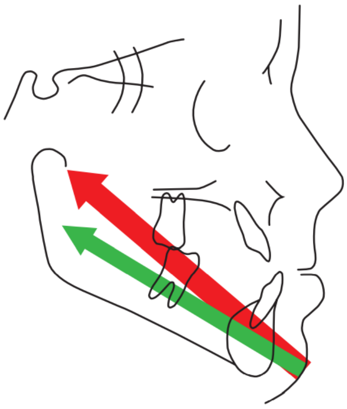

Figure 24 - Red line: heavy force aimed directly at the condyles. Green line: lighter force applied below the condyles (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 451, Copyright Elsevier).

Controversy exists over maxillary effects. Deguchi et al. (1999) reported that chin cup appliance has no influence on maxillary growth. On the other hand, Sugawara et al. (1990) argued that this therapy excludes the restricting effect of the anterior crossbite on maxillary growth.

Systematic reviews demonstrated that chin cup therapy has short-term favourable outcomes (Chatzoudi et al., 2014; Tsolakis et al., 2016). However, in terms of treatment stability, according to Sugawara et al. (1990) and Mousoulea et al. (2016), if the chin cup therapy is not progressed throughout development and until complete growth is achieved, the normal growth pattern of the mandible will be re-established.

Cases of severe mandibular prognathism must be evaluated carefully for the use of chin cup therapy, as orthognathic surgery often brings best results when implemented after complete growth is achieved. And considering that the long-term outcomes are not confidently predictable, there must be full disclosure of risks to patients' caretakers to support any decision (Zere et al., 2018).

7.1.2.3. Protraction Facemask (PFM)

Protraction Facemask (PFM) is an orthopaedic appliance used to manage Class III malocclusion with retrusive maxilla in growing patients (Graber et al., 2016; Watkinson et al., 2013). This appliance is used in late primary dentition or early mixed dentition, ideally when the permanent upper incisors erupt (approximately 8 years of age) (Kim et al., 1999).

The patient`s age is a crucial factor due to maxilla forward movement at younger age is easier and more effective. Although some reports suggest that anteroposterior changes can occur up to the beginning of adolescence (Kim et al., 1999), the chance of true skeletal change seems to decrease beyond age 8, and the chance of clinical success starts to decline at age 10 to 11. Therefore, according to Wells et al. (2006), the treatment should start promptly after diagnosis.

The appliance consists of three essential units: an extraoral protraction mask that gets attached on the forehead and the chin, an intraoral bonded maxillary splint and elastics, which are used from the extraoral mask to the intraoral splint (Figure 25). The elastic forces are typically 400–450 g per side and need to be worn 12–14 hours per day. Advice is to keep this appliance on during evening and night time when there is greater release of growth hormone. The usual total treatment time revolves between 6 to 9 months depending on the severity of the malocclusion and patient compliance (Ngan & Yiu, 2000; Zere et al., 2018).

Figure 25 - Protraction facemask appliance (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 442, Copyright Elsevier).

PFM therapy generates considerable tension in the circummaxillary sutures and the maxillary tuberosity regions. As a result, these areas become more vascularized which is followed by cellular tissues differentiation and an increase in osteoblastic activity (Tanne & Sakuda, 1991; Hata et al., 1987).

The use of protraction facemask therapy impacts the craniofacial complex, varying according to the applied moments and force at the sutures (Hirato, 1984). Therefore, a forward movement and the reduction of the maxillary rotation to a minimum are achieved through vectors that run along the centre of resistance of the maxillary complex. When forces are applied below the centre of resistance, the maxillary complex tends to rotate clockwise, while forces are applied above the centre of resistance, the maxillary complex tends to rotate counterclockwise (Nanda, 1980; Nanda & Goldin, 1980; Proffit et al., 2018).

Most children exhibit maxillary deficiency in both vertical and anterioposterior dimension, which means that a slight downward direction of elastic traction is frequently desirable, and some downward and backward mandibular rotation improves the jaw relationship (Figure 26). Further, according to Rongo et al. (2017), this mandibular clockwise rotation decreases the overbite. However, if lower face height is already increased, a downward pull would be contraindicated. Studies have shown that the most common angle of force is 30º forward and downward applied at the canine region, decreasing unwanted rotation of the palatal plane (Ngan et al., 1997; Zere et al., 2018).

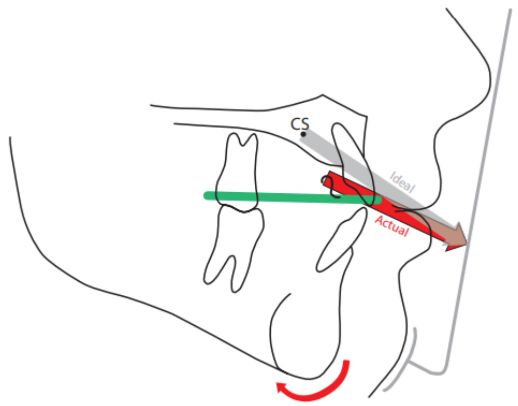

Figure 26 - With the splint attached to the maxillary arch, the ideal line of force would be directed at the centre of resistance (CS) of the maxilla, so the hooks on the splint should be above the occlusal plane. Even so, the actual line of force is likely to be below the centre of resistance, so some downward movement of the posterior maxilla and opening of the bite anteriorly can be anticipated (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 443, Copyright Elsevier).

Patients with skeletal Class III malocclusion frequently present a constricted maxilla in transverse dimension requiring Rapid Maxilla Expansion (RME) as part of their treatment. However, there are discussions around the fact that forward movement of the maxilla will be increased by circummaxillary sutures getting loosened through expansion, even when there is no transversal discrepancy. A meta-analysis found that if RME was not employed, PFM therapy was less effective in patients older than 10 years of age with a longer treatment time (Mandall et al., 2016). On the other side, a different meta-analysis concluded that PFM with or without RME treatment achieved no alteration on the anteroposterior skeletal change (Zhang et al., 2015).

Another expansion protocol is the Alternate Rapid Maxillary Expansion and Constriction (Alt-RAMEC) which was initially devised by Liou (2005). This method consists of rapid expansion for a week at 1 mm per day, followed by turning the screw in the opposite direction to constrict for another week, and continuing this over 7- 9-weeks period, leading to very mobile maxillary segments. Following completion of this protocol, protraction force is applied to move the maxilla forward.

A recent meta-analysis found little evidence suggesting that on short-term basis, Alt-RAMEC combined with maxillary protraction results in more remarkable skeletal sagittal improvement, with more maxillary protraction and less mandibular clockwise rotation when compared with the conventional approach (RME/PFM) (Almuzian et al., 2016). In a clinical trial conducted by Liu et al. (2015), although the differences between the Alt-RAMEC/PFM and RME/PFM groups for maxillary forward movement and mandibular rotation were statistically significant, the changes founded were negligible – less than 1mm and 1°, respectively – therefore not clinically relevant. On the other hand, other studies suggested that the application of the Alt-RAMEC protocol before maxillary protraction appears to be more effective than RME, improving maxillary mobility and forward movement (Al-Mozany et al., 2017; Büyükcavus, 2019).

Applying force to teeth aiming to transmit it to sutures will inevitably generate consequent tooth movement (Proffit et al., 2018). For that reason, skeletal, dental, and soft tissue changes will be within the effects of conventional facemask therapy. The treatment causes forward and downward movement of the maxilla and maxillary dentition and backwards and downwards movement of the mandible and mandibular dentition. Improvements in competence, position and posture of the lip are among the soft tissue alterations, which also include an overall straightening of the profile (Baik, 1995; Kim et al., 1999; Ngan et al., 1996; Ngan, 1998; Ngan &Yiu, 2000).

As children come closer to adolescence, mandibular rotation and displacement of maxillary teeth—rather than the maxilla moving forward—are the major components of the treatment outcome (Wells et al., 2006). According to recent researches, PFM has short-term skeletal effect and long-term dentoalveolar effects (Woon and Thriuvenkatachari, 2017).

Even though the jaw discrepancy was substantially corrected before adolescence, orthognathic surgery may still be required if the mandible outgrows the maxilla during puberty (Wells et al., 2006). However, Mandall et al. (2016) showed in their study that patients were also less likely to have orthognathic surgery if they had facemask treatment at an early age (under the age of 10), 36% compared with 66% of the control group.

In terms of retention phase, a simply fixed plate, Frankel III or chin cup are options of retainers after PFM therapy to sustain correction (Almuzian et al., 2018).

7.1.2.4. Bone-anchored appliances

The use of a tooth-borne protraction appliance frequently results in undesirable dental alterations. Therefore, in order to overcome this limitation, Bone-Anchored Maxillary Protraction (BAMP) can be employed to manage skeletal Class III malocclusions (De Clerck & Proffit, 2015).

BAMP appliances make use of elastics connected from mini-plates located in the infra-zygomatic region to mini-plates located in the mandibular canine zone or connected to the extraoral facemask (Figure 27) (Al-Mozany et al., 2017; Graber et al., 2016).

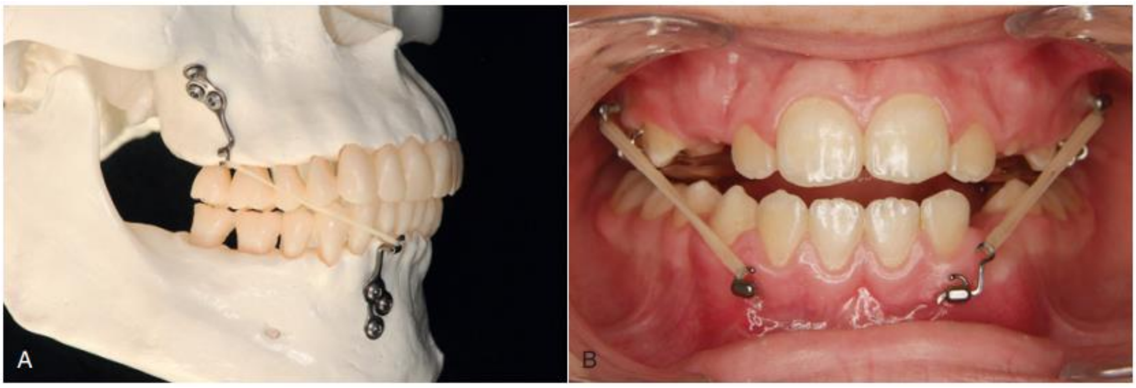

Figure 27 - Class III elastics attached between mini-plates placed in the infra-zygomatic region to mini-plates placed in the mandibular canine region (from *Contemporary Orthodontics*, Proffit et al. 2018, 6th edition, page 446, Copyright Elsevier).

The surgical technique and the thickness and quality of the bone, all affect the success of these mini-plates. In comparison to tooth-borne appliances, this interceptive approach is typically performed on slightly older patients since the bone quality, especially in the maxilla, is frequently ideal only after the infant reaches the age of 11 (De Clerck & Proffit, 2015). Therefore, BAMP is normally used at 11 years of age in girls and 12 years in boys in order to ensure maximum bone rigidity, optimise the stability of anchored plates, and reduce the risk of traumatising developing dental follicles (De Clerck et al., 2010; Graber et al., 2016).

There is a controversy about the benefits of BAMP. According to a systematic review by Major et al. (2012), it causes more orthopaedic alterations and fewer dental changes. Additionally, an initial study demonstrated infimal alterations in the vertical skeletal pattern and in the maxillary incisor inclination from the use of BAMP, but it generated a material increment of 4 mm on average on skeletal and soft tissue advancement of maxillary structures (De Clerck et al., 2010). However, a different meta-analysis concluded that BAMP is just as effective as other conventional therapy, such as PFM (Rodriguez de Guzman-Barrera et al., 2017).

7.2. Management of Class III in adults

7.2.1. Orthodontic camouflage treatment

Treatment in adults presents a higher degree of complexity due to limited options available, being a combination of orthodontic treatment with orthognathic surgery the usual optimal option. Yet, in reason of the invasive nature and high cost of the surgery most adults do not proceed with this therapy (Barreto & Santos, 2018; Park et al., 2019).

In instances where complete growth is achieved and the aesthetic is acceptable, camouflage treatment can be employed (Troy et al., 2009). This procedure started to be used around 1930 when growth modification was considered a not effective option and surgery was still in its early developments, therefore camouflaging skeletal malocclusion through tooth extraction became a popular option (Burns et al., 2010). Further to the above mentioned characteristics, Almuzian et al. (2016) established some favourable features to determine whether patients can benefit from camouflage treatment (Table 8). Goals of this therapy include achieving a satisfactory occlusion, function, and aesthetics through dentoalveolar compensation for the skeletal discrepancy (Lin & Gu, 2003).

Table 8- Favourable features for orthodontics camouflage (Adapted from Almuzian et al., 2016).

Favourable features for orthodontics camouflage includes:
Patients who have completed their growth spurt
Soft tissue profile near to normal
Normal or mild transverse relations
No apparent facial asymmetry
Mild to moderate skeletal discrepancy
Adequate vertical relationship
In the absence of displacement, the patient can achieve edge to edge bite in CR
Minimal dento-alveolar compensation
Mild lower arch crowding, allowing extraction therapy to correct the overjet.

Before establishing orthodontic camouflage as a viable option for treatment, a range of variables must be taken into account. Firstly, it is necessary to determine how much the patient's facial aesthetics have been compromised and how significant this is for the patient. In cases of significant aesthetic complaint, orthognathic surgery is required (Bou Wadi et al., 2020; Farret et al., 2016). Secondly, the maxillary and mandibular incisors' anteroposterior position and inclination need to be assessed. Thirdly, the thickness of mandibular symphysis should allow incisor retraction. Lastly, it is necessary to evaluate the anteroposterior discrepancy's severity (Farret et al., 2016).

In order to achieve camouflage, the procedure revolves around proclination and retroclination of upper and lower incisor, respectively. Intermaxillary Class III elastic traction is usually used to assist movement of the upper arch in a forward direction and movement of the lower arch in a backward direction, which might cause molars extrusion, leading to a clockwise rotation of the mandible, to an increased vertical dimension and to a reduced overbite (Burns et al., 2010).

The more severe Class III cases are more reliant on surgical intervention. According to Handelman (1996), tooth movement to camouflage a severe skeletal discrepancy may compromise significantly the soft tissue profile. In addition, the extent of existing incisor compensation for the skeletal pattern is a determinant factor in defining if a malocclusion can be managed with tooth movement alone. The upper incisors are often already labially inclined and the lowers retroclined, and for the success of orthodontic treatment it is important that this is minimal (Bou Wadi et al., 2020; Farret et al., 2016).

As a guide, when considering orthodontic camouflage for Class III malocclusion (Burns et al., 2010; Cobourne and DiBiase, 2015), there must not be a retroclination of less than 80º for the lower incisors in relation to the mandibular plane or bone fenestrations and gingival recession can occur, mainly in patients with a thin biotype. Also, there must not be a proclination of more than 120º for the upper incisors in relation to the maxillary plane, as non-axial loading, fremitus and poor aesthetics can be a consequence.

Class III malocclusions camouflage can be achieved with the help of procedures such high palatal root torque prescription in the upper incisor brackets and labial root torque in the lower incisor brackets. In order to prevent the mesial tipping of lower canines, it is also advised to switch the lower canine brackets to minimize further tipping of the lower canines and improve the intercanine relationship towards Class I if possible (Almuzian et al., 2016).

The Multiloop Edgewise Arch Wire (MEAW), which was developed in 1967 by Dr Young H., is another approach used in camouflage therapy. The MEAW technique (0.016" x 0.022" stainless steel/ bracket 0.018" slot) consists of multiple L-loops (five loops on each side of the arch) and tip-back bends, used in conjunction with intermaxillary elastics. This approach allows individual tooth movements, enabling:

upright and intrusion of posterior teeth; inclination change of the occlusal planes; correction of the occlusal sagittal relationship; and obtainment of the correct intercuspation (Beltrão, 2015; Conley & Edwards, 2018; Sato et al., 2001). In addition, the MEAW technique is indicated for patients with increased lower facial height and open bite malocclusion due to the vertical dimension control. However, this technique needs high skill and proper training to be mastered (Kuo et al., 2009).

Another non-extraction method is lower arch distalisation using Temporary Anchorage Device (TADs) which enable not only single molar distalisation but also en-masse movement of the buccal segments. Moreover, this noncompliance technique controls three-dimensionally tooth movement, minimizing molars extrusion as side effects (Chung et al., 2010; (Tan & Chen, 2017).

Camouflage therapy can involve extraction to relieve crowding in lower or upper arch. In addition, mandibular incisors may need to be moved lingually, increasing the space required in the lower arch. When premolar extractions are necessary, lower first premolars and upper second premolars are a common choice (Figure 28). Anterior teeth (first premolars) in the lower arch are preferred in order to assist retraction of the lower labial segment, whereas posterior teeth (second premolars) in the upper arch minimize incisor position change (Burns et al., 2010). If maxillary teeth are well aligned, an alternative is the extraction of lower premolars only, finishing with a Class III molar relationship after incisor retraction. Lower incisal extraction is also an alternative when there is crowding in the lower incisors or when the lower incisal inclination allows further retroclination, in order to correct Class III incisor relationship (Cobourne and DiBiase, 2015).

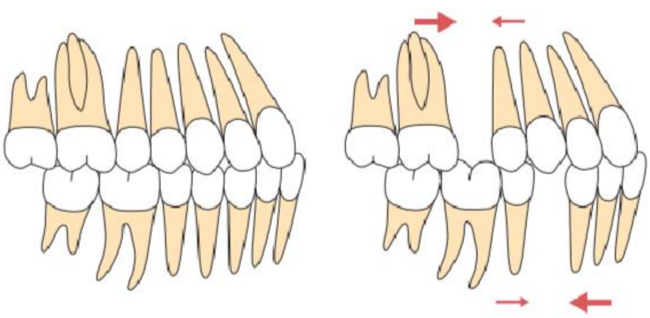

Figure 28 - In Class III malocclusion, extracting more mesially in the lower arch will help correction (from *Handbook of Orthodontics*, Cobourne and DiBiase, 2015, 2nd edition, page 246, Copyright Elsevier).

Achieving a positive overbite at the end of treatment is a critical factor in post treatment stability. Future adolescent growth will also be important for stability since an increase in mandibular prognathism will tend to deteriorate the Class III incisor relationship. If concerns still exist, it is preferable to monitor growth in patients with a Class III malocclusion ahead of making any final treatment decisions (Cobourne and DiBiase, 2015).

7.2.2. Surgical treatment (orthognathic surgery)

Non-growing patients with severe skeletal Class III malocclusion are best treated with a combined orthodontic and surgical approach while those with mild to moderate skeletal discrepancy can be treated with orthodontic approach alone. However, deciding which treatment to choose is not always simple, especially in borderline cases (Cassidy et al., 1993; Eslami et al., 2018).

The treatment decision is based on patient' concerns, in addition to the cephalometric and clinical data in all three planes of space by assessing the amount of sagittal and vertical discrepancy, dentoalveolar compensations, and facial aesthetics (Eslami et al., 2018; Stellzig-Eisenhauer et al., 2002).

Kerr et al. (1992) proposed that there will be a requirement for surgery when there is an ANB angle value below -4º and the lower incisor's inclination to the mandibular plane is less than 83º. Moreover, according to Eslami et al. (2018) patient with a Holdaway angle of less than 10.3° should be treated by combined orthodontic and surgical approach while a Holdaway angle greater than 10.3° would be treated successfully by camouflage alone. Further, this study demonstrated that Wits appraisal greater than − 5.8 mm would be effectively corrected by camouflage and less than − 5.8 mm required surgery.

Orthognathic surgery usually involves three stages (Hwang et al., 2017): pre-surgical orthodontics, surgery and post-surgical orthodontics. Pre-surgical orthodontics is the phase where most parts of the treatment are established, such as levelling, alignment, coordination and decompensation of the arches. This approach provides the grounds for a better and more precise planning and implementation during surgical phase. However, it is considered an uncomfortable period for patients since the dental decompensation caused at this stage worsens aesthetics and function (Liou et al., 2011). The phase prior to surgery normally spans from 12 to 18 months, depending on the case complexity.

The surgery is planned and a surgical guide is made by analysing patient´s profile and cephalometric measurements. Common surgical movements include maxillary advancement, mandibular setback or combination of both movements (Maruo et al., 2010).

Additionally, traversal dimension also needs to be assessed. Surgically Assisted Rapid Palatal Expansion (SARPE) is most employed when skeletal problem affects only the transverse plane of space. It is an attempt to treat traversal discrepancy without resorting to segmental surgery of the maxilla and its inherent risks. SARPE involves the use of corticotomies, and the use of a rapid palatal expander which is employed to quickly widen the upper arch (Littlewood & Mitchell, 2019).

In cases of severe maxillary constriction, some surgeons recommend SARPE as a preliminary phase before Le Fort I osteotomy to move the maxilla anteroposteriorly and/or vertically. This is because segmental expansion of the maxilla during the Le Fort I procedure could compromise the blood supply to the segments (Proffit et al., 2018).

The aim of post-surgical orthodontic treatment is to achieve a satisfactory occlusion in addition to a good interarch and intra-arch dental relationships, as well as root paralleling at any segmental osteotomy sites and detailing and settling. Its duration can vary from 5 to 11 months (Ko et al., 2011).

The best time for orthognathic surgery is when growth rate has reached adult levels and to confirm the completion of effective growth, it is recommended taking 2 lateral cephalograms 6 months apart. Moreover, Graber et al. (2016) suggested that any dentoalveolar compensation must be eliminated or minimized prior surgical approach seeking an adequate facial and occlusal result.

Surgery-first approach is an alternative to the conventional orthognathic surgery (orthodontic-first approach). According to Hwang et al. (2017), surgery-first approach brings several benefits, including a reduced treatment time by eliminating the pre-surgical stage and taking advantage of the rapid bone remodelling process, which in turn accelerates tooth movement without noticeable side effects. Additionally, worsening of facial appearance and function that occur during pre-surgical orthodontics phase is avoided, increasing patient's satisfaction. On the other hand, in this method, the occlusion cannot be used as a guide for the surgical movement, requiring more careful surgical planning and close communication between skilled orthodontists and surgeons to accurately predict post-surgical tooth movement and surgical movement. Therefore, Hwang et al. (2017) recommend only using the surgery-first approach for mild to moderate skeletal discrepancies.

There are some risks associated with orthognathic surgery depending on its type and extent (Table 9). Awareness of these risks must be raised and consent gattered with patients before treatment commences (Littlewood & Mitchell, 2019).

Table 9- Risks associated with orthognathic surgery (Adapted from Littlewood & Mitchell, 2019).

Possible risks of orthognathic surgery	
Expected surgical risk	**Possible surgical risks**
• Swelling • Bleeding • Limited mouth opening • Dietary changes and associated weight loss in the short term • Time off work and recovery • Changes in facial appearance • Changes in nerve sensation	• Permanent nerve damage to inferior dental nerve • Need for reoperation • Infection • Need to remove fixation plates • Temporomandibular joint problems • Relapse • Problems swallowing • Bleeding requiring further intervention • Tooth avulsion or other damage to periodontal support • Ophthalmic complications • Reduction in auditory capacity
Risks of anesthesia	
The risks associated with a general anaesthetic need to be discussed	

Maxillomandibular post-surgical stability relies on the technique utilised, the movement direction and the type of fixation. Figure 29 shows the hierarchy of stability and predictability of different jaw movements (Proffit et al., 2018).

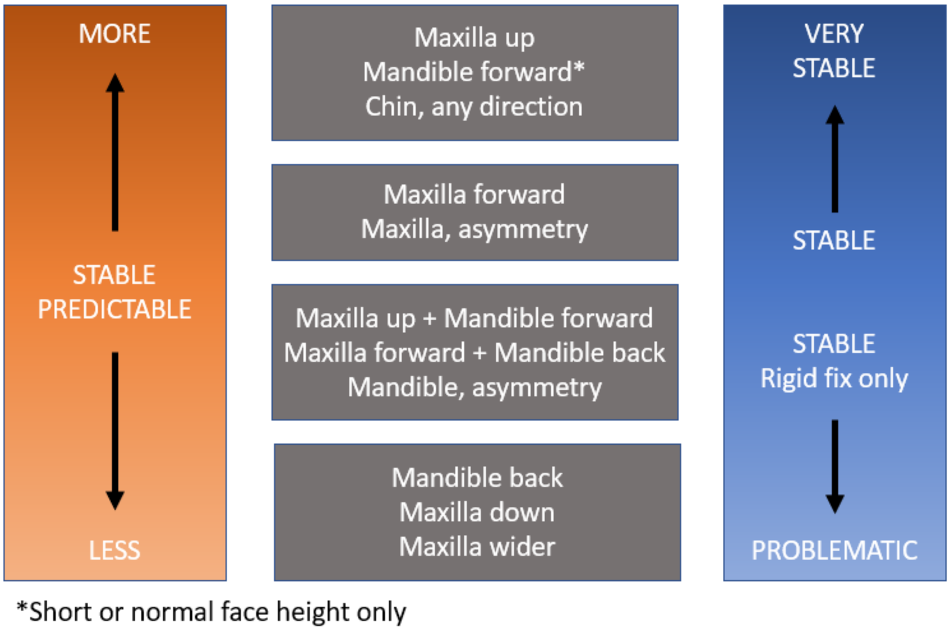

Figure 29 - Hierarchy of stability and predictability of surgical orthodontics treatment (Adapted from Proffit et al., 2018).

Retention after surgical orthodontic treatment is the same as used for conventional fixed appliance therapy (Littlewood & Mitchell, 2019). However, if the maxilla was expanded transversely, it is necessary to maintain the expansion during the finishing orthodontics phase, and also to have full-time retainer wear in the maxilla for at least 6 months. In addition, when a transpalatal lingual arch is placed after surgery, it should not be removed during the first postsurgical year (Proffit et al., 2018).

III. CONCLUSION

Class III malocclusion starts to develop early in life and it is usually not a self-correcting disharmony. It is considered complex due to its unpredictable prognosis and stability. In addition, it tends to become more severe throughout puberty as the maxilla completes its development before the mandible, and mandibular growth varies greatly in relation to direction, amount, and time.

Different approaches can be employed to manage Class III malocclusion, depending on age and its aetiology and severity. Cases of dentoalveolar or pseudo-Class III malocclusion, where skeletal discrepancy is not present, the treatment will encompass only movements of dental elements. When it is identified in growing patients, an early intervention has been recommended to reduce the risk of the malocclusion being perpetuated from the primary into the mixed and permanent dentitions. Moreover, it will reduce the possibility of a dentoalveolar problem that might evolve into a skeletal one.

Considering skeletal Class III malocclusion, the patient's age is critical to establish an appropriate management approach. For growing patients, the therapy should aim to improve or correct the skeletal discrepancy, which will provide a more favourable environment for future growth. Moreover, early intervention allows a more straightforward phase II treatment, making orthognathic surgery treatment unnecessary. Even when surgery cannot be discarded, it may reduce the extent of the surgical procedures.

According to most researches, growth modification therapy for the maxilla is more likely to be successful if it is done before the pubertal growth spurt. For this reason, a thorough understanding of craniofacial development is required to evaluate the developmental status and to assess the remaining growth.

Conversely, skeletal Class III malocclusion treatment for adults has more limitations as lesser options are available. When the malocclusion is considered mild to moderate and acceptable facial aesthetics is present the patient can benefit from camouflage orthodontic treatment. This therapy aims to achieve satisfactory function, occlusion and aesthetics through dentoalveolar compensation. However, nongrowing patients with severe skeletal Class III malocclusion will be best treated with a combined orthodontic and surgical approach.

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V. APPENDIX

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ISBN: 9780723438076
Auhtors: Martyn T. Cobourne, Andrew T. DiBiase
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Anterior Crossbite Correction in Early Mixed Dentition Period Using Catlan's Appliance: A Case Report

Prashanth Prakash [1,*] and B. H. Durgesh [2]

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