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PREDICTION OF MANDIBULAR GROWTH IN CLASS III MALOCCLUSION PATIENTS IN MIXED DENTITION

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"Prediction of Mandibular Growth in Class III Malocclusion Patients in Mixed Dentition"

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“Some failure in life is inevitable. It is impossible to live without failing at something, unless you live so cautiously that you might as well not have lived at all—in which case, you fail by default.”

J.K. Rowling

Abstract

<u>Introduction</u>: One of the major challenges in orthodontics is predicting the mandibular growth in children with a Class III malocclusion with mandibular prognathism. Investigators have attempted to predict cases with excessive mandibular growth in these patients; however, the use of cephalometric variables as a mean of prediction is complex since there are many factors that can influence this prediction.

<u>Objective</u>: The aim of this study is to elucidate to what point cephalometric variables can be useful in predicting excessive mandibular growth in children with Class III in mixed dentition.

<u>Search Strategy:</u> The literature review was based on international publications found on the Pubmed database by using combinations of key words. Inclusive and exclusive criteria were applied and, out of 122 articles found, 16 were selected for this bibliographic review analysis.

<u>Discussion</u>: Timing of intervention is a very important factor in orthodontics when presented with a skeletal disharmony, such as Class III malocclusion. During treatment planning, it is important to contemplate the variations of growth during puberty as well as differences between genders. After analyzing many studies, a wide range of variables were found amongst authors that studied the prediction of mandibular growth. This range included variables related to the maxilla, the mandible, the maxillo-mandibular relationship, the dental relationship, the condylar orientation and the cranial base.

<u>Conclusion</u>: The variety of cephalometric predictors found between authors justifies the need for an ongoing search since no author was able to create the ideal predictive model for excessive mandibular growth beneficial in a clinical situation.

<u>Keywords</u>: "cephalometric variables", "children", "Class III malocclusion", "craniofacial growth", "predict model", "predictive variables", "prognosis".

Resumo

Introdução: Um dos maiores desafios em ortodontia é prever o crescimento mandibular em crianças com má oclusão de Classe III. Os investigadores têm tentado prever casos com crescimento mandibular excessivo em pacientes deste tipo; no entanto, o uso de variáveis cefalométricas como forma de previsão é um método complexo, dado que há um conjunto de fatores que podem influenciar esta previsão.

Objetivo: O objetivo deste estudo é elucidar até que ponto as variáveis cefalométricas podem ser úteis na previsão do crescimento mandibular excessivo em crianças com Classe III na dentição mista.

Estratégia de Pesquisa: A revisão da literatura foi baseada em publicações internacionais encontradas na base de dados PubMed recorrendo a combinações de palavras-chave. Foram aplicados critérios de inclusão e exclusão e, por conseguinte dos 122 artigos encontrados apenas 16 foram selecionados para esta revisão bibliográfica.

Discussão: O tempo de intervenção é um fator muito importante em ortodontia nomeadamente perante uma desarmonia esquelética, como a má oclusão de Classe III. Ao planear o tratamento, é importante ter em conta as alterações de crescimento inerentes à puberdade e às diferenças entre géneros. Depois de analisar vários estudos, constatou-se que diferentes autores consideram diferentes variáveis no que toca à previsão do crescimento mandibular. Estas incluem variáveis relacionadas com a maxila, a mandíbula, a relação maxilo-mandibular, a relação dentária, a orientação do côndilo e a base do crânio.

Conclusão: A variedade de preditores cefalométricos encontrados entre os autores justifica a necessidade de uma pesquisa contínua, uma vez que nenhum autor foi capaz de criar o modelo preditivo ideal para o crescimento mandibular excessivo que possa ser usado na prática clínica.

Palavras-chave: “variáveis cefalométricas”, “crianças”, “má-oclusão Classe III”, “crescimento craniofacial”, “modelo de previsão”, “variáveis preditivas”, “prognóstico”.

Abbreviations

A – Point A

ALFH – Anterior Lower Facial Height

ANS – Anterior nasal spine

Ar- Articulare

B – Point B

Ba - Basion

Co – Condylion

CondAx – Condylar Axis

DA – Discriminant Analysis

FH – Frankfort Horizontal plane

FM – Face Mask

Gn - Gnathion

Goi – Gonion

LogR – Log Regression

Me – Menton

MP – Mandibular plane

N – Nasion

NL-NSL – Palatal plane angle to mandibular angle

PNS – posterior nasal spine

RME – Rapid Maxillary Expansion

RMR – Rapid Mandibular Retractor

S – Sella

SBL – Stable Basicranial Line

T – Vertical T Line

Table of Contents

List of Figures

List of Tables

I. INTRODUCTION

I. Introduction

One of the biggest challenges in orthodontics is predicting the mandibular growth in children with a Class III malocclusion with mandibular prognathism. Class III malocclusion is known as one of the most severe and complex dentofacial anomalies showing signs at an early stage. (1-3) This anomaly is not self-correcting, neither at the skeletal or the occlusal levels, rather the opposite, it becomes more pronounced in the majority of patients during the pubertal peak continuing until skeletal maturation is complete. (4, 5) The dental and skeletal components of Class III malocclusion can be seen in an early phase but these components tend to get worse as the child grows, especially the advance of the mandible in comparison to the maxilla. (4-6) This poses the question whether the prediction of mandibular growth in these patients is possible.

The facial growth of Class III malocclusion patients depends on the type of Class III anomaly. This malocclusion has both occlusal and skeletal characteristics and can differ in severity. Concerning the occlusal anomalies, this syndrome is classified by a Class III molar relationship (first mandibular molar is positioned mesially to first maxillary molar) as well as a reverse overjet (maxillary incisors are positioned lingually in comparison to mandibular incisors) or, in less severe cases, an edge-to-edge incisor relationship. In these patients it is typical to find a short narrow upper arch with crowding while the lower arch is usually broad with spaces. Crossbites, either unilateral or bilateral, may be frequently found in patients with severe discrepancy between the upper and lower arch. The skeletal discrepancy is normally based on mandibular prognathism but can be frequently associated with maxillary retrusion (retromaxilla) or a small cranial base. However, when the anomaly is associated only with the maxilla and does not involve the mandible, this is not classified as a true Class III, thus, it is important to evaluate the different components of this discrepancy. Since this syndrome has an unfavorable growth pattern, the malocclusion tends to worsen and the mandible grows excessively in most cases if not treated.(7)

In 1993, Battagel confirmed the multifactorial etiology of Class III malocclusion and found many differences between Class I (control group) and Class III children. When Class III patients undergo early treatment, their long-term results depend on numerous factors which include: facial morphology, growth patterns, environmental factors, as well as the treatment in itself, timing, duration, and the magnitude and direction of forces used. Just as in any situation, the patient’s cooperation can also influence the outcome of the treatment. (8, 9) Class III patients of both sexes tend to have a shorter cranial base length and an acute cranial base angle.(1, 9) Proclined maxillary incisors and retroclined mandibular incisors have been reported in subjects with a more severe Class III.(1) It was found that the maxilla was shorter and more retruded although the differences between the two occlusal groups were minor in comparison to the differences found in the mandible.(5, 9) The overabundance of mandibular growth is mainly responsible for the Class III incisor relationship. Within the Class III group it was proven that the mandible was more prominent not only as a consequence of an increase in total length but also because of its articulation that was found to be positioned more mesially.(1, 5) The major discrepancy between the two groups is evidently due to the mandibular growth that varies in direction, magnitude and can depend on timing of facial growth. (9, 10) Therefore, the mandible is predominantly responsible for the Class III malocclusion.

It appears that the active phase of mandibular growth in Class III malocclusion patients continues beyond the adolescent growth spurt. Meanwhile, the maxilla does not advance in conjunction with the mandible, making the discrepancy between the two, even more noticeable. During the growth phase, the mandibular protrusion, the discrepancy between the maxilla and the mandible, the negative overjet, and the Class III molar relationship all have a tendency to aggravate. By late adolescence, facial growth occurs in a vertical direction, contributing for the disharmony of skeletal and soft tissue relationship in Class III at the end of the active growth period. (5, 9)

Treatment planning of a Class III malocclusion should take into account the persistence of mandibular growth in early adulthood, especially when deciding the timing and duration of the treatment. (5) Early intervention has a significant role in recuperating skeletal and dental relations in many cases.(11) Several Class III patients that have a favorable growth pattern, should start treatment as soon as possible to eliminate prejudicial factors. (11) However, since there can be a vast discrepancy between the growth of maxilla and mandible during adolescence, patients receiving an early orthopedic treatment to correct a severe skeletal disharmony may need to be retreated in the future with a combination of orthodontic treatment and orthognathic surgery.(12, 13) In some cases, early treatment can even compromise orthognathic surgery in the future, in patients with an unfavorable growth pattern. In these cases, the orthodontic treatment should be postponed till the end of growth. (11) Orthopedic treatment techniques have improved over time, increasing the success rate of a camouflage orthodontic treatment in patients that are not qualified for orthognathic surgery. To be able to camouflage skeletal discrepancies, mandibular growth prediction is necessary for a successful orthodontic or orthopedic treatment.(12, 14) However, to date there is no precise method to forecast future mandibular growth. (12, 15)

Before considering the need for surgical procedures, each case must be carefully evaluated especially in growing individuals. The severity of the malocclusion is of extreme importance during treatment planning and could determine if the disharmony can be corrected by orthodontic means alone or if surgery has to be applied in a later phase. (1, 16) If this separation (orthodontic group or surgery group) could be performed at an early stage, the triage would be valid and the treatment plan would be based on the patient’s needs. This way, patients that could be effectively treated with orthodontic or orthopedic treatment, could be treated at an early stage, whereas the treatment plan for patients that would need orthognathic surgery in the future, could be altered appropriately. (2)

Many authors had the incentive to determine a model with high capacity of predicting therapy success or failure due to the ambiguity concerning Class III malocclusion and its long-term treatment outcome. If it was possible to calculate an unsuccessful outcome beforehand, then the timing and type of intervention could be changed accordingly. (2)

Investigators have attempted to predict the progression of mandibular growth in Class III patients; however, identifying variables as consistent predictors is extremely difficult due to many complex factors and can concern combinations of skeletal and dental disharmony. (1, 2, 9, 10, 12, 17) Therefore, precise growth prediction was considered practically impossible because facial growth in these patients can fluctuate tremendously and is known to be very inconsistent.(1) In normal cases, general growth rates and directions can be anticipated with some degree of accuracy as well as identifying favorable and unfavorable growth patterns. However, there are cases in which the growth patterns do not follow the usual trends and these cases often do not respond adequately to treatment because of unexpected growth. (1, 16) Factors such as growth spurts during adolescence, and morphological variability within ethnic groups and gender also need to be considered when evaluating the progression of a Class III disharmony.(1, 2, 9, 18) Consequently, individual growth prognosis is very restricted because of the wide range of variability. (1, 16)

The present study has two purposes:

1. Enhance understandings of the possibility to predict an excessive mandibular growth in Class III malocclusion patients at an early stage (mixed dentition), based on the literature.
2. Explore past investigations to determine which cephalometric variables can be considered to predict this abnormal growth with the highest accuracy.

II. SEARCH STRATEGY

II. Search Strategy and Results

The literature review that was conducted for the preparation of this work aimed to obtain current and relevant scientific information. The research was based on international publications found on the Pubmed database and the following key words were used: "cephalometric study", "cephalometric variables", "children", "Class iii malocclusion", "craniofacial growth", "early", "predict model", "prediction", "predictive variables", and "prognosis". Combinations of key words were used since simple key words would have very vast results and not be specific enough to the topic (Table 1).

Table 1: Search strategy and results

Key words	Results	Articles used
1.children Class iii malocclusion AND prediction	25	9
2.predictive variables AND early AND Class iii malocclusion	5	3
3. children with Class iii malocclusion AND predict model	7	1
4. Cephalometric variables AND Class iii prognosis	26	1
5. Class iii prognosis AND craniofacial growth	26	1
6. Craniofacial growth in Class iii children AND cephalometric study	33	1

The following inclusive criteria were applied: articles with full text available were used in English, Portuguese, Spanish, and French. Only publications that referred to a human population were used. This review covered the studies that were published between 1990 until 2016. The studies included were principally longitudinal controlled clinical trials, either retrospective or prospective as well as one systematic review. In this review, publications that approached Class III growing patients were included, both treated and untreated control subjects were considered. This study was based on articles that referred to the use of cephalometric variables to predict mandibular growth.

To limit the search, exclusive criteria were applied. Articles that were not accessible by the University of Porto were not used, nor were studies with little scientific relevance, such as case series, case reports, descriptive studies, review articles and opinion articles. Publications that did not refer to mandibular growth were excluded, just as studies that only took into consideration an adult population. Studies that did not focus on analyzing Class III malocclusion patients were also omitted, just as studies that included patients with anomalies, syndromes or disorders that affect the craniofacial growth. Studies without cephalometric analysis were not incorporated in this review. As well, articles with titles and abstracts that did not apply directly to the objective of this review were also excluded.

Out of 122 articles found on Pubmed, 16 were fundamental for this dissertation. During the selection process, 106 were excluded in total. 32 articles obtained during the search were duplicates.

Merely based on the title, 58 articles were removed for the following reasons: 5 of the articles found did not focus their study on class III patients; 11 articles concentrated on patients in adulthood instead of in mixed dentition; 11 did not emphasize mandibular growth; 10 discussed patients with disorders, and 21 evidently did not concern this study.

Subsequently, 16 articles were eliminated once the abstract was revised: 6 articles were not longitudinal clinical trial study, 4 were not available in full text, 3 were excluded because of the language, and 3 were not applicable to the thesis subject.

According to the inclusive and exclusive criteria, out of 122 articles found, only 16 were selected for this bibliographic review analysis. One was a systematic review, 6 were retrospective longitudinal controlled clinical trials, and 9 were prospective longitudinal controlled clinical trials. Nonetheless, other articles, dissertations and books were used to support certain ideas throughout this study.

III. DISCUSSION

III. Discussion

III.1. Factors that may influence Mandibular Growth

Ghiz *et al.* verified that there are many factors that can have a strong influence on the actual shape of the mandible, including genetics. Certain conditions must be taken into consideration, for example, occlusal stability and the function of the masticatory muscles, since these factors can also have a vast impact on mandibular growth. (12, 19)

III.1.1.Ethnicity

While some publications focused their study on an Asian population (20), others studied a Caucasian population (6, 8, 14, 21) and some even included both races in their investigation (12). Between these two populations, different standards can be found relative to cephalometric values as well as morphological variations, therefore, there can be differences in the criteria used to distinguish skeletal Class III subjects from the rest of the population.(2)

III.1.2. Growth peaks and differences between genders

Alexander *et al.* investigated growth changes in untreated subjects with Class III and found that there existed many differences between the females and males relative to the timing of growth during puberty. While the female subjects presented a mandibular growth spurt between 10 to 12 years of age, the male subjects only showed this spurt at 12 to 15 years. (6) Compared to a general sample population, it was seen that the peak of mandibular growth spurt ranged from 10 to 12.4 years in females, while and in males this spurt seems to be later, ranging from 13.6 to 14.5 years. (22)

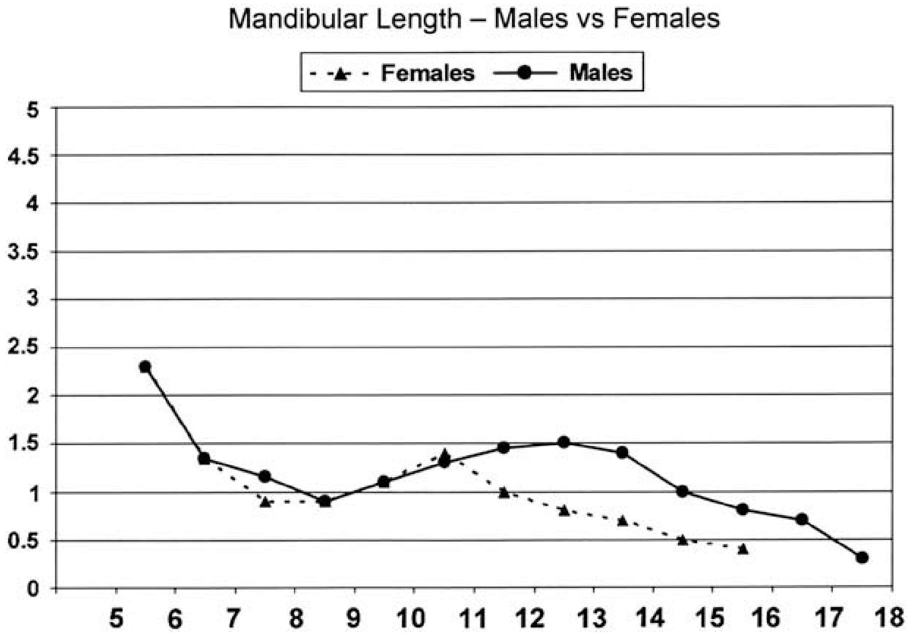

Figure 1: Mandibular Growth trends between males and females. (Adapted by Alexander et al.) (6)

As seen in Fig.1, the shape of the curve representing mandibular growth is similar between the male and female Class III subjects, although the male subjects reached their growth spurt 2 years after the female subjects, explaining the differences in growth in males and females between the ages 13 to 15. (6) Similar findings were found by Lewis *et al.*, although his results were based on a general population. His results showed that mandibular growth spurts, in general terms, happened 1.5 to 2 years later in males and these spurts seemed to be greater, compared to the female subjects. For the measurement Goi-Gn, the growth spurt happens 1.9 years later in boys, while Ar-Goi happens 1.7 years later and Ar-Gn 1.5 years later. Although the spurt happens to be later, the growth increments as well as the amount of spurt was larger in the male subjects for each of the three measurements. (23)

This graph demonstrates a vast amount of mandibular growth in early childhood and a pronounced growth peak during adolescence. These results can be compared to mandibular growth in children with normal occlusion. In subjects with normal occlusions, the maximum increase in mandibular length (Co-Gn) was found to be 3mm; meanwhile in male subjects with Class III, the mandibular length constantly increased more than 3mm every year between 12 and 15 years of age. During the pubertal growth spurt, the maximum annual increase of mandible length was reached, being 3.0 mm in the female subjects and 3.7 mm in the male subjects, on average. In the untreated Class III subjects analyzed by Alexander *et al.*, the total mandibular lengthening (distance between point condylion and point gnathion) accumulated between the ages 8 to 16 was 18 mm in the female subjects and 21.5mm in the male subjects; (6) similar results were found in other studies. (5, 6, 24)

When compared to skeletal Class I or II patients, patients with skeletal Class III malocclusion, demonstrate an excessive mandibular growth that prologues after the pubertal growth spurt. (5, 6, 17) This remaining growth tends to worsen the Class III disharmony and can cause relapse after orthopedic or orthodontic therapy. (6)

The maxillo-mandibular complex concludes its growth in a specific sequence, starting with an augment in width, around 12 years, then length, around 14 to 15 years, and ends with an increase in height. (18)

Significant differences were found between males and females in the timing and the extent of growth increments during adolescence. As mentioned above, it seems that the female and male subjects have mandibular growth spurts with different intensities and at different ages.(6)

III.2. Treated vs Untreated Class III patients

III.2.1. Treated

Timing of intervention is a very important factor in orthodontics when considering a skeletal disharmony, such as Class III malocclusion. It is important to contemplate the pubertal growth period when planning orthopedic and orthodontic therapy. This period of accelerated growth can be an advantageous or extremely disadvantageous depending on the growth pattern of the patient. In some cases, early treatment can even prevent the future need for orthognathic surgery, and in other cases it is preferable to intervene after the active growth period. (7, 14, 22)

III.2.1.1. Phase 1: Interceptive Treatment in Mixed Dentition

Different orthopedic treatment methods were used in early mixed dentition. Active treatment in the first-phase, normally has duration of 6 months to a year and its purpose is to modify skeletal and dental discrepancies at an early stage. Among the various authors studied, one of the most common methods used in Class III patients in the first-phase was Rapid Maxillary Expansion (RME) and Face Mask (FM) therapy. (8, 12, 14, 15) The duration of this treatment ranged between 6 months(15) to 1 year(14). Baccetti *et al.* found that RME and FM normally present a favorable treatment outcome when this commences in an early phase, before the pubertal growth spurt. However, there are exceptional cases. It is recommended to overcorrect the malocclusion with orthopedic treatment to maintain long-term success. (14)

Chin cup therapy has been used by many authors with the purpose to compensate the discrepancy between the maxilla and mandible in the first phase.(19, 20, 25) The length of this treatment varied between 1.4 years (20) to 3.1 years (25). With this therapy some authors even managed to slow down the mandibular vertical growth and stimulate the distal movement of the mandible. One component that cannot be corrected by chin cup therapy is the size of the mandible. It was found that it is very difficult to modify jaw growth, especially the mandible, with chin cup therapy since this depends on individual growth characteristics. Some studies state that at an early growth period, orthopedic forces may be enough to accelerate or inhibit the potential of mandibular growth with chin cup therapy while other authors believe that this type of treatment does not affect mandibular growth in any way during growth period. (19) The chin cup therapy was combined with other treatment methods such as functional or fixed appliances in some studies(19), while other authors, such as Moon *et al.* (25), used this therapy alone.

According to Franchi *et al.*, functional appliances, such as a Removable Mandibular Retractor (RMR), can have a favorable outcome on Class III patients when treating children in the first phase. This type of treatment ends when the anterior crossbite is corrected. (26) An upward and forward condylar growth is the main outcome of Removable Mandibular Retractor (RMR) in Class III malocclusion patients when compared to patients that did not receive any treatment.(26)

Meanwhile, some authors such as Kim *et al.*, did not apply the same treatment method to the whole sample and used various treatments in the first phase, such as chin cup therapy or FM with RME; and in the second phase, fixed appliances and pre-adjusted brackets. (27)

III.2.1.2. Phase 2 – Completion of Treatment in Permanent Dentition

On the other hand, second-phase treatment method uses fixed orthodontics and starts in late mixed dentition or in permanent dentition. In patients with a favorable growth pattern, first and second phase treatment methods can help correct the skeletal or dental discrepancy. However, when the patient does not have a favorable growth pattern, the anomaly cannot be corrected with first or second phase treatment and the patient would then need orthognathic surgery in adulthood. Therefore, predicting the prognosis of a Class III patient is very important during the diagnosis to be able to select the correct treatment modality.

The patients with Class III in the investigation performed by Kim *et al.*, were treated in the first and second phases. In the second-phase, the patients were treated with fixed appliances and pre-adjusted brackets. To prevent relapse, fixed lingual retainers were used on the anterior teeth of both upper and lower arches.(27)

III.2.2.Untreated

On the contrary to most authors that studied Class III patients that were treated in an early phase, Alexander *et al.* and Alhaija *et al.*, studied a population of untreated Class III subjects. The longitudinal study performed by Alexander *et al.* analyzed growth changes of untreated Caucasian subjects with Class III malocclusions and can serve as a comparison for studies that evaluated the treatment outcome of Class III in the first phase. It was found that as these untreated subjects grew, the mandibular prognathism and the sagittal relationship between the maxilla and the mandible seemed to worsen, the midfacial length increased and the mandibular plane angle decreased. (6)

Alhaija *et al.* studied a population of untreated class III subjects, and aimed to distinguish the favorable from the unfavorable growers. The population analyzed was divided in 3 subgroups: subjects with a horizontal discrepancy, long face types, and intermediate. It was found that the intermediate subgroup was the least critical type of Class III. The subgroup with a horizontal discrepancy demonstrated an increase in anterior and posterior cranial base lengths and an acute cranial base angle. While the maxilla was larger in length, the mandible was longer in both corpus and ramus; as well it was found that the mandible was protruding. It was found that these patients tend to have a sagittal growth pattern. In these patients the posterior lower facial height was increased. Meanwhile, in the patients that have a long face type, Alhaija *et al.* verified an increase in the anterior cranial base. The maxilla had a more retrusive and inferior position. The mandibular corpus was longer and inferiorly positioned. These patients reflected a vertical growth pattern. (28)

III.3. Intervention and Mandibular Growth

III.3.1.How was T0/ T1/ T2 defined?

Many authors measured the subject´s lateral cephalograms at different stages and the subjects had different ages at each stage. At the start of the treatment (T0), the ages ranged from 8.2 (8) to 10.9 (29). In some studies, the authors measured the subjects at the completion of early treatment in first-phase (T1) where the ages ranged from 9.5 (18) to 11.72 (27). While some authors measured these cephalograms after treatment in second-phase or at the follow-up of growth completion in adulthood which ranges from 15.0 (14) to 20.0 (21).

To determine end of pubertal growth, Nardoni *et al.* based this on the full pubescence for boys, and 2 years after menarche for girls. As well, hand-wrist analysis were used to define the completion of growth in this study.(15) Alexander *et al.* recorded cervical vertebral maturation in all subjects to evaluate the timing of cephalometric analysis based on pubertal growth. (6)

III.3.2. Timing of Intervention

When establishing the perfect treatment timing in the area of orthodontics many factors must be considered such as the diversity of facial growth, growth peaks during adolescence, differences between sexes and ethnicities as well as the objectives of the individual treatment. (30)

According to the systematic review by Toffol *et al.*, overall it seems that orthopedic therapy achieved in the deciduous dentition in class III patients has more effective results in terms of skeletal changes, than therapy realized in the mixed dentition. Furthermore, modification in the craniofacial skeleton appears to be more advantageous when the class III patients receive therapy in the early mixed dentition as opposed to the late mixed dentition. (31) For instance, a substantial maxillary expansion in the sagittal direction may merely be gained when treatment is performed in the early mixed dentition. When patients with Class III are treated in the late mixed dentition, an increase of anterior lower facial height can be acquired, as well as a backward rotation of the mandible. (32)

When the objective of the treatment is to modify mandibular growth, the ideal timing is when the patient is in the highest growth velocity phase. (30) To restrict mandibular growth that is related to an upward -forward condylar growth, therapy in early and late stages is encouraged. (32)

When no skeletally based retention appliance is used, the facial growth pattern of a Class III patient resurfaces a year after treatment completion. Patients that were treated in an early stage, tend to undergo relapse that impairs the sagittal expansion of the maxilla, meanwhile, relapse in patients treated in a later stage normally disturb the sagittal position of the mandible. (32)

III.3.3. Separation Criteria into Groups

Before analyzing the predictive value of the variable selected, the authors separated all subjects into two groups or three groups based on treatment results or the outcome after pubertal growth. Each author defined different criteria for this separation and different terminology was used between authors to describe these groups. Most of them separated the subjects based on early treatment results: “favorable” and “unfavorable treatment outcomes” (20); “surgery” and “nonsurgery patients” (1); “stable” and “relapse” (12, 14, 26); “stable”, “unclassified”, “relapse” (21, 25).

Many authors had different criteria for a corrected Class III malocclusion and between these studies, overjet; overbite and angle classifications were not used consistently. Ghiz *et al.* (12) defined overjet at 1mm to separate the subjects between two groups (success and relapse) meanwhile Moon *et al.* (25) defined the overjet as greater than 2mm in success cases. Battagel in 1993 (21) defined the success group when the overbite was greater than 0mm, while Moon *et al.* (25) used a different cut-off point, where overbite was greater than 1.5mm in the success group.

III.4. Prevision methods of mandible growth

III.4.1. Predictor Variables

After analyzing many studies relevant to this subject, a variety of variables were found amongst the authors. While some of the authors used common variables but with different combinations, others used unique variables.

One of the first investigators that acknowledge the importance of growth prediction in patients with Class III skeletal discrepancy was Battagel in 1993, and originated a four-variable model based on a population of 34 Caucasian subjects.(21) Battagel opened the investigation and many authors tried to respond to this challenge investigating a different sample population, different prediction models, and different early treatment methods.

Only two author used identical models, Kim *et al.* in 2009 and Moon *et al.* in 2005, where a two-variable model was selected: A-B to mandibular plane angle and A to N perpendicular distance, however different statistical methods were used to obtain these variables. (25, 27)

Certain variables can allow us to decipher a favorable growth pattern from an unfavorable one. It was found in one investigation by Yoshida *et al.* that the patients with a favorable prognosis had a maxilla that moved antero-inferiorly while patients with an unfavorable prognosis had a maxilla that moved mainly inferiorly. It was found that there was a more posterior displacement of the mandible in the group with favorable treatment outcome. (20)

Meanwhile, it was found among the Class III patients with unfavorable growth, that the mandible, during early treatment, displays a downward and backward rotation followed by an upward and forward rotation. The patients that belong to this group also presented a significant forward growth of the mandible. Both factors were highly related to poor treatment results in Class III patients that were still in the active growth period. (19)

Some authors used different reference points when calculating the variables used for their prediction model. Nardoni *et al.* used the stable basicranial line since it is a reference point that does not modify with growth after the patient is 5 years old. (15, 33) According to Schuster *et* *al.*, Nasion is not a fixed point and any change in its position can alter certain parameters such as the A-N-B angle (which defines the anteroposterior skeletal jaw relationship).(1)

Out of all the different researchers, the gonial angle seemed to be the most frequently identified variable, present in 6 predictive models that were studied throughout this review. (8, 12, 18-20, 29)

All cephalometric parameters used by previous authors can be categorized based on their location and the relationship they represent. Characteristics of the 15 investigations that were analyzed in detail throughout this study can be found in Table 3 in Appendix 1.

III.4.1.1. Mandible

Since unfavorable treatment results are usually related to mandibular growth, Ghiz came to the conclusion that cephalometric variables that are related to the mandible´s size, length, shape, and position as well as the chin´s position are all acceptable predictors for upcoming mandibular growth and were used in this study. (12, 34) The four-variable model created by Ghiz *et al.* consisted only of variables that were related to the mandible. He realized that Class III patients who had unfavorable treatment outcomes after growth were those with a shorter measurement from the cranial base to the condyle (Co-GD), a shorter ramal length (Co-Goi), a longer mandibular length (Co-Pog), as well as a larger gonial angle (Ar-Goi-Me). (12)

Tahmina *et al.* reported that within the Class III malocclusion, there exists a wide range of mandibular shapes and found that differences in mandibular shape can affect the direction and amount of mandibular growth. In this study, no significant differences were found between the patients with normal and abnormal growth relative to the size of the mandible (Ar-Go and Goi-Me), however, there were significant differences found between these two groups relative to the shape of the mandible (gonial angle and mandibular plane angle). The group with unstable treatment results was found to have a mandible that rotated downward and backwards during the first phase and then upwards and forwards, which contributed for the anterior displacement of the mandible. This was also due to an additional forward mandibular growth. (19)

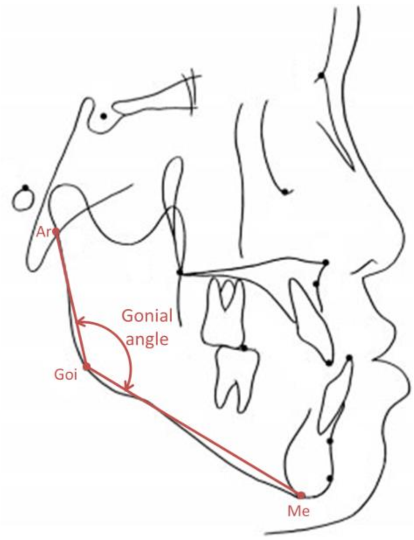

Figure 2: Gonial angle. (Adapted by Moon *et al.*) (25)

Many authors came to the conclusion that the gonial angle was significantly more obtuse in patients with unstable treatment outcomes and this angle has a tendency to increase as the patient gets older (Fig 2). (12, 19, 20, 25) Although the gonial angle was the most frequently selected variable, it is not the only variable that represents the mandibular shape. The angle between the ramus plane and S-N plane also represent the shape of the mandible and unstable treatment outcomes were associated with a wider ramus plane to sella-nasion angle. (19, 35)

The size of the mandible can be represented by many different variables. Some of these variables were selected in previous predictive models including, the mandibular length which was characterized either by Co-Gn(6, 8, 12), Co-Pog(12) or Ar-Gn(28). Ghiz *et al.* and Baccetti *et al.* considered the mandibular ramus length as a predictive variable. According to Baccetti *et al.* in 2004, a long mandibular ramus (Co-Goi) which indicates a larger posterior facial height (distance between point sella and point gonion) can be associated with an unfavorable treatment outcome in Class III patients. (14, 15)

The only author that considered the transversal parameter of the mandible was Franchi *et al.* in 1997. This parameter was represented by the width between the first deciduous molars on the mandibular arch, measured on dental casts. (26) Meanwhile, no sagittal parameter of the mandible was considered in the predictive model created by Franchi *et al.* (26)

For a long-term prediction of early intervention in Class III patients, it seems that mandibular shape and growth both play a more significant role than the sagittal relationship between the maxilla and the mandible. (12, 15, 25)

III.4.1.2. Maxilla

According to Yoshida *et al.*, the anterior displacement of the maxilla was practically the same in both groups, stable and unstable treatment outcomes. (20) These finding were supported by Ghiz *et al.*, who stated that no variable associated to the size or position of the maxilla is an adequate predictor for treatment results. (12)

However, some authors included predictors associated to the maxilla in their models, for example Kim *et al.* and Moon *et al.*, they included the perpendicular distance from point A to the N perpendicular line to FH plane (A-N perp) which defines the anteroposterior position of the maxilla, and it´s position relative to the mandible. (25, 27)

The Midfacial length (Co–A) which is defined by the distance from point condylion to point A, was included in the model designed by Auconi *et al.*, as well as the study performed by Alexander *et al.* (6, 8)

III.4.1.3. Maxillo-mandibular relationship

According to Kim *et al.*, the angle between the A-B plane and the mandibular plane (AB-MP) is used as a predictor of Class III prognosis because it defines the relationship between the anterior margin of the maxillary and mandibular alveolar bone and the mandibular plane (Fig 3). A small AB-MP angle stipulates a hyperdivergent skeletal pattern and a critical mandibular prognathism, indicating a poor prognosis for Class III malocclusions due to constant mandibular growth. (27) Meanwhile, Moon *et al.* stated that AB-MP is a predictor that considers both components of the craniofacial complex: the mandibular plane represents the vertical aspect and the A-B plane represents the anteroposterior (horizontal) relationship between the maxilla and mandible. (25) It was found that out of the two variables selected for their models, the A-B to mandibular plane angle was the most important however, together; both variables increased the accuracy when predicting the prognosis. Kim *et al.* (27) suggest that the angle between the A-B plane and the mandibular plane represents a sagittal relationship while Moon *et al.* (25) considers this a vertical parameter.

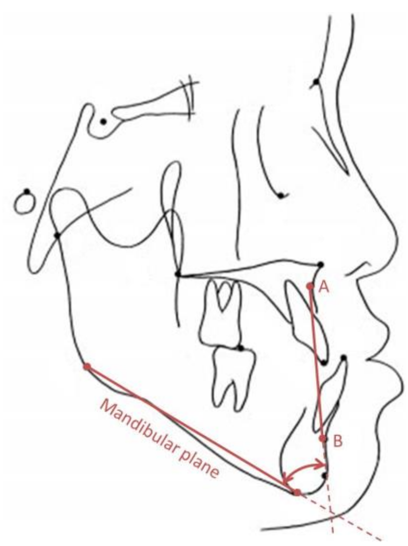

Figure 3: AB to Mandibular plane. (Adapted by Moon *et al.*) (25)

According to Yoshida *et al.*, Baccetti *et al.* and Franchi *et al.;* the vertical parameters of the craniofacial skeleton are essential for predicting Class III prognosis (14, 20, 26), which supports the findings described by Moon *et al.* who stated that variables in the vertical relationship showed significant differences between the groups. According to Moon *et al.*, no significant differences exist between groups when considering sagittal relationships between the maxilla and mandible (shown by A-N-B and Wits appraisal). (19, 25) For this reason, it was understood that characteristics of mandibular growth were more significant than the maxillo-mandibular relationship when predicting the prognosis of occlusal stability after growth. (25)

Tahmina *et al.* found that when patients, before early treatment, had a more obtuse nasion-A-pogonion angle; it was likely that they would have an unstable treatment outcome. (19)

According to Yoshida *et al.* and Nardoni *et al.*, the group that had an unfavorable treatment outcome demonstrated a larger anterior lower facial height (ALFH), which is the distance between point anterior nasal spine (ANS) and menton (Me). (15, 20) Nardoni *et al.* suggests that a larger ALFH corresponds to a vertical growth pattern. It has been proven that patients with a vertical skeletal pattern (hyperdivergent) demonstrate an unfavorable prognosis in the treatment of early Class III malocclusion. (2, 14, 25, 26) Nardoni *et al.* concluded that an unfavorable prognosis can be expected when there is an increase of ALFH and a decrease in the angle between the mandibular plane and the condylar axis, simultaneously. (15)

The angle NL-NSL (°), which represents the inclination of the palatal plane in relation to the mandible plane, was included in 3 predictive models (1, 8, 26) to demonstrate the maxillo-mandibular vertical relationship. Franchi *et al.* and Schuster *et al.* considered that patients with a greater angle between these two planes had an excess of mandibular growth and did not respond favorably to early treatment for Class III malocclusions. (1, 26)

However, Schuster *et al.* declared that vertical dimensions, for example, the gonial angle and the y-axis, were not very relevant for treatment decisions in Class III patients. According to Schuster *et al.*, the anteroposterior discrepancy, inclination of the lower incisors, and soft-tissue profile were the most important factors in terms of distinguishing these patients. (1)

Meanwhile, according to some authors, the anteroposterior jaw relationship must be taken into consideration when diagnosing children with Class III. The A-N-B angle represents the sagittal relationship between the maxilla and the mandible however, it is not considered a stable variable. As previously mentioned, this variable involves the Nasion point, thus, during growth it can alter due to changes in the cranial base or due to jaw rotation. Many authors suggested the use of A-N-B angle in conjunction with Wits appraisal to evaluate this relationship. For this reason, in the study executed by Schuster *et al.*, Wits appraisal was introduced as an “individualized A-N-B” to detach the skeletal relationship between the maxilla and mandible completely from the cranial base reference; instead, the functional occlusal plane is used as a reference. In this study, A-N-B angle, [(A-N-B)–(A-N-$B_{individualized}$)] angle and Wits appraisal demonstrated significant differences between the subjects with stable and unstable early treatment outcomes, however, only Wits appraisal was selected when the statistical analysis was applied for the prediction model. Nonetheless, Wits appraisal was also criticized since this variable is based on the functional occlusal plane which can change drastically during the eruption of the permanent dentition. (1)

III.4.1.4. Dental relationship

According to Battagel, relapse is common when there are more teeth in the anterior sector that are in crossbite and when the incisors in the upper arch are proclined to compensate the discrepancy. (21)

Overjet (mm) is the distance between the incisal edge of the maxillary central incisor to the vestibular face of the mandibular central incisor and in the study by Auconi *et al.* this variable is used in the predictive model. (8)

The lower incisor inclination is considered by some authors as the most significant factor in the decision between correcting the Class III malocclusion by orthodontics/ orthopedics therapy alone or orthognathic surgery in the future. This parameter is strongly related to the sagittal jaw relationship and can be represented by the angle between the axis of the lower incisor and the mandibular plane. (1, 36)

III.4.1.5. Condylar orientation

The condyle is recognized as a principal growth site that directly influences the mandibular length. The growth pattern of the condyle along with the rotation of the mandible is important to consider when assessing mandibular growth. (19, 35, 37) When the condylar head has an upward-forward orientation (larger CondAx-SLB), there is a higher probability that the early treatment of Class III malocclusion will have a favorable outcome. (26)

The mandibular plane in relation to the inclination of the condylar axis (CondAx-MP) is a variable that is used in conjunction with the ALFH to predict a favorable or unfavorable early treatment outcome according to Nardoni *et al*. A favorable outcome is predicted when a decrease in ALFH is found combined with a more obtuse angle between the condylar axis and mandibular plane. (15)

III.4.1.6. Cranial base

An acute cranial base angle (Ba-T-SBL) as well as a more vertically inclined mandibular plane angle (in reference to the cranial base) can accompany unfavorable treatment outcomes in Class III subjects according to Baccetti *et al.* in 2004. (14, 15)

III.4.2. Statistic Methods

According to Franchi *et al.*, Discriminant Analysis (DA) has been used in many investigations concerning the prediction of growth in Class III malocclusions and is one of the most effective statistical methods with regards to identifying the variables with the most predictive potential. (26)

Even though conventional methods such as the discriminate analysis and logistic regression were used by many authors, there is little consensus between them relative to which cephalometric predictors is ideal to forecast mandibular growth in Class III patients. In 2009, Kim *et al*. compared the efficacy of two statistical methods: the feature wrapping method and a conventional method, such as DA that was used by many authors. The feature wrapping method allows a prediction with higher accuracy and can be based on a smaller sample of patients.(27) In this study, the same data was entered into a discriminant analysis and even though the same variables were selected, the feature wrapping method had a higher classification power (97.2%) in comparison to DA (92.1%). (27)

Yoshida *et al.* used discriminant analysis and at first, selected 6 variables (71.9% accuracy). Using a stepwise method and trial-and-error approach, it was found that a two-variable model had the highest predictive power (84.4%). (20)

Schuster *et al.* used two statistical methods: DA and log regression (LogR), and applied them to the same 20 variables on a total of 88 patients with Class III malocclusion. Both methods selected the same three variables; however, LogR was classified with higher accuracy (94.3%) than DA (93.3%). (1)

III.4.2.1. Accuracy of the predictive models and limitations

According to many authors, the best method for analyzing facial growth is by longitudinal studies. The longitudinal data provides a more accurate estimate in comparison to cross-sectional data. However it is rare to find major investigations that examined untreated Class III malocclusion or that used a control group in their study.(5, 19) These studies are very limited due to the low prevalence of Class III particularly in Caucasians as well as the fact that both dental professionals and the public acknowledge the unfavorable facial characteristics and consequently, the need for early intervention. (5)

Fudalej *et al.* performed a systematic literature review to evaluate the possibility to predict early treatment outcomes in Class III patients. None of the 14 articles chosen revealed identical predictive models, although, some variables used were repeated. Even though a wide variation of variables was reported, most of the predictive models had a significant classification power.(2, 15)

The studies performed by Battagel *et al.* (21) and Moon *et al.* (25) had a low classification power, 77.8 % and 73.3% respectively.

According to the author, the three-variable model described by Franchi *et al.* was classified with a prediction power of 95.5% (26) just as the two-variable model established by Kim *et al.* was said to have a classification power of 97.2%.(27) In 2003, Schuster *et al.* developed a three-variable statistical model that also presented a very high prediction power: 93.3% (DA) and 94.3% (LogR).(1) However, this does not necessarily mean that it is possible to predict early treatment outcome in a randomized population with Class III malocclusion with such a high accuracy. It is easy to obtain a high classification when the validity of the model is calculated based on the same subjects that were originally used to obtain the model; this is why it is important to validate the predictive model on a randomized sample of patients that were not used initially. The only author that performed this validation procedure on new cases was Battagel in 1993. Nevertheless, a real assessment of this predictive model was difficult since only 8 cases were used. Since the other authors did not perform this test, the actual predictive power is undetermined. (2)

It is important to note that the combination of predictive variables is what determines the model´s classification power relative to the prediction of a successful or unsuccessful outcome. (15)

One of the limitations that was common between many authors was finding participants for the control group of Class III patients that had never been exposed to orthodontic/orthopedic treatment. Within the literature found in this review, only two authors studied mandibular growth in untreated patients and most of the remaining authors that investigated mandibular growth prediction in Class III subjects did not include a control group in their investigation.

After much research, it was found that this subject needs further investigation since no author was able to create a predictive model for Class III children with enough accuracy to be used in a clinical aspect.

III. 5. Study Proposal to predict mandibular growth

Author: Sara Teresa de Moel Belo

To design the ideal growth prediction model, one must evaluate and compare growth patterns between the general population and the class III population. As well, a control group involving untreated class III subjects is needed to compare with patients that are treated at an early phase. A longitudinal study must be performed to understand jaw growth patterns that happen over a large period of time. This study can be retrospective or prospective but must take into consideration the factor of time and these patients must be evaluated at least twice during this active growth period, ideally before and after pubertal growth. In this case, a retrospective study is perferred.

III.5.1. Sample Population

Initially, the subjects with skeletal Class III must be distinguished from the rest of the population based on the angle A-N-B, which is one of the most commonly used methods used to determine skeletal sagittal relationship between the maxilla and mandible. A normal occlusion is considered when the A-N-B angle is 2° (±2°) and when the angle is superior, a Skeletal Class II is reflected. Meanwhile, an inferior value for the A-N-B angle indicates a Skeletal Class III disharmony. (38, 39)

The objective of this study is to predict excessive mandibular growth in patients with skeletal Class III when the patient is firstly approached, whether this approach is right from the beginning in mixed dentition before early orthopedic treatment (T0), after early orthopedic treatment (T1), or after fixed orthodontic therapy in permanent dentition (T2). Ideally, this prediction should be made at T0, but not all parents of skeletal Class III children realize they need orthodontic treatment at this stage. Therefore this predictive model can be practical in various phases, it can even be applied in T2, after fixed orthodontic therapy since the patient can still exhibit further growth during adolescence and it can be useful to know if the patient will need orthognathic surgery in adulthood, T3.

The sample will encompass Class III patients with mixed dentition as well as non-Class III patients that meet the following eligibility criteria:

Inclusion criteria:

<u>Study group</u>

- Patients diagnosed with a Class III malocclusion in mixed dentition phase
  - Mesial molar relationship
  - Negative Overjet
  - Cephalometric values of Wits ≦ -1mm

<u>Control group</u>

- Patients with a Class I or II malocclusion in mixed dentition phase
  - Separation of treated and untreated patients
  - The control group must match the study group as to age at time of first and last observation as well as gender and ethnicity.

Both the study group and control group must have initial pre-pubertal records as well as final post-pubertal records

- Initial pre-pubertal records must include:
  - Age, Gender, Ethnicity
  - Cephalometric radiographs at T0 (treated patients- before early treatment, or untreated patients– before pubertal growth), with good quality.
- Final post-pubertal records must include:
  - Age, Gender, Ethnicity
  - Mandatory: Cephalometric radiographs at T3, in adulthood (treated patients- after treatment, untreated- after complete pubertal growth), with good quality
  - Optional: Cephalometric radiographs in T1(after early treatment), T2 (after fixed orthodontic therapy)

Exclusion criteria:

- Patients with anomalies, syndromes or disorders that affect the craniofacial growth, for example lip and palatal clefts and craniosynostosis, should be excluded from this study.

When Class III patients after first-phase have a stable outcome, the disharmony is likely due to the position of the maxilla. Meanwhile, the maxilla is usually not at fault when the patients have an unstable outcome after the first-phase or second-phase treatment, these cases are assumed to be a result of excessive mandibular growth.

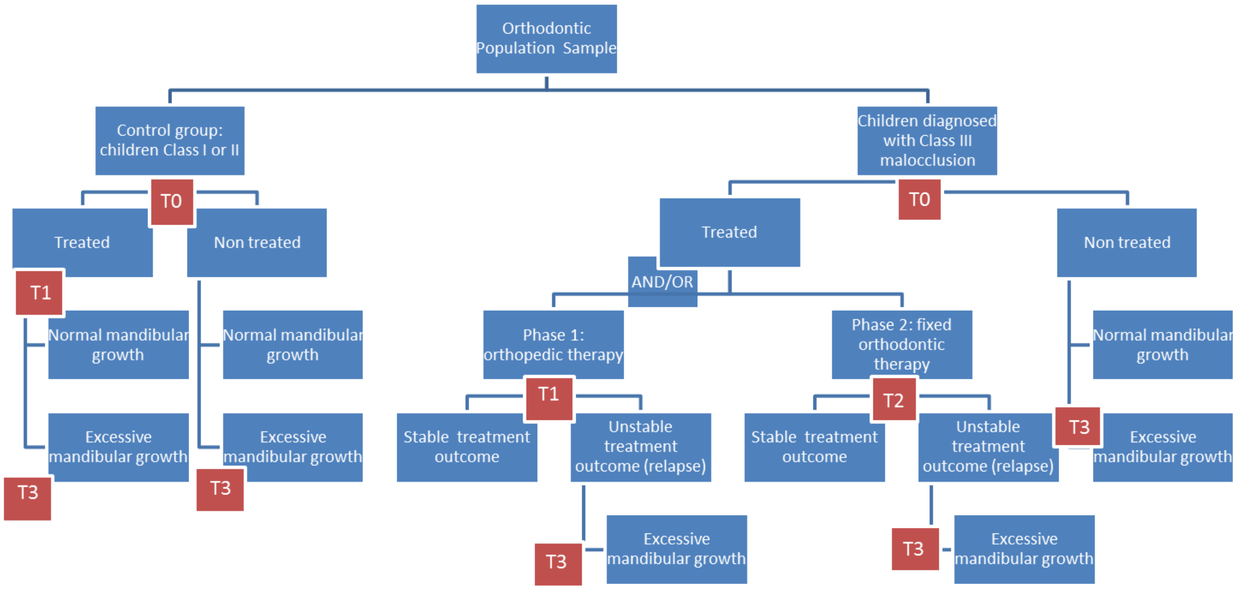

Figure 4: Study Design with Sample Prototype

III.5.2. Variables

A wide range of variables were selected representing the variables with the most potential in predicting mandibular growth in Class III malocclusion patients.

Table 2: Cephalometric variables selected for prediction model

	Variable	Definition
Maxilla	Co-A (mm)	Midfacial length as distance from point condylion to point A
	A-to-N perp (mm)	Point A to the N perpendicular line to FH plane
Mandible	Co-Gn (mm)	Mandibular length
	Co-Goi (mm)	Mandibular ramus height, distance between point condylion and point gonion
	Ar-Goi-Me (°)	Total gonial angle (°): Shape of mandible
	N-Goi to Goi-Ar lines(°)	Upper gonial angle
	N-Go to Goi-Gn lines (°)	Lower gonial angle
Maxillo-Mandibular relationship	ALFH (ANS to Me) (mm)	Lower anterior facial height
	NL-NSL (°)	Inclination of the palatal plane in relation to the mandible plane
	N-A-Pog (°)	Angle convexity
	A-B to mandibular plane (°)	Angle between the AB plane and mandibular plane (Goi-Me)
	Co-A / Co-Gn(%)	Midfacial length/ Mandibular length ratio
	Ramus plane to S-N(°)	Ramus plane to Sella-Nasion
Condylar orientation	CondAx-MP(°)	Mandibular plane (Goi-Me) in relation to the inclination of the condylar axis

	CondAx-SBL(°)	Condylar axis relative to the stable basicranial
Cranial Base	MP to SBL(°)	Mandibular plane in relation to the stable basicranial
	N-S-Ar(°)	Saddle angle
Dental relationship	Inclination of lower incisor(°)	Long axis of lower incisor to mandibular plane

In total, 17 cephalometric variables were considered for this study. Linear and angular measurements were included as well as a ratio between two linear measurements. All the variables selected as predictive measurements were defined in Table 2 and were exemplified in figures 5 through 8, systematized based on location. (40) Only two variables on the maxilla were chosen (Fig. 5), while five mandibular variables were used (Fig. 6) and six were selected to describe the maxillo-mandibular relationship (Fig.7). Two variables were used to represent the condylar orientation and two variables consider the cranial base of the patient (Fig. 8).

This prediction model aims to forecast mandibular growth in all patients, the study group as well as the control group, right at T0, when the patient is in the mixed dentition stage before any early treatment. The skeletal Class III subjects with excessive mandibular growth should be predicted with 100% accuracy.

Subsequently, statistical comparisons should be executed relevant to the different groups in the study sample as well as in the control sample, organized in the study design mentioned above.

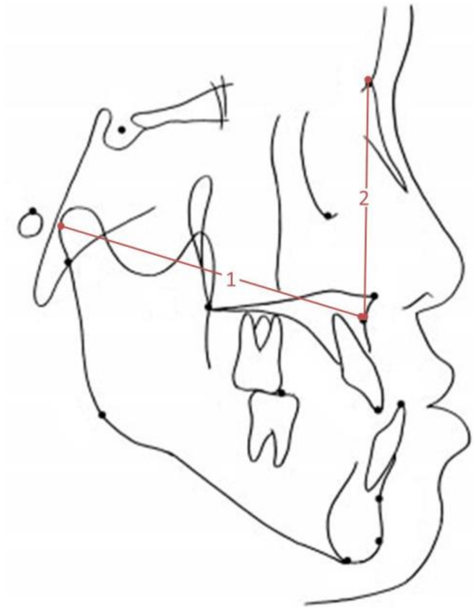

Figure 5: Maxilla. 1.Co-A; 2.N to A perp. (Adapted by Moon *et al.*) (25)

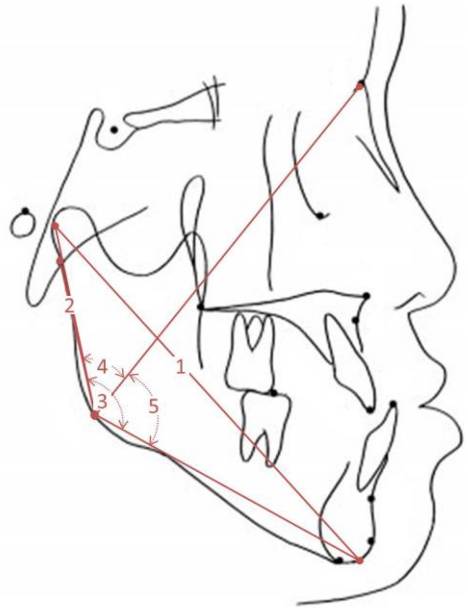

Figure 6: Mandible. 1.Co-Gn; 2.Co-Goi; 3.Ar-Go-Gn; 4. Upper Gonial; 5. Lower Gonial. (Adapted by Moon *et al.*) (25)

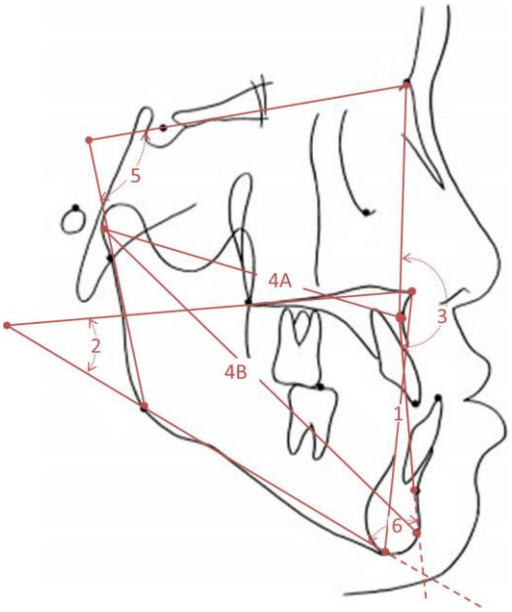

Figure 7: Maxillo-mandibular relationship. 1.ALFH; 2.NL-NSL; 3.N-A-Pog; 4.[Co-A(A) ÷ Co-Gn(B)]; 5.Ramus plane to SN; 6.AB to mandibular plane. (Adapted by Moon *et al.*) (25)

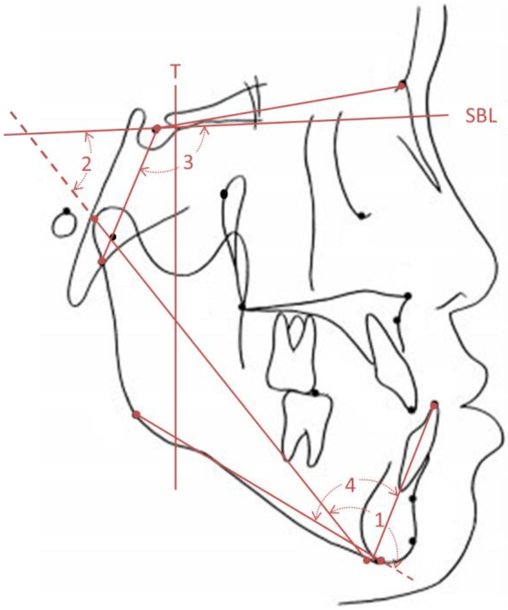

Figure 8: Condylar Orientation/ Cranial Base/ Dental relationship. 1.CondAx-MP; 2.CondAx-SBL; 3.N-S-Ar; 4.Inclination of lower incisor; 4. Inclination of lower incisor (Adapted by Moon *et al.*) (25)

IV. CONCLUSION

IV. Conclusion

Predicting mandibular growth in patients with Skeletal Class III is extremely important at an early stage, during mixed dentition, to be able to prepare an effective treatment plan and prognosis. To decide the ideal treatment timing, factors such as individual facial growth, growth spurts during adolescence, and differences between genders and race should be considered. After reviewing the literature, it was found that one of the most challenging limitations is the variety of cephalometric predictors found between authors and the infrequent concurrence between them. Out of all the predictive models created by the different authors, the gonial angle seemed to be the most frequently selected variable. The ongoing search must be continued until the ideal predictive model for excessive mandibular growth is found and this must have accurate results before it is used in a clinical situation. This flawless predictive model can be very beneficial to help the orthodontist decide whether or not the Class III patient will respond well to early treatment, or to wait until mandibular growth is completed to intervene.

V. Bibliography

1. Schuster G, Lux CJ, Stellzig-Eisenhauer A. Children with class III malocclusion: development of multivariate statistical models to predict future need for orthognathic surgery. The Angle orthodontist. 2003;73(2):136-45.

2. Fudalej P, Dragan M, Wedrychowska-Szulc B. Prediction of the outcome of orthodontic treatment of Class III malocclusions--a systematic review. European journal of orthodontics. 2011;33(2):190-7.

3. Lorenzo Franchi TB. Predictive variables for the outcome of early functional treatment of class III malocclusion. American Journal of Orthodontics and Dentofacial Orthopedics. 1997 112(No. 1):80-6.

4. Baccetti T, McGill JS, Franchi L, McNamara JA, Jr., Tollaro I. Skeletal effects of early treatment of Class III malocclusion with maxillary expansion and face-mask therapy. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 1998;113(3):333-43.

5. Baccetti T, Franchi L, McNamara JA, Jr. Growth in the Untreated Class III Subject. Seminars in Orthodontics. 2007;13(3):130-42.

6. Alexander AE, McNamara JA, Jr., Franchi L, Baccetti T. Semilongitudinal cephalometric study of craniofacial growth in untreated Class III malocclusion. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2009;135(6):700.e1-14.

7. Houston WJB, Houston WJB, Stephens CD, Tulley WJ. A Textbook of Orthodontics: Butterworth-Heinemann; 1992.

8. Auconi P, Scazzocchio M, Cozza P, McNamara JA, Jr., Franchi L. Prediction of Class III treatment outcomes through orthodontic data mining. European journal of orthodontics. 2015;37(3):257-67.

9. Battagel JM. The aetiological factors in Class III malocclusion. European journal of orthodontics. 1993;15(5):347-70.

10. Alexander AE, McNamara JA, Jr., Franchi L, Baccetti T. Semilongitudinal cephalometric study of craniofacial growth in untreated Class III malocclusion. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2009;135(6):700 e1-14; discussion -1.

11. Tai K, Park JH, Ohmura S, Okadakage-Hayashi S. Timing of Class III treatment with unfavorable growth pattern. The Journal of clinical pediatric dentistry. 2014;38(4):370-9.

12. Ghiz MA, Ngan P, Gunel E. Cephalometric variables to predict future success of early orthopedic Class III treatment. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2005;127(3):301-6.

13. Ngan P, Moon W. Evolution of Class III treatment in orthodontics. American Journal of Orthodontics and Dentofacial Orthopedics. 2015;148(1):22-36.

14. Baccetti T, Franchi L, McNamara JA, Jr. Cephalometric variables predicting the long-term success or failure of combined rapid maxillary expansion and facial mask therapy. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2004;126(1):16-22.

15. Nardoni DN, Siqueira DF, Cardoso Mde A, Capelozza Filho L. Cephalometric variables used to predict the success of interceptive treatment with rapid maxillary expansion and face mask. A longitudinal study. Dental press journal of orthodontics. 2015;20(1):85-96.

16. Jacobson A. Growth and its relation to orthodontic treatment. Journal of oral surgery (American Dental Association : 1965). 1981;39(11):817-26.

17. Reyes BC, Baccetti T, McNamara JA, Jr. An estimate of craniofacial growth in Class III malocclusion. The Angle orthodontist. 2006;76(4):577-84.

18. Mosca G, Grippaudo C, Marchionni P, Deli R. Class III dento-skeletal anomalies: rotational growth and treatment timing. European journal of paediatric dentistry : official journal of European Academy of Paediatric Dentistry. 2006;7(1):23-8.

19. Tahmina K, Tanaka E, Tanne K. Craniofacial morphology in orthodontically treated patients of class III malocclusion with stable and unstable treatment outcomes. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2000;117(6):681-90.

20. Yoshida I, Yamaguchi N, Mizoguchi I. Prediction of post-treatment outcome after combined treatment with maxillary protraction and chincap appliances. European journal of orthodontics. 2006;28(1):89-96.

21. Battagel JM. Discriminant analysis: a model for the prediction of relapse in Class III children treated orthodontically by a non-extraction technique. European journal of orthodontics. 1993;15(3):199-209.

22. Lee BS. Timing of Peak Mandibular Growth in Different Facial Growth Patterns and Resultant Mandibular Projection: University of Toronto; 2010.

23. Lewis AB, Roche AF, Wagner B. Growth of the Mandible During Pubescence. The Angle orthodontist. 1982;52(4):325-42.

24. Baccetti T, Reyes BC, McNamara JA, Jr. Craniofacial changes in Class III malocclusion as related to skeletal and dental maturation. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2007;132(2):171.e1-.e12.

25. Moon YM, Ahn SJ, Chang YI. Cephalometric predictors of long-term stability in the early treatment of Class III malocclusion. The Angle orthodontist. 2005;75(5):747-53.

26. Franchi L, Baccetti T, Tollaro I. Predictive variables for the outcome of early functional treatment of Class III malocclusion. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 1997;112(1):80-6.

27. Kim BM, Kang BY, Kim HG, Baek SH. Prognosis prediction for Class III malocclusion treatment by feature wrapping method. The Angle orthodontist. 2009;79(4):683-91.

28. Abu Alhaija ES, Richardson A. Growth prediction in Class III patients using cluster and discriminant function analysis. European journal of orthodontics. 2003;25(6):599-608.

29. Zentner A, Doll GM, Peylo SM. Morphological parameters as predictors of successful correction of Class III malocclusion. European journal of orthodontics. 2001;23(4):383-92.

30. Nahhas RW, Valiathan M, Sherwood RJ. Variation in timing, duration, intensity, and direction of adolescent growth in the mandible, maxilla, and cranial base: the Fels longitudinal study. Anatomical record (Hoboken, NJ : 2007). 2014;297(7):1195-207.

31. Toffol LD, Pavoni C, Baccetti T, Franchi L, Cozza P. Orthopedic treatment outcomes in Class III malocclusion. A systematic review. The Angle orthodontist. 2008;78(3):561-73.

32. Baccetti T, Franchi L, McNamara JA, Jr. Treatment and posttreatment craniofacial changes after rapid maxillary expansion and facemask therapy. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 2000;118(4):404-13.

33. Tollaro I, Baccetti T, Franchi L. Mandibular skeletal changes induced by early functional treatment of Class III malocclusion: a superimposition study. American journal of orthodontics and dentofacial orthopedics : official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics. 1995;108(5):525-32.

34. Nardoni DN, Siqueira DF, Cardoso MdA, Capelozza L. Cephalometric variables used to predict the success of interceptive treatment with rapid maxillary expansion and face mask. A longitudinal study. Dental Press Journal of Orthodontics. 2015;20(1):85-96.

35. Bjork A. Prediction of mandibular growth rotation. American journal of orthodontics. 1969;55(6):585-99.

36. Proffit WR, Ackerman JL. Current Orthodontic Concept and Techniques. 3rd ed. St. Louis: In: Graber TM, Swain BF; 1985. 15-148 p.

37. Bjork A. Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method. Journal of dental research. 1963;42(1)Pt 2:400-11.

38. Katayama K, Yamaguchi T, Sugiura M, Haga S, Maki K. Evaluation of mandibular volume using cone-beam computed tomography and correlation with cephalometric values. The Angle orthodontist. 2014;84(2):337-42.

39. Martins E. Estudo Comparativo da Determinação da Relação Esquelética Sagital por Diferentes Parâmetros Cefalométricos: Universidade do Porto; 2007.

40. Segner D. Orthodontic Cephalometry. The European Journal of Orthodontics. 1996;18(3):307-.

APPENDIX

U.PORTO
FACULDADE DE MEDICINA DENTÁRIA
UNIVERSIDADE DO PORTO

PARECER

Monografia de Investigação/Relatório de Atividade Clínica

Informo que o Trabalho de Monografia desenvolvido pela Estudante Sara Teresa de Moel Belo com o titulo "Prediction of Mandibular Growth in Class III Malocclusion patients in Mixed Dentition" está de acordo com as regras estipuladas na FMDUP, foi por mim conferido e encontra-se em condições de ser apresentado em provas públicas.

Porto, 27 de Maio de 2016

O Orientador

Professor Auxiliar Eugénio Martins

U.PORTO

FACULDADE DE MEDICINA DENTÁRIA
UNIVERSIDADE DO PORTO

DECLARAÇÃO

Monografia de Investigação/Relatório de Atividade Clínica

Declaro que o presente trabalho no âmbito de Monografia de Investigação/Relatório de Atividade Clínica, integrado no MIMD, da FMDUP, é da minha autoria e todas as fontes foram devidamente referenciadas.

Porto, 27 de Maio de 2016

A Investigadora

Sara Belo

(Sara Teresa de Moel Belo)

APPENDIX 1

Table 3: Characteristics of longitudinal investigations included in this study

Author	Year	Type of article	Age at treatment start, completion, follow up	Variables	Sample size, Ethnicity (n)	Statistic	Accuracy of prediction model
Alhaija *et al.* (28)	2003	Clinical trial Longitudinal Retrospective study	N/A	-Distance between projected points A and B on Sella (AB-H) -Mandibular length (Ar-Gn) -Distance from articulare to sella (Ar-H) -(Arp-Gnp) -Nasolabial angle -Li/A-Pog -Li/Mand -LiH -NNP -PNS-H	115 Caucasians	Hierarchical cluster analysis: Discriminant Analysis; Stepwise analysis for each cluster	Cluster I : 92%, Cluster II: 85% and Cluster III: 100%.
Alexander *et al.* (10)	2009	Clinical trial Longitudinal Prospective study	N/A	Lower anterior facial height Midfacial length Mandibular length	103 Caucasians	Descriptive statistics; Mann-Whitney U test Wilcoxon test	N/A
Auconi *et al.* (8)	2015	Clinical trial Longitudinal Prospective study	8.2, 14.6, N/A	-Co–A (mm) -Co–Gn (mm) -Palatal plane to mandibular plane (°) - Ar-Go-Me: Gonial angle -Overjet (mm)	54 Caucasians	Fuzzy Cluster	Unsuccessful cases: 16.7%

Baccetti *et al.* (14)	2004	Clinical trial Longitudinal Prospective study	8.6, 9.6, 15.0	Mandibular ramus length (Co–Goi), Ba–T–SBL angle, and ML/SBL angle	42, Caucasians	Discriminant analysis; Stepwise Method	83.3%
Battagel *et al.* (21)	1993	Clinical trial Longitudinal Prospective study	12.4, NA, 20.0	-Inclination of the upper incisors to the maxillary plane -The distances of labrale superior to soft tissue nasion -Distance of labrale inferior to sella certical -Number of anterior teeth in crossbite	34, Caucasians	Discriminant analysis; Stepwise Method	73.3%
Franchi *et al.* (3)	1997	Clinical trial Longitudinal Prospective study	5.6, N/A, 15.8	-Inclination of the condylar axis in relation to the stable basicranial line (CondAx-SBL). –Inclination of the nasal line to the mandibular line (NL-ML).	45, N/A	Stepwise variable selection; Discriminant analysis	95.5%
Ghiz *et al.* (12)	2005	Clinical trial Longitudinal Retrospective study	9.2, NA, NA	-Position of condyle with reference to the cranial base (Co-GD) -Ramal length (Co-Goi) -Mandibular length (Co-Pog) -Gonial angle (Ar-Goi-Me)	64: 30 Asians, 34 Caucasians	Stepwise variable selection; Logistic equation	95.5% of successful treated Class III patients 70% prediction of unsuccessful cases
Kim *et al.* (27)	2009	Clinical trial Longitudinal Prospective study	8.53, 11.72, 17.69	AB to mandibular angle (Go-Me) A to N perpendicular	38, N/A	Feature wrapping method	97.2%
Moon *et al.* (25)	2005	Clinical trial Longitudinal Prospective study	8.6, 11.7, 17.4	AB/MP angle; A to N-perp distance	45, Asians	Stepwise selection; Discriminant analysis	77.8%
Mosca *et al.*(18)	2006	Clinical trial Longitudinal	N/A, 9.5, 13.8	The A-N-B angle (A-N-B) The facial depth angle	20, N/A	N/A	N/A

		Retrospective study		The mandibular plane angle The gonial angle Facial height			
Nardoni *et al.* (34)	2015	Clinical trial Longitudinal Prospective study	8.3, N/A, 15.4	-ALFH -Inclination of the condylar axis with the mandibular plane (CondAx-MP)	26, N/A	Discriminant analysis; Stepwise analysis	88.5% success group (21) and failure group (5)
Schuster *et al.* (1)	2003	Clinical trial Longitudinal Retrospective study	9.8, N/A, 17.4	-Wits appraisal -Palatal plane angle(NL-NSL) -Individualized inclination of the lower incisors	88, Caucasians	Discriminant analysis; Logistic Regression	93.2%
Tahmina *et al.*(19)	2000	Clinical trial Longitudinal Retrospective study	9.3, 13.1, N/A	-Gonial angle - N-A-Pog angle -Ramus plane to SN plane angle	56, N/A	Discriminant analysis	85.7%
Yoshida *et al.* (20)	2006	Clinical trial Longitudinal Prospective study	10.2, 11.6, 17.0	ANS–Me Gonial angle (Ar-Go-Me)	32, Asians	Discriminant analysis; Regression analysis	84.4%
Zentner *et al.* (29)	2001	Clinical trial Longitudinal Retrospective study	10.9, N/A, 16.0	Apical base relationship and gonial angle; mid facial length/mandibular length ratio, net sum of ‘maxillary difference’ and ‘mandibular difference’	80, Caucasians	Regression analysis; Forward stepwise regression analysis	N/A